Integrated Approaches to Higher Maize Productivity in the New Millennium

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D.K. Friesen and A.F.E. Palmer (eds.)

CIMMYT
Maize Program

CIMMYT

Kenya Agricultural
Research Institute

KARI

CIMMYT® (www.cimmyt.org) is an internationally funded, nonprofit, scientific research, training, and development organization. CIMMYT acts as a catalyst and leader in a global maize and wheat innovation network that serves the resource-poor in developing countries. Drawing on strong science and effective partnerships, we create, share, and use knowledge and technology to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources. CIMMYT is one of 16 food and environmental organizations known as the Future Harvest Centers (www.futureharvest.org). Located around the world, the Future Harvest Centers conduct research in partnership with farmers, scientists, and policymakers to help alleviate poverty and increase food security while protecting natural resources. The centers are supported by the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org), whose members include nearly 60 countries, private foundations, and regional and international organizations. Financial support for CIMMYT's research agenda also comes from many other sources, including foundations, development banks, and public and private agencies.

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Abstract: This proceedings provides a comprehensive and detailed presentation of the major maize research activities and advances in Eastern and Southern Africa since the previous Regional Maize Conference held in 1998. The Conference, which included a Symposium on Low Nitrogen and Drought Tolerance in Maize, heard a total of 101 papers addressing the major constraints to maize production and productivity in the region and breeding and agronomic approaches to overcoming them, including biotic constraints (diseases and insect pests), *Striga*, and abiotic stress (low nitrogen fertility and drought) as well as constraints to farmer uptake of new technologies. These proceedings represent the work of the major portion of scientists in the region dealing with maize production and, taken together, are a useful guide to regional research priorities and testify to the considerable range of maize research undertaken.

AGROVOC descriptors: Maize; *Zea Mays*; Plant breeding; Hybrids; Open pollination; Protein quality; Herbicide resistance; Plant diseases; Disease resistance; Pests of plants; Pest resistance; Drought tolerance; *Striga*; Soil fertility; Cropping systems; Water harvesting; Water use efficiency; Green manures; Organic fertilizers; Farmyard manure; On-farm research; Technology transfer; Farmers; Economic analysis; Africa

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OPENING SESSION:

Maize and the bio-socio-economic environment

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KEYNOTE ADDRESS

QUALITY PROTEIN MAIZE DEVELOPMENT: AN EXCITING EXPERIENCE

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Maize (*Zea mays L.*) is one of the three major cereal crops of worldwide economic importance. It contributes substantially to the total cereal grain production in the world and also occupies an important place in the world economy and trade as a food, feed and an industrial grain crop. The total area under maize is about 140 million hectares with a production total of 600 million metric tons. In the developed world, maize is mostly used as a feed for the livestock (78%) and only a small percentage as food (6%). In contrast less developed countries consume at least 40% as food and the remaining 50% as feed. The remaining quantity is used in varied industrial uses and as seed. Also it may be interesting to point out that as food and feed, maize contributes 15% of the world's protein and 19% of the calories derived from the food crops. There are some 20 developing countries in the world in which maize is the single largest source of calories and protein for the poor and is the primary weaning food for the babies. Some 840 million people go hungry or face food insecurity every year (UNDP 1997). One third of all children under the age of five years are malnourished. Close to 100 million of these 185 million malnourished children are in South Asia while about 30 million in sub-Saharan Africa (Pinstrup-Andesson and Pandya-Lorch, 1997).

Malnutrition is widespread among children and women. It is estimated that five million pre-school children die from nutrition-related illnesses. Two of every five children in the developing world are stunted because of malnutrition; one in three is underweight; and one in ten is wasted defined as seriously below the normal. Demand for maize is increasing continuously. Even if the current productivity trends continue, the developing countries will need to import forty million tons of maize each year by 2020. Considering importance of maize for food and feed and as demand is accelerating rapidly, we expect next revolution will be forthcoming in maize. Enhanced potential productivity capacity of maize coupled with improved nutritional value can play a vital role in making food and nutrition security challenges in the future.

Improving nutritional quality of agricultural crops is a noble goal. This is, particularly important in cereal crops where the benefits can be spread to hundreds of millions of people in a most rapid and effective manner without changing the traditional food habits. About maize, biochemists had told us 90 years ago that maize protein is nutritionally deficient because of the limiting quantities of two essential amino acids lysine and tryptophan. Research initiatives had to wait almost 50 years until three distinguished Purdue researchers discovered high lysine mutants that paved the way for genetic manipulation to correct the deficient traits. Most maize scientists envisioned this report with great optimism and high hopes. Worldwide conversion programs produced a wide array of opaque-2 varieties and hybrids which subsequently went through extensive testing in the developed and the developing world. Yield and agronomic performance of these materials did not match normal counterparts. In general these materials had 10-15% less grain yield, the kernel appearance dull and chalky, slower drying, greater kernel rots and greater vulnerability to stored grain pests. Thus in the very first decade this maize did not pass the test of its strength. Frustration and declining interest was a consequence of its lacking competitive performance. Funding support was either reduced or completely withdrawn. Most national maize programs in the developing countries reacted in a similar fashion. Following mid-seventies, only a few institutes and programs showed continuing interest and enthusiasm. CIMMYT has been one of them. Now I take this opportunity to offer some comments on CIMMYT's work and present some of my personal views in research relating to QPM.

CIMMYT's work on QPM is considered significant. It has achieved a great scientific breakthrough in developing germplasm products that are competitive and meet acceptance of farmers and consumers preference. Several elements have contributed to this success including sustained funding, strong administrative support of CIMMYT Director Generals and Maize Directors, readiness to deploy alternate sound options in breeding when the rest of the world was witnessing declining interest, continuing evolving breeding methodologies and strategies and making constant changes as and when needed during different phases of germplasm development.

In the beginning the emphasis was on developing soft endosperm opaque-2 versions of normal materials, broad-based composites, and some population crosses. Also a number of alternative options were being explored to develop agronomically acceptable hard endosperm opaques. Enough information and confidence in alternative approach was already available when we wanted to make a switch over in our breeding approach and strategy. Another important point which I wish to make is that effort devoted to developing soft opaques was not a complete waste. It is from these materials we had to look desperately for variation in modified kernel behavior and got initial hints as to the types of genetic backgrounds which will enhance our chances of success in developing QPM.

Moving from soft opaques to hard endosperm was highly critical if such materials are to be accepted in developing countries. Any approach under consideration should therefore involve a change in kernel phenotype. Of the three options at hand at that time, a combination of opaque-2 gene and genetic modifiers was considered most appropriate to rectify phenotypic appearance and other agronomic problems affecting this maize. CIMMYT's choice of this approach has proved to be a successful and a viable strategy. No other option(s) used by other institutes has demonstrated success of a similar magnitude. Shift in strategy from soft to hard endosperm was thus a major change but at the same time an equally challenging task.

There was a lot of routine hard work, frustration in encountering modified kernel variation, lack of stability and reversion to soft texture in the ensuing generation.

Some unexpected chance events inspired confidence and aided in a big way in deploying two genetic system strategy on a grand scale. This was particularly true in a population cross of two opaque-2 versions which exhibited a very high frequency of mosaic modified kernels.

Choosing carefully a single approach/strategy was critical in contrast to several independent ones in tackling problems. Also any practical strategy in use must address the problem of yield penalty and phenotypic appearance of the kernel.

QPM germplasm development efforts were not limited to a few genetic backgrounds. Several different approaches and strategies were put into action to develop a wide array of germplasm products meeting requirements for different adaptation ecologies. The tactical strategy was to go in a big way to develop huge germplasm volume followed by merging and reorganization of germplam considering adaptation, maturity and kernel colors. This helped reducing germplasm to a manageable level and permitted systematic handling. We are harnessing benefits of this strategy without which QPM may have found only limited use in some countries.

There was a proof of continuing progress in improving germplasm which provided clear cut evidence for others to see and appreciate. Improvements were quite evident in improving kernel modification and also yield in several different backgrounds.

During QPM development over the years, a number of important lessons were learnt which have a bearing and relevance to similar other plant breeding situations in maize and other crops especially where major gene(s) are used to introduce some important attributes into the elite germplasm. Invariably major genes with drastic effects are associated with other negative and pleitropic effects which require accumulation of favorable modifying alleles and the need to work in homozygous genetic backgrounds contrary to commonly used backcross programs.

QPM development required continuous monitoring of protein quality and thus needed a strong support from biochemical laboratory. Simple analytical techniques were developed and used to analyze large number of samples in a rapid and efficient manner to provide results to the breeders in a timely fashion to make right decision at right time. This resulted in saving of resources and manpower use. Collaboration between biochemists and breeders was excellent and each group was aware of the needs, urgencies and work priorities of the other. Interdisciplinary cooperation in QPM work at CIMMYT is perhaps exemplary and without the strong support of laboratory this work may not have attained success that we are witnessing today. The roles of other disciplines also can not be underestimated especially pathology, entomology and physiology which rendered services and support in evaluating QPM germplasm under different stresses.

There have been several turning points in QPM research at CIMMYT. These related to shifts in the use of mutants or genetic systems; changing emphasis on kernel texture and other quality traits; breeding approaches and strategies; germplasm development, management, consolidation and reorganization; emphasis on QPM hybrid development and international testing of QPM products at varying periods.

Good science is not free from difficulties, frustration, and criticism. This should be viewed to generate creativity, revisiting different approaches and activities, and making constant adjustments for efficient use of resources at all levels. Periodic reviews help to de-emphasize some aspects of the program while expanding others if necessary and introducing new initiatives, which were not already in place. One good example will be hybrid initiative in Mid-1980s, which proved extremely beneficial for QPM research and promotional efforts. Without this initiative we perhaps may not have realized full potential and benefits of QPM. It is encouraging to state that we are already harnessing the fruits of this important decision. Many countries in recent years have released directly CIMMYT developed hybrids and in a few cases are using CIMMYT lines in combination with their own lines.

QPM has been an excellent training ground for maize researchers especially postdoctoral fellows and visiting scientists. Researchers could be exposed to a whole array of activities going on in the maize program in addition to QPM. Many current CIMMYT staff had the privilege of working in QPM subprogram in the initial stages of their careers.

Currently maize scientists feel proud of QPM research at CIMMYT and elsewhere. CIMMYT maize staff have gained confidence and strength and are aspiring to do more to spread the benefits of this maize to more developing countries. Recent releases and field days have been impressive (Tables 1, 2 & 3). Expectations of all of us are to have more area under this maize in the developing countries in the future. Our present Director General, Professor Timothy Reeves and Maize Director, Dr. Shivaji Pandey have been quite enthusiastic and supportive of all on-going QPM work at CIMMYT.

Table 1. Recent QPM Releases in some countries.

Country	No. of Releases		Total
	QPM OPV	QPM Hybrid	
Mexico	5	21	26
India	1	2	3
Brazil	3	-	3
Nicaragua	1	1	2
Guatemala	-	1	1
El Salvador	-	1	1
Honduras	-	1	1
China	-	5	5
Colombia	-	1	1
Mozambique	1	-	1
Mali	1	-	1
Uganda	1	-	1
Benin	1	-	1
Burkina Faso	1	-	1
Quinea	1	-	1
South Africa	-	1	1
Peru	-	1	1
Venezuela	-	1	1
Vietnam	-	1	1
Total	**16**	**37**	**53**

Table 2. Recent QPM Releases in Some Countries

Name	Type	Pedigree	Country
HQ INTA-993	Hybrid	(CML144 x CML159) CML176	Nicaragua
NB-Nutrinta	Open pollinated	Poza Rica 8763	Nicaragua
HB-PROTICTA	Hybrid	(CML144 x CML159) CML176	Guatemala
HQ-61	Hybrid	(CML144 x CML159) CML176	El Salvador
HQ-31	Hybrid	(CML144 x CML159) CML176	Honduras
Zhongdan 9409	Hybrid	Pool 33 x Temp QPM	China
Zhongdan 3850	Hybrid		China
QUIAN2609	Hybrid	Tai 19/02 x CML171	China
Yun Yao 19	Hybrid	(CML140)	China
Yun You 167	Hybrid	(CML194)	China
Lu Dan 206	Hybrid	(P70)	China
Lu Dan 207	Hybrid	(P70)	China
Lu Dan 807	Hybrid	(P70)	China
Hybrid 2075	Hybrid	(CIMMYT QPM Populations)	China
ICA-	Hybrid	(CML144 x CML159) CML176	Colombia
Susuma*	Open pollinated	Across 8363SR	Mozambique
Obatampa*	Open pollinated	Across 8363SR	Mali
Obangaina*	Open pollinated	Across 8663SR	Uganda
Obatampa*	Open pollinated	Across 8363SR	Benin
BR-473	Open pollinated		Brazil
BR-451	Open pollinated		Brazil
Assum Preto	Open pollinated		Brazil
Obatampa*	Open pollinated	Across 8363SR	Burkina Faso
Obatampa*	Open pollinated	Across 8363SR	Guinea
QS-7705*	Hybrid		South Africa
GH-132-28*	Hybrid	P62, P63	Chana
INIA-	Hybrid	CML161 x CML165	Peru
FONAIAP	Hybrid	(CML144 x CML159) CML176	Venezuela
HQ-2000	Hybrid	CML161 x CML165	Vietnam
SHAKTIMAN-1	Hybrid	(CML142 x CML150) CML176	India
SHAKTIMAN-1	Hybrid	CML176 x CML186	India
In Mexico, 21 hybrids and 5 open pollinated varieties including:			
44IC	Hybrid	CML142 x CML116	Mexico
H-551C	Hybrid	CML142 x CML150	Mexico
H-553C	Hybrid	(CML142 x CML150) CML176	Mexico
H-519C	Hybrid	(CML144 x CML159) CML170	Mexico
H-368EC	Hybrid	CML186 x CML149	Mexico
H-369EC	Hybrid	CML176 x CML186	Mexico
VS-537 C	Open pollinated	POZA RICA 8763	Mexico
VS-538 C	Open pollinated	ACROSS 8762	Mexico

Table 3. Some Prominent QPM Varieties and Hybrids Released in Different Countries

1	CML144 x 159) x CML176	-	Nicargua, Guatemala, El Salvador, Handuras, Mexico, Venezuela, Colombia
2	CML176 x CML186	-	India, Mexico
3	CML161 x CML165	-	Peru, Vietnam, Guangzi (China)
4	(CML142 x CML150) x CML176	-	India, Mexico
5	Across 83635R	-	Muzambigue, Mali, Uganda, Benia, Burkina Faso, Guinea
6	Poza Rica 8763	-	Nicaragua, Mexico

Table 4. Mean Grain Yield of Four Highest Yielding QPM Varieties, Normal Reference Variety, and Best Local Checks at 11 Locations, CIMMYT EVT 15B, 1988

Variety	Grain yield (tons/ha)	Grain yield % of normal ref. entry
Across 8563 QPM	5.68	103.2
Capinopolis 8563 QPM	5.48	99.7
Iboperenda 8563 QPM	5.47	99.4
Tarapoto 8563 QPM	5.37	99.7
Suwan 8222 NRE	5.50	100.0
Best local check	5.36	97.5

Source: CIMMYT

Table 5. Performance of Superior Tropical QPM Hybrids Across 41 Locations in Lation America and Asia, 1999-2000

Pedigree	Grain Yield (ton/ha)	Ear Rot (%)	Silking (50%)	Endosperm * Hardness	Tryptophan In sample
(CML-141 x CML-144)	6.40	5.5	55	1.6	0.088
(CML-141 x CML-144) CML-142	6.39	6.2	55	1.7	0.081
(CML-142 x CML-146)	6.28	6.3	55	2.2	0.100
(CML-142 x CML-150)	6.20	7.8	55	2.0	0.089
(CML-142 x CML-150) CML-176	6.08	7.5	55	2.0	0.086
(CLQ-6203 x CML-150)	5.80	7.2	55	2.3	0.090
(CML-144 x CML-159) CML-176	5.64	6.0	56	1.7	0.094
(CML-144 x CML-159) (RE)	5.93	5.9	56	1.9	0.093
Local Check-1	5.95	7.6	55	1.9	0.050

Rating scale 1-5; 1-completely hard, 5-completely soft

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APPLICATION OF BIOTECHNOLOGY TO MAIZE IMPROVEMENT
Past, Present and Future Prospects

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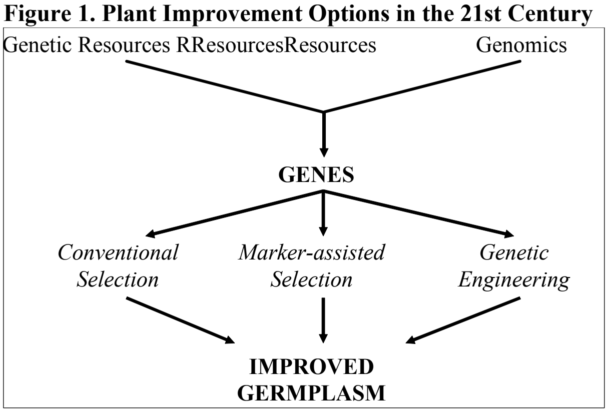
INTRODUCTION

This presentation will provide an overview of the application of molecular genetics, genetic engineering and functional genomics to maize improvement. It is not intended to provide comprehensive coverage for the crop, but to give a few concrete examples of how molecular technology has been useful in the genetic dissection and manipulation of important traits in developing improved varieties.

Today, scientists can take advantage of genes that are derived from various sources, including related and unrelated species, those identified via genetic mapping experiments and most recently from the efforts of functional genomics (the area aimed at understanding the function of all genes in an organism) (Figure 1). Through the application of molecular genetics and genetic engineering, coupled with conventional crossing approaches, these genes can be efficiency incorporated into modern plant varieties.

Molecular genetics, or the use of molecular techniques for detecting differences in the DNA of individual plants, has many applications of value to crop improvement. Such molecular markers, when very tightly linked to genes of interest, can be used to indirectly select for the desirable allele, and represents the simplest form of marker-assisted selection (MAS), whether used to accelerate the backcrossing of such an allele or in pyramiding several desirable alleles. Markers can also be used to dissect polygenic traits into their Mendelian components or quantitative trait loci (QTL), thus

Figure 1. Plant Improvement Options in the 21st Century



increasing our understanding of the inheritance and gene action for such traits, and allowing us to use MAS as a complement to conventional selection procedures. Molecular markers are also used to probe the level of genetic diversity among different cultivars, within populations, among related species etc. The applications of such evaluations are many, including varietal fingerprinting for identification and protection, understanding relationships among the units under study, efficiently managing genetic resources, facilitating introgression of chromosomal segments from alien species, and even tagging of specific genes. In addition, markers and comparative mapping of various species have been very valuable for improving our understanding of genome structure and function and have allowed the isolation of a few genes of interest via map-based cloning.

Molecular marker technology has evolved from hybridization-based detection to new sequence-based systems. Each has their advantages and disadvantages. Restriction fragment length polymorphisms (RFLPs) were the first to be developed (some 15 years ago) and have been widely and successfully used to construct linkage maps of various species, including maize and wheat. With the development of the polymerase chain reaction (PCR) technology, several marker types emerged. The first of those were RAPD markers (random amplified polymorphic DNA) which quickly gained popularity over RFLPs due to the simplicity and decreased costs of the assay. However, most researchers now realise the weaknesses of RAPDs and use them with much less frequently. Microsatellite markers or simple sequence repeats (SSRs), combine the power of RFLPs (co-dominant markers, reliable, specific genome location) with the ease of RAPDs and have the advantage of detecting higher levels of polymorphism. The AFLP (Amplified Fragment Length Polymorphism) approach takes advantage of the PCR technique to selectively amplify DNA fragments previously digested with one or two restriction enzymes. Playing with the number of selective bases of the primers and considering the number of amplification products per primer pair, this approach is certainly powerful in terms of polymorphisms identified per reaction. Most recently, systems that detect single base pair changes (termed Single Nucleotide Polymorphisms) are becoming available. While fairly expensive to develop, requiring sequencing of several alleles, they do detect high levels of polymorphism and can be detected with simple and automated technology.

Approaches to studying the molecular diversity of maize

One of the earliest proposals for the application of molecular markers was to provide unique, genetic "fingerprints" for crop varieties. In the narrowest sense, fingerprinting implies the unambiguous identification of individuals in a population or a set of lines. Such measures of genetic identity are used for assessing duplications within genetic resource collections and for varietal protection, a major concern for the commercial seed industry and, increasingly, for public breeding programs that seek to market research products.

Fingerprinting is most easily applied to homozygous (i.e., genetically uniform) lines. However, through the bulking of individuals or the use of PCR-based techniques, fingerprinting data may be used to classify more genetically diverse materials: populations or groups of related lines, open-pollinated varieties (OPVs), and germplasm bank accessions. Such studies can help elucidate the genetic structure of populations and the overall genetic diversity of a group or groups of lines, as well as shedding light on pedigrees and evolutionary relationships within and between taxa at the genus, species, or other taxonomic levels. Once fingerprinting data are available, such information can be used to develop marker-assisted selection (MAS) strategies. In addition, fingerprinting of genebank accessions allows the identification of exotic alleles of importance for introgression into elite germplasm.

Of particular interest for commercial hybrid maize, fingerprinting profiles may be used to complement pedigree records and, in some cases, confirm them (Smith and Smith 1992). It is also possible to classify closely related lines with unknown or unavailable pedigree records. Finally, fingerprinting profiles provide ways of estimating genetic distances between lines (Melchinger et al. 1990, 1991; Messmer et al. 1993). These provide criteria to support breeders in the creation of genetically unique lines that can be protected against fraud and other infringements on varietal property rights.

In developing countries, little effort has focused on the use of molecular markers to determine the diversity of the germplasm available. Markers have clearly shown that they can accurately determine relationships among maize (Hahn et al. 1995; Dubreil et al. 1996), although their use as predictors of hybrid performance is less clear between heterotic groups (Bernardo 1994), although within a heterotic group, markers can demonstrate high predictability (Melchinger et al. 1992).

Applications to tropical germplasm are limited, but this is an area that should see more emphasis as high-throughput marker systems become available (Warburton et al. 2000; Xia et al. 2000). In maize, comparisons of temperate germplasm to the great diversity in the tropics would provide the baseline information necessary to access the myriad of genes and useful alleles present.

Molecular genetics of drought tolerance in maize

Maize was one of the first major crop species for which a complete molecular marker map was developed (Helentjaris et al. 1986). Since the first publications, many other maps have been produced and are now consolidated into a consensus map using a 'bin' allocation to chromosome segment (Gardiner et al. 1993). Given the high level of polymorphism found even between highly related lines, this consensus map allows one to rapidly identify possible markers for use in further saturating a region of interest, or for developing alternative (e.g., PCR-based) marker systems. Efforts are underway to develop saturated microsatellite marker maps, and maps composed of AFLP loci are available for a number of maize populations. Most recently, efforts are focused on sequencing alleles at numerous loci to develop the information necessary for SNP analyses.

One of the most studied traits at CIMMYT is abiotic stress tolerance, especially tolerance to water-limited conditions. Plants vary tremendously in their ability to withstand abiotic stresses, both between species and within populations of a single species. Abiotic stresses limit crop productivity in every season and in every crop worldwide, yet the nature of tolerance is not well characterized. Understanding the mechanisms of tolerance will have a significant impact on crop productivity (Boyer 1982). In general, tolerance to abiotic stresses is associated with a host of morphological and physiological traits. These include root morphology and depth, plant architecture, variation in leaf cuticle thickness, stomatal regulation, osmotic adjustment, antioxidant capacity, hormonal regulation, desiccation tolerance (membrane and protein stability), maintenance of photosynthesis, and the timing of events during reproduction (Bohnert et al. 1995; Shinozaki and Yamaguchi-Shinozaki, 1996; Bray 1997; Nguyen et al. 1997; Ribaut et al. 2001). The complexity of these responses is not surprising, because plants must be able to tolerate significant variations in temperature and water potential during development. One of the most challenging traits for which to breed among the abiotic stresses is drought tolerance, due in large part to its unpredictable nature. Selected materials need to perform well under both water-limited and well-watered conditions. In addition, establishing optimal environments to select for improved performance under drought is complicated by environmental variation. Furthermore, selection is slowed because there is generally only one dry cycle per year per location.

Loss to drought in the tropics alone is thought to exceed 20 million tons of grain per year, or around 17% of well-watered production (Edmeades et al. 1998), reaching up to 60% in severely affected regions such as southern Africa in 1991-92. The magnitude of these losses has made breeding for drought tolerance a major focus of CIMMYT (for review, see Heisey and Edmeades 1999). Although impressive progress has been achieved through conventional breeding, it should be kept in mind that conventional breeding for yield improvement remains time consuming and laborious, because carefully managed field conditions are required. In addition, there is a decrease in the genetic variance and heritability of yield components that parallels an increase in environmental stress (Ribaut et al. 1997b). Considering these limitations to efficient selection, and that only one relatively rain-free crop season per year is available for selection in most tropical countries, the use of molecular genomics could provide a useful tool to complement phenotypic selection.

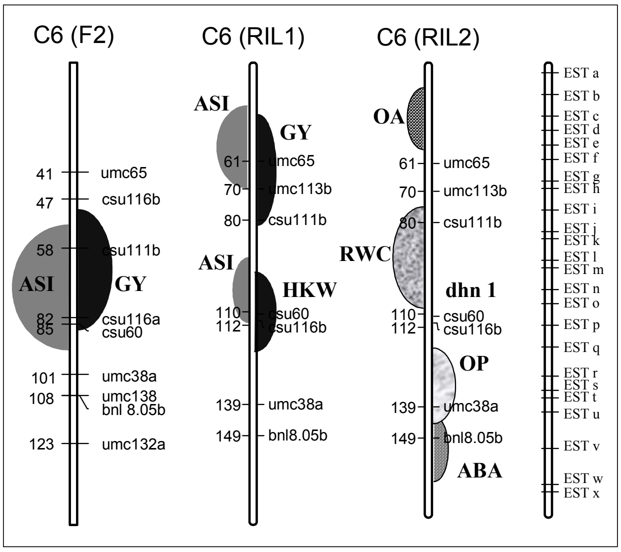
The construction of QTL linkage maps using segregating populations is routine at CIMMYT. During the past seven years, major efforts have been dedicated to the genetic dissection of drought tolerance components in maize under water-stress, before, during, and after flowering. These efforts resulted in the identification of QTLs involved in the expression of yield components and secondary morphological traits of interest, such as ASI. As presented earlier, of primary interest are secondary traits that are correlated with yield and demonstrate segregation with high heritability under water-limited conditions. To date, genetic dissection has been conducted in four different crosses, under different water regimes (WW: well-watered conditions, IS: Intermediate Stress, and SS: Severe Stress conditions) and in several environments (Kenya, Mexico, and/or Zimbabwe).

Much of our past QTL identification has focused on yield components and secondary traits of interest, each important measures for drought tolerance in maize but complex polygenic traits. To more deeply explore, at the genetic level, the maize plant’s response under water-limited conditions, it is necessary to identify the QTL involved in the differential expression of the key physiological pathways that induce the drought tolerance phenotype. To achieve this objective, a recombinant inbred line (RIL) population was developed by single seed descent from F_3 families obtained by crossing Ac7643 with Ac7729/TZSRW. The same morphological traits measured with the F_3 families have also been evaluated on this RIL population. RIL families are more suitable than F_3 families for physiological measurements because they are genetically fixed; on the other hand, they are poor material for evaluation of yield components because they usually demonstrate high inbreeding depression. In addition to the physiological parameters measured in-house, such as relative water content, osmotic adjustment, and chlorophyll content, collaborations with other research groups allowed us to evaluate root growth under hydroponics (Roberto Tuberosa, Bologna University), quantify the ABA content in the ear at the flowering stage (Tim Setter, Cornell University), and evaluate the photosynthetic apparatus and dehydration phenomena under low temperature conditions (Yvan Fracheboud, Institute of Plant Sciences ETH, Zurich). Identification at the same genomic location of QTL related to physiological and morphological traits should be expected, given that changes in physiological pathways have an impact on the plant phenotype. As an example from our first field evaluation, a QTL for chlorophyll content was identified on chromosome 2, near a QTL for ASI (under IS and SS) and grain yield (under IS only). This QTL for chlorophyll content was consistent when measurements were conducted on the ear leaf and on a young leaf close to the tassel. On chromosome 6, a QTL for relative water content corresponds exactly to a QTL for ASI (under IS and SS) and grain yield (under IS and SS). At the same chromosomic region, the identification of a dehydrin gene (*dhn1*) has also been reported (Campbell and Close 1997). Since several physiological pathways involved in the drought tolerance mechanism are well known (e.g., ABA biosynthesis), the characterization of the gene(s) corresponding to identified QTL can be achieved, making the candidate gene approach an attractive option.

Based on the QTL and mapping information, a backcross marker-assisted selection (BC-MAS) project was initiated in 1994. The line P_1 (Ac7643) was used as the drought-tolerant donor line and CML247 was used as the recurrent parent. CML247 is an elite tropical inbred line developed by CIMMYT, with outstanding combining ability and good yield per se under well-watered conditions. It is susceptible to drought, in part because its ASI is large under drought. Genetic data from a segregating F_2 population derived from the $P_1 \times$ CML247 cross were combined with F_3 evaluations in the field under different water regimes to identify QTLs for traits of interest. The QTLs for ASI identified in this cross were quite consistent with those in the original $P_1 \times P_2$ cross. Of the five QTLs originally identified from P_1 that conferred a short ASI, only the QTL on chromosome 6 was not detected in the second cross. The QTL on the short arm of chromosome 1 was shifted by 40 cM in the new cross, and the three other QTLs on chromosomes 2, 8, and 10 were in similar positions in both. A new QTL for ASI was detected on the short arm of chromosome 3. These results demonstrate the need to make a new genetic map when the recurrent line is changed in BC-MAS schemes. A single good-quality trial under drought conditions, however, might be sufficient for identifying QTLs of interest, providing QTL identification has been previously carried out in another cross involving the donor line.

Five genomic regions involved in the expression of a short ASI were selected to be transferred from P_1 into the CML247 genome. The screening of large populations (about 2,000 plants) at each selection cycle during backcrossing has been possible because of the development of reliable PCR-based markers, used here as preselection

Figure 2. Comparative maps for drought tolerance in maize



tools (Ribaut et al. 1997a). After two BCs and two self-pollinations, the best genotype was fixed from the donor line for the five target regions (12% of the genome), as well as for 7% of the genome outside the QTL regions (Fig. 2). The 70 best BC_2F_3 (i.e., S_2 lines) were identified and crossed with two CIMMYT tester inbreds, CML254 and CML274. These hybrids, as well as the BC_2F_4 families (S_3 lines) derived from the selected BC_2F_3 plants, were evaluated in 1998, 1999, and 2000 under several water regimes. Results show that under stress conditions that induce a yield reduction of at least 80%, the mean of the 70 selected genotypes performed better than the control crossed with CML254 and CML274. In addition, the best genotype among the 70 selected ($BC_2F_3 \times$ testers) performed two to four times better than the control. This difference became less marked when the intensity of stress decreased; for a stress inducing less than 40% yield reduction, hybrids resulting from the MAS or developed with the "original" version of CML247 performed the same. Although which genotypes performed best depended on the stress intensity, few of the genotypes always performed significantly better than the controls across the six water-limited trials. No yield reduction was observed under well-watered conditions.

Through the recent development of genomic technologies that provide structural and functional information (Habben et al. 1999), gene characterization (i.e., the localization, sequence, and expression framework of a gene) has received a significant boost during the last few years. To date, if one tries to establish a list of candidate genes for drought tolerance based on gene function, hundreds of genes can easily be listed (Skriver and Mundy 1990; Bray 1993; Ingram and Bartels 1996; Cushman and Bohnert 2000). The questions now are how to prioritize research aimed at characterizing the genes involved in the drought-tolerance process, and once those genes are characterized, how to identify and efficiently manipulate the elite alleles at those target loci to improve a given variety. The first question must be addressed principally by the research groups conducting basic genomic research. Of course, establishing such priorities is more or less a function of the available resources and research objectives of a group. The recent discovery of promoter regulatory elements, like DRE (dehydration-responsive element) or ABRE (ABA-responsive element) involved in both dehydration- and low-temperature-induced gene expression in *Arabidopsis* (Shinozaki and Yamaguchi-Shinozaki 1996), as well as the identification of transcriptional factors interacting with those promoters (Liu et al. 1998), are exciting developments. The characterization of the genes involved in the initiation phase of the stress response (e.g., genes encoding for stress-induced transcription factors) should be a logical priority, since they represent the "upstream keys" to global genomic responses that might involve hundreds of genes. Moreover, once they have been identified, expression of these key genes should serve as a "timing reference" to identify expression products from downstream genes involved in stress responses. This can be achieved using microarray technology, as described by Chu (1998).

Recent work has shown how different genes can provide new clues to understanding stress tolerance in plants (Shinozaki and Yamaguchi-Shinozaki 1996). They actively play a role in the biosynthesis of various osmoprotectants (Tarczynski and Bohnert 1993), modification of cell membrane structure (Kodama et al. 1994), and sometimes code for enzymes that detoxify plant cells. Analyses of the expression of dehydration-induced genes have shown that at least four independent signal pathways function in response to dehydration. Two are abscisic acid (ABA) dependent (Abe et al. 1997; Chandler and Robertson 1994), and two are ABA-independent. Several stress-induced genes, such as *rd29A*, are induced though the ABA-independent pathway. The *rd29A* gene in particular is responsible for dehydration and cold-induced expression (Yamaguchi-Shinozaki and Shinozaki 1994). Expression of the *DREB1A* gene, under constitutive promoters such as CaMV 35S, leads to strong increases in tolerance to abiotic stresses; however, it also induces growth retardation under normal growth conditions (Liu et al. 1998), raising concerns about its possible use in plant breeding. However, plants produced using the stress regulated *rd29A* promoter demonstrated increased tolerance to freezing, salt and water limited stresses, without producing changes in the normal phenotype of the transformed plants. One way to validate these candidate genes is to introduce them into a genotype via genetic engineering and test if the plant's tolerance to water stress has been improved. This approach has been followed at CIMMYT to evaluate and characterize the effect of the *DREB1A* gene under water-limited conditions when introduced into wheat germplasm.

At the 4-leaf stage, the T1 plants were subjected to water-limited stress by withholding water. The wheat lines started to show differences in the wilting of the leaves after 10 days without water. Controls started to show water-limited symptoms (loss of turgor and bleaching of the leaves) after 10 days of stress, and severe symptoms (e.g., senescence of all leaf tissue) were evident in the control samples after 15 days without water, while the transgenic plants either showed no or reduced symptoms. These preliminary results suggest that the *rd26::DREB1A* gene has a general effect on tolerance to water-limited conditions. Whether this tolerance is attributable to reduced evapotranspiration of the transgenic plants or differential regulation of the water status in the cell (e.g., osmotic adjustment) clearly needs to be determined through future physiological measurements on both the control and the transgenic plants.

The future application of biotechnology in plant improvement

What is in hold for the future? While always difficult to predict, there are some significant developments in marker technologies and functional genomics worth mentioning. While the PCR-based marker systems have allowed more effective and efficient genotyping, DNA-array technology offers to substantially increase the number of genes that can be analysed (Shalon 1995; Schena et al. 1995; Shalon et al. 1996). Currently, the cost of the arrayer (to develop the chips containing the desired genes), the array reader (to detect the presence of each gene) and a set of gene sequences (to develop primers to be arrayed), have limited the application of this new technology. Both the arrayer and reader are decreasing in price and this will make this technology available to many laboratories in the near future. Efforts are also underway to develop complete EST databases for many cereals including maize and wheat. If this data can remain in the public sector, chips containing a significant number of cereal genes will be produced and used in the not too distant future.

Marker-assisted selection for polygenic trait improvement is in an important transition phase, and the field is on the verge of producing convincing results. Considering the potential for the development of new strategies (Ribaut & Hoisington 1998), the future for polygenic trait improvement through DNA markers and the contribution of this to plant breeding efforts worldwide appear bright.

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REVIEW OF MAIZE MARKETING IN KENYA: IMPLEMENTATION AND IMPACT OF LIBERALISATION, 1989-1999.

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ABSTRACT

Maize is the key food crop in Kenya, with estimated production (1998) of 3 million tons of which about 40% are marketed. The Government strictly controlled all aspects of maize marketing until 1986 when gradual liberalisation started and this was completed in 1995. The objective of this study is to assess the degree of policy implementation and the impact of liberalisation of maize marketing on stakeholders between 1989 and 1999. The method of the study included review of available literature, conduct of interviews with stakeholders and the authors' personal observations of maize marketing activities. Results indicate that liberalisation was implemented without the formation of alternative marketing institutions. Also, maize prices fluctuated substantially according to competitive market forces with limited moderating effects from the Government through open market interventions and import tariffs. But soon the rules of regional and worldwide trading organisations will render this impossible. Private sector participation at all levels in the marketing system increased substantially. There is easy maize flow and supplies to all parts of Kenya. One recommended intervention is to form maize farmer-based institutions for the marketing of maize, provision of maize market information and credit. Further studies should assess the impact of liberalisation and continued regulation of maize imports on producers and consumers.

Keywords: Maize, marketing, Kenya, liberalisation, policy analysis.

INTRODUCTION

An Overview of the Maize Sector in Kenya

Maize is the key food crop in Kenya, constituting 3% of Kenya's Gross Domestic Product (GDP), 12% of the agricultural GDP and 21% of the total value of primary agricultural commodities (Government of Kenya, 1998). Maize is both a subsistence and a commercial crop, grown on an estimated at 1.4 million hectares by large-scale farmers (25%) and smallholders (75%). As shown in Figure 1, the total average annual production of maize between 1988 and 1998 was 2.3 million metric tons fluctuating from 1.7 million metric tons in 1993/94 to 3.14 million tons in 1988/89 (Government of Kenya, 1998; Argwings-Kodhek, 1998; Nyangito, 1997). Approximately 40% of maize produced in Kenya is marketed while the balance is used for subsistence.

Figure 2 shows the main maize surplus and deficit districts of Kenya. The major maize surplus areas are in the Rift Valley Province (Nakuru, Nandi, Kericho, Uasin Gishu and Trans Nzoia). These areas account for about 95% of the total marketed maize in Kenya. Other surplus areas include Western, Nyanza and parts of Eastern Provinces. Most arid and semi-arid lands (ASAL) of Eastern, North Eastern, Coast and Northern Rift Valley are perennial deficit areas in maize production. The Government strictly controlled all aspects of maize marketing until 1986 when there was a major policy shift towards liberalisation that was completed in 1995. State corporations that controlled maize marketing were reduced to "buyers and sellers of last resort" and were kept for maintaining strategic reserves. The general shift in policy was a trend in Eastern and Southern Africa countries that had strictly regulated the marketing of maize.

Objectives of the Study

The main objective of this study is to understand the trend, implementation and impact of liberalisation of maize marketing in Kenya between 1989 and 1999. This period covers a period of gradual liberalisation (1989-1995) and full liberalisation (1995-1999).

METHODS OF THE STUDY

This study used three different sources of data. The key source is the extensive literature on maize marketing before and after liberalisation (Appendix 1). The literature was

Figure 1. Maize production and trade in Kenya 1976-96.
(Source: Govt. of Kenya, Statistical Abstracts 1976-1998)

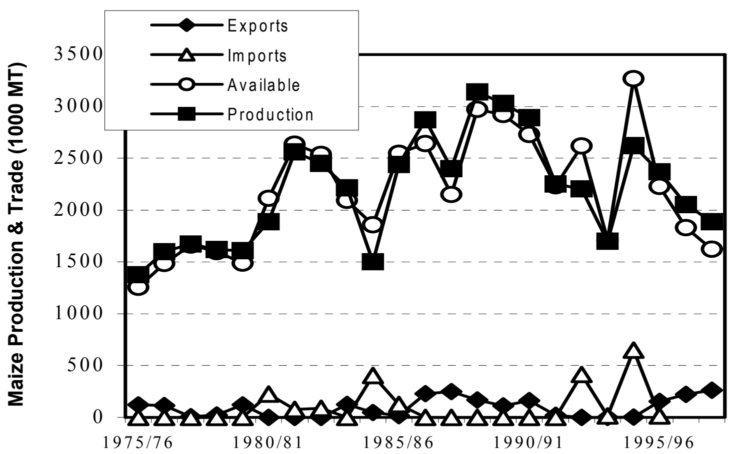


Figure 2. Maize Surplus and Deficit Districts of Kenya, 1998 (Source: Authors' design using data from Government of Kenya, Statistical Abstracts 1998)

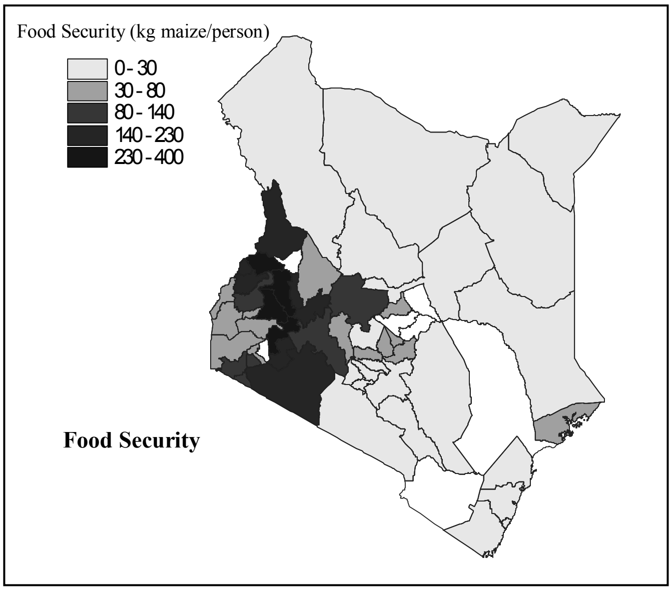


Table 1: Trends in Liberalisation of Maize Marketing in Eastern and Southern Africa

Country	Institution Controlling Maize Marketing	Monopoly control Period	Gradual decontrol period	Year of Full decontrol
Kenya	NCPB	1930s - 1986	1986-1995	1995
Ethiopia	AMC	1974-1990	1990-1995	1995
Mozambique	AGRICO, ICM	1930s-1990	1990-1995	1995
Malawi	ADMARC	Before mid 1980s	mid 1980-mid 1995	Mid 1990s
Tanzania	NMC, FSA	Before mid 1980s	1980-mid 1995	Mid 1980s
Zambia	State Board, FRA	Before early 1990s	Early 1990s-1995	1995
Zimbabwe	GMB	Before 1989	Partial control 1990s	partial control since 1990s
Uganda	none	No Controls	No controls	No controls

Source: Various Reports as cited in text.
ADMARC- Agricultural Development and Marketing Corporation
AMC - Agricultural Marketing Corporation
FRA - Food Reserve Agency
GMB- Grain Marketing Board
ICM- Instituto de Cereais de Mozambique
NCPB- National Cereal and Produce Board
NMC- National Milling Corporation

intensively reviewed to critically assess the implementation and impact of liberalising maize trade. The other main source was oral discussions with various stakeholders (policy makers, agricultural specialists, university students, traders, millers, transport agents, farmers and consumers) during informal and formal gatherings and sessions. The discussions were assessed on the basis of the general impression of the respondents. The third source of information was based on the authors' general observations of marketing events and issues before and after the liberalisation. Their views were assessed on the basis of what was expected and what they observed and their personal conclusions of what they observed. The information collected was analysed using descriptive methods, trend analysis, tables and geo-mapping to evaluate trends, status and degree of implementation and impact of liberalisation.

RESULTS OF THE STUDY

Liberalisation of Maize Marketing in Eastern and Southern Africa:

This section reports on trends in the control and liberalisation of maize marketing in Eastern and Southern Africa. As shown in Table 1, there are great similarities in the trends in the marketing of maize in the region, except for Uganda and Zimbabwe.

Franzel et al. (1992) and Legesse et al. (1992) reported that before the Ethiopian revolution in 1974, the marketing of maize was dominated by the private sector (70%) while retailers and consumers handled 30%. However, in 1976 the Ethiopian Government established the Agricultural Marketing Corporation with the mandate to buy and distribute maize and tef at fixed prices. In 1987 the Corporation purchased 570,000 tons of grain, 30-40% of the nation's marketable surplus. Concurrently, the role of private sector was sharply curtailed. By the late 1980s it was evident that the marketing system was inefficient, inequitable and resulted in chronic food shortages. As a result, in 1990 Ethiopia liberalised grain marketing, although the state still retains a significant role in grain production and marketing.

In Kenya, Mozambique, Malawi, Zambia and Tanzania, the state monopolised maize marketing through Statutory Marketing Boards from the colonial era till the mid-1980s. Between mid-1980s and 1995, the sector was gradually liberalised. After 1995, the sector was fully liberalised while retaining the statutory Boards with the role of maintaining strategic food reserves and market moderation (Ackello-Ogutu and Echessah, 1997, 1998; Minde and Nakhumwa 1998; Jayne et al., 1999; DAI 1989; Guantai, 1993; Nyangito, 1998; Argwings-Kodhek, 1999a). Zimbabwe has continued to control maize marketing through a statutory Board while Uganda has never controlled the maize sector.

Maize Marketing in Kenya before Liberalisation, 1989

The Development Alternatives, Inc. (DAI) study of 1989 provided a thorough exposition of the maize marketing status up to 1989 and set the stage and strategies for the liberalisation of the sector under the Kenya Market Development Program (KMDP) funded by USAID. The review of the maize marketing status before the liberalisation is based on the DAI report of 1989.

Table 2: Milestones in the Reform of Maize Marketing in Kenya, 1940s-1999.

Period	Role Of Government And Other Agencies In Maize Marketing	Outcomes
1940s-1963	Strict control of maize price, movement and storage Under the MCB.	Stable prices and incomes to white settlers in the highlands, assured market
1963-1979	Strict control of maize price, movement and storage under the Maize Marketing and Produce Board	Stable prices over the whole country and over time, stable incomes to all maize farmers, food security
1979-1986	Strict control of maize price, movement and storage under the National Cereal and Produce Board.	Stable territorial and seasonal prices over the whole country and over time, stable incomes to all maize farmers, food security Financial losses.
1986-1990	Limited relaxation of control of maize price, movement and storage under the National Cereal and Produce Board. First serious market reform under the CSRP conditional to EEC/WB aid	EEC/WB aid to Kenya. Stable incomes to farmers. Uniform territorial and seasonal prices. Food security. Financial losses by NCPB Gradual reduction of movement controls.
1990-1995	Gradual reduction of control of maize price, movement and storage under the National Cereal and Produce Board. Market reform under the CSRP/KMDP conditional to aid Foreign exchange liberalisation Multi-party politics legal	EEC/WB and USAID aid to Kenya. Unstable territorial and seasonal prices. Unstable incomes to farmers Mixed results of food security. Financial losses by NCPB. Delayed payment to farmers by NCPB Ksh devalued from 32 to 80/$. Many political parties formed.
1995-1999	Full liberalisation. NCPB buyer and seller of last resort. Private sector participation increased. Government intervenes- tariff & financing NCPB. WB condition for aid.	Mixed market outcomes. Territorial & seasonal prices market determined – unstable. Mixed results of food security. Limited loss of public funds. Lack of awareness on market reforms. Limited registered market institutions. Limited market information.

Kenyan policy towards maize marketing has gone through a series of distinct periods as indicated in Table 2. The colonial government tightly controlled the maize sector to provide economic support to white settler farmers in the Kenya highlands. After independence in 1963, this control was maintained for another 27 years for several reasons (DAI 1989; Guantai, 1993). First, the control guaranteed an orderly and efficient marketing with a reasonable balancing and stabilising of producer and consumer prices.

Second, the control assured food security through strategic reserves by the state boards. Third, the controls ensured regulated domestic movement of maize with strict management of imports and exports. Implicitly the state had a "social contract" with the majority of citizens to ensure the supply of maize at cheap and stable prices (Jayne, et al., 1999).

Maize marketing during the pre-liberalisation era consisted of the formal and informal systems operating side by side. The formal maize marketing system was strictly regulated and managed by the National Cereal and Produce Board (NCPB), the successor of two previous maize boards. The informal system was free, unregulated and unofficial with many market participants operating parallel to the formal system (Schmidt, 1979; and DAI 1989).

The NCPB did not provide a sure outlet for maize of all farmers and did not supply maize to many of the rural areas. The vacuum left by the Board was the niche and opportunity that the informal system filled. The informal system that had an extensive network of rural markets and traders handled 50-60% of all marketed maize in Kenya, despite the strict movement and price controls (DAI, 1989). The formal maize marketing system was mandated to purchase all maize offered for sale. This amounted to 50% of all marketed maize in the country and 25% of total domestic maize production. The Board operated through a network of Primary Marketing Centres (PMCs) purchasing (21%), cooperative societies (23%), agents (3%), and individual farmers delivering directly to the Board (53%). The Board stored the maize in a network of 90 depots located in the major towns of Kenya. The maize was subsequently resold to the few registered millers of sifted flour, traders and consumers at controlled prices.

The monopoly and monopsony powers of the NCPB made maize the property of the state once harvested. In addition, the Board controlled maize movement through the use of movement permits that had to accompany any shipment of maize of more than one bag (90kg). This was increased to ten 90 kg bags under the Cereal Sector Reform Program (CSRP) in 1988/89. The permits were costly and time-consuming and cumbersome to procure and were a source of corruption and political influence.

The Government set the prices of maize at various levels of the marketing system from producers, traders, NCPB, millers, wholesalers and consumers. The basis of pricing was cost of production and marketing and world prices. The announced prices usually lasted twelve months corresponding to one crop year from July to June. The difficult question was to determine the "right price". Furthermore, the uniform seasonal price policy did not offer any incentive to either farmers or traders to hold stocks to be sold later in the crop year, except in the informal and illegal trade.

The NCPB's monopoly powers, inefficient management and the suppression of normal market function and private sector involvement resulted in a number of problems. They included poor stock management and under-utilisation of storage capacity, excessive management and transportation costs, excessive debt, and inability to pay farmers promptly for deliveries. It became evident that the controls were costly to the Government, while providing excessive margins to a few privileged market participants. The operating losses in 1986/87 were about KSh 1.8 billion in addition to losses of KSh 3.5 billion incurred in the previous five years. These losses were written off in 1988 under the CSRP. These losses and inefficiencies were the basis for many studies and liberalisation. Initially, the Government resisted liberalisation arguing that maize was a strategic food that could not be entrusted to the private sector. In addition, the Government feared the exploitation of farmers and consumers by traders. Policy makers believed that liberalising maize marketing would lead to price and supply instability and uncertainty, possibly leading to food riots and political unrest and adverse political repercussions of the liberalisation. Thus, the Government would retreat on the reform process. Even then, the DAI (1989) study designed the policy agenda for the liberalisation of the maize sector under the KMDP. The GOK agreed to start price and movement decontrols immediately, but gradually. In turn, the KMDP would reinforce longer-term adjustments in the formal sector together with the EEC and World Bank.

Implementation and Impact of the Liberalisation Program, 1989-1998.

The liberalisation of maize marketing was implemented in four major areas:

- Elimination of the movement controls on maize
- Reduced food security stock and price stabilisation roles of the NCPB.
- Institutionalisation of Government units for improved market information and food security policy planning.
- Implementation of three changes in Government policies affecting road construction and maintenance, to ensure future sustainability of the key market-to-market linkage roads, the upgrading of which would be financed with local currency funds under the KMDP.

The implementation of the liberalisation of maize marketing was a major component of the economic recovery program (ERP) in the 80s and 90s. The EEC and World Bank supported the Cereal Sector Reform Program (CSRP). The liberalisation was further supported by USAID under the KMDP from 1989, although significant implementation started in 1993. Implementation of the liberalisation process by the Government during the 1990s was gradual and on course. This was because of the donor condition of tying donor lending and support to liberalisation (Nyangito, 1998; Argwings-Kodhek, 1999b). For the same reasons, the reforms are still intact although the Government, through the NCPB, has tended to renege on a number of issues as reviewed below.

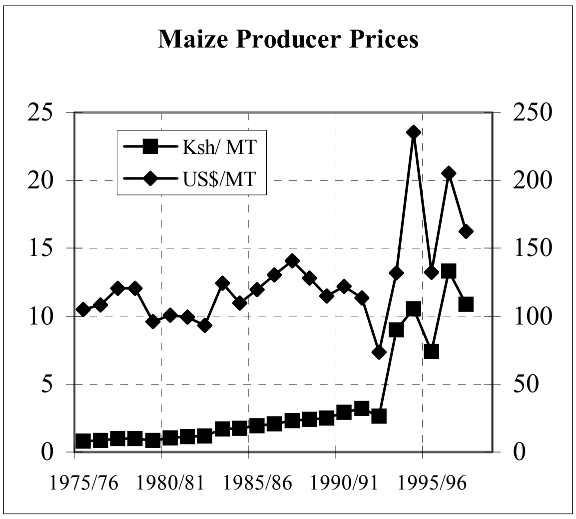
The removal of controls of maize movement was politically acceptable to the GOK and was fully and gradually implemented over three years. Until 1988 the limit was one 90 kg bag of maize. This was increased to ten 90 kg bags in 1989/90, then to forty four in 1990/91, eighty eight bags in 1991/92 and complete decontrol after 1993 (Gordon and Spooner, 1992; Nyoro 1992; Omamo, 1995; Argwings-Kodhek, 1992). There was mass media publicity by the GOK utilising funds from KMDP. A special campaign was targeted at District Administration and police to ensure that they did not interfere with the movement of maize within and outside their districts.

As a result there were more market outlets, improved distribution and availability of maize in all parts of Kenya (Mutahi, 1996; Nyangito, 1997 and 1998; Nyangito and Ndirangu, 1997; Argwings-Kodhek, 1998). Argwings-Kodhek (1998) reported that 59% of Kenyan households reported better availability of maize in the post-liberalisation era, 31% in the pre-liberalisation era and 10% saw no change in availability. On convenience of selling maize, 88% of the households preferred the present system, 7 % the old system and 5% saw no change. Overall, 61% of households prefer the present system, 34% the old system and 5% saw no change. A key impact on the maize market of decontrolling maize movement was the reduction in the costs of transportation since economies of scale were realised with larger volumes (Omamo, 1995). In addition, the number of private sector participants and fair competition increased substantially. This also improved income redistribution in the country. However, the strict conditions of delivering to the NCPB discouraged farmers from selling maize to the Board.

De-control of Prices of Maize

Figure 3 shows the movement of maize prices paid to farmers by the NCPB before and after the decontrol, 1976-1996. Prices of maize and products at all levels in the marketing channel were decontrolled fully in 1995. There was substantial price increase and fluctuation in the post-liberalisation era (1994-98). There were wider disparities between the open market prices in deficit and surplus areas (Nyangito, 1997). In 1995 prices offered outside the NCPB were relatively lower (KSh 400 to 550) than the floor price of KSh 600 per 90 kg bag set by NCPB (Nyangito, 1997). Consumer prices showed a similar trend, although they were higher than producer prices, except in 1996 when they were lower.

Figure 3. Movement of Maize Prices Paid to Farmers by the NCPB before and after the Decontrol, 1976-1996.
Source: Government of Kenya, Statistical Abstracts 1976-1998



As shown in Table 3, import parity prices increased rapidly from KSh 550 per 90 kg bag in 1992 to KSh 1,190 in 1993. These declined to KSh 1,141 and KSh 798 in 1994 and 1995, respectively, due to large global supplies. Import parity prices rose to KSh 1,376 in 1996. This price movement during these years benefited mainly urban consumers and farmers and consumers in deficit areas. Conversely, producers in surplus areas and consumers in deficit areas suffered. Despite the higher price offered by NCPB, only 36% of marketed maize was sold through this outlet compared to 64% in the private sector. The strict NCPB conditions of 100% clean maize, dusted with insecticide, in new bags and with moisture content of 12% discouraged farmers from selling maize to the Board.

Table 3: Domestic and Import Parity Prices for Maize in Kenya KSh /90kg bag.

Year	NCPB Producer Price Ksh /bag	NCPB Selling Price Ksh /bag	CIF Mombasa Ksh/bag	Import parity price in Nairobi Ksh /bag*
1992/93	470	742	508	651
1993/94	810	877	966	1190
1994/95	950	1231	850	1141
1995/96	600	690	640	798
1996/97	1200	810	1213	1376
1998/99	1280	1500	989	2147**

* CIF plus import duty (currently at 25% plus 50% suspended duty) plus port charges See Appendix 1.
Source: Nyangito, H. 1998. Towards Maize Security In Kenya: An Evaluation of the self-sufficiency Strategy; **G. Argwings-Kodhek, 1999a. Policy Issues Facing the Maize Sector in the North Rift

Despite the fact that "price" is an important factor in production, marketing, processing and consumption, there are no proper mechanisms and forums for setting the price of maize. Various stakeholders try to optimise prices through political pressure and noise, threats and advocacy without objective and factual justification for the prices demanded. Indeed, stabilisation of producer maize prices remains a big riddle due to instability in production and uncertainty in market outlets. (Nyangito, 1997 and 1998; Argwings-Kodhek, 1999a; Nyoro, 1992). Nyangito (1997) has suggested the use of buffer stock, buffer funds and compensation funds to deal with price fluctuation.

Argwings-Kodhek, (1998 and 1999a) indicated that the majority of maize producers prefer the liberalised marketing system to the controlled one. The system is easy, free, and payment is prompt. The conclusion is simplistic since preference depends on market condition i.e. seasonal and spatial prices, national and global maize supply and demand levels and other buyers and sellers in the market.

Customs Duty and Maize Trade

Until 1996 duty on imported maize was 15%, but this was increased to 25% in that year. In addition, suspended duty of 50% could be invoked by the Minister of Agriculture whenever necessary, which is tantamount to banning imports. Import duty, port charges and internal transport charges contribute 54% of the total FOB price of imported maize in million bags of maize to last 3 months (Argwings-Kodhek,1999b). It is argued that holding 3 million bags is unnecessary and expensive (KSh 400 per bag per year). Nairobi. But soon the rules of regional and worldwide trading organizations (EAC, COMESA and WTO) will render this impossible and pose a big threat to the existence of the Kenyan maize producers, unless they are cost effective. There is usually an easy flow of maize from Uganda (Nobera 1999) and Zimbabwe to Kenya or Kenya to Tanzania and vice-versa (Nyangito, 1997; Ackello-Ogutu and Echessah, 1998) that would pose a problem to the Kenyan maize farmer, unless the Government and farmers prepare for the competitive situation ahead. So far farmers and the Government are not preparing and accepting this fact of free trade.

Dissemination of Maize Market Information

Under the KMDP, market information was to be provided to stakeholders in the maize sector. This was implemented until 1995 when it was discontinued. Thus, availability of accurate information to producers, market participants and consumers remains a problem. This situation causes uncertainty in the market, leading to unjustified political noise, uneven distribution of maize in deficit and surplus areas and wide disparities between open market prices in deficit and surplus areas (Nyangito, 1997). Currently, maize prices in 15 major towns in Kenya are published once a week in the newspaper. There is an additional need for market information at the village level for farmers to make informed production, marketing and consumption decisions.

Private Sector Participation in Maize Marketing

Private sector participation in maize marketing has increased substantially although its impact has been limited by policy unpredictability. The Government still influences maize prices and imports, albeit on a sporadic basis. The private sector is left with great uncertainty, particularly about the pattern of seasonal and spatial prices. As a result, storage activities have been limited largely on-farm by small and medium producers (PAM, 1997; Sasaki, 1997). On the other hand, the private sector participation in the movement of maize is tremendous (PAM, 1997). Currently, private commodity dealers and millers serve most parts of Kenya, unless the area lacks purchasing power, such as in the current situation in Turkana.

In the milling sector the impact of liberalisation was more pronounced with large numbers of millers of sifted and whole maize flour becoming established in rural and urban areas. The severe competition of private posho millers has forced big millers of sifted flour to lower their prices in Kenya. In addition, maize milling by posho mills is more efficient and the flour is nutritious (PAM, 1997).

Food Security and Social Welfare

During the pre-liberalisation era, the NCPB maintained a strategic maize reserve and traded over 30 million bags of maize a year. In the post-liberalisation era, the NCPB maintained strategic reserves that varied between 3 and 6 million bags. The current policy is for a strategic reserve of 3 million bags that can last 3 months while awaiting imports and US$ 60 million that can be used to import another Importing maize from South Africa, Zimbabwe and high seas takes about 2 weeks and another 2 weeks for domestic transportation to various parts of the country. Thus, strategic reserves could be easily reduced to 1 million bags, thereby reducing costs of holding large strategic reserves. In any case, strategic reserves are used to raise unduly the producer prices rather than lower consumer prices. The high prices tend to benefit political elites at the expense of consumers.

CONCLUSION AND RECOMMENDATIONS

The review of literature shows clearly that the liberalisation of maize marketing in Kenya has made great strides. The expected liberalisation has been institutionalised at all levels in the marketing system. Overall, most authors agree that consumers have benefited from the lower prices of sifted and whole maize flour. In addition, consumers accessed numerous posho mills that serve mainly the poor (Jayne and Argwings-Kodhek, 1997). It is acknowledged that liberalisation adversely affected the food security status of the poor in the short-term (Carter ed., 1993). There was an upward shift in the food prices in urban areas. There is no evidence to show that liberalisation increased incomes of the poor. Even so, there is increasing awareness of the legitimacy of the difficult options of liberalisation that are short-lived. The short-run safety nets for the vulnerable groups are difficult to distinguish from the politically vocal groups who make claims without justification (Argwings-Kodhek, 1999a).

The Government continues to pursue the policy of self-sufficiency and food security through the protection of poor inefficient producers and boosting profits of the relatively well-endowed efficient producers through levying high import duties and bans. In this regard many poor consumers suffer.

During the post-liberalisation era the pruning of the role of the NCPB in the market left a big institutional vacuum. This situation is repeated every year immediately after the harvest of maize when unregistered producers haphazardly call on the Government to ban maize imports. Also there is an outcry by maize farmers every year about the high prices of fertilizers, poor seed and lack of credit. In this regard, there is a clear need for individual strong institutions of farmers that can articulate the views of their respective farmers, facilitate proper maize marketing, pricing, procuring fertilizers and, financing of their activities. In addition, there are limited vertical linkages between producers, traders, millers and consumers. Such linkages are beneficial as they increase market transparency and effectiveness.

There is a need to establish or strengthen institutions that would have the responsibility of: making orderly presentations of their views at various forums, negotiating prices, imports and exports with other stakeholders, storing, transporting and marketing maize and realising economies of scale and bargaining power, procuring bulk farm inputs and avoiding farmers being exploited by suppliers, establishing and arranging credit facilities for members instead of relying on the Government and commercial banks, and educating stakeholders on the imminent free trade era that is coming with economic integration of EAC, COMESA and WTO.

There is a need to bring awareness to stakeholders on the need of institutions and facilitate and coordinate their establishment. The Government, KARI, CIMMYT and NGOs such as Winrock International can address this issue.

Finally, stakeholders in the maize sector lack adequate market and marketing information that they require for decision-making. Many of the allegations, outcries and political noises about the status of the maize sector are often baseless and unjustified. In this regard, regular collection and analysis of information on the maize sector would benefit the stakeholders. In particular, information on maize supply, demand, price, imports, exports, relief supplies, tariffs and stocks over time and space should be regularly available to stakeholders.

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APPENDICES

Appendix 1: Calculation of Import Parity Price of Maize FOB Nairobi, 1999.

COST ITEM	COST PER TON	COST KSH/90KG BAG
Shipment load of 25,000 ton	**US$**	
FOB Durban, South Africa	130	877.57
Shipping	15	101.26
C&F	145	978.85
Insurance	1	9.79
Total CIF Mombasa (On shore)	**146 Ksh 10,984)**	**988.64**
	KSh	
CIF Mombasa	**10,984**	**988.64**
Import duty @ 25%	2746	247.16
Suspended duty @ 50%	5492	494.32
Total duty	**8238**	**741.48**
Pre-inspection 2.7%	302	27.19
Port charges US$5+15%Vat	431	38.82
Stevedoring US$ 15+15% VAT	1294	116.45
Clearing and Forwarding 1%	110	9.89
Importation charges	**2,137**	**192.34**
CIF+Duty+Import charges Mombasa	**21,357**	**1,922.45**
Transport to Nairobi	2,500	225.02
FOB Nairobi Nov 1999	**23,858**	**2,147.46**
NCPB Producer price at all depots		**1,188**

Source: Argwings-Kodhek, December 9 1999.

Appendix 2: Total Maize production, Marketed Production, Exports, Imports, and Producer Prices, 1975/76 to 1995/96.

Year	Total Production 000mt	Marketed Production 000mt	Value Of Marketed Production K F Million	Exports 000mt	Imports 000mt	Producer Prices Per 90kg Bag	
						KSH	US$
1975/76	1375	487		121	0	70	9.46
1976/77	1597	565		113	0	77	9.75
1977/78	1671	424		8	0	88	10.86
1978/79	1620	330		23	0	89	10.85
1979/80	1607	242		120	0	77	8.65
1980/81	1888	218		0	224	95	9.05
1981/82	2560	473		1	77	100	8.93
1982/83	2450	571		1	89	107	8.41
1983/84	2215	637	34,028	123	0	154	11.19
1984/85	1500	561	29,990	47	405	156	9.89
1985/86	2440	583	31,187	18	125	175	10.75
1986/87	2870	670	36,066	228	1	188	11.72
1987/88	2400	652	35,120	248	0	209	12.66
1988/89	3140	485	26,141	167	0	214	11.51
1989/90	3030	626	69.89	110	0	223	10.32
1990/91	2890	509	69.05	160	0	264	10.96
1991/92	2253	304	46.37	19	0	287	10.22
1992/93	2205	515	76.93	0.42	415	239	6.60
1993/94	1698	242	97.96	0.11	13	810	11.88
1994/95	2621	316	150.08	1.7	650	950	21.19
1995/96	2370	401	160.38	154	12	665	11.89
1996/97	2052	296	155.9	221		1200	18.46
1997/98	1887	205	140.5	264		980	14.63

Source: Kenya Government, *Statistical Abstracts*, various issues up to 1996; Kenya Government, *Economic Survey,* various issues up to 1998.

Appendix 3: Studies on Maize Marketing in Kenya, 1989-1999

YEAR	AUTHOR	TITLE	MAJOR ISSUES	RECOMMENDATIONS/ OUTCOME
1989	DAI	Economic and Social Soundness Analysis for the KMDP	Maize marketing sector was highly controlled. The sector was inefficient. There was need for decontrol.	Liberalisation of the sector. Support to the infrastructure and market information under KMDP
1992	PAM, Egerton University	Proceedings of Conference on "Maize Supply and Marketing Under Market liberalisation"	Decontrolled maize movement from 1 bag in the 1980s to 10, 44, 88 and then infinite in the 1990s.	Increased private sector participation. Increase in posho mills. Prices unstable but reflects market forces.
1993	FAO: S. Carter (Ed).	Structural Adjustment and Trade Liberalisation - Its Effect on Marketing Institutions and Social Life.	Pre-liberalisation strictly controlled by Government. Inefficient marketing. Stable and artificial market prices. Subsidies to consumers. Stable food security.	Reluctance by Government to liberalise. Difficult options of liberalisation short lived. Private trade increased. Limited capital for private traders.
1995	PAM, Egerton University	Towards 2000: Improving Agricultural Performance.	Pre-liberalisation strictly controlled by Government. Inefficient marketing. Stable and artificial market prices. Subsidies to consumers. Stable food security.	Maize prices below import parity prices. Import duty high 75%. Limited market information. Need to monitor and evaluate implementation and impact.
1996	KARI K. Mutahi	Liberalisation of the Domestic Market: Its Implications on the National Agricultural Sector and more so Agricultural Research.	Decontrol of maize movement, price imports and exports. Increased competition. Prices unstable. Mixed food security status	Monitoring and evaluation of food security status. Need market information.
1997 :	IPAR: H. Nyangito and L. Ndirangu	Farmers Response to reforms in the Marketing of Maize in Kenya: A Case Study of the Trans Nzoia District	Implementation and impact of reforms mixed. More private sector participation in the trade. Yields decline/increased. Discouraging delivery to NCPB.	Free market operation. Government interference in pricing.
1997	IPAR: H. Nyangito	A Response of the Policies on the Maize Sub-Sector in Kenya. Import tariffs of 15% ad valorum.	Price and marketing fully liberalised since 1995. NCPB buyer and seller of last resort. NCPB handle strategic stocks.	Market information system lacking. Support to infrastructure development limited. NCPB unable to stabilise prices. Import and export balance for food security
1997	Technoserve: C. Ackello-Ogutu & P. Echessah	Unrecorded Cross-Border Trade Between Kenya and Uganda: Implications for Food Security.	Informal trade growing. Import tariff 75%. Non-tariff barriers high. Imports small but important.	Monitor and evaluate impact of free trade import tariff 5% (EAC, COMESA, WTO).
1998	Technoserve: C. Ackello-Ogutu & P. Echessah	Unrecorded Cross-Border Trade Between Tanzania and Her Neighbours: Implications for Food Security.	Informal trade growing. Import tariff 75%. Non-tariff barriers high. Imports small but important.	Monitor and evaluate impact of free trade import tariff 5% (EAC, COMESA, WTO). Need for market information system on maize trade.

YEAR	AUTHOR	TITLE	MAJOR ISSUES	RECOMMENDATIONS/ OUTCOME
1989	DAI	Economic and Social Soundness Analysis for the KMDP	Maize marketing sector was highly controlled. The sector was inefficient. There was need for decontrol.	Liberalisation of the sector. Support to the infrastructure and market information under KMDP
			Private sector important in informal trade.	
1998	R.M Hassan (Ed).	Maize Technology Development and Transfer	Pre-liberalisation maize prices pan seasonal and pan-territorial.	Unstable maize prices. Increased trade. Shift in maize production regionally. Need for monitoring and evaluation of post liberalisation impact.
1998	Tegemeo Institute: G. Argwings-Kodhek	Strategies for Raising Smallholder Agricultural Productivity and Welfare	Maize production valued at Kshs 20 billion. Immediately after liberalisation prices varied substantially. Private sector import of maize well organised. Consumer prices declined. Posho mills and whole maize meal flour increased. Role of NCPB minimal in 1998.	Farmers and others need market information. Need for increased maize productivity. Establishment of stakeholder associations.
1999	Technosrve : G. Argwings-Kodhek	Policy Implication of Import and export bans on Maize, Wheat and Sugar in Kenya Unrecorded Cross-Border Trade Between Tanzania and Her Neighbours: Implications for Food Security.	Import bans and high tariffs of 75% are politically motivated. Non-tariff barriers high Economic integration will eliminate import and export barriers and tariffs.	Monitor and evaluate impact of free trade import tariff 5% (EAC, COMESA, WTO). Need for market information system on maize trade. Assess impact of relief supplies. Assess value of gains and losses due to import/export interventions.
1999	Tegemeo Institute: G. Argwings-Kodhek	Policy Issues Facing the Maize Sector in the North Rift	Pre-liberalisation maize prices pan seasonal and pan-territorial set by NCPB. Maize prices are determined by market after liberalisation. High import tariffs affect maize prices. Real prices declined by 15% in the post liberalisation era. Economic integration will affect maize prices.	Form associations and forum for consultation. Need regular monitoring and evaluation of the impact of liberalisation. Need for market information and awareness.

Source: Compiled by the author from various sources, 2000

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OPEN-POLLINATED MAIZE VARIETIES: A BACKWARD STEP OR VALUABLE OPTION FOR FARMERS?

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ABSTRACT

Maize farmers require varieties appropriate to their anticipated level of investment in inputs and with high probability of producing an acceptable grain yield when challenged by common biotic and abiotic constraints. The objectives of this study were to quantify the relative genetic advantage of hybrids over OPVs under a range of growing conditions typical for farmers in southern and eastern Africa, both when first- or second-generation ("recycled") seed is used, and to investigate scenarios under which hybrids or OPVs are the more profitable option for farmers. In our first experiment, we found that four elite hybrids consistently produced about 18% more grain yield than 10 improved elite OPVs when grown at 16 sites with mean yield between 1.8 and 7.3 t ha^{-1}. We proceeded to examine the consequences of recycling or saving grain from hybrid or OPV maize crops for use as seed for subsequent crops. Trials at five sites in Zimbabwe compared planting of F1 seed and F2 grain of 10 commercial hybrids, F1 and F2 of 10 topcross hybrids (using an OPV as male for a single cross), and F2 and F3 of 10 OPVs. Use of the advanced generation grain instead of F1 (F2 in the case of OPVs) seed resulted in 32% average yield loss for hybrids, 16% yield loss for topcrosses and 5% yield loss for OPVs. We used these results to conduct simple break-even yield analyses to identify scenarios where use of OPV rather than hybrid varieties might be economically advantageous. We concluded that in some farming systems, particularly where yield levels are low (e.g. below 1.5 t ha^{-1}) and hybrid seed and fertilizer prices are high relative to price of grain, highest return to investment may result from use of improved OPV seed, which is cheaper than hybrid seed and can be recycled with little or no yield loss. The improved OPVs are particularly advantageous if the money saved by using OPV instead of hybrid seed is used to purchase additional inputs such as fertilizer, herbicide or hiring additional labor. Although use of OPV instead of hybrid seed is a backward step in terms of expected grain yield, improved OPVs represent an economical option for resource-poor maize farmers in marginal areas or when hybrid seed and fertilizer prices are high relative to price of grain.

INTRODUCTION

Even though the first hybrid maize varieties were released in sub-Saharan Africa more than 40 years ago, less than 30% of the maize area in sub-Saharan Africa is planted today to hybrid seed (Hassan *et al*., 2001). The remaining area is planted to recycled hybrid grain, improved open-pollinated varieties (OPVs) or local varieties (see also Morris, 2001). A number of reasons account for this situation. Because considerable knowledge and capital are needed to produce hybrid seed, it is generally only available where there is an established commercial seed sector. The commercial seed sector, on the other hand, only invests in areas where purchasing frequency and sales volume for hybrid seed are sufficient to ensure profitability. It is therefore not surprising that selling hybrid seed has been found unprofitable in many African countries, particularly in remote rural areas where the purchasing power of farmers is low.

Farmers provide a range of reasons why they may not invest in hybrid seed, such as high seed costs, lack of cash at planting time, non-availability of hybrid seed at local shops, the need to also purchase fertilizer, small or no difference in yield when compared to local varieties, lack of adaptation, poor storability and poor processing quality (e.g. poundability) of commercially available hybrids. These arguments have raised the question whether hybrids have indeed an advantage over open-pollinated or local varieties under resource-poor farmer conditions where insecure seed availability, low input use, and crop failures are common.

The question of which variety type – hybrid, improved open-pollinated, or "local" - is the most sustainable for a country to achieve food security and support economic growth has several facets. The type of seed chosen may be linked to several possible benefits or disincentives (Table 1): (i) access to genetic gain in terms of productivity, disease resistance, stress tolerance etc.; (ii) the combined benefits of seed treatment and seed quality control as is typical for certified seed; (iii) purchasing seed may secure the presence of a viable seed sector that will provide this commodity in future; (iv) independence from structural and socio-economical risks. The last point refers to a situation where structural and socio-economical circumstances that are beyond the control of individual farmers may cut the delivery to certain areas, leaving the communities to fend for their own seed supply. Few of these benefits have been quantified in economic terms, making it difficult for farmers, governments, the private seed sector and non-governmental organizations to query their decision when choosing a certain variety type.

The objective of this study is to better quantify the relative genetic advantage of hybrids over OPVs under a range of growing conditions typical for farmers in southern and eastern Africa, both when first- or second-generation ("recycled") seed is used. Using simple farm-level budgets, we develop scenarios under which hybrids or OPVs are the more profitable option for farmers in southern and eastern Africa trial (Table 2). The OPVs and hybrids were chosen among the best performing OPVs and hybrids evaluated in the 1999 and 2000 Regional Trials conducted in eastern and southern Africa (Bänziger *et al*., 2000; Vivek *et al*., 2001).

The trial was grown at 16 sites or environments in Zimbabwe during summer 1999/2000 and 2000/01. Three trials were grown at Harare (17.80 S, 31.05 E, 1,468 masl) or

Table 1. Types of benefits available from maize seed and relative access to these benefits if farmers grow hybrid, improved open-pollinated or local varieties.

Type of benefit	Benefit from		
	Hybrids	Improved OPVs	Local maize
Access to genetic gain	High	Medium	Low
Benefits from seed treatment and seed quality control	High	Only when purchased as certified seed	No benefits
Presence of a viable seed sector that continues to provide access to new genetic gains	Likely	Questionable	Unlikely
Independence of farming communities	Low	Medium	High

Rattray-Arnold (17.67 S, 31.17 E, 1,308 masl) under severe N stress that reduced grain yield to about 30-35% of the well-fertilized yield at the same site. Two trials were grown during the dry season under managed drought stress at Chiredzi (21.02 S, 31.58 E, 429 masl). Three trials were grown on depleted soils (granitic sands) at Makoholi (19.83 S, 30.78 E, 1,204 masl) and Lucidale (20.38 S, 28.50 E, 1,347 masl). The other trials were grown under medium to high potential conditions at Harare, Glendale (17.08 S, 31.03 E, 1,200 masl), Kadoma (18.32 S, 30.90 E, 1,155 masl), Matopos (10 km from Lucidale) and Rattray-Arnold.

2. Establishing the effect of seed recycling on productivity of hybrids and OPVs

Ten commercial or pre-commercial hybrids, 10 open-pollinated varieties, and 10 topcross hybrids were chosen for the field trials. Topcross hybrids are crosses of a single-cross as seed parent for an open-pollinated variety as male. The 30 cultivars were planted in single-row plots, and controlled, plant-to-plant (full-sib) hand-pollinations were made within each cultivar to produce seed of the second generation. This second generation seed should be genetically similar to grain farmers would harvest if growing the varieties. Thus, the second generation seed we produced was representative of "recycled" or "saved" seed of the original cultivars. First- and second-generation "seed", 60 genotypes in total (30 cultivars x 2 generations), was used in yield trials.

Field trials were grown at five locations in Zimbabwe during summer 2000/01. One site was CIMMYT's low-N block at Harare. The other four sites were well fertilized and included Harare, Rattray-Arnold, Glendale and Matopos.

3. Crop husbandry and measurements

In both trial series, field plots were two rows, 0.75m apart and 4 m long. Plant densities were 40,000 at Matopos, Lucidale and Makoholi, and 53,000 plants per hectare at all other sites. Experimental design was an alpha-lattice (Patterson *et al*., 1978) with two replications at each site.

Standard agronomic data were recorded in addition to shelled grain weight and grain moisture content for each plot. Grain yield was adjusted to 12.5% moisture content and expressed as t ha^{-1}. Individual site analyses of variance used the lattice design, and combined analyses used lattice-adjusted means for each site.

Table 2. OPVs and hybrids evaluated to establish the effect of management level on the productivity of hybrids and OPVs.

Variety	Variety Type	Anthesis date
ZM421A	OPV	71.2
ZM421B	OPV	69.3
ZM421	OPV	68.2
ZM521A	OPV	69.8
ZM521B	OPV	69.9
SADVI1	OPV	70.1
SADVI2	OPV	70.7
ZM621A	OPV	72.8
ZM621B	OPV	73.5
ZM621	OPV	73.8
SC403	Commercial hybrid	67.7
SC513	Commercial hybrid	71.9
CML441/CML395// INTA-191-2-1-2-BBBB	Pre-commercial hybrid	72.3
CML444/CML395// CML440	Pre-commercial hybrid	72.5

RESULTS AND DISCUSSION

1. Establishing the effect of management level on the productivity of hybrids and OPVs

The hybrids initially selected for this study were on average later flowering than the OPVs (anthesis date of 72.6 d and 70.9 d, respectively). Therefore, the two latest maturing hybrids, SC709 and CML442/CML444 were excluded from the analysis to remain with 10 OPVs and 4 hybrids of similar maturity (anthesis dates of 71.1 d and 70.9 d, respectively). Similarity of maturity is an important and often overlooked precondition for valid comparison of performance among maize cultivars.

Trial means ranged from 1.78 t ha^{-1} at Lucidale 2000 to 7.32 t ha^{-1} at Rattray-Arnold 2001 (Table 3). Hybrids yielded on average 18% more than OPVs. The largest difference was 44% advantage of hybrids over OPVs at Harare low-N 2001, whereas yield of hybrids and OPVs did not differ significantly ($P<0.10$) at three locations.

Linear regressions were calculated between the mean of the trial and the average yield of the variety type (Fig. 1). These regressions were:

Yield of OPV group = -0.07 t ha^{-1} + 0.96 x Mean yield of the trial (n=16)

Yield of Hybrid group = 0.14 t ha^{-1} + 1.09 x Mean yield of the trial (n=16)

While intercepts did not differ significantly from zero and each other, slopes of regressions were significantly different from each other. Thus, hybrids showed a production advantage (18%, on average) over OPVs across all management levels, and in absolute terms, this advantage was largest under higher yielding conditions.

Comparisons between three hybrids (SC403, SC521, CML312/CML395//CML440) and two OPVs (ZM421 and

Table 3. Average grain yield of elite OPVs and hybrids evaluated at 16 locations in Zimbabwe to establish the effect of management level on the productivity of hybrids and OPVs.

Year	Site	Grain yield (t ha^{-1}) Mean	OPVs	Hybrid	*P*	Hybrids/ OPVs
2000	Lucidale	1.78	1.67	2.00	+	1.20
2000	Harare Low N	1.83	1.63	2.23	**	1.37
2001	Harare Low N	1.98	1.73	2.49	**	1.44
2000	Rattray Low N	2.51	2.36	2.80	ns	1.19
2000	Chiredzi Drought	3.06	2.85	3.49	*	1.22
2000	Makoholi	3.10	2.82	3.66	+	1.30
2001	Chiredzi Drought	4.48	4.15	5.14	**	1.24
2000	Matopos	4.59	4.39	4.99	+	1.14
2001	Matopos	4.82	4.71	5.04	ns	1.07
2001	Lucidale	4.94	5.08	4.68	ns	0.92
2001	Kadoma	5.67	5.26	6.48	*	1.23
2001	Harare	5.69	5.28	6.51	*	1.23
2000	Harare	6.04	5.65	6.80	**	1.20
2000	Glendale	7.11	6.73	7.86	*	1.17
2001	Rattray-Arnold	7.32	7.00	7.94	+	1.13
2000	Kadoma	7.14	6.59	8.25	**	1.25
	Mean	4.50	4.24	5.02		1.18

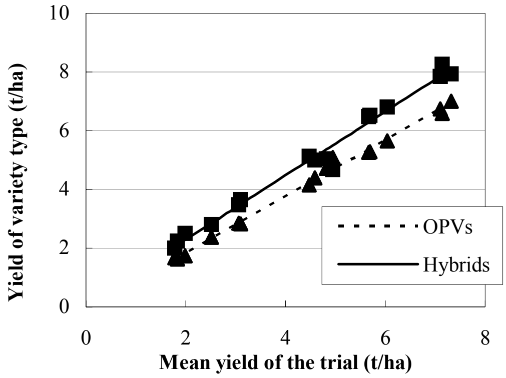
**, *, + Indicate significant differences between hybrids and OPVs at P<0.01, 0.05 and 0.10, respectively.

ZM521) were also conducted in 78 Mother-Baby trials across Zimbabwe in 1999/2000 and 2000/2001 (De Meyer and Bänziger, 2001; De Meyer *et al.*, unpublished). Grain yield of hybrids exceeded grain yield of OPVs by an average of 18%, and the corresponding regressions calculated for those trials also agreed very well with the regressions calculated in this study. They were:

Yield of OPV group = -0.11 t ha^{-1} + 0.97 x Mean yield of the trial (n=79)
Yield of Hybrid group = 0.04 t ha^{-1} + 1.08 x Mean yield of the trial (n=79)

Thus, elite hybrids out-yielded elite OPVs on average and across all management levels. Of course, there will be incidences when this is not the case for a certain location (likely because of high error variance) or for a certain hybrid-OPV comparison. In the Mother-Baby trials cited above, seven pre-commercial and commercial hybrids produced yields from 2.68 to 3.15 t ha^{-1} across 35 on-farm trials. Five OPVs evaluated in the same trials produced yields from 1.83 to 2.72 t ha^{-1} (de Meyer and Bänziger, 2001). Thus, a very good hybrid may out-yield a poor OPV by more than 70%. On the other hand, a good OPV may be similar performing or even out-yield a poor performing hybrid. This is the reason why we carefully chose the OPVs and hybrids for this study; all entries had demonstrated elite performance within their respective variety type in previous trials. Chiduza *et al.* (1994) compared ten OPVs with five commercial hybrids at eight environments in Zimbabwe and reported average yield advantage of 27 to 28% for the hybrids at two fertilizer levels. They further reported that yield of some OPVs approached that of the hybrids. When the best five OPVs were compared to the five commercial hybrids, the overall yield advantage of the hybrids was about 16% for unfertilized and 19% for fertilized plots. These values (16-19%) are quite similar to our estimates of 18% reported

Figure 1. Average grain yield of elite OPVs and hybrids evaluated at 16 locations in Zimbabwe to establish the effect of management level on the productivity of hybrids and OPVs.



above.

2. Establishing the effect of seed recycling on productivity of hybrids and OPVs

The F1 conventional hybrids produced, on average, 31% more grain yield than the OPVs and 20% more than the F1 topcross hybrids (Table 4). These results agreed with hybrid theory that crops from first generation seed of conventional hybrids should yield more than topcross hybrids, which should yield more than OPVs. Several of the OPVs used in this study were from abroad (Kenya, Zambia, Malawi and Mozambique) and were not specifically selected for good performance against low-N, drought and other prevalent stresses in Zimbabwe. This contrasts with the OPVs used in our first trial (Table 2), all of which were developed within the CIMMYT research program in Zimbabwe. Secondly, the hybrids used in this trial were significantly later maturing, having reached anthesis (male flowering), on average, 5 days later than the OPVs. Later maturity of the hybrids relative to OPVs, and use of a less elite group of OPVs (compared to our first experiment, described above), can explain the greater yield advantage of hybrids relative to OPVs in this experiment compared to Experiment 1, above (i.e. 31% vs. 18%).

The effect of planting "recycled" or second-generation seed was negligible for OPVs, severe for hybrids (>30% yield loss) and intermediate for topcross hybrids (>15% yield loss) (Table 4). All 10 hybrids had highly significant (P<0.01) yield reduction, whereas seven topcross hybrids (four at P<0.01; three at P<0.05), and only three OPVs (two at P<0.01; one at P<0.05) had yield reduction from planting recycled relative to F1 seed. These results agree reasonably well with theoretical expectations as summarized by Morris *et al.* (1999), who reported average predicted yield losses of 8.4, 17.4 and 33.5% for recycling (F2 yield relative to F1) of double-cross, three-way and single-cross hybrids, respectively. They also reported that expected yield loss for topcross hybrids was similar to that for three-way hybrids, while OPVs (if seed is recycled in isolation and adequate number of plants are sampled) are expected to suffer negligible yield reduction from recycling.

Crops grown from recycled seed of conventional hybrids produced significantly lower yield than crops from

Table 4. Comparison of variety types across generations across all five sites for yield

Variety Type	Generation of Seed Planted	Mean Yield (t ha^{-1})	Yield Loss (%)	Days to Male Flowering
Hybrid	F1	6.12 a	32.4	72.5 b
Hybrid	F2	4.14 e		74.2 a
OPV	F2	4.66 c	4.9	67.7 d
OPV	F3	4.43 cd		67.7 d
Topcross	F1	5.08 b	15.8	69.3 c
Topcross	F2	4.28 de		689.9 c
LSD		0.22		0.8

Means followed by the same letter are not significantly different from each other (DMRT), P = 0.05

first or second generation OPV seed, and significantly lower yield than crops from first generation topcross hybrid seed. Morris *et al*. (1999) reviewed literature on this topic and found a majority of reports agree with our result that crops from recycled hybrid seed generally yield less than crops from improved OPV seed.

We used controlled pollinations to simulate seed recycling in this study. In farmers' fields, recycled hybrid seed may often be contaminated through cross-pollination from other varieties growing in nearby fields. Wind may carry pollen as far as 300 m, even though most contamination is often only observed within 10 m from the field limit. Cross-pollination with other varieties may reduce the amount of inbreeding depression observed with farmer-recycled hybrid seed compared to this study, therefore, yield of crops grown from recycled seed of hybrids may be somewhat higher than measured in this study.

We compared several agronomic traits for plants grown from first generation and recycled seed of the three variety types (data not shown). Few differences between plants produced from first generation and recycled seed were significant at P<0.05. However, when grown with adequate fertilizer, first generation seed of hybrids produced taller plants, with less stem lodging than plants grown from recycled seed. We had hypothesized that, due to heterosis, plants from first generation seed of hybrids would be more tolerant to biotic and abiotic stresses than plants grown from recycled seed. This hypothesis was not confirmed at P<0.05 for most traits, although predominant trends suggested that the hypothesis might be confirmed when we repeat the experiment at more locations during 2001/2002.

3. Calculating farm-level budgets based on yield differences between OPVs and hybrids, and between first- and second-generation seed established in this study.

Given the data presented in the previous two sections, we calculated two scenarios with the following parameters:

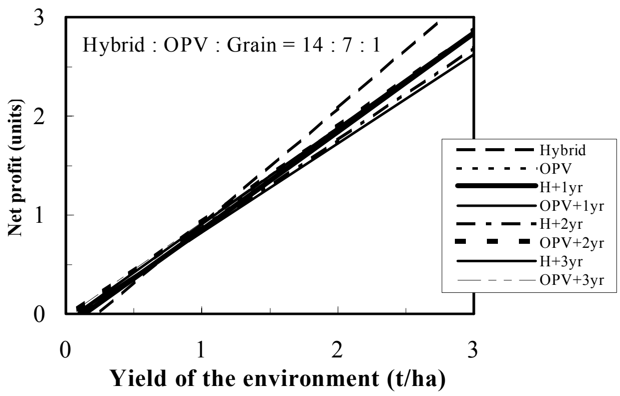
1. Elite hybrids produce 18% more grain than elite OPVs
2. Recycled hybrid seed produces 32% less grain than fresh F1 hybrid seed
3. Recycled OPV seed produces 5% less grain than fresh OPV seed
4. Seeding rates are 20 kg ha^{-1}

These calculations do not consider that purchased seed is typically of high quality and chemically treated, which may result in yield benefit, partly due to more consistent crop establishment (good plant stand). This assumption denies one of the benefits of commercially purchased hybrid seed. We also assume there is no further inbreeding depression (beyond the 32 and 5% yield reduction for hybrids and OPVs, respectively) from second and subsequent recycling of seed. This assumption should favour the hybrids, as theory predicts they will suffer additional inbreeding depression.

Constant management scenario: In this scenario, we assume that farmers choose a certain management level (i.e. fertilizer application, weeding, planting date) independent of the variety type used. If certified hybrid seed is purchased, the cost for seed will be higher than when fresh OPV is purchased or seed is recycled. The grain yield, on the other hand, at any given management level will be as follows: hybrid > OPV > recycled OPV > recycled hybrid. Thus, the market prices of grain, hybrid seed and OPV seed will determine which option will be most profitable for a farmer at a certain management level.

In the following calculations, made for a range of planting scenarios and management levels, we assume a price ratio of 1:7:14 for grain:OPV seed:hybrid seed (Table 5, Fig. 2).

Figure 2. Constant management scenario.



Given these price ratios, recycling OPV seed for two or three years appears to be the most profitable option at the 1 t ha[1] management level. Purchasing fresh hybrid seed every year becomes the most profitable option once management levels are 2 t ha^{-1} or higher. Also as management levels increase, recycling of seed becomes less profitable. Recycling hybrid seed is generally the least profitable option. The management levels at which growing hybrid seed is equally profitable as growing OPV seed can be calculated based on price ratios for hybrid and OPV seed (Table 6). For example, at price ratios of 14:1 for hybrid seed:grain and 7:1 for OPV seed:grain, growing F1 hybrid seed is less profitable than growing OPV seed that has been recycled for zero, one , two, or three years when management levels result in yields of below 1.36, 2.05, 2.25, 2.36 t ha^{-1}, respectively.

Constant investment scenario: In this scenario we make an assumption that so far has not been much promoted. We assume that farmers choose a certain investment level for their crop. Imagine a farmer going to the shop with a certain amount of cash in the pocket. If the farmer decides to invest less money on seed by either purchasing an OPV or recycling seed, that farmer has more money available for purchasing other inputs such as N fertilizer. To facilitate calculations, we

Table 5. Yield levels at which equal profits can be expected from growing F1 hybrid seed versus OPV seed at given price ratios.

Fresh OPV seed is purchased very year												
	Price ratio of OPV seed to grain											
Price ratio of hybrid seed to grain	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00											
2	0.19	0.00										
3	0.39	0.19	0.00									
4	0.58	0.39	0.19	0.00								
5	0.78	0.58	0.39	0.19	0.00							
6	0.97	0.78	0.58	0.39	0.19	0.00						
7	1.17	0.97	0.78	0.58	0.39	0.19	0.00					
8	1.36	1.17	0.97	0.78	0.58	0.39	0.19	0.00				
9	1.56	1.36	1.17	0.97	0.78	0.58	0.39	0.19	0.00			
10	1.75	1.56	1.36	1.17	0.97	0.78	0.58	0.39	0.19	0.00		
11	1.95	1.75	1.56	1.36	1.17	0.97	0.78	0.58	0.39	0.19	0.00	
12	2.14	1.95	1.75	1.56	1.36	1.17	0.97	0.78	0.58	0.39	0.19	0.00
13	2.34	2.14	1.95	1.75	1.56	1.36	1.17	0.97	0.78	0.58	0.39	0.19
14	2.53	2.34	2.14	1.95	1.75	1.56	1.36	1.17	0.97	0.78	0.58	0.39
15	2.73	2.53	2.34	2.14	1.95	1.75	1.56	1.36	1.17	0.97	0.78	0.58
16	2.92	2.73	2.53	2.34	2.14	1.95	1.75	1.56	1.36	1.17	0.97	0.78
17	3.12	2.92	2.73	2.53	2.34	2.14	1.95	1.75	1.56	1.36	1.17	0.97
18	3.31	3.12	2.92	2.73	2.53	2.34	2.14	1.95	1.75	1.56	1.36	1.17
19	3.51	3.31	3.12	2.92	2.73	2.53	2.34	2.14	1.95	1.75	1.56	1.36
20	3.70	3.51	3.31	3.12	2.92	2.73	2.53	2.34	2.14	1.95	1.75	1.56

OPV seed is recycled for one year												
	Price ratio of OPV seed to grain											
Price ratio of hybrid seed to grain	1	2	3	4	5	6	7	8	9	10	11	12
1	0.10	0.00										
2	0.29	0.19	0.10	0.00								
3	0.49	0.39	0.29	0.19	0.10	0.00						
4	0.68	0.58	0.49	0.39	0.29	0.19	0.10	0.00				
5	0.88	0.78	0.68	0.58	0.49	0.39	0.29	0.19	0.10	0.00		
6	1.07	0.97	0.88	0.78	0.68	0.58	0.49	0.39	0.29	0.19	0.10	0.00
7	1.27	1.17	1.07	0.97	0.88	0.78	0.68	0.58	0.49	0.39	0.29	0.19
8	1.46	1.36	1.27	1.17	1.07	0.97	0.88	0.78	0.68	0.58	0.49	0.39
9	1.66	1.56	1.46	1.36	1.27	1.17	1.07	0.97	0.88	0.78	0.68	0.58
10	1.85	1.75	1.66	1.56	1.46	1.36	1.27	1.17	1.07	0.97	0.88	0.78
11	2.05	1.95	1.85	1.75	1.66	1.56	1.46	1.36	1.27	1.17	1.07	0.97
12	2.24	2.14	2.05	1.95	1.85	1.75	1.66	1.56	1.46	1.36	1.27	1.17
13	2.44	2.34	2.24	2.14	2.05	1.95	1.85	1.75	1.66	1.56	1.46	1.36
14	2.63	2.53	2.44	2.34	2.24	2.14	2.05	1.95	1.85	1.75	1.66	1.56
15	2.83	2.73	2.63	2.53	2.44	2.34	2.24	2.14	2.05	1.95	1.85	1.75
16	3.02	2.92	2.83	2.73	2.63	2.53	2.44	2.34	2.24	2.14	2.05	1.95
17	3.22	3.12	3.02	2.92	2.83	2.73	2.63	2.53	2.44	2.34	2.24	2.14
18	3.41	3.31	3.22	3.12	3.02	2.92	2.83	2.73	2.63	2.53	2.44	2.34
19	3.61	3.51	3.41	3.31	3.22	3.12	3.02	2.92	2.83	2.73	2.63	2.53
20	3.80	3.70	3.61	3.51	3.41	3.31	3.22	3.12	3.02	2.92	2.83	2.73

Table 5 continued. Yield levels at which equal profits can be expected from growing F1 hybrid seed versus OPV seed at given price ratios.

OPV seed is recycled for two years												
	Price ratio of OPV seed to grain											
Price ratio of hybrid seed to grain	1	2	3	4	5	6	7	8	9	10	11	12
1	0.13	0.06	0.00									
2	0.32	0.26	0.19	0.13	0.06	0.00						
3	0.52	0.45	0.39	0.32	0.26	0.19	0.13	0.06	0.00			
4	0.71	0.64	0.58	0.52	0.45	0.39	0.32	0.26	0.19	0.13	0.06	0.00
5	0.90	0.84	0.77	0.71	0.64	0.58	0.52	0.45	0.39	0.32	0.26	0.19
6	1.09	1.03	0.97	0.90	0.84	0.77	0.71	0.64	0.58	0.52	0.45	0.39
7	1.29	1.22	1.16	1.09	1.03	0.97	0.90	0.84	0.77	0.71	0.64	0.58
8	1.48	1.42	1.35	1.29	1.22	1.16	1.09	1.03	0.97	0.90	0.84	0.77
9	1.67	1.61	1.55	1.48	1.42	1.35	1.29	1.22	1.16	1.09	1.03	0.97
10	1.87	1.80	1.74	1.67	1.61	1.55	1.48	1.42	1.35	1.29	1.22	1.16
11	2.06	2.00	1.93	1.87	1.80	1.74	1.67	1.61	1.55	1.48	1.42	1.35
12	2.25	2.19	2.13	2.06	2.00	1.93	1.87	1.80	1.74	1.67	1.61	1.55
13	2.45	2.38	2.32	2.25	2.19	2.13	2.06	2.00	1.93	1.87	1.80	1.74
14	2.64	2.58	2.51	2.45	2.38	2.32	2.25	2.19	2.13	2.06	2.00	1.93
15	2.83	2.77	2.71	2.64	2.58	2.51	2.45	2.38	2.32	2.25	2.19	2.13
16	3.03	2.96	2.90	2.83	2.77	2.71	2.64	2.58	2.51	2.45	2.38	2.32
17	3.22	3.16	3.09	3.03	2.96	2.90	2.83	2.77	2.71	2.64	2.58	2.51
18	3.41	3.35	3.28	3.22	3.16	3.09	3.03	2.96	2.90	2.83	2.77	2.71
19	3.61	3.54	3.48	3.41	3.35	3.28	3.22	3.16	3.09	3.03	2.96	2.90
20	3.80	3.74	3.67	3.61	3.54	3.48	3.41	3.35	3.28	3.22	3.16	3.09

OPV seed is recycled for three years												
	Price ratio of OPV seed to grain											
Price ratio of hybrid seed to grain	1	2	3	4	5	6	7	8	9	10	11	12
1	0.14	0.10	0.05	0.00								
2	0.34	0.29	0.24	0.19	0.14	0.10	0.05	0.00				
3	0.53	0.48	0.43	0.38	0.34	0.29	0.24	0.19	0.14	0.10	0.05	0.00
4	0.72	0.67	0.63	0.58	0.53	0.48	0.43	0.38	0.34	0.29	0.24	0.19
5	0.91	0.87	0.82	0.77	0.72	0.67	0.63	0.58	0.53	0.48	0.43	0.38
6	1.11	1.06	1.01	0.96	0.91	0.87	0.82	0.77	0.72	0.67	0.63	0.58
7	1.30	1.25	1.20	1.15	1.11	1.06	1.01	0.96	0.91	0.87	0.82	0.77
8	1.49	1.44	1.39	1.35	1.30	1.25	1.20	1.15	1.11	1.06	1.01	0.96
9	1.68	1.64	1.59	1.54	1.49	1.44	1.39	1.35	1.30	1.25	1.20	1.15
10	1.88	1.83	1.78	1.73	1.68	1.64	1.59	1.54	1.49	1.44	1.39	1.35
11	2.07	2.02	1.97	1.92	1.88	1.83	1.78	1.73	1.68	1.64	1.59	1.54
12	2.26	2.21	2.16	2.12	2.07	2.02	1.97	1.92	1.88	1.83	1.78	1.73
13	2.45	2.41	2.36	2.31	2.26	2.21	2.16	2.12	2.07	2.02	1.97	1.92
14	2.65	2.60	2.55	2.50	2.45	2.41	2.36	2.31	2.26	2.21	2.16	2.12
15	2.84	2.79	2.74	2.69	2.65	2.60	2.55	2.50	2.45	2.41	2.36	2.31
16	3.03	2.98	2.93	2.89	2.84	2.79	2.74	2.69	2.65	2.60	2.55	2.50
17	3.22	3.17	3.13	3.08	3.03	2.98	2.93	2.89	2.84	2.79	2.74	2.69
18	3.42	3.37	3.32	3.27	3.22	3.17	3.13	3.08	3.03	2.98	2.93	2.89
19	3.61	3.56	3.51	3.46	3.42	3.37	3.32	3.27	3.22	3.17	3.13	3.08
20	3.80	3.75	3.70	3.66	3.61	3.56	3.51	3.46	3.42	3.37	3.32	3.27

we assume that all money that is not used for seed is used instead for N fertilizer. We use a price ratio of 1:7:14:11 for grain:OPV seed:hybrid seed:N fertilizer, and assume that each additional kg of N applied results in a yield increase of 20 kg of grain, a quite conservative assumption (Muza *et al.,* 2002). Further, we assume that the response to fertilizer is the same for all maize crops (e.g. OPV, recycled hybrid, etc.).

In this scenario, OPVs, whether purchased or recycled, were the most profitable option at the 1 and 2 t ha^{-1} management levels (Table 6). At a management level of 3 t ha^{-1} and above, fresh hybrid seed became the most profitable option. Recycling hybrid seed was, again, the least profitable option at all management scenarios. Obviously, these calculations depend very much on the price ratio present in a certain country. Our example was based on price ratios effective in some parts of southern Africa. The profitability of various variety types may be quite different using other price ratios.

GENERAL DISCUSSION

Development and discussion of the above scenarios necessitated that we apply some simplistic assumptions. The reader may use Table 6 to explore other scenarios. For example, we learned that due to a very successful maize growing season in 2001, maize grain price in Uganda declined sharply (Justus Imanywoha, personal communication). This meant that the price of purchased seed increased relative to the value of grain, and the yield level at which purchase of hybrid seed was expected to be profitable may have been as high as 3.5 t ha^{-1}. By contrast, hybrid seed price in Zimbabwe is currently only 4 to 5 times the price of grain (Barry MacCarter, personal communication), which

Table 6. Net benefits from using various variety and seed types at various management levels (constant investment scenario).

	Annual					
	Seed Costs unit	Additional N applied kg	Grain production t/ha	Grain Value unit	Net benefit unit	Rank
Management level 1 t/ha						
Purchase hybrid seed	280	0.0	1.18	1180	900	5
Purchase OPV seed	140	12.7	1.25	1255	1115	4
Purchase hybrid and recycle for one year	140	12.7	0.99	990	850	6
Purchase OPV and recycle for one year	70	19.1	1.22	1222	1152	3
Purchase hybrid and recycle for two years	93.3	17.0	0.93	926	833	7
Purchase OPV and recycle for two years	46.7	21.2	1.21	1211	1164	2
Purchase hybrid and recycle for three years	70.0	19.1	0.89	894	824	8
Purchase OPV and recycle for three years	35.0	22.3	1.21	1205	1170	1
Management level 2 t/ha						
Purchase hybrid seed	280	0.0	2.36	2360	2080	5
Purchase OPV seed	140	12.7	2.25	2255	2115	4
Purchase hybrid and recycle for one year	140	12.7	1.98	1979	1839	6
Purchase OPV and recycle for one year	70	19.1	2.20	2195	2125	3
Purchase hybrid and recycle for two years	93.3	17.0	1.85	1852	1759	7
Purchase OPV and recycle for two years	46.7	21.2	2.18	2176	2129	2
Purchase hybrid and recycle for three years	70.0	19.1	1.79	1789	1719	8
Purchase OPV and recycle for three years	35.0	22.3	2.17	2166	2131	1
Management level 3 t/ha						
Purchase hybrid seed	280	0.0	3.54	3540	3260	1
Purchase OPV seed	140	12.7	3.25	3255	3115	2
Purchase hybrid and recycle for one year	140	12.7	2.97	2969	2829	6
Purchase OPV and recycle for one year	70	19.1	3.17	3169	3099	3
Purchase hybrid and recycle for two years	93.3	17.0	2.78	2778	2685	7
Purchase OPV and recycle for two years	46.7	21.2	3.14	3141	3094	4
Purchase hybrid and recycle for three years	70.0	19.1	2.68	2683	2613	8
Purchase OPV and recycle for three years	35.0	22.3	3.13	3127	3092	5
Management level 5 t/ha						
Purchase hybrid seed	280	0.0	5.90	5900	5620	1
Purchase OPV seed	140	12.7	5.25	5255	5115	2
Purchase hybrid and recycle for one year	140	12.7	4.95	4948	4808	6
Purchase OPV and recycle for one year	70	19.1	5.12	5117	5047	3
Purchase hybrid and recycle for two years	93.3	17.0	4.63	4630	4537	7
Purchase OPV and recycle for two years	46.7	21.2	5.07	5071	5024	4
Purchase hybrid and recycle for three years	70.0	19.1	4.47	4472	4402	8
Purchase OPV and recycle for three years	35.0	22.3	5.05	5048	5013	5

means that purchase of hybrid seed is economically attractive even at yield levels as low as about 0.5 t ha^{-1}. Chiduza *et al*. (1994) estimated discounted net benefits from use of hybrid or OPV seed, with or without fertilizer at two remote rural communities in Zimbabwe between 1989 and 1991. Hybrid seed in these communities was five times the cost of the same seed in Harare. Use (and recycling) of OPV seed together with fertilizer (75 kg N, 14 kg P and 15 kg K) gave the highest net benefit, followed by use of hybrid seed with fertilizer. They estimated (by marginal rates of return) very little benefit to farmers if switching from OPV seed without fertilizer to growing hybrid seed without fertilizer. Their conclusions were that farmers in these areas would benefit from either: 1) seed of improved OPVs for use in the then current farming scenario, or 2) reliable access to hybrid seed at cost similar to that in Harare, which would make use of hybrid seed economically advantageous.

We accept that some of our technical assumptions merit further consideration, particularly: Is the yield reduction due to recycling of grain for use as seed less in practice, because of desirable contamination from neighboring maize fields, than we estimated using controlled pollinations to develop the second-generation seed? Equally or more important, however, are the implicit non-technical assumptions in our analysis. Our scenarios assume, for example, that maize farmers are growing maize, or at least can quantify the value of their maize, as a cash crop. Yet we know that household food security, risk-aversion or hedging against risks, preferences and even tradition play an influential role in farmers' decisions about planting material and crop management practices. Similarly, household seed security is likely an important consideration (and a driving force for recycling grain as seed) for many resource-poor farmers, particularly in remote areas that may be poorly or unreliably served by the formal seed sector (e.g. the case reported by Chiduza et al., 1994). Finally, access to grain markets, where a predictable and fair price for grain is likely, must be an important consideration for resource-poor farmers deciding whether to invest in hybrid seed. Clearly, there are important social and cultural dimensions to the hybrid versus OPV issue, in addition to the technical and economic considerations we have discussed herein.

SUMMARY AND CONCLUSION

This study established that current elite maize hybrids grown from first generation (F1) seed generally yield approximately 18% more than the best OPVs available, even when grown at very low yielding conditions typical for many resource poor farmers in eastern and southern Africa. Therefore, use of OPV or recycled seed instead of F1 hybrid seed is a backward step for grain yield. If growing maize crops from recycled (2nd generation) seed, our data indicate that OPVs produce higher yields than hybrids. The profitability of growing hybrids or OPVs, or fresh rather than recycled seed, depends on the market prices of grain, OPV seed and hybrid seed. Using realistic price ratios for Africa, we conclude that in some farming systems, particularly where yield levels are inherently low (e.g. below 1.5 t ha^{-1}), recycling improved OPVs may be more profitable and sustainable than purchasing annually fresh hybrid seed. Growing OPVs becomes even more profitable if farmers use the monetary savings - that alternatively could have been invested in hybrid seed - to purchase additional inputs such as fertilizers. We conclude, therefore, that use of improved OPVs may be a valuable option for maize farmers under some circumstances that are not uncommon in eastern and southern Africa. Recycling of hybrid seed seems generally the least profitable option. When deciding on variety types for promotion, aspects such as (i) access to the benefits from research investments in genetic improvement of new varieties, (ii) access to the benefits of seed treatment and seed quality control as is typical for certified seed, (iii) the continued presence of a viable seed sector, and (iv) the livelihood strategies of resource-poor maize farmers, must be considered alongside economic analyses of returns to farmers' investments.

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SESSION 1:

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ADVANCES IN DEVELOPING INSECT RESISTANT MAIZE VARIETIES FOR KENYA WITHIN THE INSECT RESISTANT MAIZE FOR AFRICA (IRMA) PROJECT

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ABSTRACT

Lepidopteran stem borers are economically important pests of maize, a major staple in Kenya. The Insect Resistant Maize for Africa (IRMA) Project aims at increasing maize production and food security through the development and deployment of insect resistant maize. Bt maize utilizes genes that encode delta-endotoxins; proteins derived from the soil bacterium *Bacillus thuringiensis* (Bt). Suitable genes have been acquired or synthesized and backcrossed into elite maize germplasm. Clean Bt gene events containing only the gene of interest and no antibiotic or herbicide resistance markers have been developed. Bt maize leaves have been introduced into Kenya, insect bioassays carried out and the effective cry proteins against major maize stem borers identified. Insect resistant maize varieties are being developed using conventional breeding and locally adapted as well as exotic germplasm. To ensure safe dissemination of Bt maize, studies on their impacts on target and non-target arthropods mainly through their characterization and quantification have been done. Insect resistance management strategies are being developed and studies on gene flow are under way. Impact studies have revealed factors in the society that will hinder or enhance adoption of Bt maize as well as establish baseline data that will form the basis of monitoring and evaluation. Technology transfer and capacity building, creating awareness and communications are important activities in the project. These activities address the various concerns that surround the use of genetically modified organisms. This paper provides a general overview of the IRMA project, presents brief results from various activities and examines how the various concerns about GMOs are addressed within the project activities.

INTRODUCTION

Stem borers are the most widely distributed and most damaging pests to maize worldwide. In Africa, there are several economically important stem borer species. The most important borers are the spotted stem borer (*Chilo partellus* Swinhoe) and the African stem borer (*Busseola fusca* Fuller). Lepidopteran stem borers are economically important pests of maize, a major staple in Kenya (Seshu Reddy and Sum, 1991). *Chilo partellus* is found mainly in East Kenya, and is the most destructive pest of maize in warm, low-altitude regions. *Busseola fusca is* mainly in West Kenya, is native to Africa and is the major borer pest in the highlands. Host plant resistance developed through conventional breeding methods and through genetic engineering, especially Bt maize, has potential to help resource-poor farmers combat stem borer damage. Bt maize, a genetically modified organism (GMO), utilizes genes that encode delta-endotoxins; proteins derived from the soil bacterium *Bacillus thuringiensis* (Bt).

The Insect Resistant Maize for Africa (IRMA) Project is a joint project between Kenya Agricultural Research Institute (KARI) and the International Maize and Wheat Improvement Center (CIMMYT) with financial support from the Syngenta Foundation for Sustainable Development (KARI and CIMMYT, 2001). The goal of the IRMA Project is to increase maize production and food security through the development and deployment of insect resistant maize to reduce losses due to the stem borers, first in Kenya, and later in other African Countries. The IRMA project focuses on identifying the best technologies, or combination of technologies to combat stem borers, developed conventionally or through biotechnology for African farmers. The major objectives of the project are to develop insect resistant maize varieties for the major Kenyan maize growing environments, and to establish procedures to provide insect resistant maize to resource-poor farmers in Kenya

Genetically modified organisms (GMOs) hold much potential in enhancing food production through technologies that lead to reduced input use, reduced risk from biotic and abiotic stresses, increased yields, and enhanced quality of agricultural products (Mann, 1999). GMO technology has seen rapid adoption in industrial countries reaching 35 million hectares in the year 2000, with a slower but steady rate of adoption in developing countries, reaching 10 million hectares in the year 2000 (James, 2001). Most developing countries are beginning to evaluate the potential of such technologies for meeting their food security needs.

GMO technology has been debated due to various concerns regarding its use, such as risks to human health, ecological and environmental risks, and build up of resistance by target insects. Developing, testing and disseminating insect resistant maize varieties involving Bt technology, therefore, required different approaches from those employed when using conventional methods. Such approaches have to consider effects on the human communities and the environment. The IRMA project, therefore, is comprised of activities that include: product development (Bt genes and maize varieties), product dissemination (ecology and insect resistance management), impact assessment, technology transfer, and awareness creation and communications. This paper provides a general overview of the IRMA project, presents brief results from impact assessment, product development, insect resistance management and communications activities during the first two years, and describes how the various concerns about GMOs are addressed within the project activities.

RESEARCH ACTIVITIES OF THE IRMA PROJECT

Product Development – Bt genes and Bt maize source germplasm:

Bt-maize involved the first transgenes to be handled by CIMMYT and its development is viewed as a valuable component in meeting the food security needs of clients in developing countries. CIMMYT has acquired Bt-maize events from the private sector and public sector as well as synthesizing other Bt genes with partners. Research Bt maize has been enhanced and legislation in Mexico has been instituted. Some CIMMYT lines were converted through conventional backcrossing to generate backcrossed lines containing *cryIAb*. CIMMYT has produced transformed plants that show integration of the *cryIAc*, *cryIB* and *cryIE* with, maize ubiquitin and rice actin promoters.

Specifically, various *Bt cry* genes (*cry1Ab, cry1Ac, cry1B, cry1E, and cry B-1Ab*) were used to successfully transform the CML216 x CML72 hybrid maize. Backcrosses were made to CML216 and the lines (T0 - T4) have shown high levels of resistance to stem borers (Table 1). Recently, development continued on second generation events that carry only the gene of interest. These "clean genes" do not carry the selectable Basta herbicide resistance (the *bar* gene) marker, and so bypass potential risks raised by some about the technology (KARI and CIMMYT, 2001). These events are developed by using isolated *Bt* and *bar* gene sequences for transformation. In addition, the *Bt* and *bar* genes are co-transformed, and they will be inserted separately into the maize genome. This increases the possibility of separating the two genes in the final product, thus producing an insect resistant, but herbicide susceptible variety. This approach is critical in ensuring that concerns associated with Bt maize are addressed. The various events have now been characterized for molecular composition.

Table 1. First generation transgenic Bt maize..

Event	Genes introduced	Generation
E176	PEP:*cry*IAb-Pol:*cry*IAb + 35S:*bar*	T16+ (BC16+)
E5207	Ubi:*cry*IAc + 35S:*bar*-35S:gus	T4
E5601	Act:*cry*IB-35S:*bar*	T4
E1835	Ubi:*cry*IB-35S:*bar* + 35S:*bar*	T2
E602	Act:*cry*IE-35S:*bar*	T2
E7	Ubi:*cry*IB-Iab fusion-35S:*bar*	T2

One of the highest priorities is the identification of which Bt genes are most effective against each of the targeted insect pests. There are several methods to determine the activity of Bt genes such as insect bioassays using isolated Bt proteins or immunological assays of labelled Bt proteins against isolated insect mid-guts (to determine whether receptors are present in the mid-gut). In our experience, the protein bioassays are easy but often do not indicate the most effective proteins. The immunological tests are highly accurate but are technically challenging and require special expertise and infrastructure. Ultimately, the best assay is the effect the Bt maize plants have against insects. Given the early state of biosafety in Kenya and the lack of proper infrastructure in KARI to handle transgenic maize (in the lab and the field), we decided that the simplest procedure would be to import Bt maize leaves (that were grown in CIMMYT's biosafety greenhouses in Mexico) into Kenya and perform leaf bioassays in the KARI-NARL Biotechnology Laboratories.

To introduce the leaves from Bt maize into Kenya, a permit was issued by the Kenya National Biosafety Committee (Mugo *et al*., 2002, this volume). Bioassays were carried out to identify the effective Bt genes against five Kenyan stem borers. The *cry*1Ab protein was the most active against all species as shown by the least area of leaves consumed and by the low percentage of larvae that were killed. *Chilo partellus* was affected by all cry proteins, except *cry*1E. *Eldana saccharina* was the least affected by any cry protein. *Chilo orichalcocilielus* was most affected by cry1Ab and cry1B proteins. *Sesamia calamistis* was affected by *cry*1Ab and *cry*1Ab-1B proteins. *Cry*1E protein was not active against any species. The tested Bt cry proteins were not effective in the control of *Busseola fusca*. We may need a combination of cry proteins being expressed at high levels or other Bt cry proteins like *cry*IC to effectively control *B. Fusca*. A prospective control was identified for *Chilo partellus,* the most destructive and most widely distributed stem borer in Kenya.

These results will be verified under biocontainment greenhouses and open quarantine field site facilities that are being developed currently. A field site has been developed at Kiboko within the KARI-NRRC Kiboko, which will be isolated by distance planting. No maize will be grown within 200m of the one-hectare chain-link fenced field. Maize will be detasselled to prevent inadvertently effecting gene flow to the maize crop and any other plant species. Tests will be done by infesting maize containing various *cry* genes singularly and in combinations with *Chilo partellus* and *Busseola fusca* stem borers. This information will allow the better targeting of the development of Kenyan maize varieties with the appropriate combinations of genes for resistance to these stem borer species.

Product Development – Locally adapted non-transgenic and transgenic insect resistant maize germplasm:

Host plant resistance is an approach to stem borer control, by which the plant itself is resistant to the stem borers. Host plant resistance is transferred to farmers in the seed, a fact that ensures that the technology is inexpensive, safe, and that the farmers need not purchase more inputs to control stem borers. Use of stem borer resistant maize increases efficiency of farming by reducing or eliminating the expense of insecticides and reducing yield losses from stem borer damage. For resource-poor small-scale farmers in developing countries, therefore, host plant resistance packaged into improved varieties will offer a practical and economic means of minimizing stem borer losses.

The IRMA project is primarily focusing on developing stem borer resistant maize varieties, an activity that falls into two categories: 1) search for sources of resistance and development of source germplasm for insect resistance, and, 2) search for elite germplasm to backcross to Bt genes sources when these will be available. The development of source germplasm is based on utilizing genes and sources of resistance already existing in the maize plant. We have evaluated 216 Genotypes from CIMMYT and KARI, 42

MBR S4 lines from CIMMYT Mexico, and 500 inbred lines from Mexico. In the search for stem borer resistant elite germplasm, 330 maize OPVs and hybrids have been evaluated in different maize growing ecologies in Kenya. This germplasm has been evaluated for resistance to *Chilo partellus* and *Busseola fusca* stem borers through artificial infestation. The germplasm is also being screened for tolerance to local stresses such as drought and low nitrogen, resistance to maize streak virus, *Turcicum* blight, leaf rust, and weevils in storage to ensure that insect resistance will be in good adapted genetic backgrounds. Good stem borer resistant inbred lines are being crossed to heterotic testers like CML78 and CML444, while combining ability studies are being done to identify lines with good specific and general combining abilities. Suitable hybrids will be made from lines with good specific combining abilities, while synthetics will be developed from good lines with good general combining ability. Recycling of inbred lines is being done to develop elite locally adapted germplasm. We are identifying good sources, especially those carrying resistance to more than one stem borer species.

Product Dissemination – Potential effects of Bt maize on non-target arthropods.

Knowledge of the environmental impacts of Bt-gene based stem borer resistance technology on non-target organisms in the major maize cropping systems is essential for the safe deployment of *Bt*-maize. Studies have been made to identify and determine the relative abundance of the target and non-target arthropods of *Bt*-maize in major maize growing regions in Kenya (Songa *et al*., 2001, this volume.). A reference collection of arthropods has been established, that will serve as a technical reference during the monitoring of effects of Bt maize later in the IRMA project cycle. Arthropod characterization studies were conducted in three agro-ecologies: i) lowland tropics (Kilifi district), ii) dry mid-altitude (Machakos district), and iii) moist transitional (Kakamega). Different–sampling methods were used for the various groups of arthropods. For soil crawling arthropods, pit-fall traps were used. For flying arthropods, two types of traps were used: water traps using yellow basins positioned at 1.2m above ground, and sticky traps using clear glass painted with insect glue and positioned at 1.2m above ground. For soil crawling arthropods, pit-fall traps were used. In each farm, 50 randomly selected plants were inspected for stem borers and other arthropods, at each of three plant growth stages: mid-vegetative, reproductive (tasseling and silking), and maturity stages (Oloo, 1989).

Among the target organisms, the stem borers that infested farmers' maize fields were identified in each of the sites in descending order of abundance as: Kilifi - *Chilo partellus*, *Chilo orichalcociliellus*, *Sesamia calamistis*, and *Cryptophlebia leucotreta*; Kakamega – *Busseola fusca*, *C. partellus*, *S. calamistis* and *C. leucotreta*; Machakos – *C. partellus*, *S. calamistis* and *C. leucotreta*. This suggests that, in order to have an impact on stem borer damage in maize, pest management technologies (e.g. *Bt*-maize), should be targeted at each of these key stem borer species in the respective regions (Songa *et al*., 2001).

Among non-target organisms,: Most of the parasitoids of stem borers recovered in each of the study sites were the larval type, with Kilifi having the widest diversity of parasitoids (6 species), followed by Machakos (3 species) while only two species were found in Kakamega. The exotic larval endoparasitoid *C. flavipes* was recovered from Kilifi and Machakos where releases were made in 1993-1997 (Overholt *et al*., 1997), which shows good establishment and spread and the need to study the non-target effects of *Bt*-maize on *C. flavipes*.

Among arthropods, the diversity of arthropod families recovered from traps in the different maize cropping systems was 69, 67 and 59 species in Kilifi, Kakamega and Machakos, respectively. Out of the wide range of arthropods recovered, five categories of non-target arthropods of interest have been identified, including the potential biological control agents, pollinators, decomposers of organic material in the soil as the most abundant ones. Some arthropods were abundant in all the three study sites, while some were limited to specific sites.

The arthropods that were most frequently recovered from the maize plants in Kakamega, Kilifi and Machakos were Formicidae, Forficulidae, Blattidae and Araneida. Formicidae (ants) and Forficulidae (earwigs) are known to be predators of stem borer eggs and larvae (Oloo, 1989). Ladybird beetles, which are known to be predators of *C. partellus* eggs (Dwumfour et al., 1991), were also recovered, with *Cheilomenes sulphurea* (Olivier) being the most common species, especially at Kakamega

All pest management technologies will have effects on organisms dependent on the target pests for food. One objective of development of insect resistant genetically modified crops is to reduce the reliance on conventional broad-spectrum insecticides (Morton *et al*., 2000). The environmental impacts of using transgenic crops such as *Bt*-maize have therefore to be evaluated and judged alongside the commonly used conventional insecticides (Hails, 2000). Before the deployment of *Bt*-maize into Kenya, it would be useful to standardize the protocols to be used in evaluating the impacts of *Bt*-maize alongside the conventional insecticides.

A study was conducted to evaluate Thuricide, a *Bt*-biopesticide and Dimethoate, conventional insecticides in the management of stem borers and the effects on non-target arthropods, in a maize/bean cropping system to evaluate their control of stem borers in maize, their effects on non-target arthropods in a maize bean cropping system, and to standardize the protocols to be used in evaluating the environmental impacts of *Bt*-maize alongside conventional insecticides in the field

Three types of traps were used: pit-fall, sticky and water traps. The stem borers that infested maize in the insecticide trial at Katumani field station, in descending order of abundance, were: *C. partellus* (65.8%), *S. calamistis* (21.4%), *C. leucotreta* (8.3%) and *B. fusca* (4.5%). The level of stem borer infestation was lowest in the *Bt*-sprayed plots (0.019 borers per plant) followed by the conventional insecticide (CI) treated maize plots (1.02), while the untreated maize had the highest stem borer intensity (3.41 borers per plant). The *Bt*- sprayed maize had significantly lower stem borer damage, in terms of the number of moth exit holes, tunnelling length and the percentage of damaged plants, compared to the CI and the control (untreated) maize (Table 2). Although the CI maize had a significantly lower number of stem borer exit holes and tunnelling length than the untreated maize, the percentage of infested plants was similar in these two treatments.

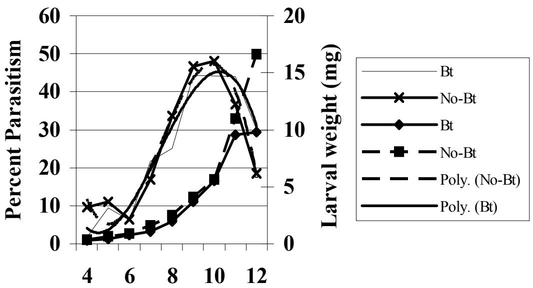
Five different parasitoids were recovered from the three treatments, although the parasitism levels were generally quite low. The untreated plot had the widest diversity of

Table 2. Mean number of stem borer exit holes, tunnel length and the percentage of maize plants infested by stem borers, in each of three treatments in Katumani.

Treatment	Exit holes*	Tunnel length (cm)*	Percent infestation**
Dimethoate	2.70 ± 0.39 b	3.93 ± 0.73 b	59.04 ± 1.66 a
Thuricide[#]	0.80 ± 0.16 c	1.80 ± 0.44 c	23.21 ± 3.34 b
Control	6.97 ± 0.90 a	12.70 ± 1.88 a	72.37 ± 6.17 a

Thuricide[#] - *Bt*-spray;
Values followed by the same lower case letter within the same column are not significantly different (Tukey's test, P>0.05). Exit holes: F=43.09; df=2,177; P=0.00;
Tunnel length: F=28.64; df=2,177; P=0.00; Percent infestation: F=26.36; df=2,6; P=0.001
*/** - Data analysis was on log (x+1) and arcsin (x/100) transformations respectively, but the values presented are untransformed.

Figure 1. Parasitism of a wasp (*Campoletis sonorensis*) on fall armyworm (*Spodoptera frugiperda*) in Bt and non-Bt maize.



Days after Infestation

parasitoids and these were *C. flavipes* (6.4%), *C. sesamiae* (0.97%) and *P. furvus* (3.1%). Only two species of parasitoids were recovered from the *Bt*-sprayed plots, and these were *C. flavipes* (2.6%) and *Pediobius furvus* (1.8%), and two parasitoid species *C. sesamiae* (0.05%) and *Cotesia ruficrus* (Haliday) (0.23%), were recovered from the CI treated maize.

Results of this study show that *Bt*- spray was more effective than the conventional insecticides (CI) in controlling stem borer damage in maize. The smaller range of parasitoids that were recovered from the *Bt*- and the CI sprayed maize, compared to the untreated one, suggests that both these treatments have some level of effects on some parasitoids of stem borers. Although a similar number of parasitoid species was recovered from the *Bt*- sprayed and CI treated maize crops, the type of species was different, thus indicating their differential effect on the parasitoids.

Another study was made at CIMMYT's headquarters in Mexico where a biosafety green house and laboratory are available to conduct transgenic trials. The experiment was designed to develop a methodology to test the impact of Bt maize on biological control agents and to identify a potential synergism between a Bt maize and a wasp which attacks a species of armyworm (*Spodoptera frugiperda*) which is similar to the armyworm species found in Kenya (*Spodoptera exigua*). Two experimental protocols were used: 1) no-choice in which the armyworm and the wasp (*Campoletis sonorensis*) which attacks its parasitoids were placed on maize leaves only with Bt (*Cry IAb* toxin) or without Bt; and, 2) a free choice experiment in which the wasps were placed inside a netting which contained both Bt and non-Bt maize infested with armyworm.

The rate of parasitism does not change between Bt and non-Bt maize, with both types of maize resulting in a peak rate of parasitism around 45% attained 10 days after armyworm placement on the plants (Figure 1). The second observation is the higher rate of parasitism on Bt maize following the peak, with 30% parasitism being observed on day 12 versus only 20% for the non-Bt maize. The reason for this difference is the reduced growth rate of the armyworm when feeding on the Bt maize. The average weight of the armyworm on day 12 was 9.7 mg for those collected on Bt maize versus 16.6 mg for those on non-Bt maize. The significance of this observation is the fact that the wasp has a long period of time to attack the armyworm feeding on the Bt maize. The significance of this observation is the fact that the wasp has a long period of time to attack the armyworm feeding on the Bt maize as once the armyworm reaches the third larval instar it is too large to be successfully attacked by the parasitoid. In this regard, the Bt maize is enhancing the efficiency of the wasp in controlling the armyworm even though the Bt maize is not directly controlling the armyworm pest. Another possible advantage to this system is the fact that with a reduced growth rate, the rate of cannibalism, which is known to occur in armyworm species, is reduced on the Bt maize. This would mean that armyworm which have been attacked and have the wasp larvae developing within them could likely have a great probability of escaping consumption by neighboring armyworm and therefore facilitate higher parasitoid populations. This hypothesis has not yet been tested but will be the subject of future testing.

This study has now established a protocol for testing the interaction between parasitic wasps and transgenic maize to quantify their impact on the control of secondary pests of maize, such as the armyworm. Once a biosafety greenhouse is in place in NARL, these types of studies will be continued in order to quantify the environmental impact of Bt maize on biological controls and other non-target organisms found in Kenya.

Product Dissemination – Development of appropriate insect resistance management strategies for resource-poor farmers in Kenya:

To counter the buildup of resistance by the borers to Bt maize, we are developing varieties that carry multiple forms of resistance—for example multiple Bt genes and combinations of Bt genes as well as conventional resistance. So a borer population would have to develop multiple resistances rather than a single resistance to the Bt. In addition, management strategies are being developed, with the help of farmers, that maintain populations of non-resistant borers that will breed with potentially resistant borers and limit the buildup of resistant populations. Any host of the borers can be used for this purpose and taken collectively they are known as "refugia".

Gould (1998) has discussed at length some of the theoretical aspects of genetically engineered crops for durable resistance, Gould (1986) has also used simulation models to evaluate different resistance management strategies. Generally, mechanisms of resistance management strategies are based on three principles; diversification of mortality sources so that a selection pressure is divided between multiple mortality factors (Georghiou, 1972), reduction of selection pressure from each mortality factor/mechanism to the target pest (Wharlon and Norris, 1996) and maintenance of susceptible pest individuals by providing refugia or promoting immigration of susceptible pests (Wharlon and Norris, 1996).

Research is needed to determine how much refugia from Bt must be provided in space and in time to slow resistance development substantially. The refugia area depends on the crop and the selected type of refugia treatment. Most cereal stem borers of maize and sorghum are polyphagous and have several graminaceous and other wild hosts in addition to cultivated crops. Wild host plants of stem borers have been documented by various workers (Ingram 1958, Bowden 1976, Seshu Reddy 1983, Khan *et al.,* 1997). The most important alternative hosts of the major stem borers (*B. fusca, C. partellus, S. calamistis and E. saccharina*) are reported to be cultivated sorghum, *Sorghum versicolour, sorghum arundinaceum,* Napier grass (*Pennisetum purpureum*) and *Hyperrhenia rufa* (Khan *et al.*, 1997).

Although stem borers oviposit heavily on some grasses only a few grasses are favourable for them to complete their life cycles (Huttler, 1996). It is therefore very important to select alternative hosts with economic value, e.g. high yielding livestock feeds or food crops which fit into the farming systems where the Bt maize will be planted. Studies on development rates of different stem borers have been done by Khan *et al.*, (1997) on maize and a few Napier grasses mainly for *Chilo partellus*. However, there is need to study development and survival rates of the common stem borer species in various agro-ecological zones on various grasses of economic value. This information is necessary to be able to synchronize the mating between susceptible insects from the refugia (forages) with the resistant insects emerging from Bt. maize. It is also important to recommend to farmers the cutting regimes for Napier grass and other forages based on the development time, to avoid harvesting Napier before the pests complete their life cycle.

Studies were, therefore, initiated within the IRMA Project to develop insect resistant management (IRM) strategies for Kenyan ecosystems based on existing cropping systems. To be accepted by farmers, IRM strategies must conform to existing cropping systems, and the refugia crops must be economically viable and socially acceptable to those making the management decisions at the farm level. Studies focussed towards verifying these tenets were also initiated. After evaluating 30 different alternate hosts for stem borers, preliminary results show Columbus and Sudan grasses as the most effective refugia for *C. partellus* and *B. fusca.* Sorghum was the best host for *Chilo* and *Busseola*, given the large number of exit holes per stem and numerous tillers. Napier grasses attracted oviposition, but were not good hosts for larval development.

Gene flow, the movement of genes between plants of the same species:

This is particularly found in cross pollinated crops like maize. Research is underway to estimate the distance that pollen travels and to assess the methods farmers use to select seeds with respect to the relative location in the field.

Most farmers in Kenya recycle seed for planting the following season. This has several implications for IRM. Unlike developed countries where farmers sign licensing contracts at the time of seed purchase, farmers in developing countries are not likely to report resistance breakdown. Therefore, techniques must be developed that will enable the early detection of resistance development so steps can be taken to replace the technology in a timely manner to avoid resistance breakdown. Screening technologies should be inexpensive and sensitive enough to detect shifts in the insect populations in a timely manner. A sampling protocol must also be developed to ensure that representative samples are taken from the major maize growing regions, especially those that have a high adoption rate of Bt technology. Agronomic studies will commence when insect resistant maize varieties are available. Seed production strategies will be developed when insect resistant maize varieties are available.

Impact Assessment – Assess the impact of insect resistant maize varieties in Kenyan agricultural systems:

IRMA's impact assessment group of social scientists have focussed on assessing various aspects of insect losses, suitability and demand of the new insect management technologies, farmers' perceptions of crop losses and control options, and assuring that the technology fits within Kenya's institutional framework. Through continuous dialogue with different stakeholders such as environmental groups, local research institutes, seed companies, and above all the farmers, IRMA has gained a clearer understanding of social, environmental and economic impacts of insect resistant maize in Kenya.

Participatory Rural Appraisals (PRAs) organized in the five maize growing ecological zones of Kenya have identified farmers' preferences for maize varieties and the constraints they face. Group interviews and discussions with more than 900 farmers were conducted. Over all the zones, most farmers plant local varieties in the low-potential areas while improved varieties dominate the high-potential areas. The most important selection criteria are early maturity and yield, followed by drought tolerance, then tolerance to field and storage pests. The major constraints to maize production were availability of cash, lack of technical know-how, and availability of good quality seed. The major pest problems, according to farmers, are stem borers and weevils. Farmers show a keen interest in new insect resistant varieties if they fit their selection criteria, even if they are moderately more expensive. However, since seed supply and quality are problems, the quality of seed needs to be guaranteed.

Results of our maize sector study show that most restrictions on maize marketing have been lifted, and that markets for fertilizer and pesticides are fairly free. Poor infrastructure, market information, and access to rural credit markets remain problematic.

Average crop loss at the national level due to stem borers is 15%, with a value of US$ 91 million, according to a calculation based on farmers' estimates. IRMA also conducted overall crop loss assessment trials in farmers' fields. The measured yield difference between plots provides an estimate of the loss due to stem borers and is estimated at 14% a value of US$ 60 million in 2000. These trials were repeated in 2001, and preliminary results show losses between 6.5% in the highlands and 10.5% at the coast. Crop loss assessment will be a continuous exercise in the IRMA project to ascertain the losses experienced by farmers.

Stem borers are the most widely distributed and most damaging pests to maize worldwide. In Africa, there are several economically important stem borer species. The most important borers are the spotted stem borer (*Chilo partellus*) and the African stem borer (*Busseola fusca* Fuller). *Chilo partellus* is found mainly in East Kenya, and is the most destructive pest of maize in warm, low-altitude regions. *Busseola fusca is* mainly in West Kenya, is native to Africa and is the major borer pest in the highlands. A very important aspect of the IRMA project is that the work carried out by KARI and CIMMYT will be used to help other African countries in the region combat maize stem borers. The IRMA project will be working in all maize production regions to develop maize varieties that both offer resistance to the most important stem borers in a given region and also produce good yields under local growing conditions. We plan to make the experiences and lessons learned -- and some of the maize germplasm that we develop in this project -- available to those of our neighbours that want to use this technology themselves.

Technology transfer, awareness creation, and communications:

In any undertaking involving new technology and technology transfer, capacity building in local institutions is critical to success and sustainability. Training of KARI scientists was done through visits to Mexico and on-site in Kenya on genetic engineering, management of biosafety and entomology laboratories and on how to conduct insect bioassays. Others were exposed to biosafety regulatory systems (development, dissemination and enforcement with the Mexican example). Other training was on impact assessment and general methods in breeding and entomology. Infrastructure support and development were realized through the planning of biosafety laboratories at the KARI Biotechnology Center, development of a biosafety level 2 laboratory, provision of logistical facilities like computers, vehicles, laboratory equipment, and support of insectaries and entomology laboratories. In a project where new technology is being developed and disseminated, communication is important for education and creating public awareness. Considerable effort has been given to creating dialogue and raising public awareness about biotechnology in general and Bt gene-based stem borer resistance. Stakeholders meetings, establishing positive media relations to achieve objective coverage, creation of print and electronic materials, working closely with local press, and participation and documentation of relevant seminars and conferences are some of the ways used to enhance communication.

CONCLUDING REMARKS

The approach of the IRMA project to the issue of risk is to conduct research to address issues within our capability, draw from experiences elsewhere, and collaborate with partners with necessary expertise on issues not easily addressed by the project staff. African scientists are generally positive towards the use of GMOs (Ndiritu and Wafula, 1998; Wambugu, 2000). Opposition to GMOs stems mainly from suspicions that not all stakeholders will benefit. Farmers particularly in developing countries, stand to gain from increased production coupled with reduced costs of production. The consumers may not feel the benefits of increased production especially in developed countries where food is plentiful and costs are low. Recent reports indicate that food made from genetically modified crops do not pose greater risks to human health than those made from non-genetically modified crops. The World Health Organization, the UN's Food and Agriculture Organization, the United States Department of Agriculture and others have declared that the Bt maize foods now on the market are safe (NRC, 2000). To avoid any undesirable effects of antibiotic resistance in Bt maize foods and feed, CIMMYT is developing genetically engineered germplasm without antibiotic resistance genes.

The IRMA project has considered risks to the environment. For Bt products, such risks include: 1) impacts of the Bt maize on non-target organisms, 2) potential development of resistance of stem borers to the transgenic Bt maize, and 3) potential of gene-flow from the transgenic maize to other cultivated and/or wild plant species (Serratos *et al*., 1997). These concerns have been addressed through activities reported here. Risks of Bt maize monoculture in Kenya are relatively low as adoption levels for any technology in maize production is usually lower than expected.

The concern about gene flow relates to gene transfer to other plant species, with possibilities of creating super weeds, "contaminating" landraces with transgenic maize, or by reducing diversity in the environment through greater competitiveness of Bt maize. Studies are under way to address the issues on gene flow. However, gene flow into other species is of less consequence in Kenya, as maize is not native to Africa and there are therefore no wild relatives that would readily cross to maize.

Development of an insect resistance management strategy will address the buildup of resistance by the borers to Bt maize. Management strategies such as the use of refugia help to forestall the development of resistance in stem borers. Varieties that carry multiple forms of resistance such as combinations of Bt genes (pyramiding resistance) and conventional resistance will be developed. Thus, a borer population would have to develop multiple resistances rather than a single resistance to the Bt toxin. This should greatly slow the build-up of resistance to the Bt toxin. Yet another strategy to be pursued is the use of two-toxin Bt maize, both at high doses. If stem borers that are able to survive on a plant with one high-dose toxin are rare, then those that will survive on a plant with two high-dose toxins will be even rarer. Research done at CIMMYT in Mexico has shown that larvae of *Diatraea grandiosella* and *D. saccharalis* will not survive beyond 8 days on Bt maize after 18 cycles of selection on Bt maize (Bergvinson, 1999). Studies are underway on dispersal behaviour of stem borer and the feasibility of natural habitats as refugia.

To address the concerns surrounding Bt maize, we have taken various approaches: 1) gathering information from various sources in literature, 2) informing stakeholders through meetings, exhibitions, published literature and newsletters, 3) carrying out field research where significant gaps in information exist, and 4) strictly adhering to national regulations at all stages of project development.

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CHARACTERIZATION AND QUANTIFICATION OF ARTHROPODS IN TWO MAIZE PRODUCTION ENVIRONMENTS IN KENYA

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ABSTRACT

***Bt*-maize offers farmers an effective and affordable option of reducing stem borer damage in maize and thus increasing food security in Kenya. However, before the deployment of *Bt*-maize in Kenya, there is need to examine its impacts on non-target organisms. Effects on non-target arthropods could have implications on biodiversity, natural control of the target pests and on the decomposition of organic matter in the soil. A prerequisite to the foregoing studies, is identification of the arthropods on which the non-target effects will be examined. For this reason, on-farm studies were conducted in five farms in each of two maize growing regions in the western and coastal provinces of Kenya for two seasons, to identify the major target and non-target arthropods of *Bt*-maize. The dominant maize cropping systems, crop varieties and agronomic practices, characteristic of each respective region, which were identified through a preliminary survey were used in the study farms. Arthropods in the maize farms were monitored weekly, using pitfall, sticky and water traps, and by destructive sampling of maize plants thrice a season. The non-targets were preserved in 70%alcohol for later identification, whereas the targets (stem borers) were identified and reared singly for possible parasitoid emergence. The stem borers in Western Province were *Busseola fusca, Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae), *Sesamia calamistis* (Lepidoptera: Noctuidae) and *Cryptophlebia leucotreta* (Lepidoptera: Torticidae), while in the Coast, they were *C. partellus*, *C. orichalcociliellus*, *S. calamistsis* and *Cr. leucotreta* in descending order of abundance. Among the non-targets, the parasitoids of stem borers in the Coast were *Cotesia flavipes* Cameron, *C. sesamiae* (Cameron), *Chelonus curvimaculatus* Cameron (Hymenoptera: Braconidae), *Goniozus indicus* Ashmead (Hymenoptera: Bethylidae), *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) and *Pediobius furvus* Gahan (Hymenoptera: Eulophidae), while in western, they were, *C. sesamiae* and *D. busseolae*. Some of the commonly recovered predator groups belonged to the families formicidae, araneida, coccinelidae, forficulidae and carabidae. Other potential parasitoid and predator groups recovered are also presented. The only pollinator was the honeybee, while the decomposers of organic matter, were termites and earthworms. The potential arthropods on which the non-target effects of *Bt*-maize may be examined are discussed.**

Keywords: Arthropods, *Bt*-maize, characterization, maize, non-target effects, transgenic.

INTRODUCTION

Maize is the main staple food crop for a majority of households in Kenya, and is mainly grown by subsistence small-scale farmers. However, grain yields in most of these farms are low averaging 1,385 kg/ha (as per the 2000 statistics) as compared to the world average of 4,230 kg/ha (FAO 2000). Damage by lepidopteran cereal stem borers is one of the major causes of these low yields. Yield losses due stem borers are variable, but are typically in the range of 20-40% of the potential yield (Youdeowei, 1989; Seshu Reddy and Walker, 1990).

Bt-maize offers farmers an effective and practical option of reducing stem borer damage in maize and thus increasing food security in Kenya. Studies elsewhere have demonstrated the high effectiveness of *Bt*-maize in controlling damage by neotropical stem borers (Koziel et al., 1993). The use of *Bt*-maize could reduce the heavy reliance on pesticides for stem borer control, especially in commercial maize production, such as is the case in western Kenya. For example, in the USA, it was reported that in 1998, 8.2 million fewer pounds of active pesticide ingredient (3.5%) were used on maize, cotton and soybeans than in 1997, and that this reduction corresponded to an increase in the adoption of genetically engineered crops (USDA, 2000). However, before the deployment of *Bt*-maize into Kenya, there is need to determine any non-target effects that this technology may have on important arthropods found in major maize cropping systems in the country. Non-target effects in this case, are defined as the unwanted effects of *Bt*-maize on arthropods living in or around the maize field that are not intended to be hurt. Effects on non-target arthropods could affect natural control of the target pests, through possible effects on their natural enemies (parasitoids and predators), have implications on biodiversity and interfere with essential soil processes such as the decomposition of organic matter. Knowledge of the magnitude of non-target effects of *Bt*-maize is therefore essential for the safe deployment of *Bt*-maize in Kenya. A prerequisite to the foregoing is identification of the major arthropods on which the non-target effects will be examined, hence the need for arthropod characterization and quantification studies.

Arthropods in a given maize habitat are influenced by the prevailing environmental conditions, the crop varieties and by the agronomic practices used. For this reason, the arthropod characterisation studies would have to be done in farms having the major maize cropping system, and using the farming practices characteristic of each of the major maize growing regions in Kenya. The objectives of this stage of the study were to: i) identify the major maize cropping systems, crop varieties and the agronomic practices used in two maize growing regions in Kenya, ii) identify and determine the relative abundance of the target and non-target arthropods of *Bt*-maize, and to iii) establish a reference collection of arthropods.

MATERIALS AND METHODS

Farmer surveys followed by on-farm arthropod characterisation studies were conducted in collaboration with personnel from the local agricultural extension service and KARI in two of the major maize growing regions in Kenya: i) moist transitional (Kakamega) and ii) lowland tropics (Kilifi), during the long and short rains of the year 2000.

Surveys: In the surveys, at least 30 farmers in a major maize growing area within each of the two regions were interviewed, and information collected on the major maize cropping systems, maize varieties, crops commonly intercropped with maize and on other pertinent crop management practices. Although a structured questionnaire was used, it was complemented by holding informal discussions with the farmers in order to collect other key information that was not addressed directly in the questionnaire. The number of respondents (farmers) to the various questions was recorded and the percentage affirmative respondents calculated.

On-farm arthropod characterisation studies:
In Kakamega and Kilifi, the participating farms were located in a major maize growing administrative division, which was also logistically accessible, in order to allow weekly collection of the arthropods. The selected study sites in Kilifi and Kakamega were Chonyi and Municipality divisions, respectively. This study was conducted in five farms in each of the two regions, and the farms were selected from a sampling frame that had been drawn up in collaboration with the extension staff. The sampling frame was drawn based on the following criteria: i) farmer willingness to participate in the study, ii) farm size relative to household size, iii) accessibility of the farm, iv) whether farmer grew maize using the major maize cropping system for the region. In each of the farms, a plot measuring 18m x 18m was established using the major maize cropping system, crop varieties and crop management practices for the respective regions, and the plot was sub-divided into four sub-plots for sampling purposes.

Different sampling methods were used for the various groups of arthropods. For soil crawling arthropods, pit-fall traps were used at the center of each sub-plot. A pit-fall trap consisted of a large plastic cup of diameter 9.5 cm and depth 11.5cm, and a smaller cup of diameter 9.0cm and depth 10 cm. The small cup was fitted into the larger cup, and were both fitted into a hole in the ground, such that the lip of the inner cup was level with the ground surface. To preserve the catch (arthropods), 250 ml of an aqueous solution of 4% formaldehyde was put into the inner cup. 20 ml of detergent was added in order to break the surface tension of the preservative solution. A 15cm x 15cm wooden cover was supported above each trap to prevent entry of rain water, reduce evaporation, and deter vertebrates from falling into the trap.

For flying arthropods, two types of traps were placed diagonally on either side of the pit-fall trap in each sub-plot, and these were, water and sticky traps. For the water traps, a yellow basin, which contained a preservative and detergent solution (1 liter of 4% formaldehyde + 50 ml detergent), was positioned 1.5 m above ground. For the sticky traps, a clear glass pane (15cm x 15 cm) coated on one side with 'tangle foot' adhesive (resin) was positioned 1.5 m above the ground. The catches from the various traps, were recovered on a weekly basis and preserved separately per farm and trap in 70% alcohol. Arthropods from the sticky traps were recovered through a procedure using turpentine which dissolved the sticky resin.

Arthropods on and in the maize plant were sampled by destructive sampling of 50 random plants during each of 3 crop growth stages: mid-vegetative, reproductive (tasseling and silking) and maturity stages (Oloo, 1989). The non-stem borer arthropods were preserved in 70% ethanol for later identification, whereas each of the stem borers recovered were identified and then reared singly in the laboratory to await possible parasitoid emergence. The parasitoids recovered were preserved in 70% ethanol followed by identification. Voucher specimens of each of the various taxa identified were kept in the reference collection at Katumani.

The on-farm study was researcher managed, but farmer implemented, with the farmer and his family being responsible for the crop management activities including planting, weeding, maintenance and security of the traps. In each maize growing region, two on-ground personnel (one from extension and the other from KARI) were responsible for the weekly collection of arthropods from the traps.

RESULTS AND DISCUSSION

Survey of maize cropping systems and some farming practices

In Kilifi and Kakamega, a majority (96.7%) of the farmers grew maize in association with other crops, with the major cropping system in Kilifi being an intercrop (relay crop) of maize, cowpea and cassava, while in Kakamega, it was an intercrop of maize and beans (Table 1).

A similar proportion of farmers grew improved and local maize varieties in Kakamega, whereas in Kilifi, most of the farmers grew local maize landraces. In Kakamega, a majority of the farmers intercropped their maize with improved varieties of beans, whereas in Kilifi, all the farmers interviewed intercropped their maize with local varieties of cowpea and cassava (Table 2).

Most households in Kilifi planted two maize crops a year, with the first crop usually planted in March/April and the second one in September/October, but in Kakamega, maize was most commonly planted only once a year in February/March (Table 3). In Kakamega, a majority of the households applied both inorganic fertilizers and farmyard manure in their farms; however, a greater proportion of these used inorganic fertilizers. In Kilifi, most of the farmers did not apply any soil amendments in their maize fields, with manure being the more commonly used method (Table 3).

Relative abundance of target arthropods (stem borer)

During the long rains (LR) 2000, the stem borers that infested farmers' maize fields in each of the respective sites in descending order of abundance were: Kilifi: *Chilo partellus* Swinhoe, *Chilo Sesamia calamistis* (Hampson)

During the short rains (SR) 2000, the relative abundance of stem borer species that attacked maize was similar to that for the LR 2000, except for an additional

Table 1. Crops most commonly intercropped* with maize in Chonyi (Kilifi District) and Municipality (Kakamega District) divisions in Kenya, in the long rains, 2000

Division	Percentage of farmers						
	Beans	Cowpea	Cassava	Green grams	Groundnuts	Bambara nuts	Sweet potato
Chonyi	60.0	86.0	80.0	76.7	-	10.0	-
Municipality	96.7	36.7	3.3	-	16.7	-	3.3

* The five major crops grown in association with maize, in decreasing order of importance

Table 2. Varieties* of maize and of the major association crops in farmers' fields in Chonyi (Kilifi District) and Municipality (Kakamega district) divisions in Kenya in the long rains, 2000.**

Division	Maize (n=30)		Bean (n =28)		Cassava (n = 11)		Cowpea (n = 21)	
	Improved	Local	Improved	Local	Improved	Local	Improved	Local
Chonyi	36.7	96.7	-	-	-	100	100	100
Municipality	83.3	86.6	92.9	46.4	-	-	-	-

* Some farmers grew both improved and local varieties. **Crops intercropped with maize
n = number of farmers growing each specific crop

Table 3. Percentage of farmers using various crop husbandry practices in Chonyi (Kilifi) and Municipality (Kakamega) Divisions in Kenya, in the long rains 2000.

Division	Soil amendments		Maize crops / year	
	Fertilizer	Manure	Two	One
Chonyi	3.3	23.3	53.3	46.7
Municipality	83.30	70.0	20.0	80.0

Figure 1. The relative abundance of stem borers that infested farmers' maize crops in Kilifi and Kakamega during the long rains 2000, and the short rains, 2000.

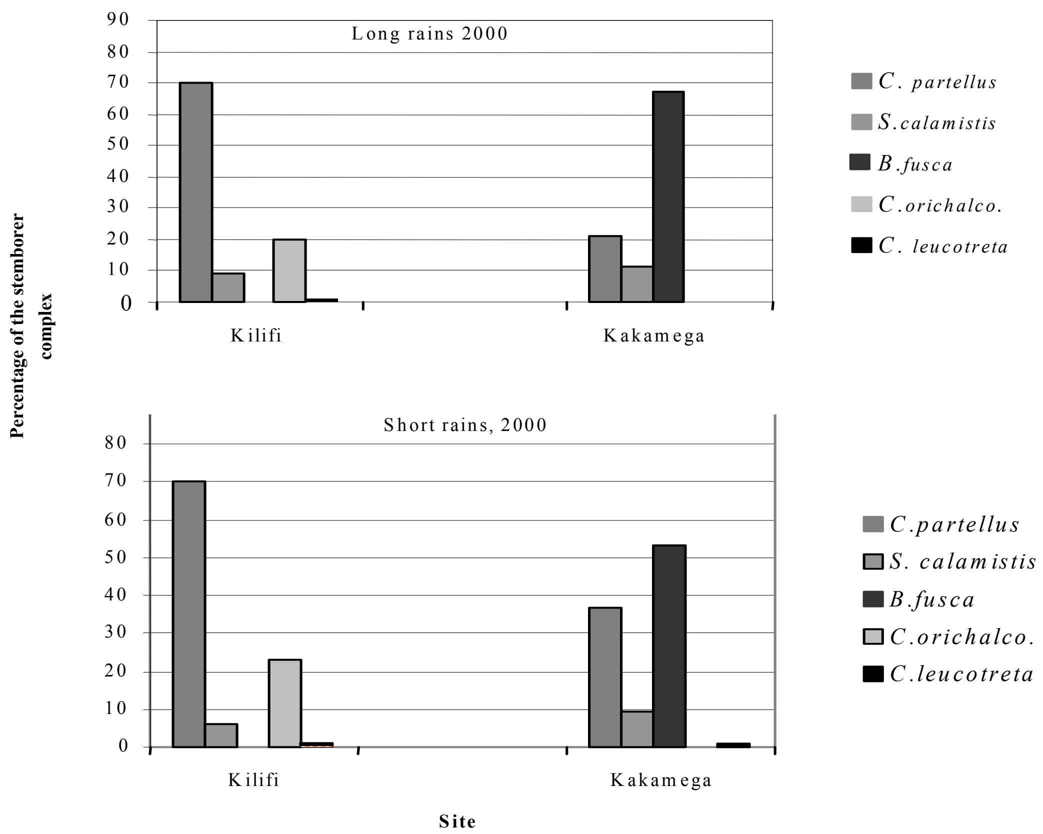

Table 4. Mean (± sem) number of stem borers per maize plant in farmers' fields in Kilifi and Kakamega during each of two seasons.

Season	Site	Mean number of stemborers / plant				
		Chilo partellus	*Sesamia calamistis*	*Busseola fusca*	*Chilo orichalcociliellus*	*Cryptophlebia leucotreta*
Long rains 2000	Kilifi	0.30 ± 0.05	0.04± 0.01	0	0.08 ± 0.026	0.01 ± 0.01
	Kakamega	0.09 ± 0.02	0.05 ± 0.03	0.27 ± 0.06	0	0
Short rains 2000/2001	Kilifi	0.56 ± 0.12	0.05 ± 0.01	0	0.18 ± 0.01	0.004 ± 0.001
	Kakamega	0.06 ± 0.01	0.02 ± 0.004	0.09 ± 0.01	0	0.001 ± 0.001

N - Number of plants sampled / site / season = 150

species (*C. leucotreta*) that was recovered in Kakamega in very low numbers. The dominant stem borers in Kilifi and Kakamega were *C. partellus* and *B. fusca* respectively, however, the highest intensity of infestation was by the exotic stemborer *C. partellus* in Kilifi during both seasons (Table 4). *C. partellus* was also the most widespread stem borer being recovered during both sites and seasons, while others such as *B. fusca* and *C. orichalcociliellus* were only limited to Kakamega and Kilifi respectively. C. *partellus* which is believed to be indigenous to Asia, was first reported in Africa, (in Malawi) in 1932 (Tams, 1932), in East Africa (Tanzania), in 1952 (Duerdon, 1953), and has since spread to all the other east African countries including Kenya.

Findings of this study agree with earlier studies at the Kenyan Coast (1991-1992) which showed that *C. partellus* was the most abundant stem borer of maize (Overholt, *et al*., 1994). The results of this study suggest that in order to have an impact on stem borer damage in maize, in these two regions, pest management technologies (e.g. *Bt*-maize), should be targeted at *B.fusca* for the case of Kakamega, and *C. partellus* for the case of Kilifi. Also, since *C. partellus* was the second most abundant stem borer that infested maize in Kakamega, and being a good colonizer of new habitats (Kfir, 1997), it is likely to continue being an important pest of maize in this region. For this reason, *Bt*-maize or any other stem borer management technology that is targeted at controlling *C. partellus*, is therefore likely to be of benefit both at Kilifi and Kakamega.

Relative abundance of non-target arthropods Parasitoids of stem borers:

Most of the parasitoids recovered from stem borers in each of the two sites were the larval type, with a greater diversity being recovered from Kilifi compared to Kakamega, during both the long and short rains, 2000 (Table 5).

In Kilifi, the 3rd - 5th instar larvae were most commonly parasitized by *Goniozus indicus* followed by *Cotesia sesamiae*, while *Chelonus curvimaculatus* was the only parasitoid that attacked the eggs, 1st and 2nd larval instars of *C. partellus* in Kilifi during both seasons. In Kakamega, the 3rd - 5th instar larvae were most commonly attacked by *Cotesia sesamiae* , while the pupae in both Kilifi and Kakamega were most commonly attacked by *Dentichasmias busseolae*.

In the planned studies on the impacts of *Bt*-maize on non-target arthropods, the larval parasitoids are of particular importance, especially the ones that attack the 1st and 2nd larval instars, like *C. curvimaculatus*. This is because the *Bt*-

Table 5. Parasitoids recovered from stem borers in farmers' maize fields in Kilifi and Kakamega during the long rains, 2000 and short rains, 2000 / 2001.

Parasitoids		Host species	Host Stage	Long rains 2000		Short rains 2000/ 2001	
Species	Order: Family			N	% Parasitism	N	% Parasitism
Kilifi							
Chelonus curvimaculatus Cameron	Hymenoptera: Braconidae	*Cp*	E/L**	86	3.5	46	4.4
Goniozus indicus Ashmead	Hymenoptera: Bethylidae	*Cp, Co*	L*	202	6.4	935	4.2
Cotesia sesamiae (Cameron)	Hymenoptera: Braconidae	*Sc, Cp*	L*	202	5.4	935	2.4
Cotesia flavipes Cameron	Hymenoptera: Braconidae	*Cp*	L*	202	1.5	935	3.0
Unknown species	Diptera: Phoridae	*Cp*	L*	-	-	935	0.2
Dentichasmias busseolae Heinrich	Hymenoptera: Ichneumonidae	*Cp*	P	30	20	-	-
Pediobius furvus Gahan	Hymenoptera: Eulophidae	*Cp*	P	-	-	53	7.5
Kakamega							
Cotesia sesamiae (Cameron)	Hymenoptera: Braconidae	*Bf, Sc*	L*	193	3.6	85	9.4
Dentichasmias busseolae Heinrich	Hymenoptera: Ichneumonidae	*Cp*	P	30	5.6	18	11.1

Number of maize plants sampled per site and season = 150
N = total number of susceptible stem borers (all species) of the life stage parasitized
Cp - Chilo partellus *Bf - Busseola fusca* Sc - *Sesamia calamistis* *Co - Chilo orichalcociliellus*
E - Egg L- Larva P - Pupa **1st and 2nd larval instars *3rd , 4th and 5th larval instars

Table 6. List of arthropods recovered from pit-fall, water and sticky traps, in farmers' maize fields in Kilifi and Kakamega during the long rains 2000 and short rains 2000/2001.

Arthropod Order / Family)	Common name	Long rains 2000		Short rains 2000 /2001	
		Kilifi	Kakamega	Kilifi	Kakamega
DIPTERA					
Tachinidae	Tachinid flies	10	-	22	30
Sarcophagidae	Flesh flies	1424	469	705	382
Syrphidae	Hover flies	97	80	9	26
Dolichopodidae	Long-legged flies	73	1911	5	888
Stratiomyidae	Soldier flies	97	10	25	34
Sciaridae	Dark-winged fungus gnats	-	1	-	7
Calliphoridae	Blow flies	421	1947	2	815
Muscidae	Muscid flies	1381	692	260	5518
Phoridae	Humpbacked flies	4	87	-	3
Diopsidae	Stalk-eyed flies	1	2	-	2
Drosophilidae	Vinegar flies	87	46	1	158
Otitidae	Picture winged flies	61	1	-	11
Tephritidae	Fruit flies	46	3	9	19
Asilidae	Robber flies	18	-	1	1
Rhagionidae	Snipe flies	1	1	-	11
Bombyliidae	Bee flies	-	-	1	-
Mycetophillidae	Fungus gnuts	5	-	-	78
Lauxaniidae	Lauxaniid flies	3	11	-	2
Agromyzidae	Leaf miner flies	28	-	5	1
Anthomyzidae	Anthomyzid flies	419	728	23	70
Sepsidae	Black scavenger flies	2	1	-	2
ORTHOPTERA					
Gryllidae	Crickets	841	2916	12187	10838
Blattidae	Cockroaches	6	40	32	359
Acrididae	Short-horned grasshoppers	31	51	2812	123
Tetrigidae	Pygmy grasshoppers	1	3	4	-
Tettigonidae	Long-horned grasshoppers	15	4	29	8
Gryllacrididae	Camel cricket	5	4	4	-
Mantidae	Mantids	3	1	164	1
DERMAPTERA					
Forficulidae	Common earwigs	28	29	7	173
Labiidae	Little earwigs	5	5	-	-
HYMENOPTERA					
Formicidae	Ants	11172	8314	6365	7996
Apidae	Honey bees	157	190	23	191
Ichneumonidae	Ichneumons	64	18	12	13
Vespidae	Vespid wasps	277	181	66	157
Pompilidae	Spider wasps	58	11	18	2
Specidae	Sphecid wasps	52	108	109	52
Cephidae	Stem saw flies	102	23	6	26
Eumenidae	Potter wasps	14	-	5	-
Braconidae	Braconid wasps	7	21	13	15
Chalcididae	Chalcidids	1	-	10	1
Megachilidae	Leafcutting bees	21	19	3	7
Tiphiidae	Tiphid wasps	3	3	2	-
Mutillidae	Velvet ants	2	-	1	-
Evaniidae	Ensign wasps	5	1	-	-
Ibaliidae	Ibaliids	2	-	-	-
Chrysididae	Cuckoo wasps	10	-	1	23
Halictidae	Halictid bees	1	1	14	9
COLEOPTERA					

Arthropod Order / Family)	Common name	Long rains 2000		Short rains 2000 /2001	
		Kilifi	Kakamega	Kilifi	Kakamega
Coccinellidae	Lady bird beetles	234	157	32	68
Carabidae	Ground beetles	76	9	1465	90
Staphylinidae	Rove beetles	182	65	8	145
Tenebrionidae	Darkling beetles	59	5	2646	35
Melyridae	Soft-winged flower beetles	35	54	725	779
Scarabaeidae	Scarab beetles	609	21	159	496
Mordellidae	Tumbling flower beetles	124	1	13	15
Chrysomelidae	Leaf beetles	401	458	55	134
Cerambycidae	Long-horned beetles	4	1	3	-
Curculionidae	Maize weevil	22	10	8	12
Elateridae	Click beetles	1	-	1	6
Lagriidae	Long-jointed bark beetles	-	3	4	2
Dasytidae	Soft-winged flower beetles	41	-	277	13
Bupestridae	Mettallic wood boring beetles	56	1	9	1
Meloidae	Blister beetles	6	-	17	14
HEMIPTERA					
Miridae	Plant bugs	10	21	22	39
Cydnidae	Burrower bugs	-	13	10	3
Reduviidae	Assasin bugs	13	3	16	3
Berytidae	Stilt bugs	-	-	1	-
Pyrrhocoridae	Stainers	14	8	333	1
Pentatomidae	Stink bugs	7	8	3	16
HOMOPTERA					
Cicadellidae	Leafhoppers	383	51	329	556
Cercopidae	Spittlebugs	1	-	2	-
Cicadidae	Cicadas	2	-	-	-
Membracidae	Treehoppers	12	24	16	31
Aphididae	Aphids	-	1	-	60
ISOPTERA					
Termitidae	Termites	43	388	1	25
Rhinotermitidae	Damp-wood termites	-	17	1	12
THYSANOPTERA	Thrips	-	-	-	-
PHALANGIDA	Harvestmen	1	30	-	3
LEPIDOPTERA	Moths*	223	160	534	142
ARANEIDA	Spiders	244	559	509	360
DIPLODA		12	6	3	-
CHILOPODA		2	5	1	-
ISOPODA		33	1	217	-
ANNELIDA		1	12	-	2
ACARI		1	1	1	-

* Moths could not be identified further as the scales had been removed in the water traps

toxins produced by *Bt*-maize are known to be most effective on the early instar lepidopteran larvae. Although the later larval instars may survive and continue developing even after feeding on *Bt*-maize, it will be useful to determine whether contamination of these larvae by the *Bt*-toxins will have any significant effects on development of parasitoids that target these stem borer larval stages, such as *G. indicus* and *C. sesamiae*. It was encouraging to note that the *C. flavipes*, the co-evolved larval endoparasitoid of the exotic stem borer *C. partellus*, was still being recovered from Kilifi, where releases had been made in 1993-1994 (Overholt *et al*., 1997). The larval parasitoids *C. curvimaculatus*, *G. indicus*, *C. sesamiae* and *C. flavipes* are therefore in the list of potential beneficial insects on which the non-target effects of *Bt*-maize will be examined.

Arthropods recovered from the traps: The diversity of arthropod families and unidentified order groups recovered from traps in Kilifi and Kakamega in the LR was 77 and 68, and during the SR it was 69 and 67, respectively (Appendix I). It is likely that the relative higher coastal temperatures in Kilifi favour a wider range of arthropods than the cooler environment in Kakamega. Out of the range of arthropods recovered, five categories of non-target arthropods of interest were identified, including the potential biological control agents, pollinators, decomposers of organic material in the soil were the abundant ones (Table 6). Some arthropods were abundant in all the three study sites, while some were limited to specific sites. For example, gryllidae and formicidae were the most abundant families of arthropods in both sites and seasons, whereas families such as carabidae and tenebrionidae were only abundant in the Kilifi site during the short rains (Appendix I). The parasitoid *C. sesamiae* was found in both sites and seasons, while *G. indicus* was only recovered in Kilifi (Table 5).

In the selection of studies and arthropods on which the non-target effects of *Bt*-maize will be conducted, a reliable system which takes into consideration the effects on diversity and on key beneficial arthropods in the country, will need to be used. The 'International Organisation on Biological Control - Global Working Group on Transgenic organisms in IPM and Biocontrol' is currently working on guidelines, one of whose objectives is to establish a list of criteria for selection of relevant organisms - on which non-target effects of genetically modified organisms. should be tested. Protocols and criteria developed by this International group, will be also be taken into consideration when conducting studies on the non-target effects of *Bt*-maize in Kenya.

Non-stem borer arthropods on maize plants: The most commonly recovered arthropods from the maize plants in Kakamega and Kilifi were formicidae (ants), aphididae (aphids) and forficulidae (earwigs) (Appendix 2). Ants and earwigs are known to be predators of stem borer eggs and larvae (Oloo, 1989). Lady bird beetles, which are known to be predators of *C. partellus* eggs (Dwumfour *et al.,* 1991), were also recovered with *Cheilomenes sulphurea* (Olivier) being the most common species, especially at Kakamega

Reference collection: One of the major activities in the arthropod characterisation process, was the establishment of a reference collection. The reference collection comprised of voucher specimens of the various specific taxa that were collected from the field. Different groups of arthropods were preserved using appropriate preservation methods, including, i) dry collection ii) and a wet collection (in ethanol). A pictorial data base is also being developed for the important arthropod groups. The reference collection will serve as a technical reference during the monitoring phase in *Bt*-maize fields, and for use by KARI entomologists.

CONCLUSIONS AND RECOMMENDATIONS

This study has generated information on the diversity of arthropods, and the important non-target groups of arthropods found in major maize cropping systems in Kakamega and Kilifi. Similar studies are on-going in the other three major maize growing regions in Transnzoia, Machakos and Embu. Once these characterisation studies are completed in all the five major maize growing regions in Kenya, the next step will be to select representative arthropods on which the non-target studies will be conducted. The selection will be done using both nationally and internationally recognised criteria. Studies on the non-target arthropods will be conducted using a three-tiered testing scheme, which involves a succession of tests of increasing scale, complexity and realism. This tiered system will be similar to the one that is used for the routine assessment of the effects of pesticides on non-target arthropods (Barret et al., 1994).

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STEM BORERS IN MAIZE: A NATURAL STRESS AND PROGRESS TOWARDS HOST PLANT RESISTANCE.

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ABSTRACT

Documented evidence has revealed that damage by stem borers *Chilo partellus* and *Busseola fusca* in maize accounts for 18-53% of yield losses in the field. All available varieties grown by the farmers are susceptible to these borers and most of the methods used to reduce damage are either ineffective or not cost effective. Since 1997, efforts have been made towards identifying new sources of resistance for use in the mid-altitude breeding programme. Germplasm consisting of inbred lines, synthetics and lines extracted from populations like P531, P391, ITSI (Intermediate Tropical lines) and MIRT (Multiple Insect Resistance Tropical) has continuously been obtained from CIMMYT, Mexico and Harare and systematically screened over years under an artificial infestation technique. Results have indicated that in terms of foliar damage on a scale of 1-9 and stem tunneling, some lines and populations have been found to possess tolerance either to *C. partellus* or *B. fusca, with* a mean foliar score of 4 and below. However, these materials were not well adapted to the local environment as evidenced by their yield levels. Breeding work in progress is to introgress borer resistance to local breeding germplasm Emap1a and 2a using the identified tolerant lines. Some crosses developed with some of the lines have already been made and evaluated. Development of synthetics in the long term and extraction of inbred lines in the short term is envisaged.

INTRODUCTION

Maize production in the mid-altitude areas of Kenya is limited by many biotic and abiotic constraints. The most important amongst the biotic constraints are the pests of which stem borers are ranked first. Survey results (KARI/CIMMYT, 1990) revealed that stem borers rank 3rd amongst other constraints as perceived by the farmers. Spotted stem borer (SSB), *Chilo partellus* Swinhoe and the maize stem borer (MSB) *Busseola fusca* (Fuller) cause the greatest damage, resulting in yield losses of between 18% and 53% (Warui and Kuria, 1983; Ampofo and Saxena, 1987; Anon, 2001). While SSB predominates in the lower wetter areas of the region, MSB predominates in the higher altitude areas. However, both insect species occur together in the mid-altitude region (600 – 1,200 m above sea level).

During the growing season and more so during the minor season, several generations of the stem borers develop and may destroy leaves and stems by leaf feeding and stem tunnelling. There are indicators that *Chilo partellus* is gaining more importance as it is replacing other species in many maize growing areas.

Reduction of damage caused by the stem borers to manageable levels involves the use of insecticides. However, these insecticides are rather ineffective due to the mode of application and lack of timeliness. Environmental considerations are also very critical.

Improvement of maize varieties for stem borer resistance is a major component for the stem borer management if the system is to be maintained at a sustainable level. This coupled with other stem borer control practices i.e. early planting, removing stover and ploughing in stubbles would reduce borer densities and subsequent losses. This is in line with CIMMYTs objectives of developing suitable maize germplasm for integrated pest management.

ICIPE and CIMMYT Mexico have developed several maize inbreds and open pollinated varieties with enhanced levels of resistance to SSB for the lowland tropics (Ajala and Saxena, 1994). There are indications that CIMMYT's MBR population is a source of SSB resistance. Maize inbreds Mp 706, Mp 707 and CML 67 have been identified as resistant to borer infestation. Little information is available on the local maize varieties for resistance against *C. partellus* and *B. fusca*. A systematic evaluation and introgression of genes for multiple borer resistance should be conducted. The major objective of this project was to develop locally adapted maize cultivars with increased tolerance to stem borers and maize streak virus. However, there were some immediate objectives of developing a rapid field screening technique of maize germplasm for resistance to stem borers and at the same time identifying new sources of resistance and then introgressing the identified tolerance to stem borer into local well-adapted populations. Therefore the main objective of this is to develop locally well-adapted maize cultivars with increased tolerance to stem borers.

MATERIAL AND METHODS

Maize germplasm known to possess moderate to high resistance to stem borers like the Southern corn borer (SCB), Fall army worm (FAW) and SSB and those that possess multiple borer resistance (MBR) have continuously been collected for prescreening for their resistance under the local conditions and borer species.

Since 1997, a total of 500 lines obtained from various sources namely CIMMYT, Mexico and Harare, Cape Town and some lines that have been bred locally have been prescreened using an artificial infestation method. The lines once obtained are planted in double row plots at a spacing of 75 x 30cm and replicated 3 times in a randomized complete block design (Alpha Lattice). The lines are then allowed to germinate and at the 6th leaf stage, they are uniformly artificially infested with SSB and MSB black heads or the 1st instar larvae. A batch of 15-20 eggs or larvae is put in the plant whorl. The newly hatched *Chilo* and *Busseola* larvae are allowed to feed and cause damage for a period of two weeks. Various damage parameters recorded at predetermined intervals are used to classify these lines into various categories i.e. susceptible, moderately tolerant and highly tolerant.

These damage parameters are: -

i) Foliar damage rating: This was done weekly from 10 plants selected at random on a scale of 1 to 9 where 1 was no damage and 9 meant severe foliar damage (After Guthrie *et al.* 1960).

ii) Stalk tunnelling: Plants in all the treatments were taken at harvesting, split open to assess the length of the tunnel made by the feeding larvae. This parameter was later expressed as a percentage of the total length.

iii) Stem borer number and species: This was done thrice in the course of the season from another set of 5 plants selected at random.

iv) Exit/entry holes: Were assessed from the plants that were used in iii. the holes were distinguished by the presence or absence of frass deposits.

The evaluated germplasm are then placed in various categories as tolerant, moderately tolerant and susceptible. The best lines selected are then put in the breeding nursery and crosses made with the local breeding lines to determine the heterotic groupings and the combining ability.

RESULTS AND DISCUSSION

Results from the 1998 long rains where 127 accessions from various sources were evaluated under artificial infestation indicated that CIMMYT lines selected for multiple borer resistance (MBR) SCB and FAW tolerance reacted differently when challenged with both *Busseola* and *Chilo*. MBR (n = 3) lines and 2 synthetics for FAW resistance showed very high tolerance to both borers for foliar damage (score of 1-3) Figure 1. The figure also indicates that the two synthetics were the best for yield and other disease tolerance.

When various crosses were made between the tolerant synthetics and drought tolerant and N resistant lines in various combinations, the resultant three-way hybrids performed equally well as the synthetics in term of foliar damage (score 4-5) Figure 2. This indicated that it is possible to incorporate stem borer resistance.

Results from over 200 S3/S4 lines derived from a drought tolerant population and tested in the Regional Nursery under *Chilo* infestation indicated that only 19 lines showing damage score of between 3 and 5 (Table 1) were promising in terms of *Chilo* tolerance. When these lines were crossed with MSV resistant lines derived from the two lines of different heterotic group from Embu results indicated that single crosses generated and reevaluated showed some promising combination in terms of damage score and tunnel length (Table 2). As in the previous testing, there is evidence that stem borer resistance though multigenic can be inherited. Resistance may be due to either tolerance or non-preference, a fact evident by some crosses having lower or higher foliar damage and a very low amount of stem tunnelling (Table 2).

Figure 1. Mean foliar damage and yields of CIMMYT's stemborer and fall armyworm tolerant lines.

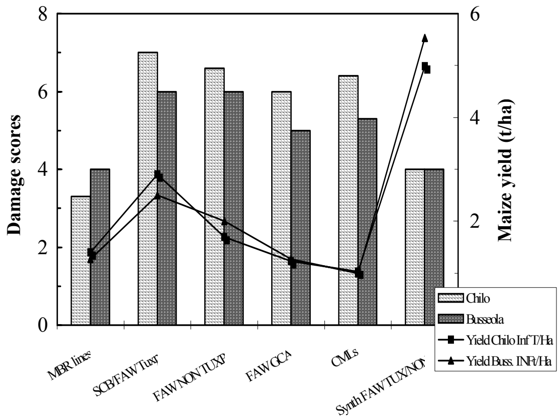

Figure 2. Foliar damage when drought and lowN resistant lines are crossed with the stemborer tolerant synthetic.

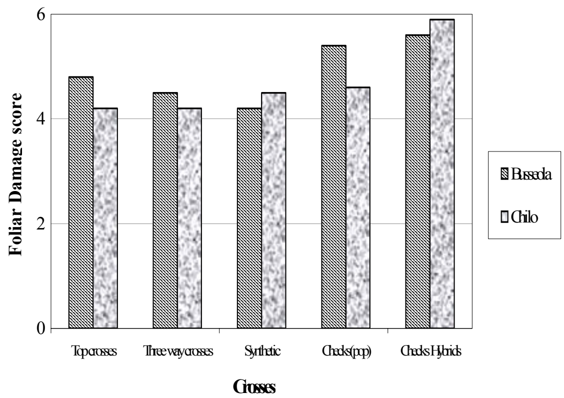

Table 1. Foliar damage scores for REGNUR lines selected from 1999/2000 evaluation for tolerance to *Chilo partellus* damage.

Pedigree	Damage score
ZM 60 C2 F1	4.0
CNW5867/P30-SR	3.7
SYSYN F2/N3/TUX	4.0
CML 197/N3/FR 808	4.0
COMPE2/P43-SR//COMPE	4.2
DRA-F2-73/DRA…….	4.0
LATB-1-2………	4.7
LATB-107…….	4.5
NAW 5867/P30-SR…	5.0
SNSYN F2(N3)TUX…	4.2
POP391 BCO BULK…	4.8
MSR 123 X 1137 TN…	5.0
K64R/P30 – SR/K64R…	4.5
SNSYNF2……..	4.0
LATA F2-138	4.8
SNSYN F2 N3/TX…..	4.2
SNSYN F2 (N3-90)….	5.0
INTA 202…	3.2
K64R (P30SR)/(K64/P30 SR)-87..	4.5

Table 2. Reaction to *Chilo* infestation for crosses made between MSV lines and REGNUR selected lines (LR 2000).

Code	Foliar Damage score	Tunnel length (mm)
EM0068	**2.3**	**9.1**
EM0069	**3.5**	**7.8**
EM0070	**2.5**	**5.7**
EM0071	5.0	10.0
EM0072	**3.4**	9.8
EM0073	5.0	11.8
EM0074	5.5	13.2
EM0076	4.3	5.5
EM0077	4.8	0.0
EM0078	4.8	11.7
EM0079	6.0	7.4
EM0080	6.0	21.5
EM0081	5.5	9.4
EM0082	6.0	7.4
EM0083	5.5	12.6
EM0084	5.5	5.3
EM0085	6.0	5.2
EM0086	5.0	11.2
EM0087	5.5	13.1
EM0088	5.3	8.5
EM0089	6.5	12.3
EM0090	4.8	11.4
EM0091	5.5	5.0
EM0092	5.5	12.2
EM0093	6.3	23.9
EM0094	5.5	8.1
EM0095	5.0	15.4
EM0096	5.5	7.1
EM0097	5.5	5.8
EM0098	4.3	2.8
EM0099	4.0	

Table 3. Mean foliar damage scores on maize artificially infested with both *Busseola and Chilo* 1st instar larvae, Long rains 1999

Pedigree	Mean *Busseola* score	Mean *Chilo* score	Blight	Rust
MIRT C4 Am F2 bulk	5.3	3.8	5.0	2.0
MIRT C4Bco F2 bulk	*3.5*	*2.8*	2.0	2.5
ITS1 T Am G1 F2 bulk	*4.3*	*5.7*	2.5	2.0
ITS1 T Am G2 F2 bulk	*5.3*	*5.3*	1.5	2.0
ITS1 T Am G3 F2 bulk	5.3	6.2	2.5	1.5
ITS1 T Am A1xB1 F1 bulk	5.7	5.2	1.5	2.0
ITS1 T Am A1xB2 F1 bulk	***4.3***	***3.7***	2.0	2.0
ITS1 T Am A2xB1 F1 bulk	***5.2***	***3.3***	2.0	2.0
ITS1 T Am A2xB2 F1 bulk	5.8	5.8	2.5	2.0
ITS1 T Bco G1 F2 bulk	5.7	5.8	2.0	2.5
ITS1 T Bco G2 F2 bulk	***5***	***4.5***	2.5	2.5
ITS1 T Bco G3 F2 bulk	***5***	***3***	2.0	2.0
ITS1 T Bco G4 F2 bulk	6	5	2.5	2.5
ITS1 T Bco G5 F2 bulk	***6***	***3.7***	2.0	2.0
ITS1 T Bco A1xB1 F1 bulk	***4.7***	***4.8***	2.0	2.5
ITS1 T Bco A1xB2 F1 bulk	***5.2***	***4.8***	2.0	2.5
ITS1 T Bco A1xB3 F1 bulk	6.5	5.3	2.0	2.5
ITS1 T Bco A2xB1 F1 bulk	6.2	***3***	2.0	2.0
ITS1 T Bco A2xB2 F1 bulk	***6.2***	***3.7***	2.0	1.5
ITS1 T Bco A2xB3 F1 bulk	***6.5***	***3.5***	2.0	2.0
ITS1 T BcoB1xA1 F1 bulk	***5.7***	***3.5***	2.0	2.5
ITS1 T Bco B1xA2 F1 bulk	***5***	***4.7***	3.0	2.0
ITS1 T Bco B2xA1 F1 bulk	***5.2***	***4.5***	2.0	2.0
ITS1 T Bco B2xA2 F1 bulk	***4***	***5.3***	2.0	2.5
ITS1 T Bco B2xA1 F1 bulk	5.7	5.8	2.5	2.5
ITS1 T Bco B3xA2 F1 bulk	***4***	***4.3***	2.5	2.0
INBRED A	8.2	7.2	2.5	2.0
MUTINDA 10	6.2	5.7	3.0	2.5
LSD at p=0.05	**0.48**	**0.35**	**0.883**	**1.01**

Similarly, 28 lines, out of which 26 were Intermediate Tropical lines (ITSI) and Multiple Insect Resistance Tropical (MIRT) lines obtained from CIMMYT, Mexico through AMS and two checks were evaluated. Results indicated that some of these lines were promising in terms of reduced damage (Table 3) and several ITSI and MIRT lines were selected as tolerant to borers on the basis of their foliar damage and stem tunnelling.

In the year 2000 long rains, another batch of lines from 3 different multiple borer resistant populations namely MIRT (40 lines), P391 C_2 (14 lines) and P591 C_2 (10 lines) were screened for resistance to *B. fusca* and *C. Partellus* again at RRC-Embu.

The mean foliar damage rating, stem tunnelling and yield are shown in Tables 4-6. As in the previous evaluation, MIRT lines with damage ratings between 1 and 4.5 were selected as good either for *B. fusca* or *Chilo* tolerance (Table 4).

Only a few lines were selected for tolerance to both Chilo and Busseola from P391 as the damage was high with scores of 5.9 and below being considered as tolerant (Table 5). Table 6 for P591 show a similar scenario. But in this case, scores below 5.5 were considered as tolerant.

Overall, the data for the year 2000 showed that Chilo was more damaging than Busseola. This was attributed to weather as the season experienced little or no rainfall. Most of the crop relied on irrigated water. Temperatures were also extremely high. This agrees with earlier workers that *Chilo spp* prefer warmer areas while *Busseola* is predominant in cooler areas.

From over 500 accessions that have been screened for borer tolerance, over 20 of them have been identified as either tolerant to stem borer damage which are well adapted to their local conditions.

These best lines that were selected for borer and were crossed to the two local breeding lines Embu 12 line 210 and Embu 11 line 133 to determine their heterotic grouping and also determine patterns that could be used as single cross. A yield trial involving 210 of the crosses made was planted in two sites, to determine the best hybrids in terms of yield and agronomic traits. From the total, eight of the best crosses have now been planted in Advanced Yield Trials.

The way forward is in three categories namely, Long term that will involve introgressing borer resistance into local populations EMAP 1a and 2a using the already identified resistant populations and, secondly, development of synthetics that possess stem borer tolerance adapted to the local environment. The other category is the medium term out of which lines that are tolerant to stem borers will be used to form topcrosses using testers identified in the AMS region. This forms a part of pedigree breeding program, which is in collaboration with CIMMYT. Thirdly as short-term measure hybrids are already being developed.

Table: 4. Mean foliar damage rating, tunnel length (above and below ear), grain yield and larvae/plant when MIRT lines were infested with *Busseola* larvae.

Entry	Damage score		Tunnel length (cm)	Yield (t/ha)
	Busseola	*Chilo*		
1	4.51	5.79	11.19	0.77
2	5.03	5.50	7.63	1.25
3	5.44	4.29	11.12	2.05
4	5.65	5.65	4.47	1.40
5	4.93	5.66	2.40	1.09
6	5.50	5.94	5.56	1.74
7	5.02	5.11	1.23	2.36
8	5.79	4.98	8.52	0.51
9	**3.94**	4.80	**7.47**	**1.93**
10	5.74	5.09	5.73	1.82
11	5.02	5.28	5.12	1.58
12	5.64	4.96	3.09	0.98
13	5.34	5.81	7.19	2.22
14	5.21	4.45	6.90	2.31
15	4.80	**3.87**	7.77	2.09
16	**4.00**	4.64	**5.76**	**1.78**
17	4.81	5.95	2.98	1.17
18	**3.54**	5.53	**3.03**	**0.79**
19	5.74	5.94	3.41	0.59
20	4.50	6.50	2.12	2.55
21	5.20	5.29	7.62	0.29
22	4.73	6.02	5.00	1.01
23	5.30	5.87	4.17	1.04
24	5.54	6.23	5.60	2.30
25	**4.09**	4.79	**1.14**	**1.15**
26	**4.14**	4.97	**2.19**	**1.91**
27	**4.41**	5.42	**4.17**	**2.59**
28	**4.21**	5.67	**1.61**	**1.58**
29	**4.20**	6.02	**2.42**	**0.86**
30	**4.01**	**3.30**	**3.00**	**0.58**
31	**3.74**	**3.92**	**1.64**	**1.08**
32	5.40	4.80	3.00	0.46
33	4.25	5.32	3.99	1.41
34	5.20	5.50	2.35	1.64
35	5.64	6.15	2.75	0.99
36	5.40	6.74	2.42	1.25
37	5.07	5.52	0.48	0.45
38	4.94	5.61	6.96	1.82
39	5.03	6.15	4.32	1.71
40	4.71	5.77	3.92	2.75
LSD	1.47	2.03	1.05	1.46

Table 5. Mean foliar damage rating, tunnel length (above and below ear, yield/ha. and larvae/pupa/plant when lines from P391 were infested with *B. fusca* and *C. partellus* larvae (LR 2000).

Entry	Foliar Damage score		Tunnel Length (mm)	Yield (t/ha)
	Busseola	*Chilo*		
1	6.32	**5.73**	11.61	1.15
2	6.29	5.87	5.08	2.99
3	7.07	6.09	10.46	0.24
4	6.69	4.80	10.42	4.52
5	6.91	6.18	12.11	4.89
6	6.19	6.68	6.68	0.27
7	7.19	6.29	17.32	1.27
8	5.84	6.63	6.05	2.10
9	6.71	5.76	10.08	1.39
10	6.56	6.28	9.64	1.54
11	5.36	6.55	6.45	2.86
12	6.79	6.20	16.87	1.39
13	6.29	6.19	11.52	3.04
14	6.34	6.14	10.88	2.13
LSD	0.83	**1.38**	12.50	2.89

Table 6. Mean foliar damage rating, tunnel length (above and below ear,) yield and larvae/pupa/plant when lines from P591 were infested with *B. fusca* and *C. partellus* larvae (LR 2000).

Entry	Foliar damage score		Tunnel Length (mm)	Yield (t/ha)
	Busseola	*Chilo*		
1	3.47	6.09	5.57	8.53*
2	5.17	5.74	8.91	2.97
3	6.27	5.91	10.37	0.29
4	6.21	6.33	6.02	1.39
5	5.50	5.16	4.89	1.89
6	5.42	5.60	9.19	2.94
7	6.06	5.91	2.15	3.21
8	6.36	5.91	11.31	1.74
9	5.97	6.79	6.26	3.64
10	5.53	5.77	8.37	4.02*
LSD	1.30	1.31	4.75	1.64

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PROGRESS IN BREEDING FOR RESISTANCE TO MAIZE STEM BORERS *SESAMIA CALAMISTIS* AND *ELDANA SACCHARINA* IN WEST AND CENTRAL AFRICA.

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ABSTRACT

The pink stem borer (*Sesamia calamistis* Walker (Pyralidae)) and the sugarcane borer (*Eldana saccharina* Hampson (Noctuidae)) are among the most damaging pests of maize in West and Central Africa, a region where IITA invests considerable effort in improving productivity of maize-based systems. The use of host plant resistance (HPR) is central to any Integrated Pest Management (IPM) programme; therefore, development and use of maize varieties with resistance to *Sesamia* and/or *Eldana* are integral to IPM activities in the region. Early research efforts resulted in the establishment of mass rearing facilities and screening procedures for both insect species, and the development of maize genotypes with resistance to *Sesamia* and/or *Eldana*. S1 selection has been used successfully to improve levels of resistance. New genotypes with resistance to both borer species have been developed by either broadening the genetic base of existing genotypes or by classifying the developed genotypes into heterotic groups and pooling each group to form a reciprocal pool for further improvement. Artificial infestation has identified levels of cross resistance in a number of genotypes. Inbred lines with resistance to either of the borer species have been isolated and tested. Stem borer resistant varieties are currently being grown on-farm in Nigeria, Ghana and Cameroon. There is, however, the need to correctly classify the mechanism of resistance in the identified genotypes to improve efficiency of selection and to combine different mechanisms of resistance into different genotypes.

INTRODUCTION

Stem borers are among the most important insect pests of maize in Africa. Three species of stem borers, *Sesamia calamistis*, *Eldana saccharina* and *Busseola fusca*, are of economic importance to maize in West and Central Africa. A few other species including *Sesamia poephaga* damage maize but are not of economic importance (Schulthess and Ajala, 1999). Both the pink stem borer (*Sesamia calamistis*) and the sugarcane borer (*Eldana saccharina*) attack maize especially in the lowland regions while the African stem borer (*Busseola fusca*) is found commonly in the Cameroon mid-altitude region. Both *Sesamia calamistis* and *Busseola fusca* attack maize early in the life of the plant while *Eldana saccharina* is a later infesting borer. In the lowland region of West and Central Africa, stem borer population build-up would generally reach very high damaging levels in the second season. Scientists at IITA have been conducting research on the integrated control of stem borers especially in the lowland regions of West and Central Africa where *Sesamia* and *Eldana* predominate, and host plant resistance has been a major component of this effort.

The pink stem borer (*Sesamia calamistis*) lays its eggs between the leaf sheaths of young plants at about three weeks after emergence. When the larvae hatch, they penetrate either the whorl or the stem resulting in leaf or stem damage and also deadheart formation. The sugarcane borer, *Eldana saccharina* lays its eggs on dry leaves and debris on the soil but also on the hairy margins of the leaves. *Eldana* larvae usually attack maize at the flowering stage resulting in stalk tunnelling, breakage and cob damage. The overall effect of stem borer infestation is reduction in yield ranging from 20-70% depending on severity. Total crop failure had been reported in a few instances (Usua, 1968a and b; Bosque-Perez and Mareck, 1991; Gounou *et al*. 1994; Schulthess and Ajala, 1999).

Kling *et al*. (1994) reported early progress made at IITA to screen and breed for resistance to both *Sesamia* and *Eldana*. These efforts included the development and use of controlled and uniform artificial infestation which in turn was made possible by the development of mass rearing techniques for both insect species and the formation of stem borer resistant populations (Bosque-Perez *et al*., 1989). Since then, significant progress has been made in improving and developing better performing maize genotypes with resistance to stem borer attack.

PROGRESS IN BREEDING STEM BORER RESISTANT GENOTYPES

Three populations, each with resistance to *Sesamia* and *Eldana,* were developed in the late 1980s. These were named TZBR (Tropical Zea Borer Resistant) Sesamia or Eldana 1, 2 and 3. Both TZBR Sesamia 2 and TZBR Eldana 2 were eventually discontinued due to low levels of resistance to their respective pests. TZBR Sesamia 1 was obtained by crossing five inbred lines from various sources with Tzi 4. While TZBR Sesamia 3 was also formed by crossing 29 lines mostly from CIMMYT with Tzi 4. Tzi 4 is a tropically adapted maize inbred line with resistance to both *Sesamia* (IITA, Maize Research Program Annual Report, 1986) and ECB2 (Kim *et al*., 1988). TZBR Eldana 1 was formed from 14 selected backcrosses obtained by screening 102 accessions mostly from CIMMYT with resistance to various stem borers. The accessions were screened as testcrosses and the selected testcrosses were backcrossed to their original accessions. Selecting and recombining superior S1 lines from DMRLSR-W, La Posta and TZSR-W resulted in the formation of TZBR Eldana 3. Because TZBR Eldana 3 was developed from elite adapted populations, it quickly proved its worth as a high yielding stem borer resistant material in multilocational trials at NARS testing sites within the region.

Table 1. Evaluation of progress from selection in TZBR Eldana-1 estimated from field trial at Ibadan in 1999.

Genotypes	% Stem Tunnelling	Cob damage (1-9)*	Grain yield (kg/ha)	
			Infested	Un-infested
TZBR Eld -1 C0	2.1	4.8	3096	3192
TZBR Eld -1 C1	3.6	4.3	2078	2711
TZBR Eld -1 C2	3.2	5.0	3013	2913
TZBR Eld -1 C4	5.3	4.0	3146	3227
TZBR Eld -1 C5	4.3	4.3	3356	3598
TZBR Eld -1 C7	1.6	3.8	3913	4194
Mean	4.6	4.0	3731	3798
SED	2.7	0.5	519	498
CV (%)	84	16	20	18

*1 = resistant, 9 = susceptible

Improvement of stem borer resistant populations:

The developed populations are being improved through S1 family testing. For this method, between 250 and 500 progenies are generated per population. Progenies are usually evaluated under artificial infestation with *Sesamia* and/or *Eldana* under non-infested conditions at Ibadan and in two additional locations at Ikenne and Egbema, all in Nigeria. Ibadan and Ikenne are in the south-western part of Nigeria and are separated from one another by approximately 90 km. Ikenne is used in our breeding programme for screening against foliar disease including lowland blight, *Curvularia* leaf spot, rust and ear rot. Egbema is approximately 700 km east of Ibadan and it is a stem borer hotspot location in south-eastern Nigeria. Ratings and measurements of stem borer resistant parameters are made on leaves, stem, cob and grain yield for the infested trials and for other agronomic traits including disease ratings for the uninfested trials. A base index is then used to select desirable progenies based on the damage parameters and grain yield and disease ratings. Using this approach, seven cycles of selection have been completed in TZBR Eldana 1, three in TZBR Eldana 3 and three each in TZBR Sesamia 1 and TZBR Sesamia 3. Evaluation of progress from selection in TZBR Eldana 1 carried out in 1999 and presented in Table 1 revealed that changes in gene frequencies due to S1 recurrent selection had resulted in increased grain yield with reduced insect damage symptoms.

Formation of new stem borer resistant maize populations:

Out of the four stem borer resistant populations developed in the mid 1980s, only TZBR Eldana 3 that was formed from adapted materials had immediate usefulness in on-farm trials. In order to increase the number of populations developed from adapted genotypes, two new synthetics, TZBR Syn-W and TZBR Syn-Y, were formed from six and eight selected inbreds, respectively. Although TZBR Syn-W performed well in multilocational trials, the two synthetics had low acceptance and are now being used as sources of resistant lines. The demand for stem borer resistant maize varieties also increased with the launching in 1997 of the African Maize Stress (AMS) Project, a joint initiative between CIMMYT and IITA that aims to address the yield limiting stresses of drought, low soil fertility, *Striga* and stem borers in appropriate ecologies. This project thus provided the added impetus needed to identify and develop new maize varieties for strategic on-farm deployment.

Two approaches were followed in developing the new stem borer resistant varieties. One approach was to develop better performing new genotypes from adapted populations, while the other was to introgress genes from other populations into existing resistant genotypes or to pool resistant genotypes together to form broad- based genotypes having combined resistance to the two borer species. The earlier approach resulted in the development of a stem borer resistant population (Ama TZBR-W) that was tested on-farm and it is now being deployed in south-eastern Nigeria. Ama TZBR-W C1 was developed by growing bulk seeds from each of ten populations in a hotspot location (Amakama) of south-eastern Nigeria. Individuals with stem borer damage rating of ≤ 3 (1 = resistant and 9 = susceptible) from each of the populations were selfed *in situ*. Further selection was done at Ibadan by planting seeds of the selfed plants ear-to-row in the screen house and artificially infesting these with egg masses of *Sesamia calamistis* at three weeks after emergence and *Eldana saccharina* at flowering.

From these evaluations, a total of 37 S1 lines made up of 26 from DMRLSR-W, seven from TZBR Eld 3C2, three from TZBR Syn-WC1 and one from TZBR Ses 3C3, were selected. Plants having damage ratings of ≤ 3 from each row were then tagged and used for recombination to form C0 of Ama TZBR-W. A cycle of mass selection was again carried out in this population by planting and infesting bulk seeds in the screen house followed by recombination of selected individuals with ratings of ≤ 3 to form Ama TZBR-WC1. This new variety has consistently performed well in trials across the region and it is currently being disseminated through on-farm trials in south-eastern Nigeria.

In 2000, 215 S1 lines from Ama TZBR-W C1 and five checks were evaluated in three environments of Nigeria. One of the environments is a hotspot location of Egbema in south eastern Nigeria, while the other two environments were two trials planted at Ibadan that were artificially infested with *Sesamia* and *Eldana*, respectively. Primary data obtained from these evaluations and presented in Table 2 showed that enough variability existed in the population for selection to be effective. Consequently, selection indices involving both the damage and desirable agronomic features were constructed to utilize the variability inherent in the populations and 30 lines have been selected and recombined to form C2 for further evaluation and improvement.

Stem borer attack is more severe in the forest ecology of West and Central Africa, an area that also harbours an array of foliar diseases, ear rot and downy mildew. It is therefore desirable to have appreciable levels of resistance to all these other stresses in genotypes destined for the forest ecology. Selection against foliar diseases and ear rot is routinely practised at Ikenne, while a separate breeding program is maintained for downy mildew. Progress in breeding for downy mildew resistance has reduced levels of infection in most populations to less than ten percent (IITA, Project 4 Annual Report, 2000). Furthermore, evaluation of forest adapted populations had identified three downy mildew resistant populations with acceptable levels of resistance to stem borers. Consequently, a programme of tandem selection was initiated in three (Acr 9922 DMRSR, Acr 9928 DMRSR and Acr 9943 DMRSR) widely cultivated downy mildew resistant populations to upgrade resistance to stem borers. Acr 9922DMRSR is for example a downy mildew (DMR) and streak (SR) resistant population obtained from upgrading Ak 9522 DMRSR for DMR in 1999. Ak 9522 DMRSR is currently being used in on-farm trials for

Table 2. Primary data obtained from the evaluation of 215 S1 lines from Ama TZBR-W and five checks in three environments of Nigeria in 2000.

Variable	Mean	Min.	Max.	Range	CV (%)
Egbema					
Days to silk	64	56	75	19	5
Plant ht. (cm)	157	85	240	155	17
Plant Aspect Rating*	4	2	7	5	23
Stalk Breakage No	2	0	10	10	74
Ear damage Rating	3	1	7	6	33
Leaf feeding Rating	2	1	7	6	39
Plant damage Rating	2	1	7	6	32
Deadheart count	2	0	10	10	105
Grain yield (kg/ha)	2625	164	7730	7566	4
***Sesamia* infested**					
Days to silk	66	57	78	21	5
Plant ht. (cm)	135	70	197	127	15
Plant aspect Rating	4	2	7	5	20
Stalk breakage count	2	1	5	4	45
Deadheart count	1	0	7	7	169
Stem tunnelling (%)	9	0	31	31	69
Grain yield Inf. (kg/ha)	1169	0	3521	3521	48
Grain yld Uninf (kg/ha)	1120	15	2871	2856	46
***Eldana* infested**					
Days to silk	63	58	74	16	5
Plant ht. (cm)	140	76	214	138	18
Stalk breakage count	2	1	8	7	58
Cob damage count	2	0	7	7	56
Stem tunnelling (%)	10	0	37	37	68
Grain yield Inf. (kg/ha)	1093	17	4441	4424	59
Grain yld Uninf (kg/ha)	1090	53	4080	4027	57

* Rating is on 1 – 9 scale with 1 = resistant and 9 = susceptible

Busseola control in Cameroon. In 2001, S1 lines from each of the three populations were evaluated in three environments one of which was under artificial infestation with egg masses of *Sesamia* at Ibadan, the second being under natural infestation at Egbema, while the third was for disease screening at Ikenne. Results from each of the three populations revealed wide genetic variation for effective selection. For example, results obtained from the evaluations of Acr 9922 DMRSR and pooled across environments (Table 3) revealed wide variability for effective selection of stem borer resistance parameters and desirable agronomic characteristics.

The second approach used in the development of new stem borer resistant populations resulted in the formation of three stem borer resistant populations namely TZBR Eldana 4, TZBR Comp 1 and TZBR Comp 2. TZBR Eldana 4 was developed by introgressing genes from nine other populations into TZBR Eldana 1, an unadapted but stem borer resistant population. To form TZBR Eldana 4, nine populations with moderate to high levels of resistance to *Sesamia* and *Eldana* were crossed to TZBR Eldana 1. Selfed progenies from these crosses were artificially infested with *Sesamia* and *Eldana* and selected lines backcrossed to the recurrent parent. After two generations of backcrossing, progenies were mass selected under artificial infection with maize streak virus and allowed to random mate twice in isolation. S1 progenies from TZBR Eldana 4 were evaluated in 1999 and the results obtained (Table 4) revealed that increased levels of resistance to stem borer attack with desirable changes in other agronomic characters were feasible.

Table 3. Primary data obtained from the evaluation of 263 S1 lines from Acr 9922 DMRSR and five checks in three environments of Nigeria in 2001.

Variable	Mean	Min.	Max.	Range	CV (%)
Set A					
Days to silk	62	57	72	15	5
Plant ht. (cm)	155	90	215	125	13
Ear damage Rating*	3	2	8	6	27
Leaf feeding Rating	4	2	8	6	26
Plant damage Rating	3	2	6	4	28
Deadheart count	2	0	10	10	91
Stem tunnelling (%)	6	0	37	37	71
Curvularia leaf spot rating	5	2	7	5	16
Grain yield (Kg/ha)	1226	37	4396	4359	50
Set B					
Days to silk	63	58	72	14	4
Plant ht. (cm)	154	89	232	143	14
Ear damage Rating	3	2	5	3	25
Leaf feeding Rating	4	1	8	7	31
Plant damage Rating	3	2	6	4	29
Deadheart count	0	0	6	6	216
Stem tunnelling (%)	5	0	23	23	76
Curvularia leaf spot rating	4	3	8	5	21
Grain yield (Kg/ha)	1613	159	4584	4425	43

* Rating is on 1 – 9 scale with 1= resistant and 9 = susceptible.

Eberhart *et al* (1967, 1991) had proposed a comprehensive breeding program to, among other things, articulate breeding efforts through the creation of reciprocal pools that would serve the dual purpose of generating improved open pollinated populations and first generation inbreds for hybrid production. Furthermore, noting that different stem borer species occur together and infest maize in the same ecology, a desirable situation was to generate a pair of broad-based reciprocal pools with combined resistance to both *Sesamia* and *Eldana*. Thus in 1997, a ten parent diallel was made from among six stem borer resistant populations and four other forest ecology adapted maize populations including an acid tolerant population (ATP). In addition, the ten populations were crossed to a pair of reciprocal populations as testers for evaluation and assignment into alternate heterotic groups. Both the diallel and the tester crosses were evaluated from 1998 to 1999 and both general (gca) and specific combing abilities (sca) were estimated. Results obtained from the evaluation of the diallel crosses in ten environments of Nigeria are presented in Table 5. Using information gathered from both gca and sca effects from both diallel and tester analyses, five maize populations each were assigned to form TZBR Comp1 and TZBR Comp 2. Thus TZBR Comp 1 was formed from TZBR Eldana 1, TZBR Sesamia 1, TZBR Syn-W, TZBR Syn-Y and Ak 9445 DMRSR. The other five populations (TZBR Eldana 3, TZBR Sesamia 3, ATP, DMRLSR-W and Suwan-1 SR) formed TZBR Comp 2. Both composites are undergoing reciprocal full-sib and half-sib selection (Obilana *et al.* 1979; Betran and Hallauer, 1996) to upgrade levels of resistance.

Extraction of inbred lines:

Inter-mating adapted and non-adapted populations in various forms formed the first generation of stem borer resistant populations. Open pollinated genotypes thus developed were improved further using an S1 recurrent

Table 4. Performance of the best 12 entries of selected 22 entries from 196 S1 progenies of TZBR Eldana 4 evaluated at Ikenne, Egbema and under artificial infestation at Ibadan in southern Nigeria in 1998.

Entry	Stalk breakage	Cob damage (1-9)	Days to silk	Plant height (cm)	Ear aspect (1-9)	Grain Yield (kg/ha Infested	Un-infested	RSI
S1 – 168	1.3	3.3	58.5	191.0	3.0	2826	4016	83
S1 – 165	1.3	3.3	59.3	194.8	3.3	2495	4131	95
S1 – 104	1.0	3.0	58.0	206.5	2.5	3169	3497	120
S1 – 39	1.3	3.8	61.0	230.0	2.3	3627	4123	171
S1 - 83	1.3	3.3	62.3	165.8	3.8	2556	3026	171
S1 – 136	0.8	3.3	55.3	212.8	3.3	3267	2657	174
S1 – 60	0.8	3.5	60.0	198.8	2.5	3160	3665	185
S1 – 13	1.8	3.0	58.5	236.5	2.3	4105	4730	190
S1 – 102	0.8	3.5	58.5	216.3	2.8	2926	3197	191
S1 – 30	0.5	3.3	60.0	189.5	2.8	3076	2854	210
S1 – 174	0.8	3.5	56.3	175.8	3.5	2127	2362	214
S1 - 93	2.0	3.3	59.3	213.0	3.5	3497	3417	215
Mean of all entries	2.1	4.0	59.4	197.9	3.3	2702	2996	
Mean of selected 22	1.3	3.4	59.4	199.0	3.0	3006	3227	
SED	0.1	0.1	0.2	1.0	0.1	59	53	
*Sel differential (%)	-38.1	-15.0	0	0.6	-9.1	11.2	7.7	

* Selection differential estimated as a proportion (%) of the mean of all entries

Table 5. Gca (on diagonal, bold and italics) and sca (off diagonal) effects for grain yield from a ten parent diallel of stem borer resistant populations evaluated in ten environments of Nigeria from 1998 to 1999.

Crosses	1	2	3	4	5	6	7	8	9	10
1	***-75.7***	322.2	-258.5	147.1	-183.3	-2.9	92.6	-16.6	18.3	-119.0
12		***49.7***	60.4	-185.8	208.3	-42.9	-130.1	-72.5	-101.7	58.6
23			***-130.8***	-33.7	-85.8	-190.3	-28.9	35.9	246.0	254.4
34				***47.1***	-25.1	307.7	3.0	-323.5	9.5	100.9
45					***-144.3***	85.0	141.6	6.6	-33.0	-114.3
56						***-99.3***	145.8	102.7	-222.9	-183.0
67							***-112.2***	35.0	-43.6	-215.9
78								***259.4***	12.0	199.8
89									***113.3***	115.4
910										***92.8***

selection procedure. However, the extraction and use of resistant inbred lines from improved cycles of selection, synthetics and new varieties will significantly boost the development of stem borer resistant varieties. An advantage of the S1 recurrent selection procedure is that lines selected for recombination can be bred to homozygosity until desirable genes are fixed. Using this approach, several lines are generated and tested each year as lines *per se* or in topcross trials. In 2000 alone, over 250 inbreds at different levels of inbreeding were tested in topcross trials. Additionally, 71 preselected S5 lines from two synthetics were evaluated as lines *per se* under artificial infestation with *Sesamia* and/or *Eldana* in Ibadan and in Cotonou, Benin Republic. Results obtained from the evaluation of the white S5 lines are presented in Tables 6 and 7. In general, eight inbreds with resistance to *Sesamia calamistis* were identified. Six of the identified lines originated from two ancestors 11 and 27 (Table 6). Results obtained from the evaluations of the same set of lines under artificial infestation with *Eldana* also identified seven resistant lines (Table 7) with four of them, 9-1, 11-1, 27-1 and 27-3 having cross resistance to *Sesamia calamistis*.

Deployment of stem borer resistant varieties:

Interdisciplinary efforts are required to develop stem borer resistant varieties. However, such efforts are wasted if the varieties are not distributed and utilized by farmers. In addition to host-plant resistance, other research interventions

Table 6. Evaluation of S5 lines from TZBR-Syn-W C2 for resistance to the pink stem borer *Sesamia calamistis* in three environments in 2000.

Line	Damage ratings* Ibadan SH+	Ibadan Field	Cotonou
S5 9-1	1 (13)**	3 (85)	3
S5 11-1	1 (12)	2 (45)	3
S5 11-2	2 (64)	3 (24)	3
S5 11-3	2 (31)	2 (49)	3
S5 25-2	1 (28)	3 (78)	4
S5 27-1	1 (53)	4 (57)	6
S5 27-2	1 (83)	4 (49)	7
S5 27-3	2 (38)	3 (19)	4
Checks			
S5 19-1	4 (96)	5 (98)	5
S5 20-2	3 (94)	7 (112)	9
Tzmi 103	3 (47)	4 (78)	5
4001	4 (57)	5 (62)	6
Mean	3	4	5
SED	1	1	1
CV (%)	32	32	27

*Rating is on 1 = resistant and 9 = susceptible
**Values in parenthesis represent Rank Summation Indices (RSI), an aggregate resistant trait.
+SH = Screen House

Table 7. Evaluation of S5 lines from TZBR Syn-W C2 for resistance to the sugarcane borer *Eldana saccharina* in two environments in 2000.

Line	Damage ratings*		
	Ibadan SH+	Ibadan Field	RSI**
S5 9-1	4	4	34
S5 11-1	3	2	42
S5 12-1	2	3	41
S5 26-2	3	4	9
S5 27-1	3	4	24
S5 27-3	4	2	42
S5 34-1	2	3	52
Checks			
S5 19-2	5	4	80
S5 20-2	4	4	72
Tzmi 103	4	4	80
4001	5	3	40
Mean	4	3	
SED	2	1	
Cv (%)	42	31	

*Rating is on 1 = resistant and 9 = susceptible
**Rank Summation Indices (RSI) generated to obtain an aggregate resistant trait + SH = Screen House

for the control of stem borers include biological control including the use of bio-pesticides and habitat management involving different combinations of crops. Strategic deployment of host plant resistance in appropriate intercrop patterns is usually considered since it often involves minor changes in farmer's practice. Farmers in the region usually intercrop their maize, thus, only a change of the maize variety being grown may be required to increase maize yield on-farm. Using this approach, several on-farm trials involving stem borer resistant maize cultivars have been conducted using different crop combinations. On-farm trials conducted in south-eastern Nigeria during the second planting season of 2001 revealed highly significant differences in the number of marketable cobs obtained with the use of Ama TZBR-W C1, a stem borer resistant variety (Olaoye, G. pers. comm.). Well-filled maize cobs with good ear aspect are considered marketable for green maize production. The use of strip relay intercropping, a system that allows for the double planting of maize in a year gave the most marketable ears followed by the use of the traditional maize-cassava intercrop system but using the improved variety. In both cases, borer damage on maize was not significant whereas, in all the farmers' fields, the use of a local variety intercropped with cassava produced the least number of marketable cobs and had the highest borer damage. (Table 8).

DISCUSSION AND CONCLUSION

A complex interaction of several factors determines the resistance/susceptibility of maize to stem borer attack. This is further compounded when different stem borer species attack maize at different growth stages. The challenge therefore is to breed varieties that will minimize yield loss and exhibit synergistic interaction with other IPM options. This challenge has been achieved to a large extent especially with the deployment of a stem borer resistant variety in south-east Nigeria. Similar deployment programs have been reported by collaborators in the Kumasi area of Ghana and around Yaounde in Cameroon.

Table 8. On-farm performance of Ama TZBR-W C1 in 23 farmers' fields during the second season of 2001 at Umuahia, south-eastern Nigeria.

Treatment	Stem borer damage		No. of marketable cobs
	%	Rating*	
Cassava + Local maize (Farmers' practice)	69.0 a	4.0 a	23.3 c
Cassava + Ama TZBR-W C1 (Farmers' practice)	34.3 b	2.5 b	41.9 b
Cassava + Ama TZBR-W C1 (Strip cropping)	38.7 b	2.6 b	48.3 a

Source: Olaoye G. (personal communication)
*rating: 1 = good, 5 = bad

Breeding for resistance to stem borers is greatly enhanced when genotypes can be screened effectively thus the development of mass rearing techniques and appropriate rating schemes have greatly aided breeding programmes for *Sesamia* and *Eldana*. Significant progress has been made in developing varieties resistant to both borer species and that also exhibit some level of resistance to *Busseola fusca* commonly found in Cameroon. Moderate to high levels of cross resistance have been determined for all stem borer resistant populations and programmes of selection to improve on resistance to alternate borer species have been undertaken. Thus, all materials have some level of resistance to the two prevailing borer species. Several studies (Starks and Doggett, 1970; Mohyuddin and Attique, 1978; Barry *et al.,* 1983; Barry, 1989; Ampofo, 1986; Barrow, 1987; Bosque-Perez and Mareck, 1991; Ajala 1994, 1995: Ajala and Saxena, 1994; Gounou *et al.*, 1994) have reported moderate to high correlation for damage parameters and yield loss thus concluding on the most important parameters to use in breeding for stem borer resistance. Kling and Bosque-Perez (1994) reported on a positive relationship between stalk breakage and ear damage, while positive relationships are also known for stem tunnelling and stalk breakage. In effect, selecting for reduced levels of stem tunnelling for *Sesamia calamistis* resistance would positively influence selection for reduced stalk breakage and also, cob damage from *Eldana* attack. Thus, good progress can be made from breeding for resistance to both borers.

Reduction in larval establishment and poor utilization of ingested food have been shown to be responsible for resistance to *Sesamia* attack in selected maize lines (R. Aroga. pers. comm.). Isolating and characterizing stem borer resistance factors will greatly aid selection for higher levels of resistance. Furthermore, mechanisms of insect resistance in transgenic crops are known (Hilder and Boulder, 1999). Although, the use of transgenic sources of resistance can greatly enhance breeding activities, bio-safety regulations that would allow testing of transgenic sources of resistance are still being formulated across the region. Nonetheless, there is a need to elucidate the molecular mechanism of resistance including the development of marker systems for rapid screening.

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ECOLOGICAL MANAGEMENT OF CEREAL STEM BORERS IN ETHIOPIA

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ABSTRACT

Three lepidopterous stem borers were reported on maize in Ethiopia. Although complete crop loss is evident in some areas, the average yield loss of maize caused by cereal stem borers in Ethiopia can be estimated between 20 and 50%. As resource-poor farmers produce over 87% of maize, inexpensive, ecologically sound and effective cereal stem borer control methods are indispensable. To this end, surveys and field experiments were conducted in 1999 and 2000. Surveys were conducted in major maize growing areas of eastern, western, southern and northern Ethiopia. In the surveys, four stem borers, 20 species of parasitoids, 14 species of predators and seven entomopathogens were investigated. These natural enemies gave about 18% reduction of cereal stem borers. Of these natural enemies *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) alone gave 13% reduction. Intercropping of maize with beans significantly (P<0.01) reduced density per plant of stem borers and increased the diversity and parasitism of the parasitoids. Some maize lines were also found to be resistant to cereal stem borers. In conclusion, conservation/augmentation of the natural enemies existing in the agro-ecosystem of maize and the use of intercropping are the best options of cereal stem borer management in Ethiopia. Besides, work on varietal resistance should be continued to identify the best resistant genes which can be incorporated into commercial maize varieties with desirable agronomic traits such as high yield and disease resistance.

Key words: Biological control, cereal stem borer, ecological management, Ethiopia, intercropping, integrated management, survey, varietal resistance.

INTRODUCTION

Maize is an important crop in much of the developing world. It grows over a wider geographical range and variety of environments than any other cereal crop and is the third most important cereal crop on a global basis (CIMMYT & EARO, 1999). In Ethiopia, maize is grown on over one million hectares of land, which is about 17 percent of the cultivated area (CSA, 1998).

The national average yield of maize, which is about 1.7 ton ha^{-1}, is well below the world average of 3.7 ton ha^{-1}, but slightly better than the average for Africa (Benti and Ransom, 1993). The poor performance of maize in Africa in general, and Ethiopia in particular, could be attributed to unfavorable agroclimatic conditions, poor soil fertility, and the prevalence of numerous insect pests and diseases (CIMMYT & EARO, 1999). Lepidopterous stem borers are considered to be the most important insect pests of maize in Africa (Maes, 1997). About 18 species of cereal stem borers from three families (Crambidae, Noctuidae and Pyralidae) attack maize in Africa (Maes, 1997). In Ethiopia, the exotic crambid, *Chilo partellus* (Swinhoe) and the indigenous noctuids, *Busseola fusca* Fuller and *Sesamia Calamistis* Hampson were the three lepidopterous stem borers recorded (Assefa, 1985; Emana and Tsedeke, 1999). However, their distribution was not known in great detail. The species composition was not also comparable with other countries like Kenya which has similar ecology. The natural enemies associated with these stem borers were not explored and the extent to which these natural enemies suppress the stem borer population was also not documented (Emana *et al*., 2001).

In Ethiopia, insecticides are commonly used for the control of stem borers. As the great majority (87%) of maize is grown by smallholders in Ethiopia, the use of insecticide is not feasible apart from its environmental problems (Emana and Tsedeke, 1999). More than half of the maize farmers in Ethiopia practise mixed cropping (Emana *et al*., 2001). In the mixed cropping systems the stem borers were few and the natural enemies were diverse and abundant (Emana *et al*., 2001). However, this was not experimentally quantified.

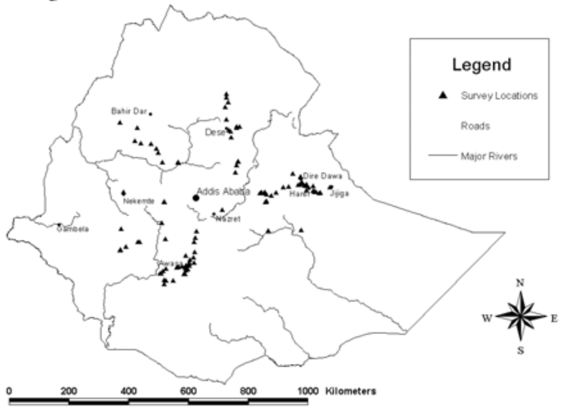
CIMMYT developed resistant maize populations against stem borers (Ransom et al., 1997). However, resistance is governed by many factors among which the species of the stem borer is the most important one (Ransom et al., 1997). Varieties may behave differently to the same species due to differences in ecological population.

The main objective of these studies was to look for ecologically sound management of cereal stem borers in Ethiopia which includes exploration of natural enemies, intercropping and varietal resistance which can form integrated management of cereal stem borers in the country.

MATERIALS AND METHODS

Surveys: In 1999 and 2000, surveys were conducted in major maize- and sorghum-growing regions of Ethiopia. In 1999, surveys were conducted at the vegetative and maturity stages of the crop, while in 2000 only at the maturity growth stage. Major maize-growing regions were selected based on production statistics. From each region, districts known for maize production were listed. From the lists, 2-3 districts were randomly selected for the survey. In each selected district, 2-3 maize fields were sampled based on accessibility. In each field, 10 plants at the vegetative stage and five plants at the maturity stage were randomly selected and cut at ground level. Each plant was checked for the presence of eggs, neonate larvae and any stage of parasitoids and predators. Each plant was then dissected, insects were counted and tentatively categorized into species or higher level classification. In both years the same locations were considered in the surveys (Fig.1). Each year 130 locations were surveyed. The insects found were categorized into species and taken to the laboratory for parasitoid emergence, pathogen growth or stem borer emergence.

Fig. 1: **Ethiopian Survey Sites - 1999**



Intercropping: Maize was planted intercropped with haricot beans and in monoculture at Melkasa and Awasa in 2000. BH-540 at Awasa and Melkasa-1 at Melkasa were the maize varieties used. The experiment was designed in a randomized complete block design in four replications. The plot size was 9 m x 9 m. The spacing was 0.30 m between plants and 0.75 m between rows. Haricot bean was planted two weeks after the emergence of maize halfway between maize plants (0.15 m) and maize rows (0.38 m). Two weeks after the planting of the companion crop, both destructive and presence/absence data collection were started and continued every two weeks up to harvest time. On each sampling date, 5 plants per plot per cropping system were randomly selected and cut at ground level. Each plant was checked externally for the presence of all stages of stem borers and their natural enemies (egg, larvae, pupae and parasitoid cocoons). Then the plant was dissected and checked for stem borer larvae, pupae and parasitoid cocoons. All stages of insects collected were held individually (egg batch, larva, pupa, cocoon mass) and taken to the laboratory for further rearing. The larvae were given pieces of maize or sorghum stems. New stem pieces were given every three days until the larvae pupated, parasitoids emerged or died. Data on stem borer density per plant, percent infestation and percent parasitisation were collected. Because of hail damage and lodging, data on percent infestation were not recorded at Awasa.

Percentage data were transformed to arcsine and the count data were transformed to logarithmic transformation. Data were analyzed using SAS (PROC GLM) (SAS Institute, 1999-2000). Means were separated using Tukey lines. Data were transformed to square root (Gomez and Gomez, 1984) before being subjected to SAS for analysis (SAS Institute, 1999-2000).

Varietal screening: Seven stem borer resistant populations of CIMMYT and five local populations were planted at Melkasa in 1999. The plot size was 3m x 3.6m. The design was a randomized complete block design in three replications. The spacing was 0.30 m between plants and 0.75 m between rows. The populations were:

CIMMYT maize populations: TL 98A 1752-B, TL 98A 1751-B, TL 97B 6790-9, TL 98B 6760B, PR 98A 751-B, TL 97B 6790-5 and PR 98A 766-B

Local maize populations: Aw 1192, Aw 1292, Aw 1492, Aw 1592 and Aw 1692. Percent infestation by stem borers was recorded at seedling, tasseling/silking and maturity growth stages of the crop. At harvest, five plants were randomly selected per plot and dissected to look for the number of holes and density per plant. Percentage data were transformed to arcsine and the count data were transformed to logarithmic transformation. Data were analyzed using SAS (PROC GLM) (SAS Institute, 1999-2000). Means were separated using Tukey lines.

RESULTS

Results are shown in Tables 1-5 and Figs 2 and 3. Four species of stem borers were recorded on maize in Ethiopia at an elevation ranging between 1,030 and 2,320 meters above sea level (masl) with density per plant ranging from 0.02 to 2.12 borers per plant (Table 1). Twenty primary parasitoids (Table 2), 14 predators (Table 3) and seven pathogens/ nematodes (Table 4) were recorded in association with cereal stem borers in Ethiopia.

Maize intercropped with haricot bean had lower stem borer density per plant, lower percent infestation and higher percent parasitism than maize monoculture (Figs 2 and 3). CIMMYT population TL 98A 1752-B had significantly ($F<0.001$) greater resistance to *C. partellus* as it had the lowest percent infestation across all stages, lowest mean number of exit holes and the lowest mean stem borer density per plant (Table 5).

DISCUSSION

Previously in Ethiopia three stem borers, seven parasitoids, two predators and one pathogen were recorded in maize-based agro-ecosystems (Assefa, 1985; Emana and Tsedeke, 1999; Mullugetta, 2001). In our surveys of 1999 and 2000, we recorded one additional stem borer and many more parasitoids, predators and pathogens. The differences might be because of our extensive surveys which covered the major maize growing regions of the country.

In terms of pest status, our result agrees with the previous work such that *B. fusca* and *C. partellus* are the dominant stemborers in Ethiopia. The elevation at which

Table 1. Stem borers recorded in Ethiopia in 1999 & 2000.

Stem borer	Order	Family	Elevation (m)	Density per infested plant
Chilo partellus	Lepidoptera	Crambidae	1,030-1,900	1.00±0.020
Busseola fusca	Lepidoptera	Noctuidae	1,030-2,320	2.12±0.040
Sesamia calamistis	Lepidoptera	Noctuidae	1,040-1,830	0.12±0.001
Sesamia nonagrioides botanephaga	Lepidoptera	Noctuidae	1,450-1,550	0.02±0.001

Table 2. Parasitoids of stem borers in Ethiopia in 1999/2000.

Parasitoids	Order	Family	Host insect	Host stage attacked	Percent parasitism
Cotesia flavipes Cameron	Hymenoptera	Braconidae	Cp, Bf, Sc	Larva	7.47
Dolichogenidea fuscivora Walker	Hymenoptera	Braconidae	Bf, Cp	Larva	1.22
Cotesia sesamiae (Cameron)	*Hymenoptera*	Braconidae	C p, Bf, Sc	Larva	0.55
Dentichasmias busseolae Heinrich	Hymenoptera	Ichneumonidae	Cp, Bf	Pupa	0.36
Sturmiopsis parasitica (Curren)	Diptera	Tachinidae	Bf, Cp	Larva	0.04
Dolichogenidea polaszeki Walker	Hymenoptera	Braconidae	Bf	Larva	0.23
Procerochasmias nigromaculatus (Cameron)	Hymenoptera	Icneumonidae	Bf, Cp	Pupa	0.19
Pediobius furvus (Gahan)	Hymenoptera	Eulophidae	Bf, Cp	Pupal	0.18
Chelonus curvimaculatus Cameron	Hymenoptera	Braconidae	Cp	Egg-larval	0.04
Cotesia ruficrus (Haliday)	Hymenoptera	Braconidae	Cp	Larva	0.03
Telenomus busseolae Gahan	Hymenoptera	Scelionidae	Bf	Egg	0.02
Eurytoma oryzivora Delvare	Hymenoptera	Chalcidoidae	Bf	Larva	0.01
Stenobracon rufus Szepligèti	Hymenoptera	Braconidae	Cp, Bf	Pupa	0.01
Siphona murina (Mesnil)	Diptera	Tachinidae	Bf	Larva	0.01
Psillochalcis soudanensis (Steffan)	Hymenoptera	Chalcididae	Bf	Pupa	0.01
Bassus sublevis (Granger)	Hymenoptera	Braconidae	Bf	Larva	0.01
Glyptapanteleus maculitarsis (Cameron)	Hymenoptera	Braconidae	Bf	Larva	0.01
Trichgrammatoidea lutea *Girault*	Hymenoptera	Trichogrammatidae	Cp, Bf	Egg	0.01
Sarcophaga sp.	Diptera	Sarcophagidae	Cp, Bf	Larva	0.01
Bracon sesamiae Cameron	Hymenoptera	Braconidae	Bf	Larva	0.01

Cp = *Chilo partellus*; Bf = *Busseola fusca*; Sc = *Sesamia calamistis*

Table 3. Predators of stem borers in Ethiopia.

Predators	Order	Host insect	Host stage	Distribution
Forficula rehm Kurr	Dermaptera	Cp, Bf	Egg, larva	+
Forficula senegalensis (Sorv.)	Dermaptera	Cp, Bf	Larva	+++
Diaperasticus erythrocephala (Ström)	Dermaptera	Cp, Bf	Larva	++
Euborellia sp.	Dermaptera	Cp, Bf	Larva	+
Doru lineare (E. Scholtz)	Dermaptera	Cp, Bf	Larva	+
Euborellia annulepsis (Hincks)	Dermaptera	Cp, Bf	Larva	++
Labia minor (Hincks)	Dermaptera	Cp, Sc	Egg, larva	+
Pheidole megacephala Forel	Hymenoptera	Cp	Larva	+++
Cardiocondyla emeryi Forel	Hymenoptera	Cp	Larva	+
Cheilomenes sulphurea Olivier	Coleoptera	Sc	Larva	+
Cheilomenes propinqua Mulsant	Coleoptera	Bf	Larva	+
Ganoaphlus simplex Mulsant	Coleoptera	Bf	Larva	+
Crysopa sp.	Hemiptera	Sc	Egg	++
Tibellus sp.	Acarina	Bf	Egg	++

* + = recorded at 1-2 sites; ++ = recorded at 3-10 sites; +++ = recorded at > 10 sites
Cp = *Chilo partellus*; Bf = *Busseola fusca*; Sc = *Sesamia calamistis*

Table 4. Pathogens of stem borers in Ethiopia.

Pathogen	Type	Host insect	Host stage	Abundance
Aspergillus flavus	Fungus	Cp, Bf	Larva	+++
Beauveria bassiana	Fungus	Bf	Larva	++
Metarrizium anisopleae	Fungus	Cp, Sc	Larva	+
Panagro lamimus	Nematode	Cp	Larva	++
Hexamermis sp.	Nematode	Cp	Larva	+
Steinernema intermedia	Nematode	Bf	Larva	+++
Heterorhabditis sp.	Nematode	Sc	Larva	+

** + = recorded from one sample (larva); ++ = recorded from 2-5 larvae; +++ = recorded from > 5 larvae

Table 5. Response of different maize populations to stem borers in Ethiopia (Melkasa), 1999.

Varieties	Mean (±se) percent infestation at:			Mean (±se) no. of holes/plant	Mean (±se) stemborer density per plant
	Seedling	Tasseling/Silking	Maturity		
Aw 1292	31.24 ±2.1 b	36.15 ±1.8 b	36.08 ±2.0 b	8.67 ±0.9 b	2.17 ±0.2 b
TL 97B 6790-9	30.66 ±2.0 b	37.35 ±1.8 b	35.76 ±2.0 b	8.83 ±0.9 b	1.67 ±0.1 a
PR 98A 751B	30.23 ±2.0 b	28.84 ±1.2 b	26.77 ±1.2 b	4.50 ±0.6 a	1.67 ±0.1 a
Aw 1192	29.04 ±1.9 b	37.53 ±1.8 b	26.12 ±1.2 b	12.00 ±1.2 b	3.17 ±0.3 b
TL 97B 6790-5	28.72 ±1.9 b	31.56 ±1.6 b	27.86 ±1.3 b	10.33 ±1.1 b	3.17 ±0.3 b
TL 98B 6760 B	27.60 ±1.8 b	24.65 ±1.0 ab	19.67 ±1.0 a	5.50 ±0.7 a	1.50 ±0.1 a
Aw 1492	25.74 ±1.6 b	33.04 ±1.7 b	30.19 ±1.5 b	10.33 ±1.1 b	2.17 ±0.2 b
TL 98A 1751-B	24.67 ±1.6 b	24.67 ±1.0 ab	22.91 ±1.1 a	7.17 ±0.8 b	1.50 ±0.1 a
TL 98A 1752-B	17.26 ±0.9 a	20.98 ±0.9 a	10.89 ±0.8 a	5.17 ±0.7 a	1.00 ±0.1 a
Aw 1692	15.17 ±0.8 a	19.32 ±0.9 a	15.91 ±0.9 a	5.67 ±0.7 a	2.50 ±0.2 b
PR 98A 766-B	23.38 ±1.6 a	31.82 ±1.6 b	26.12 ±1.2 b	8.67 ±0.9 b	1.12 ±0.1 a
TL 98B 6760 B	27.60 ±1.8 b	24.65 ±1.0 ab	19.67 ±1.0 a	5.50 ±0.7 a	1.50 ±0.1 a

* Means followed by the same letter (s) within a column are not significantly different.

Fig. 2: Effect of growth stage and intercropping on the density per plant at (A) Melkasa and (B) Awasa.

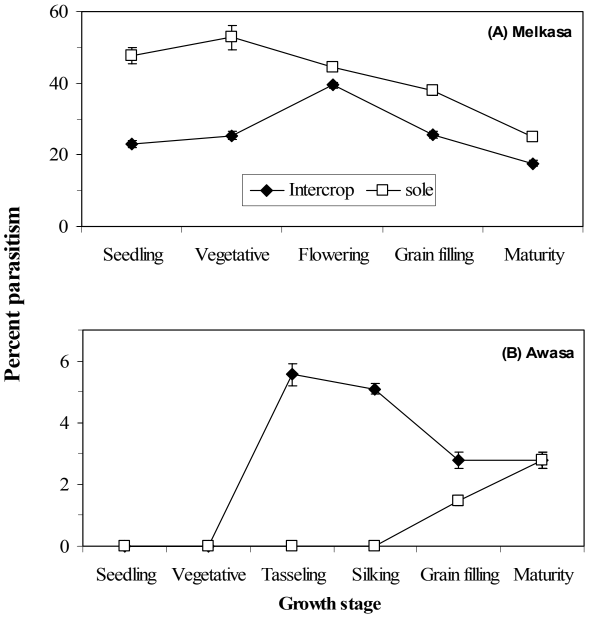
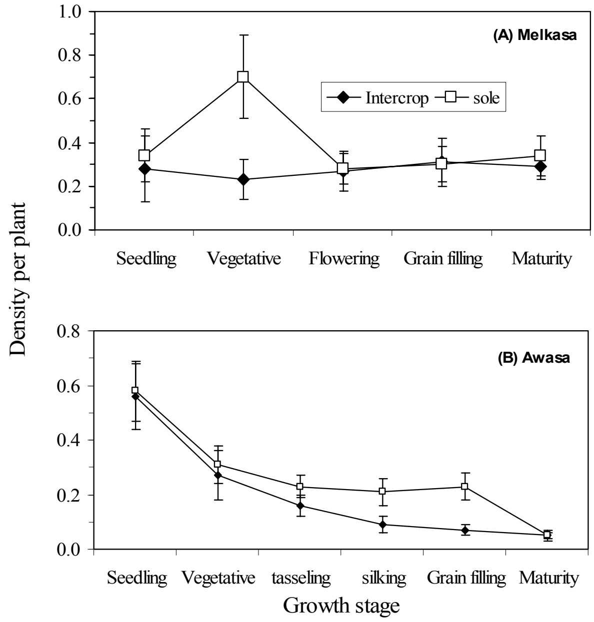


Fig. 3: Effect of growth stage and intercropping on percent parasitism at (A) Melkasa and (B) Awasa.



we recorded *C. partellus* is higher than the previous record in Africa which is less than 1,700 masl (Seshu Redy, 1983; Assefa, 1985). *Chilo partellus* is the only exotic stem borer which invaded Africa from Asia sometime in the 1930s when it was first recorded in Malawi (Tams, 1932). Since its arrival in Africa, it has been a devastating pest of low elevation areas below 1,700 masl in eastern and southern Africa. In Ethiopia, high potential maize producing areas of the country lie between 1,850 and 2,000 masl (Benti and Ransom, 1993). In these areas, *B. fusca* was reported to be the most important stem borer. The fact that *C. partellus* expanded its ecological niche may intensify the loss of maize by stem borers.

In the previous study, few parasitoids were recorded in Ethiopia, of which *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) was reported to be the most abundant parasitoid in Ethiopia (Assefa, 1985; Ytafera and Assefa, 1994). However, in our surveys, we recorded 20 parasitoids, of which *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) was found to be the most abundant parasitoid. *Cotesia flavipes* is a larval endo-parasitoid of stem borers which originated in Asia. It was introduced in 1991 to Kenya for the control of *C. partellus* in eastern and southern African countries. *Cotesia flavipes* was not released in Ethiopia. The origin of *C. flavipes* in Ethiopia could be from Kenya, Uganda and Somalia where the parasitoid was released earlier. In the surveys made before 1999 in Ethiopia, *C. flavipes* was not recorded (Mullugetta, 2001). Overall, parasitoids gave over 11% of parasitism to stem borers in Ethiopia. Though the parasitoids recorded were larval, pupal and egg parasitoids, the larval parasitoids gave the highest proportion of parasitism.

Previously, only two predators were recorded in Ethiopia in association with stemborers (Assefa, 1985). However, our surveys of 1999 and 2000 discovered 14 species of predators feeding on larvae and eggs of *C. partellus*, *B. fusca* and *S. calamistis*. *Forficula senagalensis* (Sorv.) and *Pheidole megacephala* Forel) were the abundantly found predators. Bonholf *et al*. (2000) reported some of these predators in other parts of Africa.

Information on entomopathogens of stem borers was very scanty in Ethiopia (Benti and Ransom, 1993) unlike other African countries (Polaszek, 1998). However, we recorded seven entomopathogens associated with larvae of stem borers suggesting the tremendous potential of the agent in suppressing the stem borer population. *Aspergillus flavus* and *Steinernema intermedia* were the most abundant entomopathgens recorded.

The resource concentration and enemy hypotheses explain the mechanism involved in intercropping in the control of insect pests (Root, 1973). In the current study both theories worked in that intercropping significantly had lower stem borer density per plant and higher parasitism suggesting that intercropping of maize with beans is one candidate for integrated stemborer control in Ethiopia.

In Ethiopia, there was no adequate work which looked into the resistance ability of different maize populations to stem borers because of low variability (Assefa, personal communication). However, our current work suggests that there is significant variability among the different populations of maize suggesting the need for more work to come up with a resistant maize population to stem borers in Ethiopia.

In conclusion, conservation of natural enemies, use of intercropping and resistant varieties are ecologically sound stem borer control options in Ethiopia. However, further studies are required on how to maximize the efficiency of natural enemies and screening the best resistant maize populations which can be incorporated into maize genotypes with desirable traits such as high yield and disease resistance.

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GREY LEAF SPOT DISEASE OF MAIZE – LOSS ASSESSMENT, GENETIC STUDIES AND BREEDING FOR RESISTANCE IN ZAMBIA.

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ABSTRACT

With the introduction and spread of a previously unreported disease, Grey Leaf Spot (GLS) of maize in the country in the mid 1990s, all old hybrids succumbed to the disease. These hybrids were developed by Government research supported by various donors and availed to Zambia Seed Company Ltd. (Zamseed) who had exclusive rights to produce and market government-bred material. Phasing out of donor support at this critical stage created a vacuum in maize breeding. To fill the gap, the company was forced to start a research department to take control of its research needs. In response to the GLS problem, the research department adopted a dual pronged approach to firstly improve genetic resistance of old hybrids as a short-term measure and, secondly, initiated a long-term resistance breeding programme. Replacement of susceptible parents by resistant versions in old hybrids brought remarkable improvement in most hybrids. Yield losses due to GLS ranged from 28 to 54% with an average loss of 33.5%. In diallel studies both GCA and SCA variances were found highly significant for GLS indicating the importance of both additive and non-additive components although GCA was relatively more important. GCA effects of parents were good indicators of hybrid performance in general but failed to explain performance of all hybrids. Screening of germplasm revealed abundance of resistance in local material and prospects of breeding for resistance appear good.

Keywords: Additive and dominance gene actions, analysis of variance (ANOVA), diallel mating system, general combining ability (GCA) and specific combining ability (SCA), gray/grey leaf spot (GLS), line x tester mating system, quantitative trait loci (QTL).

INTRODUCTION

Two decades of donor supported government research in Zambia produced a good range of maize hybrids, some of which became very popular among farmers. Zambia Seed Co. (ZAMSEED) was a direct beneficiary of the government breeding programme as it was given exclusive rights on government-bred cultivars.

Introduction and spread of devastating Grey Leaf Spot (GLS) disease of maize caused by *Cercospora zeae-maydis* in the mid 1990s demonstrated that all Zamseed hybrids were highly susceptible to the disease. Withdrawal of donor support in the same years created a vacuum in Zambian maize breeding when some serious efforts were required to address the challenge posed by GLS.

In order to compete effectively on the market, ZAMSEED started a full-fledged Research and Development Department in 1999 to take charge of the company's research needs. The Research Department was therefore faced with an immediate task of developing GLS resistant cultivars in the shortest possible time, as resistance to GLS had since become one of the most important criteria of measuring the performance of hybrids across companies, especially so amongst large commercial farmers.

Little was known about GLS in the country, including yield losses due to the disease and its genetics. One of the greatest resources that the company had, however, was a large set of germplasm (over 4,000 lines), which was being maintained in the company for some time after inheriting it from the Government at the time of phasing out of donor support to the maize programme. Using this resource, the research department embarked upon a multi-faceted resistance breeding program for GLS in the main season of 1999/2000. Main features of the programme and salient results are reported and discussed herein.

MATERIAL AND METHODS

Screening and evaluation of germplasm for GLS

In the first year, all commercial hybrids, their parents and the entire breeding material were evaluated for resistance to GLS by planting them on the company's farm near Lusaka which had over the past few years, turned into a good "hot-spot" for the disease due to continuous cropping of susceptible cultivars. All materials other than commercial hybrids were planted in a single row unreplicated observation plot of 5 m length spaced 90 cm apart. Commercial hybrids were replicated three times in 4-row plots while their parents were evaluated in large plots of 20 rows each primarily for seed multiplication.

Disease loss assessment

Simultaneously, two disease loss assessment trials were also conducted. In the first trial, 5 experimental hybrids having varying levels of susceptibility to GLS were used as main plots in a Split-Plot Design with and without spraying of ERIA 187.5 SC as subplots. Eria 187.5 SC is a registered fungicide of Novartis South Africa that contains difenoconazole (trizole) and carbendazim. Two to three sprays of Eria 187.5 SC are normally recommended for the control of GLS. The experiment was planted late in the season (Dec. 29) in a plot surrounded by early planted maize to maximize disease pressure. Five sprays were done at intervals of 10 days starting from February 18, 2000. The experimental unit was 6 rows 10 m long spaced 90 cm apart. Data were recorded from the 4 central rows.

Parallel to the above experiment, yield losses were also estimated from a hybrid (ZEM 620) in which different numbers of leaves were stripped off 15 days after anthesis. In the first treatment, all leaves below the cob were removed, and in subsequent treatments, two extra leaves above the cob were removed. In the last and fifth treatment, all leaves except for the flag leaf were taken out.

Genetic studies

Diallel and Line x Tester crosses were made in the following off-season with the dual purpose of initiating a long term GLS resistance breeding programme and for studying the genetic behaviour of the disease. Twenty-three inbred lines including some of the most GLS resistant and susceptible inbred lines, and best known combiners (parents of commercial hybrids) were grouped in two maturity classes to produce all possible crosses while ensuring that each group contained both extremes of susceptible and resistant lines. Thus, the "Early Diallel" had 13 parents and "Late Diallel" had 10 inbreds, respectively.

F1 crosses and parents of each diallel were grown in two separate trials in the main season of 1999/2000 following a Randomized Complete Block Design with 3 replicates. Hybrids and parents were blocked separately in each replicate. A plot size of 2 rows of 5 m long 90 cm apart was used. In addition to recording all regular agronomic variables, three scores of GLS were taken in between anthesis and maturity on a scale of 1-5 (1 being immune to GLS and 5 being most susceptible). The third score was used for analysis without any transformation. Only GLS and grain yield are reported here.

In view of the debate surrounding the suitability of parental material in the application of Fixed and Random models of Diallel Cross Analysis of F1s and parents (Method 2) of Griffing (1956), genotypes were considered fixed (Model 1) for general analysis using Mstat C statistical programme. SCA effects were calculated manually following Singh and Chaudhary (1977). Relative importance of general and specific combining ability effects was determined by computing a ratio of $2\ \sigma^2 g\ /\ (2\ \sigma^2 g + \sigma^2 s)$ from the mean squares of the fixed model as proposed by Baker (1978).

In addition, genetic parameters were calculated using Random Model – more as a matter of curiosity, but also for comparing the results of GLS with grain yield, especially because both diallels were made up of fairly large numbers of parents, 13 and 10, respectively.

In the off-season of 2000, attempts were made to testcross a set of 898 promising inbred lines of F6 or higher generations with four GLS resistant inbred testers in separate isolations. Three of these testers were commercial inbreds. Not every line produced sufficient seed for trials in combination with each tester. However, 1,585 successful testcross hybrids were evaluated in various combinations of Line x Testers in the main season of 2000/2001. Some tester combinations made more than one trial as only a maximum of 100 entries were kept in a trial. Trials were laid in Alpha Lattice design following a single row plot of 5 m long spaced 90 cm apart with three replicates. Data on all agronomic characters including yield and GLS were collected.

RESULTS AND DISCUSSION

Improving genetic resistance of old hybrids

GLS scores of commercial hybrids and their parents (Table 1) showed that: (1) All Zambian hybrids were in a range of susceptible to highly susceptible genotypes, (2) The susceptibility of most hybrids was close to the susceptibility of the most susceptible parent (3) Each hybrid was susceptible - mainly due to the involvement of one or, at the most, two susceptible parents, and (4) Only three out of a total of 10 commercial inbreds were susceptible to GLS.

Table 1. GLS scores (1-5)* of commercial Zambian maize hybrids and their parents.

Hybrid	GLS	Parents with their scores (in parentheses)
MM 502	4.0	L 12' (2.2) X L 9 (4.5)
MM 441	4.2	L 710 (2.5) X L 9 (4.5) X L 2 (2.2) X L 334 (3.8)
GV 412	3.9	L 710 (2.5) X L 9 (4.5) X MMV 400 (2.5)
GV 470	3.8	L 2 (2.2) X L 334 (3.8) X L 917 (1.5)
GV 512	3.2	L 12 (2.2) X L 12' (2.2) X L 9' (2.5)
MM 601	4.5	L 3233 (4.2) X L 9 (4.5)
MM 603	4.3	L 3233 (4.2) X L 9 (4.5) X L 12' (2.2)
MM 604	4.5	L 12' (2.2) X L 9 (4.5) X L 3233 (4.2)
MM 752	4.0	L 3233 (4.2) X L 5522 (1.5)
GV 704	4.0	L 9 (4.5) X L 9' (2.5) X L 5522 (1.5)

* 1 = Most resistant; 5 = Most susceptible.
' Modified version of the parent

Screening of germplasm revealed abundant resistance to GLS in local germplasm. A critical review of the related/sister lines of susceptible commercial lines revealed that some of the versions were fairly resistant to GLS. In the past, such versions have been used to replace original lines in some hybrids for improving their seed yields. This was the reason why the so called "sister versions" of commercial lines were developed and maintained. Most of these versions were, however, developed without much backcrossing.

Based on the above simple observations of disease behaviour and choice of germplasm available, separate breeding strategies were adopted for short- and long-term goals. In the short term, it was decided to improve the resistance of existing hybrids by replacing their susceptible parent(s) by suitable GLS resistant sister line(s) after checking the performance of new hybrid combinations.

Proper substitutes for two of the three susceptible parents were identified in the first year itself. Preliminary yield data (Table 2) on the comparison of old and new versions of commercial hybrids showed remarkable improvements in all but one hybrid - both in terms of GLS resistance and yield without altering many of the other characteristics. These new and rejuvenated resistant versions of old hybrids stayed green and fresh in the field for a longer period and appeared competitive on the market.

Yield loss assessment

The analysis of variance for yield loss assessment trial (Table 3) showed highly significant differences due to sub-plots (sprayed vs. unsprayed) while differences due to main plots (genotypes) were not significant. Mean square for the interaction was significant only at 5% probability level.

Grain yield differences in sprayed and unsprayed treatments ranged from 27.7 to 54.3% depending on the

Table 2. Performance of old and new versions of hybrids in 2000/01.

Hybrid	Grain yield**		GLS	Anthesis	Height (cm)		Shelling	Moisture
	Kg/ha	% gain	Score	Days	Plant	Ear	%	%
GV 412 (Old)	4990		3.5	64	230	110	85	14.0
GV 412 (New)	**5942**	**19**	**2.5**	**64**	240	**125**	86	13.3
MM 441 (Old)	3722		4.2	63	232	118	83	12.8
MM 441 (New)*	**4672**	**25.5**	**3.5**	**63**	240	**115**	87	13.2
GV 470 (Old)	6054		3.5	65	255	135	89	14.3
GV 470 (New)	**6805**	**13.2**	**2.5**	**66**	245	**125**	88	12.7
MM 501 (Old)	3892		4.5	63	215	115	83	12.6
MM 501 (New)	**5945**	**52.7**	**1.5**	**64**	230	**110**	88	13.5
MM 502 (Old)	4099		4.5	64	243	110	85	12.7
MM 502 (New)	**8060**	**96.6**	**1.5**	**65**	248	**115**	88	14.4
GV 512 (Old)	6138		3.2	65	248	110	86	13.2
GV 512 (New)	**6039**	**-1.6**	**2.5**	**65**	250	**125**	85	16.5
MM 601 (Old)	3471		5.0	66	241	122	85	12.5
MM 601 (New)	**6346**	**82.8**	**1.5**	**66**	245	**118**	89	14.6
MM 603 (Old)	3908		5.0	65	210	107	84	13.3
MM 603 (New)*	**7984**	**104.3**	**2.5**	**65**	247	**128**	88	15.7
MM 604 (Old)	3558		5.0	65	240	118	83	12.9
MM 604 (New)*	**5527**	**55.3**	**3.2**	**64**	240	**115**	85	13.5
GV 704 (Old)	6204		3.2	67	260	129	87	16.5
GV 704 (New)	**6872**	**10.7**	**2.8**	**68**	240	**128**	87	18.2

* Only one susceptible parent replaced so far.
** Based on a plot size of 4 rows of 10m long 90cm apart on Zamseed farm

Table 3. ANOVA of yield loss assessment trial.

Source of variation	d. f.	M S
Blocks	2	8.05
Varieties	4	47.04
Error (a)	8	19.18
Spraying	1	842.73**
Variety x Spraying	4	36.3*
Error (b)	10	7.634
CV%		11.2

*,** Significant at 0.05 and 0.01 level, respectively.

susceptibility of the genotype (Table 4). Since Eria controls a number of leaf diseases in addition to GLS, the differences in yields were due to a combined effect of all diseases present. Fortunately, leaf blight was the only other disease noticed in the trial for which the differences between sprayed and unsprayed plots were not as large. So the above loss figures may be a slight overestimate of the actual loss by GLS. The figures reported here are in agreement with several reports from the USA where yield losses of 10-50% have commonly been reported (Gevers and Lake, 1994; Saghai Maroof *et al.,* 1993; Saghai Maroof *et al*., 1996).

Yield loss in the leaf stripping trial ranged from 25 to 84% (25% when all leaves below the cob were stripped off, 57% when two additional leaves above the cob were removed, 67% when 4 additional leaves were removed, 80% when 5 extra leaves were removed, and 84% when only the flag leaf was retained). The highest figure of 84% is in close agreement with those of extreme losses of 73.8% to 88.5% reported from South Africa by Ward *et al*. (1993) as quoted by Pixley (1997). However, such extreme losses are unlikely to occur under field conditions.

Diallel cross analysis

Analysis of variance for GLS and yield (Table 5) indicated highly significant differences among genotypes in both diallels. Variances due to GCA and SCA were also highly significant for both characters in both experiments indicating that differences among hybrids were due both to GCA and SCA effects. Significant GCA and SCA mean squares were also reported by Gevers and Lake (1994), Huff, *et al*. (1988) and Elwinger, *et al.* (1990).

In trying to establish, the relative importance of GCA and SCA in determining progeny performance, the ratio of 2 σ^2 g / (2 σ^2 g + σ^2 s) was found close to unity in the case of GLS indicating that GLS reaction of hybrids should be predictable on the basis of GCA effects of the parents. The same conclusion is drawn from the straight comparisons of GCA and SCA variances where GCA variances for GLS was 12 and 15 times greater in Early and Late Diallels, respectively as compared to 1.6 and 1.9 times for yield. Most studies (Thompson, *et al.,* 1987; Ulrich, *et al*., 1990; Donahue, *et al*., 1991; Huff, *et al*., 1988) and Gevers and Lake, (1994) have also concluded that GCA effects were more important than SCA effects. However, Elwinger, *et al.* (1990) using generation mean analysis concluded that dominance was important in addition to additive gene action and fewer rather than many genes controlled the resistance. Hohls and Shanahan (1995) using a variance and covariance graphical technique outlined by Hayman (1954) on a 12 x 12 diallel concluded that the resistance to GLS can be expressed in terms of an additive-dominance model with dominance almost complete as it appeared to be the case in old susceptible hybrids (Table 1).

Although it may not be appropriate to compute additive (σ^2_A), dominance (σ^2_D) variances and in turn, the heritabilities of traits based on a random model analysis of a diallel cross from the lines which do not represent a population, broad and narrow sense heritabilities for GLS were 77 and 51% and 87 and 64 %, respectively in Early Diallel and Late Diallel as compared to 85 and 7% and 96 and 13 % for yield. Sughroue and Hallauer (1997) comparing genetic parameters estimated from random model diallel analyses using lines representing a random sample of a population with those not representing a population found that the estimates of additive (σ^2_A) and

Table 4. Performance of hybrids in Eria sprayed and unsprayed plots and % yield loss due to diseases.

Cultivars	Treatment	Yield (kg/ha)	Disease Scores (1-5)* GLS	Leaf blight	Yield Loss %
ZEM 620	Sprayed	8100	1.00	1.30	
	Un-sprayed	5694	3.67	3.33	29.7
(L5527*L917)*L3243	Sprayed	7592	1.00	1.33	
	Un-sprayed	5000	4.00	2.33	34.1
(L5527*L917)*L872	Sprayed	8889	1.00	1.00	
	Un-sprayed	6204	3.17	2.33	30.2
(L917*L710)*L1214	Sprayed	6528	1.00	1.33	
	Un-sprayed	4722	3.80	3.20	27.7
L2*L334	Sprayed	4453	1.00	2.33	
	Un-sprayed	2037	4.83	3.83	54.3
Mean	Sprayed	7112	1.00	1.46	
	Un-sprayed	4731	3.90	3.00	33.5

LSD (0.05) main plots (yield) 1618.9
LSD (0.05) sub-plots (yield) 624.5
LSD (0.05) sub-plots within main (yield) 1396.3
*,** 1 being disease free and 5 being the most diseased

Table 5. Analysis of variance for diallel experiments

Source of variation	Early Diallel d.f.	Early Diallel Mean squares GLS	Early Diallel Mean squares Yield	Late Diallel d.f.	Late Diallel Mean Squares GLS	Late Diallel Mean Squares Yield
Reps	2	1.582*	50.442*	2	0.312	1.660
Genotypes	90	1.793**	9.765**	54	2.855**	16.695*
GCA	12	8.851**	14.441**	9	12.873**	28.088**
SCA	78	0.708*	9.045**	45	0.852**	14.416**
Error	180	0.166	0.525	108	0.135	0.735
CV%		10.6	15.9		11.9	14.9
Ratio 2 $\sigma^2 g$ / (2 $\sigma^2 g + \sigma^2 s$)		0.980	0.870		0.970	0.800

dominance (σ^2_D) differed significantly for nearly half of the traits studied while heritabilities were underestimated slightly for all eight traits when parents were not representing the population. They concluded that the average level of dominance is overestimated while the additive component is underestimated when the lines do no represent the population.

So there is a likelihood of actual heritabilities to be greater than those reported here, more especially the narrow sense heritabilities. These results are different from those of 33% heritability for GLS reported by Manh (1977) as quoted in Bubeck, *et al.* (1993). In any case, the results suggest that in comparison with yield, GLS is a far more heritable trait and this agrees with the conclusions of Thompson, *et al.* (1987*)* and Donahue, *et al*. (1991).

Results of GLS being a relatively simple quantitative trait are best supported by Saghai Maroof, *et al*. (1996) who found the presence of the main QTLs for GLS only on chromosomes 1, 4 and 8 and smaller QTLs on chromosome 2. Further, they reported that resistance QTLs on chromosome 1 and 2 had additive effects while those on chromosome 4 and 8 had dominant and recessive effects, respectively.

The mean GLS scores and general and specific combing effects of genotypes for GLS from Early and Late Diallels are presented in Table 6 and Table 7, respectively. Differences in GLS scores of susceptible and resistant genotypes were much narrower in the Early Diallel than in the Late one. This is probably due to the fact that early maturing materials tend to get much higher pressure of the disease and develop bigger lesions than do the late material probably because of the cooler weather that follows late in the crop season.

Saghai Maroof, *et al*. (1996) also found late maturing lines to be more resistant than early lines. In supporting the speculations of Bubeck, *et al.* (1993) they stipulated that QTL 4 could either be an entity directly contributing to GLS resistance or a confounding effect of a factor controlling late maturity on chromosome 4. Elsewhere, while evaluating germplasm for GLS towards the end of the season, it was noticed that GLS resistance may often be confounded with the stay-green character of some lines which appear resistant because they remain much greener up to the end of the crop season while early materials give a dry appearance. This observation needs to be confirmed in future.

In the Early Diallel, L917 and L726 were the most resistant inbreds followed by L632 while inbreds L3233 and L911 followed by L 631 were most susceptible. The remaining parents were intermediate to susceptible in their reaction. Based on GCA values, L917 followed by L3243 were the best lines and produced several GLS resistant progenies followed by L3234, L726, L190, L631 and L913 all of which had significant negative GCA effects from zero. L911 and L3233, followed by L3237 had highest positive effect. The performance of hybrids generally agreed with the GCA effects of lines but the relationship was not strong as there were several resistant hybrids like L631 x L725, L631x L632, L 631 x L3234 whose parents were susceptible with low GCA effects. Hybrids like L917 x L 3243, L917 x L3234, L 917 x L190, L632 x L190, L725 x L 3243, and L631x L3234 must be exploited in future breeding programmes. In the Late Diallel, the two most resistant parents were L5522 and L880 followed by L1214 and L5527. On the other hand, L995 and 990 followed by L874 were the most susceptible inbreds. The remaining 4 lines were intermediate in susceptibility. In terms of GCA effects L5522

Table 6. Means (bold) and estimates of general (g_i) and specific (s_{ij}) combining ability effects for GLS in Early Diallel.

Parent	L710	L911	L913	L917	L631	L632	L725	L726	L3233	L3234	L3237	L3243	L190
L710	0.050**	0.140	0.171	-0.706**	-0.017	0.260*	-0.029	-0.129	0.271**	0.783**	0.294**	-0.263**	0.716**
	3.333	4.500	4.000	2.333	3.833	3.833	4.000	3.667	4.833	4.500	4.667	3.166	4.500
L911		0.750**	0.304**	0.590**	0.116	-0.273**	0.271**	0.505**	-0.429**	0.250**	-0.073	-0.462**	0.348**
		4.833	4.833	4.333	4.667	4.000	5.000	5.000	4.833	4.667	5.000	3.667	4.833
L913			-0.061**	0.238*	0.261*	0.038	-0.417**	0.089	0.216*	-0.439**	0.071	-0.317**	0.160
			3.500	3.167	4.000	3.500	3.500	3.833	4.667	3.166	4.333	3.000	3.833
L917				-0.850**	0.550**	-0.006	0.205*	0.105	-0.161	-0.317**	0.027	-0.696**	-0.551**
				2.500	3.500	2.667	3.333	3.000	3.500	2.500	3.500	1.833	2.333
L631					-0.038**	-0.817**	-0.607**	0.067	-0.700**	-0.800**	0.049	0.000	0.305**
					4.500	2.667	3.333	3.833	3.833	2.833	4.333	3.333	4.000
L632						0.316**	0.338**	0.404**	-0.029	0.149	0.827**	0.271*	-0.750**
						3.000	4.000	3.833	4.167	3.500	4.833	3.333	2.667
L725							0.139**	0.116	0.349**	-0.139	0.038	-0.850**	0.299**
							4.333	4.000	5.000	3.667	4.500	2.667	4.167
L726								-0.094**	0.083	-0.300**	0.271*	0.049	0.527**
								2.667	4.500	3.333	4.500	3.333	4.167
L3233									0.673**	0.660**	-0.328**	-0551**	-0.073
									5.000	5.000	4.667	3.500	4.333
L3234										-0.172**	0.849**	-0.206*	-0.289**
										3.333	5.000	3.000	3.333
L3237											0.484**	0.638**	-0.120
											3.333	4.500	4.500
L3243												-0.461**	-0.440**
												3.833	2.833
L190													-0.105**
													3.333

*,**Significantly different from zero at the 0.05 and 0.01 probability levels, respectively. SE ± (Mean) = 0.407

Table 7. Mean score (bold) and estimates of general (g_i) and specific (s_{ij}) combining ability effects for GLS in Late Diallel.

Parent	L 1212	L 880	L 1214	L 872	L 874	L 99O	L 995	L 5522	L 5527	L 5530
L 1212	0.007	-0.444**	-0.694**	0.067	0.028	-0.457**	0.554**	0.053	0.361**	0.361**
	3.167	**2.000**	**2.167**	**3.000**	**3.000**	**3.167**	**5.000**	**2.333**	**3.500**	**3.500**
L 880		-0.646**	0.459**	0.387*	-0.152	0.528**	-0.096	0.375**	-0.653**	0.181
		1.500	**2.667**	**2.667**	**2.167**	**3.500**	**3.667**	**2.000**	**1.833**	**2.667**
L 1214			-0.229**	0.303**	0.264**	-0.222**	0.820**	-0.375**	0.264**	0.097
			2.167	**3.000**	**3.000**	**3.167**	**5.000**	**1.667**	**3.167**	**3.000**
L 872				-0.157**	-1.141**	-0.128	-0.086	0.716**	-0.642**	0.192*
				2.933	**1.667**	**3.333**	**4.167**	**2.833**	**2.333**	**3.167**
L 874					-0.118**	-0.500**	0.376**	-0.320**	-0.181*	-0.014
					3.667	**3.000**	**4.667**	**1.833**	**2.833**	**3.000**
L 990						0.534**	0.056	0.028	0.334**	0.000
						4.333	**5.000**	**2.833**	**4.000**	**3.667**
L 995							1.326**	-0.93**	0.542**	0.542**
							4.667	**2.660**	**5.000**	**5.000**
L 5522								-0.813**	1.181**	-0.819**
								1.500	**3.500**	**1.500**
L 5527									0.048**	0.153
									2.500	**3.333**
L 5530										0.048**
										2.833

*,**Significantly different from zero at the 0.05 and 0.01 probability levels, respectively
SE ± (Mean) = 0.367

had the highest negative effect followed by L880, L1214, L872 and L874. L995 had the highest positive GCA value followed by L 990. The two most susceptible lines with highest positive GCA effects produced the most susceptible hybrids generally higher than both the parents indicating dominance of susceptibility. Although lines with negative GCA effects did tend to produce resistant hybrids, the relationship was not as good as it was in the case of those parents with positive effects. In fact, some lines with moderate resistance and moderate GCA effects produced exceptionally resistant hybrids. L872 x L874 was one of those very striking exceptions. L5530 x L5522, L5527 x L880, L5522 x L1214, L880 x L1214, and L1212 x L1214 must be exploited in future breeding.

In both diallels, GCA effects alone were not sufficient to predict the performance of hybrids suggesting the presence of non-additive gene actions as well. The significance of SCA variance in the ANOVA table of diallels should not be ignored. In fact, the only two studies suggesting the presence of dominance are both based on generation mean analysis. The suggestions of Pratt, *et al*. (1997) that different resistant gene products may be operational for GLS and that a diallel or generation mean analysis may not be adequate to reveal individual contributions of genes or that genetic background effects on expression of resistance are substantial appear to hold ground. Behaviour of different QTLs on different chromosomes reported by Saghai Maroof, *et al.* (1996) also point in the same direction.

Genetic analysis of large sets of Line x Testers has not been done yet. But many hybrids combining high GLS resistance with other desirable agronomic traits have been selected for advanced trials. A large number of lines with good general as well as specific combining ability have been identified. Good lines against individual commercial testers will be used to synthesize broad-based populations for selection and exploitation following different recurrent selection schemes, including the reciprocal recurrent selection. On the other hand, lines with high GCA effects will be used to develop synthetics, which will be utilized both as hybrid parents and open pollinated varieties after improving them by recurrent selection procedures that exploit additive gene action.

In conclusion, replacement of susceptible parents in old hybrids improved the performance of all popular hybrids. They appear rejuvenated, revived and competitive on the market. With the changes made, Zamseed will only be marketing GLS resistant hybrids from now onward and prospects for further progress appear good as the genetics of the disease does not appear very complex and the company has plenty of resistant germplasm.

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REGIONAL DISEASE NURSERY (REGNUR): A UNIQUE OPPORTUNITY FOR DEVELOPING MULTIPLE-DISEASE-RESISTANT MAIZE

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ABSTRACT

Maize is grown on 15 million ha in eastern and southern Africa. Several diseases, including maize streak virus (MSV), grey leaf spot (GLS) and *turcicum* leaf blight (ET) are of common occurrence in the region and regularly result in significant yield losses. With funding from The Rockefeller Foundation, a regional disease nursery (REGNUR) project was initiated in 1998 to promote and enhance regional collaboration to address the common disease and insect problems of maize. The REGNUR project aims to identify and increase access to disease resistant germplasm, generate and disseminate information on disease and insect resistance sources, and facilitate National Programs to develop resistant varieties. A recent REGNUR project was a diallel mating among 12 elite inbred lines identified by REGNUR collaborators. The trial was grown at 7 sites during 2001. Results showed that both general combining ability (GCA) and specific combining ability (SCA) effects were highly significant for GLS, MSV, head smut, *Phaeosphaeria* Leaf Spot (PLS), *turcicum* and rust (*P. sorghi*), whereas only GCA was important for ear rot resistance. On average, GCA determined 69% of resistance to diseases and only 37% of variation for grain yield. This implies that the approach to developing multiple disease resistance should involve identifying lines with good per se resistances to diseases with final selection for good combining ability for yield. Correlations between GCA effects for disease scores were generally non-significant, implying that it is possible to pyramid the genes for resistances to the different diseases into inbred lines. This underlies the need for screening specific diseases using artificial inoculation or reliable "hot-spots" and highlights the importance of a project like REGNUR, which enables such collaboration.

INTRODUCTION

Successful maize varieties generally have the ability to produce large grain yield when grown under favorable conditions. More important to most farmers, however, is that these varieties have a low probability of failure in the face of common production constraints. These constraints vary among growing areas and between cropping seasons, but considerable commonality exists within maize production zones of eastern and southern Africa. The warm climate and/or high rainfall common to many maize production zones of eastern Africa, permits two crops or even continuous cropping. The climate in southern Africa generally allows only one maize crop per year, but conditions are often warm with extended periods of moisture. Winters throughout eastern and almost all of southern Africa are mild, such that disease inoculum and insect pests readily survive on crop debris or alternate hosts from one season to the next. These conditions generally result in frequent disease epidemics and insect pest outbreaks that reduce maize yields. Endemic maize diseases, particularly leaf blight (ET), caused by *Exserohilum turcicum*, common rust (PS) caused by *Puccinia sorghi*, maize streak virus (MSV), gray leaf spot (GLS) caused by *Cercospora zeae maydis*, ear rots (ER) caused by *Fusarium* and *Diplodia*, head smut (HS) caused by *Sphacelotheca reiliana* (Kuhn) and increasingly *Phaeosphaeria* leaf spot (PLS) caused by *Phaeosphaeria maydis* affect much of the maize crop in most years.

Turcicum leaf blight is distributed worldwide and can cause yield losses of more than 60% in susceptible germplasm (Raymundo and Hooker, 1981). Common rust is also found worldwide and has been reported to cause economic losses on some 7.8 million hectares or 34% of the maize in subtropical-through-highland maize ecologies. Head smut has been reported in the USA, Mexico, Australia, New Zealand, Africa, Southern Europe and parts of Russia and causes yield and quality reduction (Njuguna, 1999). GLS is considered a disease of major concern in many parts of the world and yield losses to GLS have been estimated at 60% in South Africa (Ward et al., 1997). This disease has become important in the southern and eastern African regions, where the incidence and severity of GLS epidemics have been increasing (Tembo and Pixley, 1999). Maize streak virus (MSV) was first reported in east Africa and is now also found in many countries in sub-Saharan Africa and some islands in the Indian Ocean, the South Pacific, India and South-East Asia (Bonga, 1992). Total crop loss has been reported during severe MSV epidemics, and 1-5% loss is common. Although not reported in epidemic proportions, incidence of *Phaeosphaeria* leaf spot has been increasingly observed by researchers in the past few years and is becoming an important disease affecting maize yields. Ear rots frequently cause significant yield loss and damage to grain quality.

A wide range of chemical control methods from seed dressing to foliar spraying could reduce incidence and severity of most diseases, but the most economical management for most diseases is through host plant resistance. Through the regional maize disease nursery project (REGNUR), collaborators across eastern and southern Africa evaluated hundreds of inbred maize lines for different biotic stresses. Lines with moderate to high level of per se resistance to diseases were identified. The objective of this study was to evaluate the combining ability of these lines to enable collaborative development and identification of germplasm products.

MATERIALS AND METHODS

Twelve advanced maize lines developed by CIMMYT and its collaborators, possessing mainly subtropical adaptation, intermediate to late maturity and white grain color, were chosen to form a diallel mating design. Pedigrees of the lines are presented in Table 1. Lines were planted in paired rows of 4 m length for each cross combination. All 66 cross combinations were made, including reciprocals. Seed from each cross and its reciprocal were bulked to represent a particular cross.

Table 1. Pedigrees of parents used in the diallel

P1	CML202: ZSR923-S4BULK-5-1-BBB
P2	CML387: [EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-1-1-X-X-3-BB
P3	CML389: [EV7992#/EV8449-SR]C1F2-334-1(OSU9i)-8-6(I)-X-X-3-BB
P4	CML390: [EV7992]C1F2-430-3-3-3-X-7-BB
P5	CML393: [R201/TZMSRW]#B-18-1-1-3-2-X-1-BB
P6	CML395: 90323(B)-1-X-1-BB
P7	[MSRXPOOL9]C1F2-176-4-1-4-X-X-2-B-B-2-1-1-B
P8	(87036/87923)-x-800-3-1-X-1-B-B-1-1-1-B
P9	[MSRXPOOL9]C1F2-205-1(OSU23i)-5-3-X-X-1-B-B-B-1-B
P10	Ac8342/IKENNE{1}8149SR//PL9A]C1F1-500-4-X-1-1-BB-1-BB
P11	FR810/TZMSRW-5-2-1-X-1-B-B-B
P12	[AC8232/NPPXSC/GWEBI{1}TZMSR-W]#b]#b-144-5-4-1-3-X-X-1-B-B-B-B

Trials involving the 66 crosses were planted in six environments (Table 2) during 2001. The experimental design was an alpha (0,1) lattice with two replications in each environment. The experimental unit consisted of one 4 to 5 m row spaced 75 cm apart. Two seeds were planted per hill and thinned to one, with 25 cm between hills, resulting in a final density of 53,333 plants per hectare. Grain yield (GY) in tons/ha was calculated using ear weight at harvest or shelled grain weight adjusted to 12.5% moisture. Diseases were scored on a 1 to 5 or 1 to 9 scale (1 = good or resistant; 5 or 9 = bad or susceptible). Disease scores were converted to a 1 to 5 scale where the scale used was 1 to 9.

Statistical Analysis

Least square means for grain yield, days to anthesis, and disease scores were calculated using plot data for each location separately (data not shown). The combining ability analysis was conducted using the least square means. Analysis was done for individual environments as well as for combined environments. Environments were considered random and genotypes as fixed effects. Griffing's method 4 (Griffing, 1956; Dhillon and Pollmer, 1978) was used to obtain estimates of GCA and SCA effects.

The F-tests for the ANOVA were done as follows: Main effects such as entries and its sub-partitions, were tested against their respective interactions with environment, and all other terms were tested against the pooled error. For example, mean squares (MS) for GCA was tested against the mean squares for (GCA x Environment) and that for SCA against (SCA x Environment).

RESULTS AND DISCUSSION

Mean square for SCA x Env effects was non-significant for ET and PLS. Mean square for environment effects was non-significant for PLS and ER, while mean square for SCA effects was non-significant for ER. All other sources of variation were significant for all the diseases and for grain yield (Table 3). Contribution of general combining ability (GCA) to the entry sum of squares was 37% for GY, and ranged from 60 to 78% for ER, ET, GLS, PLS, PS, HS and MSV (Table 4). All the diseases had larger variance of GCA than SCA effects. On average, GCA determined 69% of variance for resistance to diseases and only 37% of variation for grain yield. Estimates of heritability averaged 60% and ranged from 45% to 70% for these diseases. This indicated that additive effects were more important than non-additive effects in determining resistance to these diseases. This implies that an effective approach to develop multiple disease resistance would involve identifying lines with good per se resistances to diseases with final selection for good combining ability for yield.

Correlation of GCA effects (Table 5) between ER and GY (-0.76) was the only significant correlation ($P<0.01$). This indicates that lines with best ER resistance tended to produce higher-yielding hybrids than ER-susceptible lines. Significant correlations for SCA effects were noted between HS and GY (-0.37) and HS and GLS (0.34) (Table 6). Thus, hybrids with good head smut resistance had better than expected (based on additive effects) GLS resistance and grain yield. However, caution is exercised in making this conclusion as head smut was screened at only one location. All other correlations of GCA and SCA effects between diseases were non-significant. Lack of significant negative correlations amongst lines and hybrids for resistance to the diseases implies that it is possible to pyramid resistance into one line and consequently develop hybrids and OPVs with multiple disease resistance. However, absence of any significant positive correlation between disease resistances highlights the need to evaluate each disease using artificial inoculation or "hot-spots" and signals the importance of a project like REGNUR, which enables such collaboration.

P12 and P6 were the inbred lines with the best weighted total of GCA effects across diseases and grain yield (Table 8). Further work would be needed to ascertain if these lines are indeed worthy of use as testers in a breeding program for disease resistance. The crosses P4/P9 (6.7 t/ha) and P4/P12 (6.9 t/ha) were the best hybrids in the earlier maturity category, while P3/P9 (8.3 t/ha) and P2/P8 (7.4 t/ha) were the best hybrids in the later maturity category (Table 7).

The REGNUR project has succeeded, in just three years, in forming a team of maize scientists in Ethiopia, Kenya, Uganda, Tanzania, Malawi and Zimbabwe who work together to evaluate the disease and insect resistance of experimental germplasm. Each collaborator has identified promising and potentially useful germplasm (Ngwira and Pixley, 2000). Several collaborators have proceeded to use REGNUR lines in their breeding programs, and two have identified and advanced hybrids to pre-release evaluation stages (Tanzania and Malawi). Information from this diallel can be used to predict, form and test three-way and double-cross hybrids. Within heterotic group single crosses could serve as sources for pedigree populations useful for regional inbred line development efforts. In summary, results from the above diallel show the usefulness of regional collaboration to develop and identify products, not possible otherwise given the geographic expanse and diversity of the environments in sub-Saharan Africa.

Table 2. Sites used for evaluation.

Location	Country	Biotic stress evaluated	Source of inoculum	Scoring scale
Kakamega	Kenya	ER, GLS, rust, turcicum	Natural	1 to 5
Muguga	Kenya	Head smut	Head smut inoculation	%
Namulonge	Uganda	GLS, turcicum	Natural	1 to 5
Bako	Ethiopia	GLS, rust, turcicum	Natural	1 to 5
Harare	Zimbabwe	ER, GLS, rust, PLS, MSV	MSV infestation	1 to 5
Harare	Zimbabwe	ER, GLS, rust, turcicum, MSV, PLS	Natural	1 to 9

Table 3. Analysis of variance of grain yield and 7 major diseases of eastern and southern Africa.

Source	GY		HS		MSV		ET		PLS		PS		ER		GLS	
	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS
Env	4	198.4**					1	2.27**	1	0.11ns	2	7.76**	2	60.9ns	4	6.75**
Entry	65	6.1**	65	679**	65	0.46**	65	0.21**	65	0.14**	65	0.32**	65	103.5**	65	2.50**
GCA	11	13.2**	11	3140**	11	2.03**	11	0.77*	11	0.53**	11	1.32**	11	364.6**	11	11.35**
SCA	54	4.7**	54	177**	54	0.14**	54	0.10*	54	0.06**	54	0.11*	54	50.3ns	54	0.69**
Entry*Env	260	1.4**					65	0.09**	65	0.04*	130	0.13**	130	42.0**	260	0.21**
GCA*Env	44	2.1**					11	0.24*	11	0.07**	22	0.41**	22	53.8**	44	0.82**
SCA*Env	216	1.3**					54	0.06ns	54	0.03ns	108	0.08**	108	39.6**	216	0.09**
Residual	265	0.7					106	0.05	106	0.02	159	0.04	159	24.1	265	0.06

Table 4. Estimates of percent GCA, SCA and heritability of grain yield and evaluated diseases

	GY	ER	ET	GLS	PLS	PS	HS	MSV	Average of diseases
GCA	37	60	61	77	65	70	78	74	69
SCA	63	40	39	23	35	30	22	26	31
Heritability	18	64	45	61	55	65	70	62	60

Table 5. Pearson correlation coefficients for GCA effects of grain yield and evaluated diseases

	ER	ET	GLS	GY	PLS	PS	HS	MSV
ER	1	0.21	0.49	-0.76**	0.35	-0.40	-0.34	-0.14
ET		1	0.12	-0.50	-0.02	0.39	0.07	0.16
GLS			1	-0.32	0.07	0.28	-0.24	-0.46
GY				1	-0.44	0.15	0.25	-0.23
PLS					1	-0.18	-0.44	0.22
PS						1	0.27	-0.25
HS							1	0.33
MSV								1

** p-value < 0.01

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ON-FARM EVALUATION OF IMPROVED MAIZE VARIETIES IN NORTHWEST ETHIOPIA.

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ABSTRACT

On-farm evaluation of improved maize varieties (BH-660, BH-540 and Kuleni) was carried out for two consecutive cropping seasons (1998 and 1999) across locations on 19 sites in northwest Ethiopia. The main objectives of the experiment were to evaluate the performance of maize technology and to demonstrate the package to the farmers and the extension personnel and to collect feedback from participants. The experiment was conducted by comparing improved varieties with their full package of practices (fertilizer rate, inter- and intra-row spacing, land preparation and weeding) with a local variety with farmers' traditional practice. The agronomic and economic analysis clearly indicated that the improved technology is superior to the local variety and farmers' practice. The average mean grain yields of the improved varieties (BH-660, BH-540 and Kuleni) were 9,527, 5,377 and 4,896 kg/ha, respectively. There was an overall yield advantage of 5,696, 1,546, 1,065 kg/ha of the improved varieties (BH-660, BH-540 and Kuleni) and a percentage increase of 148.7, 40.4 and 27.8%, respectively over the farmers' method of maize production. The marginal rate of return (MRR) for improved varieties (BH-660, BH-540 and Kuleni) was 499.8, 62.8 and 41.3%, respectively. Farmers perceived the higher yield potential of the improved technology. As a result, many farmers showed a great demand for improved varieties. So, large-scale dissemination of the improved varieties with their production package is recommended.

Keywords: Maize, marginal rate of return, package, technology, variety.

INTRODUCTION

Northwestern Ethiopia is a vast part of the country that encompasses five administrative zones. The region has potential for various food crops production. It contributes about 30% cereals, 40% pulses and 30% oil seeds production of the country (CSA, 1992).

Among the cereals, maize ranks second in production after "tef" and third in area coverage after tef and barley in Gojam and Gondar (CSA, 1992). Maize in northwestern Ethiopia is used directly for human consumption as food or local drinks. In addition, maize leaves are used for feed to animals and dry stalks are used as a fuel and for construction of fences. Both the area and volume of production of maize has been growing steadily for the last two decades throughout the region in spite of the fact that it is a recently introduced crop. However, it suffers much from low fertility, low management, lack of improved varieties, very severe infections of foliar diseases like turcicum leaf blight, high infestations of Striga and stalk borers (Assefa , 1998; Settie, *et al*.,1998). As a result, farmers produce a grain yield lower than 1,500 kg/ha in maize. On the other hand, a variety adaptation trial carried out at four locations for three years in the region revealed that varieties BH-660, BH-540 and Kuleni had high mean yields of 10,496, 8,804 and 7,889 kg/ha, respectively (Alamnie Atanaw, unpublished, Adet Research Centre, 1998). However, due to lack of awareness, farmers did not make use of these varieties.

Therefore, evaluation and demonstration of hybrid and open pollinated varieties along with the locally adapted variety was very vital in the mid and highland areas of West and East Gojam and South Gondar areas of Northwest Ethiopia. The overall objectives of this study were to evaluate the performance of maize technology, to demonstrate the package to extension personnel and farmers and to collect the feedback from the participants.

MATERIALS AND METHODS

On -farm evaluations of improved maize varieties (BH-660, BH-540 and Kuleni) were conducted across locations in South Gondar, East and West Gojam for two cropping seasons (1998 and 1999) on 19 sites with a plot size of 1000m^2 for each.

The experiment was conducted using improved varieties with all their packages of practices and adjacent to them a local cultivar with farmers' traditional practice for comparison purposes. The improved maize production package included fertilizer rate (100/75 kg/ha N/P_2O_5), inter- and intra-row spacing (75 and 30cm), land preparation (3 times ploughing) and two times weeding.

Before demonstrating the technology, a strong linkage was created with extension personnel and farmers and then thorough discussions were held with them on the objectives and merits of the activity. The selection of farmers was made in collaboration with Development Agents and Woreda (district) Experts. Then improved seed and fertilizer were delivered to the farmers from the research centre. Field days were organized and leaflets were also dispatched.

All data regarding agronomic, labour, attitude of farmers and extension personnel and other production inputs were collected. Data were analyzed using simple statistics, partial budgeting and marginal rate of return techniques.

RESULTS AND DISCUSSION

The results revealed that, particularly BH-660 and BH-540 with their production package out-yielded the local variety with farmers' traditional practice at all sites. However, the local variety out-yielded Kuleni at one site. This is because the farmer used a recycled hybrid as a local check .Due to high rainfall problem, the open pollinated variety out- yielded the hybrid at Mecha area, although the farmers appreciated the hybrid.

Table 1. Mean grain yield (kg/ha) of improved and local maize varieties in Ethiopia.

Location (district)	No. of demonstration sites				Average grain yield (kg/ha)			
	BH -540	BH -540	Kuleni	Local	BH –660	BH -540	Kuleni	Local
Yilman Densa	-	1	1	2	-	4729	3431	2656
Bahir Dar Zuria	-	1	1	2	-	4722	4651	3338
Mecha	-	1	1	2	-	3494	6149	2765
Fogera	-	2	1	3	-	6849	4099	3431
Dera	1	4	1	6	9242	7091	6240	4651
Huletiju Enesse	2	-	2	4	9812	-	4809	6149
Mean					9527	5377	4896	3831
Mean grain yield advantage (kg/ha)	5696	1546	1065					
Mean percentage increase (%)		148.68	40.35	27.79				

Table 2. Partial budget analysis of improved and local maize varieties.

Factors	Farmer's method ETB/ha	Improved method ETB/ha		
		BH –660	BH –540	Kuleni
Variable cost				
Seed(ha)	31	169.51	169.51	32.28
Fertilizer(ha)	290	760.18	760.51	760.28
Weeding/Slashing	17.50	73.50	73.50	73.50
Total variable Cost	338.5	1003.19	1003.19	865.50
Benefit	2681.7	6668.9	3763.9	3427.2
Net Benefit	2343.2	5665.71	2760.1	2561.24

Notes: Cost of seed during planting:
Improved seed = Hybrid 565.05ETB/Qt
= Pioneer 107.06ETB/Qt
Local seed = 06.04ETB/Qt
Maize average price = 70 ETB/Qt
Average local fertilizer price: DAP = 260 ETB/Qt
UREA = 219 ETB/Qt
Average local day's pay = 3.5 ETB/Man day
1US$ = 8.55ETB
1Qt = 0.1ton

The local variety with farmers' practice gave yields ranging from 2,656-6,149 kg/ha with an overall mean grain yield of 3,831 kg/ha. The improved production package (BH-660, BH-540 and Kuleni) gave grain yields ranging from 9,242-9,812, 3,494-7,091 and 3,431-6,240 kg/ha, respectively, with an overall mean grain yield of 9,527, 5,377,and 4,896 kg/ha in that order. There was an overall yield advantage of 5,696, 1,546 and 1,065 kg/ha and percentage increase of 148.7, 40.4 and 27.8%, respectively, over the farmers method of maize production (Table 1).

The total costs that vary for the farmers' practice was lower than the improved method. However, the use of the improved production package (BH-660, BH-540 and Kuleni) gave a higher net benefit of ETB 5,665.71, 2,760.71 and 2,561.24 kgha^{-1}, respectively whereas the net benefit for the farmers' method was ETB 2,343.2 ha^{-1} (Table 2).

The Marginal Rate of Return (MRR) for improved maize varieties (BH-660, BH-540 and Kuleni) was 499.8, 62.81 and 41.33%, respectively. This implies that for one birr increase in the improved technology (BH-660, BH-540, and Kuleni), an additional Birr of 4.99, 0.62 and 0.41 can be obtained after paying the input costs. The economic return to investment for BH-540 and Kuleni is not a promising one as compared to that of BH-660. The low economic return is mainly due to low grain yield (Table 3). Farmers in normal growing seasons prefer variety BH-660, BH-540 and Kuleni in descending order. Whereas in risky seasons, such as late on-set and early termination of rain, they choose BH-540, Kuleni and BH-660 in order of their preference.

Farmers strongly commented that the demonstration should include a local variety with improved management and also they strongly commented on the time of urea application at knee height. They suggested that near tasseling would be better than knee height application.

Table 3. Marginal analysis of the improved and local maize varieties

Factors	Varieties			
	BH 660	BH 540	Kulien	Local
Net Benefits (Birr/ha)	5665	2760	2561	
Marginal Net Benefit (Birr/ha)	3322	417	218	2343
Costs that Vary (Birr/ha)	1003	1003	866	
Marginal Cost (Birr/ha)	664	664	527	388
Marginal Rate of Return (%)	500	63	41	

CONCLUSION

In general, the overall mean grain yield of the improved production package significantly out-yielded the local variety with the farmers' practice. Farmers have perceived the higher yield potentials of the improved varieties and also showed a great interest to use the package of technology in the next cropping season. So, large-scale dissemination of the improved varieties with their production package is recommended.

The demonstration plot should include a treatment of local variety with improved management to give a chance to the farmers to compare the yield of local and improved varieties.

Input suppliers should deliver a basket of choice of improved varieties for the needy farmers to pick one, two, or all depending on the situation. Backup studies should take the feedback into account, i.e. investigation on time of urea application on maize.

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ON-FARM ADAPTABILITY OF FOUR MAIZE VARIETIES UNDER RECOMMENDED CULTURAL PRACTICES IN THE HIGHLANDS OF RWANDA.

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ABSTRACT

On-farm trials were conducted in Congo-Nile Crest and Volcanic Highlands regions during 1999 to assess the adaptability of four improved highland maize varieties under recommended practices. The experimental design was a split-plot with cultural practices as main factor and variety as sub-factor. The varieties tested were Mugamba, Isega, Pool 9A, Pool 8A and farmer's local variety. The treatments of cultural practices were the farmer's practices versus the recommended practices. Statistical analysis of results indicated differences between varieties and between practices but not between farmers. Moreover, the interaction practice x variety was not significant. In Congo-Nile Crest region, the recommended practices out-yielded the farmer's by at least 1.2 t/ha while the improved materials out-yielded the farmer's variety by at least 0.8 t/ha. Therefore, farmers chose Pool 9A and alternatively Mugamba and appreciated the recommended cultural practices. Pool 8A was discarded because of its yellow grain colour. In Volcanic Highlands, however, the recommended cultural practices out-yielded the farmer's by less than one t/ha and farmers chose Pool 8A while Pool 9A ranked second. Thus, Pool 9A and Mugamba should be released for Congo-Nile Crest under recommended practices while Pool 8A and Pool 9A should stay the most popular varieties of Volcanic Highlands.

Key words: Congo-Nile Crest, commune, cultural practices, farmer, maize, varieties, Volcanic Highlands.

INTRODUCTION

Maize (*Zea mays* L.) is an important crop in Rwanda ranking fifth in area under cropping and in production among food crops (after banana, haricot bean, sorghum and sweet potatoes) and second among cereals after sorghum (Dintinger, 1989). It is cultivated throughout the country but the highlands alone account for 60 % of the total national production with 30 % from Congo-Nile Crest region, 22 % from Volcanic Highlands and 8 % from other highland regions such as Buberuka (Castanié, *et al*., 1988). Maize is mainly intercropped with beans, but monocropping occurs in the highlands (Castanié, et al., 1988) where it is the staple food for small-scale farmers (Banyangabose, 1989).

Efforts to enhance maize production in the Volcanic Highlands of Rwanda were made through a project called PMB ("Projet Maïs des Birunga") that started in 1986 (Castanié and Karangwa, 1989). In that effort, the project released four improved varieties namely Mugamba, Isega, Pool 9A, and Pool 8A and cultural practice technologies such as inorganic and organic fertilizers combined with proper planting density (Ngaboyisonga and Ndayire, 1998).

This study focussed on the adaptability of the four varieties under recommended cultural practices in Congo-Nile Crest region, which were released for Volcanic Highlands of Rwanda. Furthermore, the trials acted as a test of comparison of adoption between Volcanic Highlands region and Congo-Nile Crest zone, two regions that are situated apart in the country and have several differences although they are both highlands.

MATERIALS AND METHODS

Trials were carried out in four communes – Nshili, Kivu, Muko and Gisovu- of Congo-Nile Crest region during 1999. They were repeated in one commune – Mutura of Volcanic Highlands as verification and a comparison of adoption. The first region is located in the south-east of Rwanda between longitude 29°24E - 29°38E and latitude 2°03S- 2°33S whereas the second is located in the north-west between 29°18E-29°47E and 1°20S-1°40S.

The soils of Congo-Nile Crest are predominantly Ultisols (Soil Taxonomy) with a pH ranging from 4 to 5 while in Volcanic Highlands they are Inceptisols (Soil Taxonomy) and have a pH of 6 on average. The two regions have a bimodal rainfall of 1,200 mm/year on average; their altitudes range from 1,900 to 2,700 masl and possess the lowest temperatures of the country that fluctuate around 15°C on average per year.

Farmers were selected in each commune at a radius of approximately 3 km from the commune office in different directions. Likewise, the distance between two neighbour-selected households was approximately 3 km so that trials were implemented throughout the commune but not in one place. Furthermore, other interested farmers could walk 3 km and visit the trials.

The farm size varied from 0.5 ha to 1.5 ha and all selected households were engaged in agriculture and cultivated maize as the main crop. Furthermore, the heads of households were either progressive farmers or heading rural communities so that several neighbours could visit the trials. Table 1 shows the number of farmers that carried out the trials; moreover, it shows that not all households harvested due to several reasons such as fields destroyed or cobs used before maturity.

The experimental design was a split-plot with the factor cultural practices (CP) being the main plot and the factor variety (V) the subplot. Each farmer or household was considered as a replication within each commune.

Four improved varieties: Mugamba (V1), Isega (V2), Tamira (V3) and Mamesa (V4) were tested against the local farmer's material or variety (V5). Mugamba and Isega were developed in Burundi by half-sib selection, the former from Pool 9A and the latter from a local high altitude population

Table 1. Number of farmers involved in on-farm trials in Congo-Nile Crest region and Volcanic highlands.

Region	Commune	N° of on-farm trials	N° of harvested trials
Congo-Nile Crest	Nshili	5	4
	Kivu	5	5
	Muko	5	3
	Gidovu	5	3
Volcanic Highlands	Mutura	5	3
Total		25	18

and Isega were developed in Burundi by half-sib selection, the former from Pool 9A and the latter from a local high altitude population (Rufyikiri, 1989). Tamira and Mamesa were the CIMMYT Maize Highlands Gene Pools (CIMMYT, 1981), respectively, Pool 9A (Highland Late White Dent) and Pool 8A (Highland Late Yellow Morocho). All these four open-pollinated varieties were introduced and selected for Volcanic Highlands of Rwanda (Ngaboyisonga and Ndayire, 1998).

The cultural practice factor comprised two levels: farmer's cultural practices i.e. broadcast planting combined with farmyard manure or compost applications (CP1) and recommended practices i.e. 60 kg N/ha + 75 kg P_2O_5/ha + 30 kg K_2O/ha + planting density of 55,000 plants/ha (CP2). However for the sake of comparing farmer's and recommended practices in the same conditions, all treatments received a base application of 5 t/ha of either farmyard manure or compost.

Farmyard manure or compost, like the common farmer's practice, were weighed, applied uniformly and covered with approximately 15 cm of soil during land preparation two weeks before planting. The mineral fertilizers were weighed and placed into the planting rows before sowing. They were covered by a little soil to avoid direct seed and fertilizer contact and therefore to minimise potential seed injuries.

The experimental unit (plot) was six rows of 5 m length for recommended practices. Planting was carried out with 0.60 m between rows and 0.30 m between hills, however only four middle rows were considered for data and hills near borders were discarded for harvest. Moreover, maize was planted at two seeds per hill and thinned three weeks later to one plant per hill. The same surface area for farmer's practices was delimited and sufficient seeds provided to farmers to sow, as they wanted. In the same way during harvest, care was taken to delimit and to consider the same surface as recommended practices.

Local farmer's variety seed was provided by the farmers themselves and therefore varied from household to household and from location to location. No chemical was used to control insects while weeding was performed by hand for all treatments. Besides, farmers were asked to plant a buffer area of at least two local variety rows and not to harvest before completion of the trial.

Even though yield was the main variable recorded, other characters were measured such as height, maturity and insect damage because they were very influential in adopting a variety. Furthermore, farmer's choices were recorded with the main criteria that led them to choose or to reject one material rather than another. A questionnaire was given to the farmers. They were asked to rank the varieties and to give the characteristics that were important to them besides the yield. The analysis of variance to compare farmers, cultural practices, varieties and to assess the interactions between the two factors was performed on yield using the MSTATC package programme.

Table 2. Analysis of variance for yield.

Commune	Source	DF	MS	F	P
Nshili	Farmers	3	7512337	7.11	0.07
	Practices	1	25472412	24.11	0.02
	Error	3	1056278		
	Varieties	4	525849	15.58	0.00
	Practices x Varieties	4	277241	0.82	>0.05
	Error	24	337568		
Kivu	Farmers	4	9595202	4.22	0.10
	Practices	1	48404731	21.33	0.01
	Error	4	2269803		
	Varieties	4	3691193	5.84	0.00
	Practices x Varieties	4	1669526	2.65	0.51
	Error	32	630497		
Muko	Farmers	2	1181913	6.20	0.10
	Practices	1	26972496	141.65	0.01
	Error	2	190420		
	Varieties	4	678130	3.59	0.03
	Practices x Varieties	4	515279	2.73	0.07
	Error	16	188960		
Gisovu	Farmers	2	7192300	7.37	0.12
	Practices	1	29344420	30.05	0.03
	Error	2	976372		
	Varieties	4	4295523	12.23	0.00
	Practices x Varieties	4	91973	0.26	>0.05
	Error	16	351304		
Mutura	Farmers	2	9572502	8.82	0.10
	Practices	1	7171282	6.61	0.12
	Error	2	1085121		
	Variety	4	2932037	4.21	0.01
	Practices x Varieties	4	130481	0.18	>0.05
	Error	16	694871		

Table 3. Hierarchical analysis for yield comparing farmers within communes.

Source	DF	MS	F	P
Between communes	4	12802383	1.15	0.33
Between farmers within communes	10	111299889	5.97	0.00
Error	135	251874064		

RESULTS

The analysis of variance (Table 2) showed that there were no significant differences between farmers for yield (P>0.05) while their were significant differences between cultural practices and varieties (P<0.03) in all communes. Furthermore, the interaction practice x variety was not significant (P>0.05). However, in Mutura commune (Volcanic Highlands), differences between cultural practices were not significant (P= 0.12).

Additionally, the hierarchical analysis was used to compare farmers within communes. However, before this analysis, one farmer in Nshili and two in Kivu communes have been randomly removed to make the design balanced and analysis possible. This analysis showed that there were highly significant differences between farmers within communes for yield (P = 0.00) unlike the differences among farmers in each commune (Table 2), however, no differences between communes were observed (Table 3). In some communes, farmers got an average yield of 5 t/ha while in others they got less than 3 t/ha (Table 4).

In Mutura (Volcanic Highlands), on the other hand, the yield rise was less than 1.2 t/ha for all varieties, it was 900 kg/ha on average (Table 5). This yield still leads the majority of farmers (60 %) to appreciate the recommended practices rather than their own procedures. The recommended cultural practices out-yielded the farmer's practices by at least 1.2 t/ha for all varieties including the farmer's local material in Congo-Nile Crest region. In some communes, the yield increase was as high as 2 t/ha (Table 5) for Mugamba (V1), Pool 9A(V3) and Pool 8A(V4). This led farmers to appreciate the recommended practices although 20% of interviewed farmers argued that they were not easy to implement because chemical fertilizers were costly and row planting took more time than broadcasting.

Overall, the improved varieties performed better than the local farmer's material under both farmer's and recommended cultural practices by about 0.8 t/ha on average. Nevertheless, Mugamba in Mutura and Isega in Nshili and Mutura yielded less than the local farmer's variety. Furthermore, compared to the farmer's variety, the yield rise was very important for Pool 9A, Pool 8A and Mugamba exceeding 1.5 t/ha for some cases under recommended cultural practices (Table 5).

Among the improved varieties, Pool 9A was highly appreciated by farmers of Congo-Nile Crest region firstly because of its better yield and secondarily its better performance for additional characteristics as cited by farmers themselves. These were white semi-dent grain, acceptable height, aspect, tolerance to insects and uniformity in the field (Table 6).

Mugamba with a good yield, a good plant aspect, white semi-dent grain and a good ear shape ranked second because of its height (tall) and its less uniformity in the field (Table 6). Mamesa in the Congo-Nile Crest

Table 4. Farmers average yield (kg/ha) within the five communes.

Commune	F1	F2	F3	F4	F5	Avg.
Nshili	2120*	3721	2508	3853	-	3051
Kivu	5832	4399*	5062	3237	5149*	4736
Muko	3174	4100	4032	-	-	3769
Gisovu	3762	5205	5256	-	-	4741
Mutura	4360	3425	5281	-	-	4389

* Farmers randomly removed for hierarchical analysis to compare farmers within communes.

Table 5. Yield (kg/ha) of five varieties under two cultural practices.

Commune	Variety	Cultural practices		
		CP1	CP2	Average*
Nshili	V1	2931	4957	3944 a [1]
	V2	1312	2561	1937 c
	V3	2319	4206	3262 b
	V4	2764	4390	3577 ab
	V5	1937	3128	2533 c
	Average	2253	3849	3051
Kivu	V1	4425	6066	5245 ab
	V2	3854	5373	4613 bc
	V3	2834	6260	4547 bc
	V4	4557	6229	5393 a
	V5	3089	4669	3879 c
	Average	3752	5720	4736
Muko	V1	3262	4469	3866 a
	V2	2871	4367	3619 ab
	V3	3075	5217	4146 a
	V4	2583	5302	3942 a
	V5	2311	4331	3271 b
	Average	2821	4717	3769
Gisovu	V1	3993	5658	4826 bc
	V2	3636	5437	4537 c
	V3	4180	6423	5302 ab
	V4	4520	6712	5613 a
	V5	2430	4418	3424 d
	Average	3752	5730	4741
Mutura	V1	3162	3904	3533 a
	V2	3533	4615	4047 ab
	V3	4216	5250	4733 bc
	V4	4684	6071	5378 bc
	V5	3904	4548	4226 c
	Average	3900	4878	4389

* Mean separations by DMRT at P=5%, (1) means followed by the same letter are not significantly different from each other.

region, despite a good yield, an acceptable height, a good level of tolerance to insects and early maturity was discarded mainly because of its yellow and flint grain type (Table 6).

In Volcanic Highlands (Mutura), however, Pool 8A ranked first and Pool 9A second (Table 6). When asked about the yellow kernel colour, farmers in Volcanic Highlands responded that the yield and the maturity were the main factors while the grain colour was a second priority. They said, however, that if a white semi-dent variety that performs as well as Pool 8A could be available, they could choose it.

Although Isega was early of maturity, it was not chosen because firstly, it yielded less than the local farmer's variety. Secondly, it was a mixture of colours and was susceptible to insects like the local materials. Finally, it had unacceptable ear size and plant aspect (Table 6).

DISCUSSION AND CONCLUSIONS

This paper discusses the adaptability of four improved maize varieties under improved cropping practices in Congo-Nile Crest region that have been tested and adopted in Volcanic Highlands of Rwanda (Ngaboyisonga and Ndayire, 1998). Additionally it compares adoption of innovations

Table 6. Additional characteristics and farmer's choices.

Commune	Variety	Yield ranks	Height (cm)	Mid-silk (d)	SB (1-5)	Kernel Colour	Kernel type	Farmer's choices
Nshili	V1	1	284	93	2.13	White	Semi-flint	2
	V2	5	264	83	2.50	Mixed	Semi-dent	4
	V3	3	254	94	2.13	White	Semi-dent	1
	V4	2	248	87	2.13	Yellow	Flint	3
	V5	4	254	91	3.50	Mixed	Semi-dent	5
Kivu	V1	2	284	93	2.00	White	Semi-flint	2
	V2	3	263	84	2.20	Mixed	Semi-dent	3
	V3	4	264	93	2.13	White	Semi-dent	1
	V4	1	253	88	2.13	Yellow	Flint	4
	V5	5	255	90	2.50	Mixed	Semi-dent	5
Muko	V1	3	283	92	2.00	White	Semi-flint	2
	V2	4	260	83	2.00	Mixed	Semi-dent	3
	V3	1	267	92	2.00	White	Semi-dent	1
	V4	2	258	89	2.00	Yellow	Flint	5
	V5	5	257	90	2.00	Mixed	Semi-dent	4
Gisovu	V1	3	280	92	2.00	White	Semi-flint	2
	V2	4	259	85	2.25	Mixed	Semi-dent	4
	V3	2	266	93	2.00	White	Semi-dent	1
	V4	1	256	88	2.00	Yellow	Flint	3
	V5	5	258	90	2.50	Mixed	Semi-dent	5
Mutura	V1	5	287	94	2.25	White	Semi-flint	4
	V2	4	261	88	2.25	Mixed	Semi-dent	5
	V3	2	270	96	2.15	White	Semi-dent	1
	V4	1	271	92	2.00	Yellow	Flint	2
	V5	3	265	90	2.25	Mixed	Semi-dent	3

between two important highlands regions of Rwanda.

Trials carried out in the highlands regions have shown that improved varieties yield better than the local farmer's and increase significantly the yield and therefore are preferred (Table 6). It is worth noting that the local farmer's variety, unlike improved varieties, is a mixture of various materials, several colours and textures without uniformity and yield stability.

Likewise, it was shown that application of fertilizers and manure together as reported by Onyango, *et al*. (1998) improves the yield significantly compared to application of manure or inorganic fertilizer alone. When inorganic fertilizers together with manure are combined with a proper plant population, the yield increases even more. However, the benefit of improved cropping systems is higher in the more fertile Congo-Nile Crest region (>1.2 t/ha), and lower in the less fertile Volcanic Highlands (≤ 0.9 t/ha),.

Furthermore, it was shown that the interaction cultural practices x varieties was not significant (Table 2), improved varieties under recommended cultural practices always increase the yield (Table 5). At commune level (district) farmers do not differ significantly while they differ among communes. Therefore, farmers have the same maize cropping systems at commune level and can apply in the same manner the innovations while this is not so for farmers within communes (Table 3 and Table 4).

Besides the yield, farmers in each highland region have other criteria (height, maturity, uniformity, yield stability, grain colour, tolerance to insects) that influence them to adopt a variety (Table 6). These criteria should be taken into account together with the yield when releasing a maize variety in the highlands of Rwanda. Following the farmer's criteria in addition to the yield, Pool 9A and Mugamba were appreciated in Congo-Nile Crest region while Pool 8A and Pool 9A were chosen in Volcanic Highlands region.

The trials have been carried out during two seasons within one year. For proper recommendations further testing over years and more systems such as manure alone, inorganic fertilisers alone and both combined, may be needed. However, they have shown that Pool 9A and Mugamba were highly appreciated in Congo-Nile Crest region because besides the yield they fit the farmer's criteria. They additionally out-yield the local farmer's material under both recommend cultural and farmer's practices. Moreover, recommended cultural practices combined with improved varieties always increase the yield. Therefore, Pool 9A and Mugamba should be released for Congo-Nile Crest region while Pool 9A and Pool 8A should remain the important varieties in Volcanic Highlands.

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ON-FARM EVALUATION OF CIMMYT'S QUALITY PROTEIN MAIZE VARIETIES IN ETHIOPIA.

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ABSTRACT

Since improved normal maize varieties released to producers are low in some essential amino acids content (lysine and tryptophan), protein malnutrition is common in areas where maize is a major staple food in Ethiopia. On-farm trials were conducted in the year 2000/2001 in the major maize growing areas, namely Bako, Pawe, Awasa, Jima, Alemaya, Melkassa and Ambo for the evaluation of the performance of four promising QPM varieties under farmers' conditions against the previously released normal maize hybrid, BH-540. The design used was a randomized complete block design (RCBD) using each farmer's field as a replication. Participatory evaluation methodology was also used to acquaint the farming communities and the extension workers with the QPM varieties and to facilitate effective dissemination of farmer-preferred QPM varieties in the future. Results revealed that the performance of the varieties varied significantly across locations. Analysis also showed that there were significant yield differences among the varieties tested at Bako and Awasa ($p<0.01$) and at Ambo ($p<0.10$). In Ambo and Awasa areas (high altitude areas), all the QPM varieties gave significantly lower yields than the check while in Bako (mid-altitude areas), the QPM variety (CML-144 x CML-159) x CML-176 gave significantly higher yield than other varieties including the local check. Besides, farmers' assessment revealed that they were interested in this QPM variety because of its higher grain yield, nutritional value and moderate tolerance against the major diseases such as Gray Leaf Spot (GLS) and Turcicum Leaf Blight (TLB). Hence, the QPM variety, (CML-144 x CML-159) x CML-176, which showed moderate tolerance against the major diseases and gave comparable yields to the check was recommended for possible release especially for the mid- and low altitude areas (1000-1800 masl) of Ethiopia.

Key words: Maize, QPM, variety.

INTRODUCTION

Food security in the larger sense includes food production in the agricultural sector and, human nutrition and health aspects (Jansonius, 1988, cited in Mosisa, 1997). Past research efforts on maize in Ethiopia rarely considered the improvement of the nutritional value of maize, unlike other African countries, though the improvement of maize started in the early 1960s (Legese *et al*, 1997). Millions of smallholder farmers in the major maize producing regions of Ethiopia depend on maize for their daily food throughout the year and they have almost no access to protein sources like meat, eggs and milk for their daily consumption. Since normal maize varieties are low in two nutritionally vital amino acids content (lysine and tryptophan) (Osolon and Frey, 1981), they cannot provide good quality protein and sustain acceptable growth and adequate health.

Cognizant of this fact, improvement of the nutritional value of maize especially in protein quality was started and a strategic plan was systematically outlined and used as a guideline for quality protein maize (QPM) breeding at the national level. About five years have elapsed since this program was started. Since then, several QPM hybrids and populations obtained from CIMMYT with high lysine and tryptophan content were introduced and tested in the mid- and high altitude areas of Ethiopia to identify varieties with comparable yield potential and other agronomic traits to normal maize varieties under production (Mosisa, et al, 1997; Legese *et al*, 1998; and Aschalew *et al*, 1998). Recently, some QPM varieties obtained from CIMMYT were observed to give promising results under on-station conditions in testing areas.

To this effect, on-farm evaluation of these promising QPM varieties was conducted in year 2000 with the objective of evaluating their performance under farmers' conditions using a previously released normal maize variety as a check.

MATERIALS AND METHODS

The trial was conducted at seven locations namely, Bako, Ambo, Pawe, Nazreth, Jima, Awasa and Alemaya areas. Before starting the fieldwork, selection of the host farmers was made based on their representativeness of the majority of smallholder farmers and their ability to disseminate the information to other farmers. The design used was a randomized complete block design (RCBD) using each farmer's field as a replication. The varieties were (CML-141 x CML-144) x CML-176, CML-174 x CML-176, (CML-144 x CML-159) x CML-176, GH-132 –28 and the Local check, BH-540.

Participatory evaluation methodology was also used to acquaint the farming communities and extension workers with the QPM varieties for facilitating their wider dissemination in the future. The gross plot size was $100m^2$ and the net plot size was $88.36m^2$. Frequent monitoring of the trials by researchers and host farmers was made throughout the cropping season to collect data on agronomic, disease and insect pest reaction and farmers' assessments. During the implementation of the entire activities, farmers and extension agents in the vicinity of the trial sites have participated in the trial management and they have given their views about the varieties. Individual and combined analyses of variance were conducted. Bartlett's test was done for homogeneity of variance before combined analysis.

RESULTS AND DISCUSSION

The analysis of variance of grain yield at each site (Table 1) revealed non-significant differences among the varieties tested except at Ambo (P<0.05), Awasa (P<0.01) and Bako (P<0.01). In Ambo and Awasa (high altitude areas), the local check (BH-540) was high yielding and superior to the QPM varieties while in Bako (mid-altitude area), the QPM varieties, (CML-144 x CML-159) x CML-176 and GH-132-28 gave significantly higher yield and superior performance to other varieties including the local check.

Results of the Bartlett's test revealed that there was no homogeneity of error variances and hence, locations which contributed highly to the variability of error variances, Alemaya and Pawe, were excluded from the combined analysis. The results of the combined ANOVA from five locations (Bako, Ambo, Awasa, Jima and Melkassa) showed that the yield differences contributed by location, genotype and genotype x location interaction were highly significant (Table 2).

This indicated that there is a differential response of the tested varieties across the range of environments tested and all varieties responded differently to different environments. In other words, it shows the specific adaptability of certain varieties to certain environments. For instance in Bako area, the QPM varieties, (CML-144 x CML-159) x CML-176 and GH-132-28 gave higher yields than other varieties including the local check. Whereas in Ambo and Awasa the local check was superior to the QPM varieties. This indicates that there is a need to verify QPM varieties which give significantly higher yield and perform better than others in the mid-altitude areas of Ethiopia

Farmers' assessments of the five varieties were also elicited both before and after harvest in Bako area (Table 3). In pre-harvest assessment, yield potential, lodging and disease tolerance were reported by most farmers as important pre-harvest traits determining the varietal preferences. Regarding crop maturity and disease infestation, the QPM variety CML- 175 × CML-176 is highly disliked by the farmers due to its high disease suceptibility and early maturity. Farmers were indifferent among the varieties on the grain filling and grain size.

Table 1. Mean yields (t/ha) of the varieties over locations in Ethiopia.

Variety	Alemaya	Ambo	Awasa	Melkassa	Bako	Pawe	Jima
(CML-141 × CML-144) × CML-176	10.217	6.625	7.935	9.257	7.05	6.810	8.253
CML-175 × CML-176	10.967	4.475	7.610	10.447	5.07	7.335	7.697
(CML-144 × CML-159) × CML-176	12.110	6.965	8.285	9.517	7.71	6.440	9.083
GH -132-28	13.873	6.890	8.805	10.873	7.77	7.130	8.170
BH-540 (Local Check)	11.390	8.695	10.765	10.327	7.29	4.535	8.067
CV(%)	21.420	7.720	3.830	14.630	10.66	21.25	8.610
LSD(5%)	-	1.454	0.922	-	1.40	-	-

- shows non-significant difference among the varieties at 5% level of significance.

Table 2. Pooled analysis of variance for grain yield of four CIMMYT QPM Varieties and one local check in five environments of Ethiopia (2000)

Source of Variation	DF	Sum of Squares	Mean square	F value	Prob-value
Location	4	90.386	22.596	4.0148*	0.0798
Reps within location	5	28.141	5.628		
Treatments	4	20.215	5.054	15.4339***	0.0000
Location × treatments	16	24.280	1.517	4.6343***	0.0008
Error	20	6.549	0.327		

CV = 6.95 %   *, ** and *** shows level of significance at 10 %, 5% and 1% respectively

Table 3. Pre- and Post-harvest farmer assessments of the varieties.

Criteria	GH-132-28	(CML-144 x CML-159) x CML 176	CML-175 x CML-176	(CML-141 x CML-144) x CML-176	Local Check (BH-540)
Diseases					
TLB	4	2	5	2	3
GLS	3	2	5	4	2
Plant height	3	2	3	5	1
Lodging	1	2	2	4	1
Maturity	-	-	Early Maturing	-	-
No of cobs per plant	4	1	3	2	5
Bare tipped	5	3	1	2	4
Yield	2	1	5	3	4
Plant aspect	3	2	5	2	2

Where 1= best------------5 = worst

Table 4. Rank of the varieties across locations.

Variety	Yield Rank					
	Ambo	Awasa	Melkassa	Bako	Jima	Overall Rank
(CML-141 x CML-144) x CML-176	4	4	5	4	2	4
CML-175 x CML-176	5	5	2	5	5	5
(CML-144 x CML-159) x CML-176	2	3	4	2	1	2
GH-132-28	3	2	1	1	3	1
BH-540	1	1	3	3	4	2

CONCLUSION

In Bako area, the variety (CML-144 × CML-159) × CML-176 was significantly higher yielding than other tested varieties except GH-132-28, which was less liked by the farmers due to its relative susceptibility to diseases (GLS and TLB) and lodging problems. Furthermore, variety (CML-144 × CML-159) × CML-176 received a favorable evaluation among tested varieties for most pre- and post-harvest evaluation criteria. Non-parametric stability analysis also confirmed that this QPM variety gave more stable yields over locations (Table 4). Thus, the variety (CML-144 × CML-159) × CML-176 should be given a high priority for release for the peasant farm communities of Bako (mid-altitude) and similar areas of Ethiopia. The results of the current study will be forwarded to the National Variety Release Committee for consideration.

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INFUSION, DEVELOPMENT AND IMPROVEMENT OF HIGHLAND MAIZE GERMPLASM IN EASTERN AFRICA.

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ABSTRACT

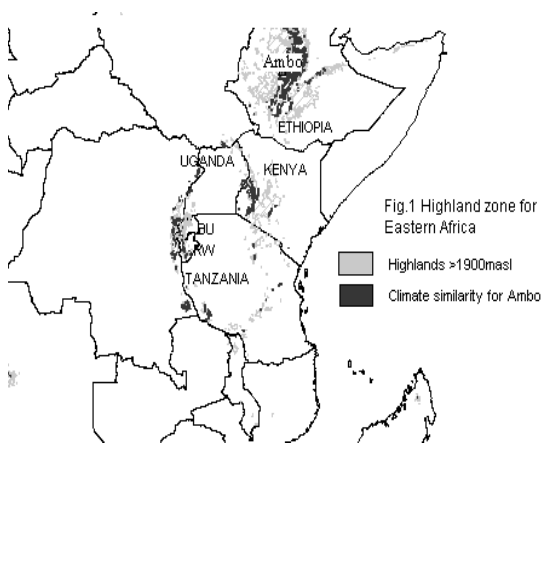
Maize is a major crop in eastern Africa in terms of production, consumption and income generation for both resource-constrained men and women. Maize research, therefore, ranks first in ASARECA's regional research priorities. A significant proportion of maize in the region is produced in the highland zone, which represents a very favorable maize growing environment. However, maize production is affected by major biotic constraints (leaf blight *E. turcicum*, common rust *Puccinia sorghi*, *Fusarium* ear rot, stalk borers and stalk lodging) and abiotic stresses (frost, hail and waterlogging on vertisols). In spite of these constraints, highland maize breeding had received little attention since the introduction of Ecuador 573 into Kenya in 1959. It was in the recognition of these factors that the Highland Maize Gene Pools Project was initiated in October 1997 with the objectives to introduce, develop and improve the highland maize. Six countries in the region (Ethiopia, Kenya, Tanzania, Uganda, Rwanda and Burundi) directly participated in the project. About 1,200 items of local germplasm were collected in the six countries in 1998 and were evaluated in the respective countries. More than 4,000 lines of CIMMYT mid-altitude and highland transitional zone maize were evaluated at a regional highland nursery at Ambo, Ethiopia with emphasis on screening for the major biotic and abiotic stresses and general adaptation. Selected inbred lines were topcrossed to three regional testers [Kitale Synthetic II, Ecuador 573 and Kuleni (Pool 9A)] and evaluated in the region. Line x tester analysis was carried out to determine the combining ability and the heterotic groups of selected lines. The CIMMYT transitional highland maize germplasm entries were much earlier in maturity than the earliest locally available materials in the region. The transitional zone materials derived from Pool 9A had good adaptation to the regional highland zone. Pool 9A lines topcrossed to the three local testers produced significantly higher grain yield than the testers indicating good levels of heterosis. Line x tester analysis showed that the three testers were effective in separating the lines into heterotic groups based on their SCA effects. The data were used to group the CIMMYT transitional and mid-altitude lines into three distinct heterotic groups based on the Ecuador-Kitale pattern and on Kuleni. Germplasm products generated from the project and made available to collaborators included inbred lines classified into heterotic groups, hybrids and local landraces.

Key words: Maize, highland, topcrosses, GCA, SCA, hybrids, synthetics

INTRODUCTION

Maize (Zea mays L.) is the most important staple cereal grain in Eastern Africa providing more than half the daily calorie and protein intake of most of the population. Maize is also a principal and popular component of the diets across the region. It is largely used directly for human food but increasing quantities are used for animal feed. Maize production, processing and utilisation provide vital employment and income generation activities for a large cross-section of the population including men, women and children. Maize research, therefore, ranks first in the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) regional research priorities. Maize is cultivated in all the major agro-ecological zones in the region up to altitudes of 2,400 masl. A significant proportion of maize in the region is produced in the highland zone (Fig 1), which represents a very favourable maize growing environment. However, low yield potential arising from an ever-narrowing genetic base of highland maize

Figure 1. Highland Zone for Eastern Africa.



germplasm in the region is widely recognised. The current 5-year Research Plan of ECAMAW (East and Central Africa Maize and Wheat Network under the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) lists low yield potential of maize (especially in the highlands) as topmost among its regional research priorities. The major biotic constraints are *E. turcicum* leaf blight, *Puccinia sorghi* rust, *Fusarium* ear rot, stalk borers and stalk lodging.

The abiotic stresses in the highland zones include frost, hail and waterlogging (on vertisols). Also the highland zones are greatly influenced by small changes in elevation especially at the higher altitudes where genotype-by-environment interactions become very significant (Lothrop, 1994)

Until recently, little attention had been given to expanding and improving the genetic base of eastern African highland maize. The last major effort was perhaps in 1959 when the variety Ecuador 573 was introduced into Kenya which together with the Kitale II Synthetic still dominates as the source germplasm in the region (Lothrop, 1994). In spite of this, highland maize improvement research in the region had generally lagged behind those of other ecologies until it was stepped up in 1997 through a project to improve highland maize in Eastern Africa. Across the region, the highland maize cultivars have been dominated by open-pollinated local cultivars and a few hybrids derived from the Ecuador and Kitale populations which are targeted for the highland zones up to 2,000 masl (Bisanda, 1996, Zeleke, 1993). Maize varieties extensively grown beyond 2,000 masl are local cultivars with longer maturity duration, vulnerability to frost, extremely tall plant/ear height and poor stalk quality which together contribute to low yield potential. The objective of the highland maize improvement program was therefore to introduce and improve maize with adaptation to highland ecologies in eastern Africa, facilitate the collection, evaluation and documentation of regionally important highland maize germplasm, develop heterotic gene pools and to enhance and facilitate collaboration between the NARS in the Region.

MATERIALS AND METHODS

CIMMYT began collaborative work in October, 1997 with financial support from the *Bundesministerium fur Wirtschaftliche Zusammenarbeit* (BMZ, Germany) to improve highland maize in eastern Africa. As part of this, a senior CIMMYT maize breeder was posted to Ethiopia to coordinate the project. A small grant research support programme was made available through the Project for strengthening collaborative research on highland maize. The small grant support program was operated alongside those conducted in the region under the ECAMAW Maize Steering Committee. In order to better target research products, information was gathered on the different highland ecologies in the zone so as to better define the highland environment. Highland maize scientists in the region met annually to develop a common strategy for highland maize improvement.

A regional nursery was established at Ambo, Ethiopia in 1998 for maize germplasm enhancement to develop maize with adaptation to highland ecologies. Potentially useful base maize germplasm entries for the improvement program were obtained from regional NARS highland populations, true/transitional highland materials from CIMMYT-Mexico and mid-altitude maize from CIMMYT-Zimbabwe. Local maize landraces were collected in the six countries in 1998 and evaluated for *per se* performance in the respective countries in 1999. In Ethiopia, 289 local germplasm accessions were evaluated at 4 locations, Ambo, Kulumsa, Alemaya and Adet in 1999. The Zimbabwe materials had previous improvement for resistance to the maize streak virus (MSV) and the gray leaf spot *Cercospora zeae-maydis* (GLS) important diseases in the highlands. Inbred lines were developed from the various materials and screened annually at the regional nursery. Emphasis was placed on selection for tolerance against diseases (especially *turcicum* leaf blight and common rust) as well as vigour and general adaptation to the highland environment. Crosses between promising introductions and three local population testers (Ecuador 573, Kitale Synthetic II and Kuleni) were made and evaluated in six participating countries (Ethiopia, Kenya, Tanzania, Uganda, Burundi and Rwanda) to determine their potential agronomic performance and their heterotic patterns. The Kitale-Ecuador heterotic pattern well known in the region was used but in addition to this, a third grouping was introduced based on Kuleni. Kuleni (derived from CIMMYT Pool 9A in Ethiopia) was originally synthesized from eastern African germplasm and Kitale and Ecuador populations. About 30 topcross trials were generated and evaluated in the region in 1998-2000. The Alpha (0,1) lattice design was used for the evaluations. One row plots spaced at 75 cm were used with plants spaced 25-30 cm within rows. Standard agronomic practices used in respective locations were employed by collaborators. Preliminary analyses of variance were carried out on the data. General combining ability (GCA) and specific combining ability (SCA) were computed for characters that showed significant differences among crosses following line x tester analysis (Kempthorne, 1957) using SAS 2001 computer programmes. The enhanced highland maize germplasm entries were classified into heterotic groups based on their combining ability patterns.

RESULTS

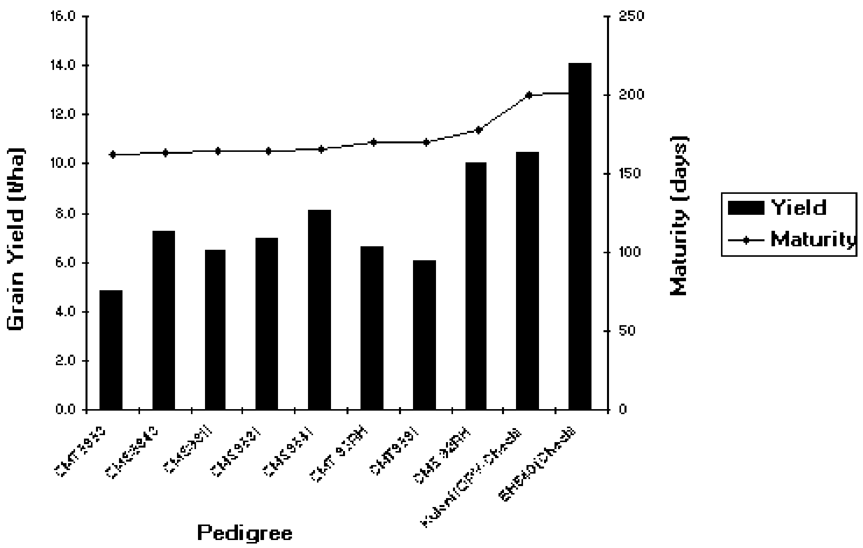
Germplasm Introduction: Results from the highland evaluations showed that farmers in the highlands planted a wide range of unimproved local highland germplasm. The materials were widely diverse in grain yield and other agronomic characteristics (Table 1). The general distinguishing characteristics of the collected germplasm were very tall plant heights (up to 300-400cm) with equally high ear placement up to 200cm (Table 1). Grain characteristics were widely variable in terms of colour and texture. These wide ranging variations indicated that the materials differed markedly from recently released varieties. The diversity of phenotypic expression was an indication that that the materials could be used for a long-term injection of novel maize germplasm into the highland zone.

Variety evaluation: The transitional zone and true highland materials from Mexico were much earlier than any of the currently available highland germplasm in eastern Africa. For example, in Ethiopia, the highland transition zone late hybrids were particularly impressive in respect to earliness (Fig. 2). They were as much as 30 days earlier in maturity than the earliest locally available highland varieties in Ethiopia (Fig. 2). Also, in Ethiopia it was found that while in 1999 the highland late white hybrids were wiped out by *E. turcicum* leaf blight at Ambo (2,225 masl), the same materials looked very impressive, clean, uniform and early. The mean grain yield of the transitional zone materials across

Table 1. Grain yield, height and maturity of local maize landraces and evaluated at four locations in Ethiopia in 1999.

Pedigree	Grain Yield t/ha	Rank	Plant Height cm	Ear Height cm	Maturity days
AW--048	9.39	2	324.3	187.3	203.8
AL-42	8.072	3	328.0	206.0	207.4
BAC-0028	7.606	4	313.8	191.3	192.6
AL-46	7.569	5	288.0	170.3	200.3
AD--05-013-061	7.554	6	319.5	185.8	198.5
AL-43	7.499	8	324.5	208.8	208.3
BAC-0058	7.302	9	312.0	177.0	195.4
AD-03-08-051	7.284	10	298.5	159.0	196.6
AL-16	7.261	11	353.0	202.8	207.5
BAW-002	7.253	12	343.8	207.0	205.6
AD-02-10-012	3.699	285	245.8	113.8	181.1
BAC-0039	3.425	286	232.5	117.0	180.0
AW-005	3.293	287	343.3	233.3	207.1
AW--006	3.265	288	346.3	239.0	205.6
BAC-0055	3.034	289	267.3	121.0	181.3
Checks					
AL-COMP	7.507	7	272.0	138.0	190.4
KULENI	6.999	20	278.5	140.3	198.5
BH-660	10.643	1	304.3	154.5	201.3
MEAN	5.844		312.69	179.22	196.95
LSD (0.05)	1.28		24.32	20.40	6.02
CV%	5.822		7.94	11.58	3.12

Figure 2. Grain yield and maturity of CIMMYT highland transitional zone hybrids evaluated at three sites in Ethiopia in 2000.



Heterotic classification of highland maize germplasm: Performance rating of the various nurseries showed that the transitional zone materials derived from CIMMYT Pool 9A had the good adaptation to the regional highland zone. Topcross hybrids formed by crossing CIMMYT Pool 9A lines to the three regional testers performed significantly better than the testers indicating good levels of heterosis (Tables 2 and 3). They had acceptable levels of tolerance to rust and GLS (Table 2).

A number of Pool 9A lines from CIMMYT-Zimbabwe and CIMMYT-Mexico had high positive GCA effects (Tables 4 and 5) indicating that they could be used to form synthetics for the highland zone. It was noteworthy that these lines had high specific combining ability with Kuleni though basically both the inbred lines and this population originated from the same source materials. Line x tester analysis showed that the three testers were effective in separating the lines into heterotic groups based on their SCA effects (Table 4 and 5). The data were used to group the CIMMYT transitional zone and mid-altitude lines into three distinct heterotic groups based on the Ecuador-Kitale heterotic pattern and on Kuleni (Pool 9A). A number of products adapted to the highland zones of eastern Africa are now available for collaborators (Table 6).

location ranged from 4.8 to 10.0 t/ha compared to 10.4-14.1 t/ha for the local checks (Fig. 2). However, the relative earliness of the exotic materials gave them the advantage to escape frost which frequently occurs late in the season at highland zones above 2,200 masl. The performance of the materials reinforced the need of better targeting of materials for the highland zones in Eastern Africa.

Table 2. Performance of Pool 9A topcrosses evaluated at three sites in Ethiopia, Kenya and Tanzania highlands in 1999.

Pedigree	Grain Yield t/ha	Days to50% Flower	Plant Height cm	Ear Height cm	P. sorgi 1-5	GLS 1-5
[POOL9Ac7-SR(BC2)]FS45-3-2-2 #52/143EC	10.31	100.0	250.7	156.0	1.7	1.5
[ECU573(R12)C6/SNSYNF1[SC/ETO-B-90]]F2-	10.10	102.8	243.5	143.8	2.3	1.8
[POOL9Ac7-SR(BC2)]FS202-1SR-2-1 #160/143EC	9.39	103.2	253.0	143.0	1.8	1.3
[POOL9Ac7-SR(BC2)]FS104-1SR-2-1 #103/143EC	9.27	98.5	211.2	137.2	2.2	1.8
[POOL9Ac7-SR(BC2)]FS67-1-2-1 #75/142KS2	9.25	105.5	246.0	147.5	2.1	1.7
[POOL9Ac7-SR(BC2)]FS59-4-1-2 #62/143EC	9.23	100.7	207.2	147.3	1.8	1.7
[POOL9Ac7-SR(BC2)]FS67-1-2-1 #75/143EC	9.20	102.0	240.2	147.8	1.5	1.2
[POOL9Ac7-SR(BC2)]FS108-1SR-3 #108/143EC	9.08	98.2	237.3	141.8	1.8	1.5
[POOL9Ac7-SR(BC2)]FS112-4-2-3 #112/147P9A	9.05	93.8	213.8	125.7	2.2	1.3
[POOL9Ac7-SR(BC2)]FS59-4-1-2 #62/147P9A	9.04	97.7	231.3	136.7	2.1	1.3
Local Hybrid Checks	9.21	102.2	232.3	143.2	2.1	1.6
Testers:						
Check - 1 Kitale Syn-2 ET	3.35	108.2	230.8	139.3	1.8	2.2
Check - 3 Pool 9A ET (Kuleni)	7.22	99.2	227.3	132.7	2.3	1.9
Check - 2 Ecuador 573 ET	4.92	101.7	227.3	132.5	2.2	1.9
Mean	7.60	100.3	232.6	135.8	2.1	1.7
LSD (0.05)	1.62	3.5	20.0	14.3	0.7	0.5
CV (%)	14.06	0.0	0.1	0.1	0.3	0.3

Table 3. Performance of CIMMYT highland transitional zone topcrosses evaluated at three sites in Ethiopia, Kenya and Rwanda in 1999.

Pedigree	Grain Yield (t/ha)				Days to 50% Flower	Plant Height
	Ambo	Kitale	Gakuta	Across		cm
B.T.Z.T.V.C 64-2 #26/143EC	9.33	10.82	7.95	10.4	115.3	265.2
B.T.Z.T.V.C 171-1-1-1 #13/143EC	9.43	11.15	7.12	10.1	115.8	269.0
B.T.Z.T.V.C 64-2 #26/147P9A	9.17	10.69	11.15	10.0	115.7	254.0
B.T.Z.T.V.C 176-1-2-3 #16/147P9A	10.12	9.57	7.49	10.0	109.8	231.5
B.T.Z.T.V.C 286-1-1-1 #23/143EC	8.13	11.38	6.72	9.9	116.5	272.7
B.T.Z.T.V.C 134-B-1-1 #8/143EC	9.45	10.11	9.33	9.7	130.2	246.8
B.T.Z.T.V.C 65-1 #27/143EC	9.46	11.02	10.69	9.5	118.3	268.2
B.T.Z.T.V.C 286-1-1-1 #23/142 KS2	9.51	10.02	10.11	9.3	115.3	264.2
B.T.Z.T.V.C 266-B-1-1 #18/147P9A	8.61	9.33	8.89	8.9	112.7	247.0
B.T.Z.T.V.C 65-1 #27/147P9A	9.69	9.55	8.52	8.9	115.2	253.7
B.T.Z.T.V.C 97-B-3-1 #4/143EC	6.74	10.24	6.26	8.8	116.7	261.5
Testers:						
KITALE SYN2 ET	5.54	2.85	8.52	4.8	119.7	252.8
EC573 ET	7.92	5.11	11.15	6.8	111.2	228.8
POOL 9A ET KUL	7.37	7.40	11.38	7.72	112.0	251.5
MEAN	8.13	8.40	8.40	8.1	114.9	251.6
LSD	2.09	3.67	3.67	2.0	8.2	17.4
CV(%)	11.92	21.51	21.51	21.4	6.3	6.1

Table 4. GCA and SCA effects of the 10 top-yielding Pool 9A S3 lines crossed to three testers and evaluated in three eastern Africa countries in 1999.

Pedigree	Grain Yield Across Testers t/ha				GCA t/ha	SCA of Line x Tester t/ha		
	Kitale Syn. II	Ecuador 573	Kuleni	Mean		Kitale Syn. II	Ecuador 573	Kuleni
[POOL9Ac7-SR(BC2)]FS67-1-2-1 #75	9.25	9.20	8.20	8.88	1.23	0.70	-0.25	-0.45
[POOL9Ac7-SR(BC2)]FS59-4-1-2 #62	7.50	9.23	9.04	8.59	0.93	-0.76	0.07	0.68
[POOL9Ac7-SR(BC2)]FS108-1SR-3 #108	8.13	9.08	8.47	8.56	0.90	-0.09	-0.05	0.14
[POOL9Ac7-SR(BC2)]FS112-4-2-3 #112	8.44	8.14	9.05	8.54	0.88	0.24	-0.97	0.74
[POOL9Ac7-SR(BC2)]FS202-1SR-2-1 #160	8.10	9.39	7.81	8.43	0.78	0.01	0.38	-0.39
[ECU573(R12)C6/SNSYNF1[SC/ETO-B-90]]F2-132/129-8-1 #261	6.34	10.10	8.64	8.36	0.70	-1.69	1.17	0.52
[ECU573(R12)C6/SNSYNF1[SC/ETO-B-90]]F2-132/114-8-3 #256	7.70	8.75	8.50	8.32	0.66	-0.28	-0.14	0.42
[POOL9Ac7-SR(BC2)]FS85-3SR-2-1 #91	7.86	8.80	7.91	8.19	0.53	0.00	0.04	-0.04
[POOL9Ac7-SR(BC2)]FS48-1-1-1 #176	7.72	7.96	8.39	8.03	0.37	0.03	-0.63	0.60
[POOL9Ac7-SR(BC2)]FS123-1-1-1 #114	7.62	8.18	8.12	7.97	0.31	-0.02	-0.36	0.38
Mean	7.32	8.23	7.43	7.66				
GCA (Testers)	-0.34	0.57	-0.23					
SE		0.26			-0.55		0.58	

Table 5. GCA and SCA effects of the top-yielding CIMMYT transitional zone S3 lines crossed to three testers and evaluated in three eastern Africa countries in 1999.

Pedigree	Grain Yield Across Testers t/ha				SCA of Line x Tester t/ha			
	Kitale Syn. II	Ecuador 573	Kuleni	Mean	GCA	Kitale Syn. II	Ecuador 573	Kuleni
B.T.Z.T.V.C 64-2 #26	7.83	10.57	9.85	9.42	1.13	-1.13	0.46	0.67
B.T.Z.T.V.C 171-1-1-1 #13	8.50	10.03	8.76	9.10	0.81	-0.15	0.24	-0.10
B.T.Z.T.V.C 286-1-1-1 #23	9.50	9.92	7.62	9.02	0.73	0.94	0.22	-1.15
B.T.Z.T.V.C 176-1-2-3 #16	7.83	8.50	9.88	8.74	0.45	-0.46	-0.93	1.38
B.T.Z.T.V.C 347-1-2 #24	8.55	8.99	8.01	8.52	0.23	0.48	-0.22	-0.27
B.T.Z.T.V.C 134-B-1-1 #8	8.24	9.71	7.17	8.37	0.09	0.32	0.64	-0.96
B.T.Z.T.V.C 270-B-2-2 #21	8.65	8.61	7.81	8.35	0.07	0.75	-0.44	-0.31
B.T.Z.T.V.C 266-B-1-1 #18	8.14	7.93	8.94	8.34	0.05	0.26	-1.10	0.84
B.T.Z.T.V.C 65-1 #27	5.95	10.09	8.83	8.29	0.00	-1.89	1.10	0.78
Mean	7.84	8.98	8.05	8.29				
GCA (Testers)	-0.45	0.69	-0.24					
SE		0.24					0.53	

Table 6. Grain yield and maturity of CIMMYT highland transitional maize hybrid at three sites in Ethiopia in 2000.

Pedigree	Code Pedigree	Grain Yield (t/ha)				Maturity (days)			
		Ambo	Holeta	Kulumsa	Across Yield	Ambo	Holeta	Kulumsa	Across Maturity
CMT99901693	CMT9993	2.9	7.6	4.3	4.8	161	192	136	163
CMS989243	CMS9843	5.5	10.2	6.0	7.2	166	196	129	164
CMS989211	CMS9811	3.0	11.9	5.2	6.5	164	198	132	165
CMS989031	CMS9831	3.1	12.0	6.3	6.9	164	193	139	165
CMS989241	CMS9841	4.0	12.5	7.3	8.1	165	200	134	165
CMT 939011(RH)	CMT 93RH	3.4	11.1	5.8	6.6	170	200	142	170
CMT99901691	CMT9991	3.8	9.7	5.0	6.0	174	198	139	170
CMS 929001(RH)	CMS 92RH	6.3	15.1	7.9	10.0	173	209	149	178
Kuleni	Kuleni (OPV-Check)	8.8	13.6	9.1	10.4	203	233	164	200
BH540	BH540 (Check)	10.5	21.6	9.8	14.1	217	233	158	202
MEAN		4.7	11.8	6.4	7.6	174.3	202.8	140.0	172.4
LSD (0.05)		1.4	2.2	1.4	1.0	12.3	6.0	13.7	6.3
CV (%)		16.1	11.1	12.8	14.1	3.9	1.6	5.9	3.9

CONCLUSION

Maize local germplasm collected from farmers in the highland zones in eastern Africa as well as elite highland maize materials obtained from NARS and CIMMYT were effective means of mobilizing novel maize germplasm for infusion into the eastern Africa highlands. Germplasm prescreening at a regional nursery at Ambo, Ethiopia followed by topcrossing and line x tester analysis were also effective in generating inbred lines classified into heterotic groups. Several highland maize germplasm products including inbred lines classified into heterotic groups, hybrids and local landraces were made available for use in the eastern Africa highland zones.

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FARMING COMPONENTS RESPONSIBLE FOR GRAY LEAF SPOT DISEASE SEVERITY IN DISTRICTS OF CONTRASTING INCIDENCE.

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ABSTRACT

Gray leaf spot is a disease of economic importance in many maize growing countries including Uganda. During a countrywide survey conducted in Uganda in 1997, several factors which predispose maize crops to the disease were found being practised by farmers. The study was carried out to ascertain the role of farmers' practices in causing GLS disease. Three factors; leaving stover on the soil surface, variety and continuous cropping of maize were noted to play a significant role in perpetuating the disease. In Mubende, a district of high incidence, leaving stover on the soil surface was practised by 40% of the collaborating farmers and the associated maize crop had average severity of 3.1 during the 2000B season; and 35% of farmers with average severity of 2.7 in the 2001A season. In Tororo, it was practised by 40% and 45% of the collaborating farmers with average severity of 2.3 and 2.8 in the 2000B and 2001A seasons, respectively. The type of variety, particularly hybrid 624 was highly associated with high incidence and severity of 69.6% and 2.8 respectively, in Tororo. On the other hand, in Mubende district it was cropping history (monocropping) and crop management (leaving stover on the soil surface), which were associated with high incidence and severity.

INTRODUCTION

Gray leaf spot (GLS) caused by Cercospora zeae-maydis is a fungal foliar disease causing severe yield losses (Stromberg, 1986). When maize is planted into no-till fields with infested maize residues remaining on the soil surface and environmental conditions are favorable for GLS development, epidemics usually progress faster and reach more damaging levels than in fields where infested residues are either absent or greatly reduced (de Nazareno et al., 1992; Ward et al., 1998). The history of gray leaf spot in Uganda is not well known but the first epidemic was recorded in 1994 (Bigirwa et al., 1999). For the following three years, the disease levels were high and this was followed by some decline. Ward et al (1999) reported that GLS severity is unpredictable and may vary from year to year or field to field. Tillage operations aimed at reducing the amount of initial inoculum from the previous season's crop residue have been recommended as a means of managing GLS (Huff et al., 1989; de Nazareno et al., 1993; Freppon et al., 1996). During a GLS countrywide survey conducted in Uganda (Bigirwa et al., 2000), several farming practices were observed. It is not known how these diverse cropping systems and planting patterns influence epidemics of gray leaf spot. These include, continuous cropping of maize in the same field, planting of maize in a field where stover is left on the soil surface, intercropping of maize in either banana or coffee plantations which are mulched with maize stover, and piling of stover in several heaps in a newly established maize field. The objective of the study was to investigate the farming components responsible for the development of GLS epidemics. These aspects need to be studied to provide a basis for effective and affordable management options.

MATERIALS AND METHODS

The study to identify the farming components responsible for high disease incidence was carried out on farmers' fields in 2 districts, one with high and the other with low GLS disease incidence as reflected in a previous survey. Mubende was the district with high incidence and a total of 20 farmers were selected; 10 in Sekanyonyi sub-county and 10 in Busimbi. Twenty farmers were also selected in Tororo district, 10 from Osukuru sub-county and 10 from East Municipality. Data collection was made on incidence and severity from 40 plants; 10 from four different positions in the field. Severity was scored using a 1-5 scale where, 1 = no or very few lesions and 5 = very many lesions and leaves severely blighted. Additional information was recorded on cropping history, variety being grown, companion crop, management practices and weather data.

RESULTS

Various farming components were observed; leaving stover on the soil surface, continuous maize cropping, recycling of seed, monocropping and mulching banana and coffee with stover. The latter was only found in Mubende district. During the second season of 2000, the system was found being practised by 20% and 30% in the first season of 2001. The associated incidence and severity was 51.6% and 2.2 respectively in the season of 2001 (Tables 1 and 2). Leaving stover in the field was practised by 35% farmers in Mubende with a severity score of 3.1 while in Tororo, 40% practised it and the associated severity was 2.7. In the 2001 cropping season, 40% of the farmers in Mubende practised it and the associated disease incidence and severity were 73.8 and 3.1 respectively. In Tororo it was carried out by 55% farmers and disease incidence was 43% with average severity of 2.4.

Cropping history revealed three main cropping systems; continuous cropping of maize, previous crop being a non-cereal, and leaving land under fallow. Of these three, continuous cropping was most common and associated with a lot of disease. For instance in Mubende during 2000 cropping season, the practice was carried out by a percentage of 40

Table 1. Number of farmers carrying out various practices and the associated gray leaf spot disease severity during the second season of 2000.

Cropping component	District					
	Mubende			Tororo		
	Percentage of farmers	Severity (1-5 scale)	Yield (kg/ha)	Percentage of farmers	Severity (1-5 scale)	Yield (kg/ha)
Companion crop						
Sole maize	35	2.5	5340	40	2.0	4617
Legume	20	1.4	4440	15	1.4	3380
Banana	15	1.7	2163	0	0.0	0
Cassava	5	1.6	4765	25	1.6	3892
Coffee	15	2.1	1404	0	0.0	0
Others	10	1.4	3450	20	1.3	4889
Crop management						
Mulch	20	2.7	4913	0	0.0	0
Old maize crop nearby (source)	45	1.6	4349	40	1.9	5851
Stover left in the field	35	3.1	3133	40	2.7	4212
Cropping history						
Previous crop maize	40	2.2	4923	40	2.0	4318
Previous crop non-cereal	35	1.7	5012	50	1.6	4415
Fallow	25	1.3	5314	10	1.3	3855
Variety						
Longe 1	45	1.8	4785	25	1.2	4440
Longe 2H	20	2.3	4275	10	1.4	4089
Kenya hybrid	0	0.0	0	30	3.1	3949
Local	15	2.1	3262	15	1.7	2496
Recycled Longe 1	20	2.3	4514	20	1.8	3923
Mean		2.1	3845		1.4	3400
SE		0.2	382		0.2	457
Minimum		0.0	0		0.0	0
Maximum		3.1	5340		3.1	5851

Table 2. Number of farmers carrying out various practices and the associated gray leaf spot disease severity during the second season of 2001.

Cropping component	District							
	Mubende				Tororo			
Companion crop	Percentage of farmers	Incidence (%)	Severity (1-5 scale)	Yield (kg/ha)	Percentage of farmers	Incidence (%)	Severity (1-5 scale)	Yield (kg/ha)
Sole maize	15	56.8	3.0	3065	35	43.3	2.2	4380
Legume	10	24.3	1.9	2837	25	46.6	1.6	4183
Banana	15	51.6	2.2	4111	5	24.0	1.2	3410
Cassava	20	45.5	2.3	3635	25	60.0	2.4	4005
Coffee	15	65.0	2.3	3635	-	-	-	-
Others	20	51.7	2.7	4112	10	74.6	2.2	4509
Crop management								
Mulch	30	51.6	2.3	2653	-	-	-	-
Old maize crop nearby	30	22.5	1.4	3008	45	58.8	2.3	3702
Stover left in the field	40	73.8	3.1	4361	55	43.0	2.4	4954
Cropping history								
Previous crop maize	40	71.8	3.1	4223	40	56.4	2.3	4291
Previous crop non-cereal	40	42.1	2.0	3747	35	42.0	1.6	3895
Fallow	20	30.8	1.6	3750	25	50.0	1.9	3010
Variety								
Longe 1	30	48.8	2.1	4287	35	32.5	1.9	3786
Longe 2H	20	74.3	2.8	6455	20	38.7	2.4	4200
Kenya hybrid	-	-	-	-	20	69.6	2.8	4093
Local	15	31.4	2.3	2416	20	41.8	2.1	2580
Recycled Longe 1	35	69.0	2.9	3447	5	20.0	1.3	2451
Mean		50.7	2.5	3734		46.8	2.2	3837
SE		5.0	0.9	341		4.1	0.6	298
Maximum		74.0	3.8	6455		69.6	74.6	4954

farmers with a severity of 2.2; while in Tororo the percentage of farmers was 40 and severity 2.0. During the 2001 season, in Mubende the percentage of farmers continuously growing maize in the same field was 40 with the associated incidence of 71.8% and severity of 3.1. In Tororo, incidence was 40%, incidence 56.4% and severity 2.3 (Tables 1 and 2). Companion crops did not have an effect on the disease, however severity was slightly higher in sole cropped maize as opposed to when it was intercropped.

The type of variety grown by the farmer was also noted to be important and responsible for the development and severity of the disease. Five categories of varieties were identified; improved open pollinated variety (Longe 1), recycled Longe 1, local, Longe 2H (hybrid) and Kenya hybrids (H614 and H511). In Tororo, fields grown to H614 and H511 tended to have higher severities; 3.1 in the 2000 season and 2.8 in 2001. This was followed by recycled Longe 1. In Mubende district, it was recycled Longe 1 and Longe 2H with high incidence and severity of 74.3% and 2.8 respectively (Table 2).

DISCUSSION

The most damaging gray leaf spot epidemics have been reported in fields where tillage practices permit the pathogen to become endemic (Perkins *et al*., 1995). When maize is planted into no-till fields with infested maize residues remaining on the soil surface and environmental conditions are favorable for GLS development, epidemics usually progress faster and reach more damaging levels than in the fields where infested residues are either absent or greatly reduced (Payne and Waldron, 1983; Stromberg, 1986; de Nazareno *et al*., 1992; 1993; Ward *et al*., 1996). De Nazareno *et al* (1993) found a significant positive association between the amount of residue on the soil surface and disease severity. Thus, tillage operations aimed at reducing the amount of initial inoculum from the previous season's crop residue have been recommended as a means of managing GLS (Huff *et al*., 1988; Lipps *et al*., 1998). In USA, stover is left in the field because of the no-till method but in the case of Uganda, it is a result of the method of land clearing. Occasionally land preparation is made hurriedly to put the next crop in the field or stover is deliberately put in heaps which are collected piecemeal for either fuel or construction. In Tororo such stover is at times fed to livestock. The longer it remains in the field, the more the crop is exposed to the inoculum.

There is considerable evidence to suggest that continuous maize cropping or maize following maize in a rotational system significantly increase the incidence and severity of gray leaf spot. This is because the absolute rate of disease development increases as the amount of infested residue increases (Ward *et al*., 1977; Payne et al., 1987; de Nazareno *et al*., 1993). In Uganda there are several reasons why farmers crop maize continuously; easiness to prepare land as most seasons are back to back and shortage of land, among others.

Variation in response of maize varieties to *Cercospora zeae-maydis* is normally attributed to the background of the host material under test, those with susceptible background succumb. This has resulted in the loss of various materials. Susceptibility is expressed in terms of incidence, severity and lesion type (Pratt *et al*., 2000). From this study it is observed that hybrids like H 624 and H 511 registered high levels of GLS disease which in a way corroborates with earlier findings by Bigirwa *et al*. (1999), who observed that most hybrids from the Kenya Seed Company tended to succumb.

In conclusion, this particular study has shown that GLS epidemics are to a great extent due to various farming components; leaving previous season's stover on the soil surface, type of maize variety, continuous maize cropping and planting of maize in coffee or banana plantations mulched with infected stover. In developing management options these are some of the factors to consider.

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MAIZE SCREENING FOR MULTIPLE STRESS TOLERANCE AND AGRONOMIC TRAITS.

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ABSTRACT

Maize is the principal crop and staple food in Mozambique. The most important constraints to maize production in the country are drought, soil infertility, diseases and pests. Therefore, the main attention in the breeding program is given to the selection for tolerance/resistance to maize streak virus, downy mildew, borers, drought and soil infertility. Among the agronomic traits, attention is given to quality protein maize (QPM), grain texture and earliness. In order to achieve the goal, selected populations or lines with alleles conferring the desirable traits were used. To create stress conditions for strong selection pressure on selected traits, combinations of different procedures were implemented. The breeding method of reciprocal recurrent selection was applied. The same methods were used for normal maize and QPM. Data obtained revealed that remarkable improvement for the traits under selection was achieved. The greatest progress was obtained in selection for streak resistance, flintiness and earliness. In the case of drought stress, statistical analyses revealed significant negative correlations between yield and the anthesis-silking interval, and between yield and days to silk, but a positive correlation between yield and grain weight per ear.

INTRODUCTION

Maize is grown in all agro-ecological zones and is the principal crop and major staple food in many zones of Mozambique. There are 2.5 million agricultural family units, of which 1.9 million (78%) grow maize, with an average maize area of 0.7 to 0.9 hectares (MINAG, 1994). Maize production by the family sector occupied 39% of total arable land, or an area of 1.74 million hectares. It is estimated that the family sector occupies about 95% of the total maize area and produces 90% of the national maize crop. Grain yield of maize grown on peasants' farms has been about 0.6 t/ha (FAO, 1995), whereas in the 1995 season it ranged from 0.2 to 1.2 t/ha (DINA, 1995). Agriculture in Mozambique, as in many other Sub-Saharan African countries, is primarily small-scale, subsistence-level, and labor-intensive. It is characterized by low use of external inputs, low to medium productivity, high diversity of products, and by a strategy of minimizing risks (Kieft, 1993).

THE PROBLEM

The main constraints in maize production were identified (Nunes et al., 1985). Thus, among the agro-ecological conditions in southern Mozambique, the main constraints are: a) lack of rainfall; b) diseases – maize streak virus (MSV) and downy mildew (DM); and c) pests – borers and storage pests. In the central and northern parts of the country, the main constraints are: a) low soil fertility; b) periodic droughts in lowland areas; c) diseases – stem/ear rots, leaf blights and rusts at higher altitudes, maize streak virus (MSV) and downy mildew (DM) in Manica and Sofala provinces; and d) storage pests. Among the other production constraints are the serious shortage of trained manpower, insufficient management expertise and poor cultivation practices, such as inadequate intercropping, poor soil preparation, poor irrigation techniques, poor weeding and poor planting practices.

Agricultural productivity is often hampered by poor infrastructure, which limits access to inputs and markets. Much of the existing and available maize germplasm is adapted to higher elevation and higher productivity environments, that are about 15 to 20 % of the total arable land in Mozambique (Denic, 1994). Similarly, existing maize production (crop management) technologies do not address the specific needs of the resource-poor family sector.

OBJECTIVES

Based on the constraints to maize production, the main objective in this work is to develop, evaluate and select maize genotypes resistant or tolerant to the principal biotic and abiotic factors which are limiting production in the principal maize-growing areas. Thus, among biotic factors, attention is given to the selection for resistance to MSV (SR) and downy mildew (DMR), *Peronosclerospora sorghi.* In the case of abiotic factors, attention is given to the selection to tolerance to drought (DT). In addition to this factor, a large part of the work is oriented to selection for the agronomic traits earliness (E) and for a hard type of grain texture (GT). Due to the fact that maize is the staple food, attention is also given to the creation of varieties with high nutritional value in terms of protein quality (QPM), with flinty grain and resistant to the principal diseases.

MATERIALS AND METHODS

The work was done at the Experimental Research Station in Umbeluzi (30 km from Maputo). Breeding populations of normal (common) maize were created by crossing lowland tropical populations without DMR from the International Maize and Wheat Improvement Center (CIMMYT), Mexico with DMR-SR commercial varieties Matuba or SEMOC 1, both originating from the DMR-E-SR-W population of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The group of entries with existing DMR background consisted of 11 DMR populations from IITA, 11 inbred lines extracted from Population 8072 DMR or from Population 8075 DMR, and 11 S3 DMR-SR lines from CIMMYT, Harare. This material at the season of evaluation was in C8 of selection for SR, earliness (E) and flintiness (F), and in C5 of selection for DMR.

In the case of QPM the donors of the *opaque-2* gene were Ghanaian line entry 5 (E-5Q) or SEMOC S4 lines extracted from Pool 15 QPM (BC4) SR (SMLQ). Donors for DMR-SR were SEMOC S4 lines extracted from Matuba (MTL) or SEMOC inbred lines (SML) extracted from Population 8072DMR or Population 8075DMR . QPM material was in C3 of selection for SR and endosperm modification and in C1 of selection for DMR).

All materials were subjected to heavy disease infection in nurseries of DM and MSV. For evaluation of a large number of breeding materials, the method of spreader rows was recommended (Williams, 1984). To facilitate strong disease infection and increase the number of entries for evaluation, the method of spreader rows (Cardwell, 1994) was modified and combined with late and continuous planting (Denic, 1996).
Double plant density in the nurseries was maintained for 5 weeks after germination and then plants with DM were rogued out. The numbers of diseased and healthy plants were recorded and % of plants with systemic DM disease was calculated. Evaluation of SR of QPM entries was done by CIMMYT, Harare, using artificial infestation with MSV vector from genus *Cicada*.

During anthesis, the early-flowering plants from selected progenies with good aspect, DMR and SR were either self-pollinated or crossed by hand pollination. At harvest , ears with good aspect were selected. Preference in selection was given to the ears from early-flowering plants and to flint and semi-flint type of grain. In the case of QPM, kernels with good endosperm modification were selected using light tables.

RESULTS AND DISCUSSION

Screening for multiple stress tolerance and agronomic traits in normal maize

Data from three groups of entries of normal maize, after C8 of selection for SR and C5 of selection for DMR, show similar mean values of indices of SR and % of plants with DM symptoms (Table 1). In the case of earliness and grain texture, Group 2 (with selection for DMR initiated in C1) and Group 3 (with selection for DMR initiated in C3), exhibited earlier flowering and harder grain texture in comparison to the Group 1 (entries with existing DMR background). In the case of DMR, however the same two groups showed somewhat higher means and very high variation of % of plants with DM in comparison with Group 1. It should be pointed out that, in C1 of selection for DMR, means of % of plants with DM were 33.3 for Group 1, 53.5 for Group 2 and 75.6 for Group 3 (unpublished data). The difference in DMR between Group 2 and Group 3 illustrates the importance of immediate selection after recombination.

Data across the groups of populations are shown in Table 2. By analyzing mean values of the traits, it is possible to see that on average there is good SR, DMR and semi-flint grain texture. Further analyses of number and frequency distribution of FS families related to the studied traits under disease pressure show that 939 progenies (24.1 % of total) and 1,242 progenies (37.8 % of total) exhibited strong SR and DMR, respectively. The same data show that 447 progenies (14.6 %) belong to the group of very early maturity and 760 progenies (24.9 %) belong to the group of early maturity. The greatest progress was achieved in the case of grain texture. It was found that 35.8 % (1,130 FS families) and 39.8 % (1,258 FS families) exhibited flint and semi-flint grain texture, respectively.

From this material, 720 DMRSR progenies were selected, planted in the cold season (off-season) and were subjected to intermediate drought stress. Data obtained in C2 of selection for drought tolerance are presented in Table 3. The average yield of the trial was 3.0 tones per hectare, and represents about 40 % of yield of checks grown under good irrigation. The yield of the highest yielders was 54 % higher than average trial yield, and 82 progenies (11.4 % out of 720) gave yields over 4 tons per hectare. There are no differences in days to pollen shed and days to silking between trial means and the means of the best yielders. This finding excludes the possibility that top yielders are performing better due to the longer vegetative period. Significant negative correlation and regression was found between yield and days to silking. Significant negative correlation and regression was also found between yield and anthesis-silking interval (ASI) and a positive correlation and regression between yield and grain weight per ear. One hundred and seventeen progenies (16.3 %) exhibited negative ASI and 144 progenies (20 %) gave over 100 g of grain per ear.

Screening for disease resistance and endosperm modification in QPM

Breeding work on QPM in Mozambique was initiated in 1998. Three cycles of selection for SR, grain texture and endosperm modification, and one cycle of selection for DMR were completed. Data on SR were recorded on 419 S1 and S2 lines from four populations created by the program and variety Sussuma, which originated from a commercial SR variety Obatampa (Table 4). Mean values of indices of SR of three experimental populations, with incorporated genes

Table 1. Indices of streak resistance (SR), % of plants with downy mildew (DM), days to pollen shed and indices of grain type of FS.

Agronomic trait	Selection cycle	Group 1:With DMR background				Group 2: DMR selection intd. in C1				Group 3: DMR selection intd. in C3			
		Mean	S.D.	C.V.%	Total No	Mean	S.D.	C.V.%	Total No	Mean	S.D.	C.V.%	Total No
Indices of SR*	8	1.76	0.48	27.3	556	1.92	0.41	21.5	2,205	1.74	0.26	14.7	904
Plants with DM - %	5	29.3	6.32	21.6	798	33.1	16.9	51.1	1,667	38.2	23.8	62.3	821
Days to pollen shed	8	59.8	2.03	3.4	504	53.7	1.72	3.2	1,690	53.8	1.67	3.1	704
Indices of grain type**	8	2.37	0.58	24.5	680	1.76	0.49	27.7	1,751	1.93	0.33	17.1	726

*Indices of SR 1 to 5; 1 being strong, 5 being very susceptible.
** Indices of grain type 1 to 5; 1 being flint, 5 being dent.

Table 2. Summary of data on indices of streak resistance (SR), % of plants with downy mildew (DM), days to pollen shed and indices of grain type (GT) of FS families of 3 groups of populations of normal maize.

Trait	Cycle	Mean	S.D.	C.V. %	Number of fmls.	Number (No) and frequency distribution (%) of FS families									
						No	%	No	%	No	%	No	%	No	%
Indices of SR*						**0 - 1.4**		**1.5 - 2.4**		**2.5 - 3.4**		**3.5 - 4.4**		**4.5 - 5.0**	
	8	1.85	0.39	21.2	3,903	939	24.1	2,424	62.1	515	13.2	25	0.6	0	0
Plantswith DM-%						**0 - 20**		**21 - 40**		**41 - 60**		**61 - 80**		**81 - 100**	
	5	33.5	15.1	45	3,286	1,242	37.8	983	29.9	647	19.7	335	10.2	79	2.4
Days to pollen						**<50**		**51 - 53**		**54 - 56**		**57 - 59**		**60 - 65**	
	8	54.8	1.75	3.2	3,052	447	14.6	760	24.9	933	30.6	588	19.3	324	10.6
Indices of GT**						**1.0 - 1.4**		**1.5 - 2.4**		**2.5 - 3.4**		**3.5 - 4.4**		**4.5 - 5.0**	
	8	1.93	0.45	23.1	3,157	1,130	35.8	1,258	39.8	649	20.6	103	3.3	17	0.5

*Indices of SR 1 to 5; 1 being strong, 5 being very susceptible.
** Indices of grain type 1 to 5; 1 being fkint, 5 being dent.

Table 3. Data on yield and some secondary traits on 720 selected DMRSR FS families subjected to intermediate drought stress in C2.

Trait	Trial mean	Mean of 3 best yielders	Best yielders Trial mean	Correl. coeff.	Regress. coeff.	Prob.	Number (No) and frequency distribution (%) of FS families									
							No	%	No	%	No	%	No	%	No	%
Yield ($t\ ha^{-1}$)							**<2.0**		**2.0 - 2.9**		**3.0 - 3.9**		**> 4.0**			
	3.0	4.61	1.54	-	-	-	92	12.8	238	33.1	308	42.8	82	11.4	-	-
Days to pollen							**<78**		**78 - 80**		**80.1 - 82**		**82.1 - 84**		**>84**	
	81.3	80.9	0.95	-0.381	-0.079	0.097	80	11.1	149	20.7	247	34.4	156	21.7	87	12.1
Days to silking							**<78**		**78 - 80**		**80.1 - 82.0**		**82.1 - 84**		**>84**	
	83.4	82.5	0.99	-0.562	-0.098	0.009	35	4.9	66	9.2	156	21.8	200	27.9	260	36.2
Anth-Slk Interval							**< - 1.0**		**1.0 - 2.0**		**2.1 - 3.0**		**3.1 - 4.0**		**> 4.0**	
	2.1	1.55	0.74	-0.779	-0.469	<0.001	117	16.3	303	42.1	152	21.1	75	10.4	72	10
Ear per plant							**<0.80**		**0.80 - 0.89**		**0.90 - 0.99**		**1.00 - 1.19**		**>1.20**	
	0.9	1.01	1.12	0.357	0.441	0.133	142	20.7	162	23.6	209	30.5	159	23.2	13	1.9
Grain per ear (g)							**<70**		**70 - 80**		**81 - 90**		**91 - 100**		**>100**	
	85.2	109	1.28	0.883	0.033	<0.001	163	22.6	115	16	159	22.1	139	19.3	144	20
Grain moisture (%)							**<16.0**		**16.0 - 17.0**		**17.1 - 18.0**		**18.1 - 19.0**		**>19.0**	
	17.8	18.3	1.03	241	0.102	0.305	86	11.9	180	25	161	22.4	126	17.5	167	23.2

conferring SR and DMR, indicate better SR than the commercial variety. The number and frequency distribution of lines from the same populations with strong SR clearly demonstrate better SR than the commercial variety.

Data on % of plants with DM, though still high with mean of 63.9 %, illustrate some DMR in comparison with susceptible checks, which are reaching 95 to 100 % of diseased plants (data not shown). Big differences between SR and DMR of the same materials are largely due to the difference in number of cycles of selection for SR (C3) and for DMR (C1). Perhaps, a part of the difference might be ascribed also to the difference in number of genes conferring resistance to these two diseases. It is believed that DMR is controlled by at least two major genes.

These data are part of the extensive programme on screening for disease resistance and endosperm modification in QPM, which in C1 of selection for DMR included 38 experimental populations with 933 progenies (Table 5). Here again, on average, a relatively high % of plants with DM was recorded (64.5 %). Different types of progenies showed some kind of distinctive classes of DMR with class intervals of 10 %. Larger class interval of 20 % is between FS families and BC families. The higher DM susceptibility of BC families can be ascribed to the influence of backcrossing with the susceptible QPM pollen parent.

Analyses on number and frequency distribution of progenies related to DMR show that, across all groups of progenies, 11.7 % of progenies (109 progenies) exhibited strong DMR (Table 5). Lower means of % of diseased plants of progeny groups (S1 and S2 lines) were followed by higher frequency distribution of DMR progenies, and *vice versa*, higher means of progeny groups (BC and FS families) were followed by absence (BC families) or low frequency distribution of DMR progenies (FS families).

The same data consistently show larger variation in DMR within populations (*i.e.* between the progenies within the same populations), than between the populations. Similar results were obtained also with normal maize (data not shown). This variation makes selection for disease resistance more efficient.

Table 4. Mean, number (No) and frequency distribution (%) of selected QPM population related to resistance to MSV (C3) and downy mildew (C1).

Entry No.	Population	Stage	Mean score	No of lines	Number (No) and frequency distribution (%) of lines									
					No	%	No	%	No	%	No	%	No	%
	Indices of maize streak virus				**0 - 1.4**		**1.5 - 2.4**		**2.5 - 3.4**		**3.5 - 4.4**		**4.5 - 5.0**	
1	Matuba lines/LSMQ lines	S2 lines	2.7	79	24	30.4	38	48.1	8	9.9	7	8.9	2	2.5
2	Matuba lines/Entry 5Q	S2 lines	2.3	78	18	23.1	40	51.3	14	17.9	4	5.1	2	2.6
3	SML/LSMQ x MTL/LSMQ	S1 lines	2.3	9	2	22.2	4	44.4	3	33.3	0	0	0	0
4	LSMQ/Pl 15 EWFQ	S1 lines	3.5	68	3	4.4	11	16.2	26	38.2	18	26.5	10	14.7
5	Sussuma (Obatanpa)	S1 lines	3.2	185	0	0	57	30.8	81	43.8	42	22.7	5	2.7
	Mean or total	S1 & S2	2.8	419	47	11.2	150	35.8	132	31.5	71	16.9	19	4.5
	Plant % with downy mildew				**0 -20**		**21 - 40**		**41 - 60**		**61 - 80**		**81 - 100**	
1	Matuba lines/LSMQ lines	S2 lines	72.5	74	7	9.5	6	8.1	15	20.3	12	16.2	34	45.9
2	Matuba lines/Entry 5Q	S2 lines	63.3	72	6	8.3	10	13.9	19	26.4	14	19.4	23	31.9
3	SML/LSMQ x MTL/LSMQ	S1 lines	56.0	9	0	0	2	22.2	2	22.2	5	55.6	0	0
	Mean or total	S1 & S2	63.9	155	13	8.4	18	11.6	36	23.2	31	20	57	36.8

Table 5. Means of % of plants with DM, variation, number (No) and frequency distribution (%) of progenies related to DMR of QPM in C1 of selection for DMR.

Group of plant progenies	Group mean of plants with DM (%)	Std. dev.		Coef. of var. (%)		Total no. of progeny	Number (No) and frequency (%) of progenies related to DMR									
		Betw. Pops.	Within pops.	Betw. Pops.	Within pops.		No	%	No	%	No	%	No	%	No	%
							0 - 20		**21 - 40**		**41 - 60**		**61 - 80**		**81 - 100**	
FS families	70.5	18.5	21.1	26.2	32.7	205	14	6.8	9	4.4	32	15.6	48	23.4	102	49.8
BC families	89.4	6.7	7.8	7.5	8.9	102	0	0	0	0	2	2.0	13	12.7	87	85.3
S1 lines	50.8	3.9	26.3	7.7	51.6	284	40	14.1	71	25.0	59	20.8	60	21.1	54	19.0
S2 lines	61.8	16.1	28.8	26.1	50.5	342	55	16.1	56	16.4	61	17.8	48	14.0	122	35.7
Across all	64.5	10.6	21.2	16.5	37.8	933	109	11.7	136	14.6	154	16.5	169	18.1	365	39.1

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained in this work, the following conclusions can be drawn:

1. Using adapted lowland tropical germplasm with DMR and SR background, disease resistance of susceptible populations can be improved, both in normal maize and QPM.
2. The method of spreader rows, combined with late and continuous planting, is suitable for the screening of large numbers of entries, with the possibility to include more stress factors.
3. Large variation of DMR, SR, grain texture and earliness was found. Satisfactory fractions of progenies with improved traits under selection were found.
4. Early selection for DMR under disease pressure is recommended after introgression.
5. FS recurrent selection, combined with S1 and phenotypic selection, is suitable for participatory maize breeding, *i.e.* early testing of breeding material involving small-scale farmers.

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RESPONSE OF COMMERCIAL VARIETIES AND OTHER GENOTYPES OF MAIZE FOR RESISTANCE TO THE MAIZE WEEVIL (*SITOPHILUS ZEAMAIS* MOTSCH.) (COLEOPTERA: CURCULIONIDAE)

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ABSTRACT

Commercial varieties and various maize genotypes including hybrids, composites and lines at different breeding stages obtained from CIMMYT and local sources (Bako and Melkassa Agricultural Research Centres) were evaluated for resistance to *Sitophilus* weevils in no choice tests in the laboratory at the Bako Agricultural Research Center, western Ethiopia, between 1996-1998. One hundred grams of maize grain were infested with 20 unsexed and approximately equal age weevils in a glass jar with a ventilated lid. The experiment was laid out in a completely randomized design with three replications except for the 1998 experiment, which was not replicated. Inspection for progeny emergence count was started a day immediately after the first progeny emergence was observed and continued until all progeny weevils had emerged. The number of progeny weevils emerged (F_1), percentages of grain damaged and weight losses, and an index of susceptibility were the parameters considered for evaluation. Most of the commercial varieties of maize were found susceptible, and several of the genotypes including Abo Bako, Across 87-Tz-VT-W, AW 8047, Golden Valley, JCML-196-xJM-1 etc., were identified to be relatively resistant to the maize weevil. The promising genotypes should be promoted to further tests in a more refined way in order to get better weevil resistant germplasm.

Key words: Maize, resistance, *Sitophilus* weevils

INTRODUCTION

Worldwide, grain losses ranging from 20 to 90% have been reported for untreated maize due to weevil (*Sitophilus zeamais Motsch*) attack (Giga, *et al*., 1991; De Lima, 1987 as cited by Derera, *et al*., 1999). *Sitophilus* weevils followed by *Sitotroga cerealella* are the major pests of stored maize in western Ethiopia (Abraham, 1997). Grain damage levels of up to 100% have been observed in some grain samples obtained from farm stores after 6-8 months of storage in the Bako area, although the loss due to insect pests was about 16.3% (Abraham, 1991; 1997). Legesse and Asfaw (1992) also indicated that storage losses of maize range from 25-33% in the western zone.

Infestations by weevils start from the field making its management more difficult. Furthermore, the high cost of pesticides, the danger of resistance building up and the potential hazards of pesticides in the hands of unsophisticated users make alternative control measures highly important for stored product insect pests.

Considering these problems and the need for an integrated pest management system, the incorporation of resistant varieties into the system for the protection of stored maize should have been a long-term goal. The most attractive feature of using pest resistant varieties is that virtually no skill in pest control or cash investment is required of the grower.

However, varietal resistance has always been considered secondary to yield improvement because insect pests have generally been relatively easy to control effectively and cheaply by insecticides (Dent, 1991). Consequently, high yielding cultivars became more susceptible to attack by storage pests than the local varieties they were intended to replace (Arnanson, *et al*., 1994).

According to Serratos, *et al*. (1987), a promising solution in order to reduce storage losses is to identify resistant lines in the maize gene pool, determine the mechanism of resistance, and to focus on stable heritable characters for breeding programmes. Therefore, the objective of this study was to evaluate the level of resistance of commercial varieties and various maize genotypes to weevils of the *Sitophilus* species for practical use in breeding programmes.

MATERIALS AND METHODS

Various maize genotypes including lines, hybrids, and composites at various breeding stages were obtained from CIMMTY and local sources (Bako and Melkassa Agricultural Research Centres).

Stock cultures of weevils were established in the laboratory in order to produce weevils of known age (10-15 days) in a sufficient supply for the experiment. Maize germplasm seeds obtained from the different sources were cleaned and their moisture contents were measured (12-13%). One hundred grams of seed of each germplasm were put in a glass jar with a ventilated lid and arranged in a completely randomized design replicated three times except for the 160 materials tested in 1998, which were not replicated because of a shortage of the CIMMYT materials. Twenty unsexed and approximately equal age adult weevils were randomly picked from the laboratory cultures and were introduced into each jar of maize except for the uninfested control.

After a week the parent weevils were removed and the jars were kept in the laboratory for progeny emergence. Progeny emergence was inspected daily until all the F_1 adults had emerged. The parameters used to evaluate the resistance or susceptibility of the maize genotypes were the number of progeny weevils emerged, percentages of grain damage and grain weight losses, and index of susceptibility (I.S.). The data were subjected to statistical analysis using MSTATC computer programme. The index of susceptibility was calculated using the formula used by Dobie 1974:

I.S. = Log$_e$ F/D x 100, where F is number of F_1 progeny weevils produced and D is the time required for the emergence of 50% of the progeny.

% weight loss = (UNd-DNu/U(Nd+Nu)) X 100, where U is weight of undamagedgrain, D is weight of damaged grains, Nu is No. of undamaged grain and Nd is No. of damaged grains.

RESULTS

Maize genotypes showed significant differences ($p \leq 0.05$) in terms of mean number of progeny weevils emerged and percent grain damaged (Table 1). Out of the 52 genotypes Abo Bako, Across 87-TZ-VT-W, AW8047, CML, Gusaw, INT-A, Kamianesh (1) 8567, Pob-62 TLWF-QPM, Pob-63 TLWD-1 QPM, POb-65 TLYF-QPM, POB-70 SYD QPM, S86 P68, S89 SYQ ACG, Tlaltizapan 8468, Tuxpeno C6, Tuxpeno C20 and UCB (Awasa), and CML-47 showed relative resistance to weevil damage which was expressed by no or small number of damaged grains and progeny weevil emerged. In contrast, late population recombination C4, ACV-3 and SC-22 had significantly high ($p \leq 0.05$) number of progeny weevils. Furthermore, percentage of grain damage was high in ACV-3 (24.1%) followed by F-H625-276 (11.89%), late recombination C4 (7.3%), and CG-4141 (7.1%) compared to the above-mentioned genotypes.

On the other hand, no significant differences were observed in mean number of progeny emerged and percent grain damaged among the twenty genotypes obtained from Melkassa (Table 2). However, no progeny emergence and grain damage records were made from EEW pop cz/(K64R/P30-SR(52#), PL31-pool 16SR/2/PL9A) CL SEL, (92 SEN-1)#-# and TEWF-DRTO SYN./K64R/P30-SR(52#). These four genotypes performed relatively better than genotypes (C60 A/AC 8530), (89 (27/DRSYN HI YIELD), (89(C27/TWD-GOOD SINC), and (92 SEN-2), which had mean progeny emergence numbers of 11, 7, 8 and 7, respectively.

The 58 (Table 3) and 18 (Table 4) genotypes from Bako/CIMMYT and Melkassa respectively exhibited significant differences in their reaction to weevil damage. The least susceptible genotypes were ACV-3, F-H625-254, Alemaya Composite, Pob-70-SYD QPM, Pob-62 TLWF QPM and Abo-Bako out of the 58 materials. Golden Valley and TEWF were also more resistant than the other germplasm included in the test. Genotypes S91 SLY, Pob-67-SWF QPM, Across 87-TZVT-W, Poza Rica, Ba-Composite, Tlaltizapan 8670, and Pool-36, Arun II, Kalahari early pearl, Pop-146 from Bako/CIMMYT and Melkassa, respectively have a higher index relative to others (Table 3 and 4). The number of progeny weevil emergence ranged for the 18 materials from the Melkasa Research Center, except for Golden Valley, which was with no weevil emergence record (Table 4). The response of the other genotypes for percentage grain damage also varied significantly from resistant to susceptible.

A higher degree of variability existed among the maize genotypes tested in the year 1998 (Table 5). Data on grain damage of these materials after nine months of storage showed that many of the genotypes were damaged by weevils while some of them were not damaged at all. Genotypes with entry numbers 9, 16, 30, 32, 33, 43, 44, 50, 54, 69, 70, 78, 80, 87, 91, 98, 105, 109, 121, 130, 131, 132, 140, 144 and 159 appeared to have no progeny weevils emerged from them, indicating that they were not attacked by the maize weevil. However, few to many progeny weevils were also emerged for the other relatively resistant and susceptible entries, respectively.

The range for mean progeny weevils emerged varied between zero (for relatively resistant entries such as entry numbers 9, 16, 30, 32, 33, 43, 44, 50, 54, 69, 70, 78, 80, 87, 91, 98, 105, 109, 121, 130, 131, 132, 140, 144 and 159), and 139 (for the most susceptible entry number 133). Entry numbers 154, 148, 135, 126, 117, 115, 113, 95, 59, 56, 37, 116 (with 57, 94, 90, 50, 52, 66, 57, 52, 100, 55, 71 and 44 mean progeny weevil emergence, respectively) may also be classified as susceptible when compared to those genotypes with zero progeny weevil emergence.

Percentage of damaged grains also ranged between zero for entry numbers: 9, 16, 30, 32, 33, 43, 44, 50, 54, 69, 70, 78, 80, 87, 91, 98, 105, 109, 121, 130, 131, 132, 140, 144 and 159, and highly damaged for entry numbers 133, 154, 148, 135, 126, 117, 115, 113, 95, 59, 56, 37 and 116.

Percentage grain weight loss ranged between zero for the relatively resistant entries and 28.2, 11.6, 17.5, 13.2, 11.2, 12.1, 11.9, 9.4, 14.4, 17.6, 11.2, 12.9, 12.8, for entry numbers 133, 154, 148, 135, 126, 117, 115, 113, 95, 59, 56, 37 and 116, respectively.

On the other hand, the commercial improved varieties of maize showed a wide variation in progeny emergence and grain damage percentage (Table 6). Only UCB (Jimma) followed by A-511, which were found relatively resistant, had very few progeny emergence (one and fifteen) with the least grain damage percentage of 0.3 and 8.3, respectively, and were significantly different to those susceptible varieties with relatively higher number of progeny emergence and grain damage percentage. BH-140 was found highly damaged by weevils having 84 and 25.7 progeny emergence and grain damage percentage records, respectively. Emana and Assefa (1996) carried out a similar experiment to study response of some maize varieties to Angoumois Grain moth, *Sitotroga cerealella* (Olivier) and found out that UCB, H-8151, and H-501 were resistant in a free choice test. However, in a no choice test, UCB become less resistant, which may be explained in terms of resistance mechanism.

DISCUSSION

The susceptibility of most of the commercial varieties to attack by the maize weevil verified that the breeding program has not been assessing the resistance to stored maize pests, as a result of which the introduction of improved varieties has often resulted in greater post-harvest losses despite increases in yield. Derera *et al*., (1999) also reported that maize breeding has until recently emphasized yield at the expense of nutritional quality and maize weevil resistance. Hence, this result pinpoints pest resistance breeding as equally important to yield improvement.

During the year 1996, genotypes AW 8047, Brachytic-2, Kamianesh (1) 8567, Pob-62 TLWF-QPM, Pob-65 TLYF-QPM, S86 P68, Tuxpeno C6, Tuxpeno C20, UCB (Awassa) from Bako, genotypes EEW Pop CZ/ (K64R/P30-SR(52#), PL31-Pool 16SR/2/PL9A)C1 SEL, (92 SEN-1) #-# from Melkasa, showed no damage. Moreover, in 1997 only Golden Valley and in 1998 germplasm with entry numbers 9, 16, 30, 32, 33, 43, 44, 50, 54, 69, 70, 78, 80, 87, 91, 98, 105, 109, 121,

Table 1. Response of maize genotypes from Bako and CIMMYT to damage by maize weevils, 1996.

Treatment No.	Entry name	Mean progeny weevils emerged		Grain damage (%)	
1.	Abo Bako	0	h	0.0	k
2.	Across87-Tz-VT-W	0	h	0.0	k
3.	ACV-3	11	a	24.1	a
4.	Alamora white	2	c-h	0.6	f-k
5.	Al composite	1	d-h	1.2	e-k
6.	Al composite Rc	1	d-h	0.8	f-k
7.	AW 8047	0	h	0.0	k
8.	Beletech Recombination ($RC_{0)}$	2	c-h	3.2	d-j
9.	Beletech Rc_1	5	b-f	1.8	e-k
10.	Brachytic-2	0	h	0.0	k
11.	CG 4141	4	b-e	7.1	bcd
12.	CML	0	h	0.0	k
13.	101-e	1	d-h	0.9	f-k
14.	EAH-75	3	c-h	2.5	e-k
15.	EC-573-(93k)	1	d-h	0.2	ijk
16.	Gusaw	0	h	0.0	k
17.	Gutto S_1.,line No. A	2	c-h	0.2	d-I
18.	Gutto S_1.,line No. 50	1	d-h	0.4	g-k
19.	Gutto S_1.,line No. 55	1	d-h	4.1	e-k
20.	F-H625-276	4	b-f	11.9	b
21.	Ikenne-87TZPB-SR	1	d-h	1.0	e-k
22.	INT-A	0	h	0.0	k
23.	INT-B	1	d-h	0.2	I-k
24.	Kamianesh (1) 8567	0	h	0.0	k
25.	Late Popn. Recomb. C4	9	ab	7.3	bcd
26.	Medium recomb. C-5	4	b-f	4.6	c-g
27.	Pob-62 TLWF-QPM	0	h	0.0	k
28.	Pob-63 TLWD-1 QPM	0	h	0.0	k
29.	Pob-64 TLYD-2 QPM	1	d-h	0.5	g-k
30.	Pob-65 TLYF- QPM	0	h	0.0	k
31.	Pob-66 TLYP	1	d-h	0.4	g-k
32.	Pob-67 SYF- QPM	1	d-h	0.9	f-k
33.	Pob-68 SWD QPM	1	d-h	1.1	e-k
34.	Pob-70 SYD QPM	0	h	0.0	k
35.	Poza Rica	2	c-h	0.5	g-k
36.	S86 P68	0	h	0.0	k
37.	S87 P67 QPM	1	d-h	0.8	f-k
38.	S89 SYQ ACG	0	h	0.0	k
39.	S91 SLW QPM	1	d-h	0.6	g-k
40.	S91 SIY	1	d-h	0.4	g-k
41.	Synth. RC-2	3	c-h	6.1	c-f
42.	SC-22	8	abc	4.3	c-h
43.	Tlaltizapan 8468	0	h	0.0	k
44.	Tlaltizapan 8670	1	d-h	0.9	f-
45.	Tuxpeno C6	0	h	0.0	k
46.	Tuxpeno C10	1	d-h	0.1	I-k
47.	Tuxpeno C15	4	b-f	3.6	e-k
48.	Tuxpeno C20	0	h	0.0	k
49.	UCA	3	c-h	2.1	e-k
50.	UCB (Awassa)	0	h	0.0	k
51.	ACV6 (Awassa)	1	d-h	2.8	d-k
52.	CML-47	0	h	0.0	k
SE (±)		1.3		1.7	
CV (%)		54.0		49.7	

Means followed by a common letter(s) within a column are not significantly different at the 5% level of the Duncan's Multiple Range Test (DMRT).

Table 2. Response of twenty maize genotypes received from Melkassa to weevil damage (1996).

Treatment No.	Entry name	∗Mean no. of Progeny weevils	∗Grain damage (%)
1	Birkata	1	1.2
2	(89(27/DRSYN HI YIELD)	7	5.2
3	(89(C27/TWD-GOOD SINC)	8	4.6
4	(89(C28/TTEW-TRS POOL) #)	5	4.1
5	(C60 A/AC 8530)	11	4.1
6	EEW Pop cz/(K64R/P30-SR(52#)	0	0.0
7	HTS 89 c28-2/AC 8530	5	2.0
8	INTA C2F2 #	3	3.2
9	INT BC2F2#	5	3.3
10	P-32-SR /R20/	2	1.2
11	PL16-Sr/BC4) r2000)FS#	2	1.6
12	PL31-pool 16SR/2/PL9A)C1 SEL	0	0.0
13	Pool 15C23/(K64R/P30/SR(52#))	1	0.4
14	Pool 16C21/pool 27/WLF INT)	3	2.7
15	(92 SEN-1)#-#	0	0.0
16	(92 SEN-2)	7	2.8
17	TEWDSR-DRTO LSYN/POOL27/W.FLINT	2	0.9
18	(89/32/TEWF-DRSYN)	1	1.1
19	TEWF-DRTO SYN./K64R/P30-SR(52#)	0	0.0
20	(TEWF.SYN POOL 27(W.FLINT)	1	0.4
SE (±)		3.1	1.4
CV (%)		75.5	51.6

∗- Non significant

130, 131, 132, 140, 144, 159, had no progeny weevil emergence and grain damage records. This could be due, in part, to the unsuitability of the germplasm for oviposition, and/or that the germplasm may have some sort of resistance mechanisms to repel the ovipositing weevils. Derera *et al.* (1998) indicated that the pericarp of hybrid seed presents a barrier to weevil penetration to lay eggs and to feed on the endosperm, hence it affects the weevils' reproduction potential (index of susceptibility). Eubanks and Thorne (2000) in their study of weevil resistance in Tripsacum/multiple/ Zea diploperennis hypothesized that Tripsacum kernels are enclosed in a hard shell-like seed coat, the hardness of the seed was responsible for lack of weevil oviposition.

The reaction of some genotypes (e.g. ACV-3) was inconsistent over the test periods. This difference could be due to variations in moisture content and the growing conditions of the genotypes. According to Borgemeister *et al.* (1998), early harvested treatments had significantly higher maize weevil densities than the late harvested maize, possibly because of higher grain moisture content at harvest. Growing conditions during multiplication of grains can also play a great role on the resistance or susceptibility behaviour of that particular genotype. Varying climatic, soil conditions and nutrient levels during growth may modify the physical and chemical characteristics of grain (Dobie, 1977). Recent work by Arnason *et al.*, (1994) has shown that the phenolic compounds are important in resistance in two ways, through mechanical resistance and antibiosis. Phenolic acid content was found to correlate strongly with hardness of grain, which is related to the mechanical contributions of phenolic dimers (diferulate) to cell wall strength. On the other hand, in the aleurone layer phenolic acid amines have been detected to have toxic effects on insects.

In most of the genotypes the number of damaged grains increased with the increase in the number of progeny weevils emerged while in some genotypes the situation was different for unknown reasons, i.e. there are genotypes with a low number of progeny emerged but large number of damaged grains. Arthur (1992) also reported that maize weevils caused kernel damage in the test bioassays, even when populations were extremely low.

CONCLUSIONS

Since resistance is a relative term, we were also able to observe that there were differences among the maize genotypes in resistance or susceptibility to the maize weevil. Therefore, this difference in reaction among maize genotypes to the maize weevil should be exploited by repeated and refined tests to screen out the best material(s) for practical use in breeding programmes to develop resistant varieties and/or resistant versions of the existing commercial varieties.

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Table 3. Response of fifty-eight maize genotypes received from Bako and CIMMYT to weevil damage (1997).

Treatment No.	Entry name	F_1 progenies emerged		Grain damage (%)		Weight loss (%)		Index (I.S.)
1	*F-7238	11	g-l	3.1	h-k	0.8	b	3.8
2	F-H625-276	10	g-l	7.6	d-k	1.2	b	3.9
3	Abo-Bako	5	i-l	4.6	f-k	0.3	b	1.5
4	F-H625-259	6	h-l	3.9	h-k	0.9	b	3.1
5	F-H625-263	4	jkl	2.6	h-k	0.1	b	1.7
6	121-a	5	i-l	1.5	jk	0.4	b	2.0
7	F-H625-251-1	6	g-l	8.3	d-k	0.2	b	2.4
8	F7237	4	k-l	4.0	h-k	1.4	b	2.5
9	ACV-3	1	l	0.2	k	0.1	b	1.2
10	Gutto original	35	b-l	16.4	c-k	11.6	c	5.9
11	CML-181	14	f-l	8.6	d-k	0.9	b	6.3
12	MGB-2	18	b-l	15.0	d-k	0.7	b	4.5
13	A7033	12	f-l	7.5	d-k	0.7	b	4.0
14	SC-22	11	g-l	6.8	e-k	0.1	b	4.2
15	SS-22-560(44)X124-b-113	31	b-l	24.4	c-j	0.1	b	5.7
16	F-H625-254	1	l	1.2	jk	0.2	b	0.6
17	Pop-43	13	f-l	8.8	d-k	0.6	b	4.9
18	ACV-6	9	g-l	6.8	e-k	0.5	b	2.7
19	Guto LMS	46	a-j	28.1	b-f	1.8	b	6.8
20	CG-4141	58	a-d	38.9	abc	4.1	b	6.3
21	Pob-69	15	f-l	68.1	d-k	1.6	b	4.8
22	Tuxpeno-C20	1	g-l	7.6	d-k	0.4	b	3.9
23	Late popn. Recombination	22	c-l	17.1	c-k	1.4	b	5.0
24	Tlaltizapan 8468	30	b-l	17.0	c-k	2.5	b	6.2
25	Alamora white	38	b-l	25.8	b-i	1.5	b	6.0
26	Alemaya composite	2	l	1.7	jk	0.4	b	0.9
27	Synth. RC2	31	g-l	27.8	b-g	1.4	b	6.0
28	Guto line	25	c-l	12.0	d-k	0.4	b	6.1
29	Pob-66 TLYP	6	g-l	3.8	h-k	0.3	b	2.6
30	Gusaw	15	f-l	8.7	d-k	0.9	b	3.4
31	Meka	30	b-l	10.7	d-k	4.8	bc	5.6
32	Guto S1 line no.A	24	c-l	9.1	d-k	0.4	b	5.5
33	S91 SLY	48	a-g	19.2	d-k	1.4	b	7.3
34	EC-573(93K)	20	c-l	14.0	a-d	1.3	b	4.5
35	Pob-67-SWF QPM	53	a-f	3.3	jk	5.2	b	7.5
36	Pob-70-SYD QPM	1	l	1.9	e-k	0.1	b	0.9
37	Pob-29	10	g-l	6.5	d-k	0.8	b	3.5
38	Tuxpeno C10	18	d-l	10.1	d-k	0.3	b	5.2
39	Tuxpeno C6	28	b-l	13.6	d-k	0.5	b	5.8
40	Tuxpeno C15	12	f-l	7.2	d-k	1.1	b	2.5
41	KCC	8	g-l	6.5	e-k	0.3	b	3.5
42	S86 P68	10	g-l	6.4	e-k	0.4	b	2.9
43	Pob-62 TLWF QPM	6	h-l	4.5	g-k	0.5	b	2.0
44	Kamianash (1) 8567	7	g-l	5.3	f-k	0.5	b	2.8
45	Guto S1, line no.50	44	b-l	19.5	c-k	2.2	b	6.1
46	Across 87-TZVT-W	57	a-e	29.0	b-e	3.3	b	7.5
47	EAH-75	30	b-l	21.7	c-k	15.6	a	5.1
48	A-cross 8569	19	d-l	9.1	d-k	0.9	b	5.9
49	Bukuri	8	g-l	4.9	f-k	0.4	b	3.3
50	Poza Rica	45	b-k	26.3	b-h	2.4	b	6.7
51	Pob-63 TLWB-1QPM	6	h-l	2.3	ijk	0.3	b	2.5
52	Medium recombiation	35	b-l	18.3	c-k	0.9	b	6.6
53	Ba-composite Co	85	a	49.7	a	3.9	b	8.4
54	Pob-61-TFYF QPM	13	f-l	9.5	d-k	1.0	b	4.3
55	K-synth.II	16	e-l	10.8	d-k	1.7	b	3.5
56	Tlaltizapan 8670	48	a-h	21.2	c-k	1.9	b	7.0
57	Tuxpeno CO	47	a-i	24.6	c-j	1.6	b	5.3
58	AW-8047	34	b-l	19.3	c-k	1.3	b	4.8
CV (%)		40.7		35.1		27.3		_

Means followed by a common letter(s) within a column are not significantly different at the 5% level of the Duncan's Multiple Range Test (DMRT). *F-Female parent

Table 4. Response of 18 maize genotypes received from Malkassa to weevil damage in 1997.

No.	Entry name	F_1 progeny	Grain damage (%)	Weight loss (%)	Index (I.S.)
1.	SEW-2	12.3 cde	6.9 de	0.3 bc	4.1
2.	Pool-36	42.7 b	30.9 bc	2.3 b	6.8
3.	EEW-pop	24.0 b-e	19.5 b-e	1.8 bc	6.1
4.	TEWF	2.7 de	0.9 de	0.4 bcd	1.5
5.	INT BC2	16.7 cde	10.7 cde	1.0 bc	3.9
6.	POP-101	26.0 bcd	23.5 bcd	0.7 bc	5.7
7.	Arun II	65.7 a	34.0 b	7.1 d	7.8
8.	Kissan	15.3 cde	11.4 b-e	1.0 bc	4.8
9.	SPE	11.3 cde	11.1 cde	0.2 bcd	4.2
10.	Ganesh	30.7 bc	20.2 b-e	1.5 bc	6.0
11.	DTPZ	20.3 b-e	11.8 b-e	0.4 bc	5.4
12.	Kalahari early pearl	31.0 bc	81.1 a	9.1 a	7.0
13.	NZS	7.0 cde	9.5 cde	0.8 bc	2.6
14.	Golden Valley	0.0 e	0.0 e	0.0 bc	0.0
15.	Ilonga	17.3 cde	11.5 b-e	0.7 bc	5.1
16.	Pop-146	22.0 b-e	13.5 b-e	5.4 cd	7.4
17.	Hararghe	16.0 cde	14.2 b-e	1.8 bcd	4.9
18.	Melkassa 92DTP,C6	17.7 cde	15.9 b-e	0.8 bc	4.7
CV (%)		31.7	39.8	50.3	_

Means followed by a common letter(s) within a column are not significantly different at the 5% level of the Duncan's Multiple Range Test.

Table 5. Response of 160 maize genotypes received from Bako and CIMMYT to weevil damage (1998).

Entry no.	Treatments	Mean No. of progeny emerged	Grain Damage (%)	Weight Loss (%)
1	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-114	16	4.8	4.1
2	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-65	26	5.7	5.1
3	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-111	15	3.4	3.5
4	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-120	46	9.1	8.3
5	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-107	15	2.4	1.9
6	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-75	72	17.8	14.5
7	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-191	29	6.8	6.3
8	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-43	17	4.1	3.7
9	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-154	0	0.0	0.0
10	52-B-421-O-S_3xGutto LMS	1	1.6	1.2
11	65-B-177- O-S_3 x Gutto LMS	16	2.4	2.4
12	33-C-01--30-S_9xGutto LMS	2	0.3	0.2
13	JCML-196-xGutto LMS	5	1.2	0.9
14	27-B-341-74/JCML-226xSC-22	15	5.1	4.7
15	Pop-43x16B3482/JCML-235	7	2.9	3.0
16	JCML-199xJM-1	0	0.0	0.0
17	127-B-455-O-S_3xSC-22	7	1.3	1.1
18	Pop23C_4-S_2xpop49 (C_6S_4)"RRS-FS" COFS-158	33	6.5	6.1
19	CML-20xF-7238	4	2.1	1.7
20	27-B-341-74/JCML-226xGUTTO LMS	2	0.7	0.4
21	TL-95-B6204-55xgutto LMS	3	1.2	0.8
22	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-151	2	1.5	1.2
23	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-159	10	2.6	2.6
24	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-84	15	2.4	1.6

Entry no.	Treatments	Mean No. of progeny emerged	Grain Damage (%)	Weight Loss (%)
25	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-110	5	1.2	1.1
26	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-87	2	0.5	0.5
27	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-124	2	0.8	0.9
28	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-17	32	10.2	8.3
29	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-157	4	0.5	0.3
30	19-B-34192/JCML-228xSC-22	0	0.0	0.0
31	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-40	6	1.2	1.2
32	53-B-400-O-S3xGutto LMS_5	0	0.0	0.0
33	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-2	0	0.0	0.0
34	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-35	7	1.4	1.1
35	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-3	8	0.3	0.3
36	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-65	12	7.5	6.5
37	104-B-65-O-S_3xSC-22	71	14.3	12.9
38	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-42	2	1.0	0.9
39	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-63	5	0.8	0.6
40	SC-22x124-B(109)xF 7189	12	6.0	5.9
41	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-7	5	1.4	1.4
42	FH-625 251-1xF-7215xCML-97	1	0.5	0.6
43	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-187	0	0.0	0.0
44	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-1	0	0.0	0.0
45	SC-22xG-7462	2	0.2	0.1
46	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-173	2	0.7	0.5
47	124-b(113)xG-7462	3	2.6	2 .2
48	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-30	1	2.4	1.6
49	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-167	2	0.2	0.2
50	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-90	0	0.0	0.0
51	PHB-435-6 X (WF)xGutto LMS	2	1.1	1.0
52	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-106	2	1.4	1.3
53	BH-540xPHB 435 X6	5	3.3	2.7
54	67-B-61-O-S3xGutto LMS	0	0.0	0.0
55	82-B-414-O-S3-gutto LMS	6	0.2	0.2
56	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-164	55	12.3	11.2
57	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-118	37	3.8	3.6
58	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-67	27	9.1	8.1
59	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-126	100	20.4	17.6
60	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-152	15	3.9	3.4
61	77-B-159-O-S3xSC-22	4	1.7	0.9
62	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-170	1	1.1	0.9
63	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-125	33	7.4	6.4
64	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-103	10	3.6	3.6
65	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-162	42	8.6	6 .3
66	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-115	31	5.0	4.4
67	F-7215xCML-20	12	4.1	3. 4
68	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-158	29	5.4	4.1

Entry no.	Treatments	Mean No. of progeny emerged	Grain Damage (%)	Weight Loss (%)
69	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-93	0	0.0	0.0
70	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-122	0	0.0	0.0
71	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-38	6	1.7	1.7
72	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-136	25	6.0	5.2
73	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-99	36	11.0	9.4
74	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-141	38	9.4	8.5
75	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-37	41	9.4	8.2
76	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-47	27	8.2	7.1
77	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-143	8	2.4	2.2
78	CML-20XF-7237	0	0.0	0.0
79	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-189	5	2.9	2.2
80	PR-95A303-57-1ÄxSC-22	0	0.0	0.0
81	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-172	1	0.2	0.2
82	140-B-478-O-S_3 xSC-22	1	0.7	0.8
83	6-CML-208/JCML-208 x Gutto LMS	3	1.7	1.5
84	6-CML-208/JCML-229	5	0.8	0.5
85	28-CML-209/JCML-209xGutto LMS	3	0.9	0.7
86	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-109	4	1.2	0.8
87	F-7215 x CML-33-G-7462	0	0.0	0.0
88	PHB 435-9 Ä SC-22	8	1.2	1.0
89	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-108	16	8.3	7.2
90	112-B-168-O-S_3 x Gutto LMS_5	6	2.4	2.9
91	124B (153)x7462 x LMS-176	0	0.0	0.0
92	Early-MTD-1/ Katumani-SRJ	8	1.2	1.5
93	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-128	21	5.8	5.8
94	A-7032xF-7215 x 136-d	52	17.1	14.4
95	A-7032-G7462 x CML-197	1	0.5	0.3
96	11-B-33870/JCML-22 x Gutto LMS_5	1	0.3	0.3
97	11-B-33870/JCML-22 x SC-22	24	7.2	5.9
98	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-194	0	0.0	0.0
99	120-B-40-O-S3-x Gutto LMS_5	2	1.4	1.4
100	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-77	34	5.9	4.8
101	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-129	4	0.2	0.2
102	F-7237-CML-194	40	6.6	6.3
103	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-22	20	4.5	3. 7
104	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-122	7	1.9	1.4
105	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-16	0	0.0	0.0
106	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-83	48	5.7	8.9
107	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-165	46	8.3	8.0
108	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-183	2	0.2	0.2
109	TL-95B CML-313xGutto LMS_5	0	0.0	0.0
110	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-29	57	12.2	9.4
111	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-64	7	3.0	2.8
112	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-177	66	13.5	11.9

Entry no.	Treatments	Mean No. of progeny emerged	Grain Damage (%)	Weight Loss (%)
113	S-91 SJWK QPM SYN (146)	44	13.9	12.8
114	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-25	52	13.5	12.1
115	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-160	21	7.7	7.2
116	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-80	32	9.7	8.5
117	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-52	13	5.4	4.9
118	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-10	10	5.5	4.9
119	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-196	1	1.3	1.2
120	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-79	13	2.7	21.5
121	106-B-471-O-S_3xGutto LMS_5	0	0.0	0.0
122	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-48	50	19.3	11.2
123	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-22	4	1.4	1.3
124	NSCM 41 1924 (75) x SC-22	5	1.6	1.1
125	100-B-430-O-S3 x SC-22	14	2.2	1.4
126	64-B 93-O-S3 x Gutto LMS_5	3	0.9	0.9
127	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-6	139	30.5	28.2
128	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-76	4	2.5	2.2
129	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-166	35	12.3	10.2
130	101-B-40-O-S3 x SC-22	0	0.0	0.0
131	A-7024 x SC22-124-B(113)	0	0.0	0.0
132	109-B-134-O-S3xO-S3xSC-22	0	0.0	0.0
133	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-123	46	8.7	7.8
134	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-169	32	8.0	6.2
135	120-B-40-O-S3 x SC-22	24	5.2	4.3
136	SC-22 x F-7189	1	2.7	3.1
137	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-127	1	1.0	1.1
138	42-B-98-O-S4xGutto LMS	4	1.9	1.7
139	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-171	24	3.4	2.9
140	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-155	0	0.0	0.0
141	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-117	94	21.2	17.5
142	POOL-9A-7-$Ä_1$ xGutto LMS	7	2.5	1.5
143	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-49	8	3.1	2.8
144	129-B-319-O-S3xSC-22	0	0.0	0.0
145	129-B-319-O-S3xSC-22	4	3.4	2.2
146	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-163	14	3.1	2.4
147	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-121	57	12.7	11.6
148	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-102	12	2.6	2.4
149	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-91	17	6.2	4.9
150	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-188	13	2.0	1.2
151	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-193	6	2.3	1.6
152	BH-540 x MGB-4	1	1.7	1.7
153	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-161	7	2.5	2.2
154	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-24	44	11.4	10.3
155	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-19	7	2.6	2.3
156	Pop23-C4S_2xpop49(C_6S_4)"RR-FS"COFS-89	5	1.5	0.9

Entry no.	Treatments	Mean No. of progeny emerged	Grain Damage (%)	Weight Loss (%)
157	TL95BCML-314 x SC-22	24	6.0	5.2
158	G-7462 x CML-176	10	1.7	1.5
159	4-CML-207/JCML-207 x 207 x Gutto LMS_5	0	0.0	0.0
160	PR95A303-71-1ÄxGutto LMS_5	41	7.1	6.2

Table 6. Response of nine released commercial varieties to the maize weevil at Bako (1996).

Treatment Number	Entry name	Mean number of progeny weevils emerged	Grain damage percentage
1.	Kuleni	32 cd	12.0 bc
2.	Beletech	49 abc	17.9 ab
3.	A-511	15 d	8.3 cd
4.	UCB (Jimma)	1 e	0.3 d
5.	BH-540	64 ab	25.6 a
6.	BH-140*	84 ab	25.7 a
7.	BH-660	35 bcd	13.6 bc
8.	Sweet corn	61 ab	20.0 ab
9.	Gutto LMS	31 cd	9.5 bc
SE (±)		10.0	2.9
CV (%)		31.0	58.3

*- Susceptible check

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SCREENING CRY PROTEINS PRODUCED BY Bt MAIZE LEAVES FOR ACTIVITY AGAINST KENYAN MAIZE STEM BORERS

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ABSTRACT

Lepidopteran stem borers infest up to 87% of maize growing areas in Kenya causing grain yield loss of 15% annually. The Bt technology for maize that utilizes genes that encode delta-endotoxins; proteins derived from the soil bacterium Bacillus thuringiensis (Bt) has been developed. The Bt toxins protect the plants against the pests but are harmless to humans, animals, and most other insects. Transfer of Bt based resistance to adapted maize germplasm in Kenya is being pursued. A permit to introduce leaves from maize transformed with Bt genes was issued by the Kenya National Biosafety Committee. Bioassays were carried out to identify the effective Bt genes against five Kenyan stem borers: Chilo partellus, Chilo orichalcocliellus, Busseola fusca, Eldana saccharina, and Sesamia calamistis. The cry1Ab protein was the most active against all species as shown by the least area of leaves consumed and by the high percentage of larvae that were killed. Chilo partellus was affected by all cry proteins, except cry1E. Eldana saccharina was the least affected by any cry protein. Chilo orichalcocliellus was most affected by cry1Ab and cry1B proteins. Sesamia calamistis was affected by cry1Ab and cry1Ab-1B proteins. Cry1E protein was not active against any species. The tested Bt cry proteins were not effective in the control of B. fusca. Perhaps a cocktail of 2-3 cry of those proteins being expressed at high levels or other Bt cry proteins like cryIC may show control. These results also indicate the specificity of Bt toxins even among lepidopteran stem borers. A prospective control has therefore, been identified for the most destructive borer, C. partellus which is also the most widely distributed in Kenya.

INTRODUCTION

Increasing intensification of maize production has brought with it dramatic changes in pest ecology and increased susceptibility of the maize crop to losses from insects and diseases. More than 60% of the maize growing area in Eastern and Southern Africa suffers from devastating pest infestations each year. The most critical insect problems are due to stem borers. In Kenya, stem borers infest up to 87% of maize growing areas annually, leading to yield loss of 15% (De Groote 2001). This is a very high loss considering that Kenya is a net maize importing country. With maize being the nation's major food crop, stem borer damage ultimately affects food security and the agricultural economy.

The four general approaches to stem borer control are chemical, biological, cultural, and host plant resistance (HPR). HPR is preferred for small-scale subsistence farmers as it is a relatively cheap and safe technology. HPR is developed through conventional breeding methods or through molecular technology. In molecular technology, quantitative trait loci (QTL) conferring resistance to stem borers are identified in source germplasm and transferred to susceptible but adapted germplasm through marker assisted selection (MAS) procedures (Groh et al., 1998, Khairallah et al. 1997). More recently, transgenic technology for maize has been developed.

Using genetic engineering, scientists have transferred several genes from the common soil bacterium Bacillus thuringiensis (Bt) into maize. Each of these genes produces a protein in the maize plant that is toxic to certain groups of insects, particularly stem borers. While Bt proteins protect the plant against these very destructive pests, the proteins have been shown to be harmless to humans, animals, and most other insects (Croft, 1990). Having the plant produce its own pesticide means that farmers do not have to buy or apply costly and potentially hazardous insecticides. For resource poor farmers who lack the money or time to use insecticides, Bt maize could make the difference between a successful harvest and a very poor one. The Insect Resistant Maize for Africa (IRMA) Project is pursuing the transfer of Bt based resistance to adapted maize germplasm in Kenya. The project is a collaborative effort between scientists at KARI and the International Maize and Wheat Improvement Center (CIMMYT).

In March 2000, a meeting of Kenyan Stakeholders in the maize industry brought together maize farmers, researchers, policy makers, commercial firms and religious leaders to discuss development of insect resistant maize for Africa including the use of Bt genes (Mugo 2000). Farmers felt that Bt maize holds promise to reduce the costs of maize production and thereby reducing costs of food to consumers. Since then, a small but significant step toward the introduction of Bt maize into Kenya and Eastern Africa was taken in February 2001, when an experiment at the KARI Biotechnology Center provided scientists with data on how effective the genetically modified Bt maize would be against Kenyan stem borers. An application to introduce leaves from maize transformed with Bt genes was lodged with the National Biosafety Committee (NBC) through the KARI Institutional Biosafety Committee (IBC) and a permit to allow importation of the leaves was granted. The objective was to screen and identify the effective Bt genes (cry genes) in maize (Zea mays L.) leaves for resistance to Kenya stem borers, Chilo partellus, Chilo orichalcocliellus, Busseola fusca, Eldana saccharina, and Sesamia calamistis. This information would then allow us to better target the development of Kenyan maize varieties with the appropriate combinations of genes for resistance to these stem borer species. This paper discusses the procedure followed and results obtained following the introduction of leaves from Bt maize to Kenya.

MATERIALS AND METHODS

Maize Leaves. The Bt maize tissues that were introduced were from the following six transgenic lines.

1. Leaves from fifth generation (T4) plants containing Event 5207 [cry1Ac driven by the maize ubiquitin promoter (plasmid pU02) co-transformed with the bar gene driven by the enhanced CaMV 35S promoter (plasmid pHP620)].
2. Leaves from fifth generation (T4) plants containing Event 5601 [cry1B driven by the rice actin promoter and bar driven by the CaMV 35S promoter (plasmid pCIRAD3)].
3. Leaves from second generation (T1) plants containing Event 1835 [cry1B driven by the maize ubiquitin promoter and bar driven by the CaMV 35S promoter (plasmid pCIRAD4) co-transformed with the bar/gus genes driven by the maize ubiquitin promoter (plasmid pACH25)].
4. Leaves from third generation (T2) plants containing Event 602 [cry1E driven by the rice actin promoter and bar driven by the CaMV 35S promoter (plasmid pCIRAD58)].
5. Leaves from second generation (T1) plants containing Event 7 [cry1B-1Ab driven by the rice actin promoter and bar driven by the CaMV 35S promoter (plasmid pCIRAD7)].
6. Leaves from plants containing Event 176 [cry1Ab driven by the maize pollen-specific promoter and cry1Ab driven by the maize PEP carboxylase promoter (plasmid pCIB4431) co-transformed with the bar gene driven by the CaMV 35S promoter (plasmid pCIB3064)].
7. By using leaf tissue for the experiment, the scientists ensured that no seed or living maize plants could inadvertently "escape" into the environment before the necessary environmental studies have been conducted.

Transport from Mexico to KARI/NARL, Nairobi. Leaf tissue from maize plants planted in the CIMMYT Applied Biotechnology Center's Biosafety Greenhouses in Mexico were brought to Kenya on February 2, 2001. Each set of leaves from each event was moistened and wrapped in sealed Ziploc plastic bags and carried in a sealed box. They were hand carried during the 24 hour journey through Amsterdam to Nairobi by a CIMMYT Scientist. Kenya Plant Health Inspectorate Service (KEPHIS) officials were on hand to receive the package at the airport and took custody of the package until it reached the Biosafety Level II laboratory at KARI Biotechnology Center at NARL Kabete where the bioassays were carried out.

Bioassay protocols. The maize lines were cut into three cm square sections across the leaf blade. Each section was placed in a five cm diameter petri dish containing moistened filter paper with the abaxial side facing up. Ten neonate larvae of one of the five stem borer species were placed on the leaf tissue using a camel hair brush. The petri dish was then sealed with parafilm.

Ten replicates were set up for each of the six events, for the non-transgenic tropical hybrid from Mexico (CML216), a local maize hybrid (H614D), and for each target stem borer: spotted stem borer (Chilo partellus), coastal stem borer (Chilo orichalcocliellus), African pink borer (Sesamia calamistis), African sugarcane borer (Eldana saccharina), and African maize stem borer (Busseola fusca). The petri dishes were kept at room temperature and total darkness in the biosafety laboratory. After five days, the mortality of the larvae and leaf damage were assessed and recorded. The area consumed was measured using a millimeter grid.

After recording the number of live and dead larvae, all larvae were stored in 70% alcohol in preparation for autoclaving and disposal. The petri dishes and other reusable equipment were soaked in a disinfectant (sodium hypochlorite) for one hour, and then washed with a detergent. All plant tissue; insects and disposable items were placed in biohazard bags and autoclaved at 15-psi pressure at 121^0C for one hour. The autoclaved biohazard bags were then burnt after soaking in kerosene in an open pit at the KARI Biotechnology Center Compound. A KEPHIS Inspector supervised the disposal of all the autoclaved material.

RESULTS

The leaf tissue was still fresh enough to support insect damage even after two days of transit and/or up to eight days when stored in the refrigerator. There were highly significantly differences between the cry proteins, and stem borers for both leaf area consumed and percent of dead insects recovered (Tables 1 and 2). There was extensive damage in all replications in the controls of the non-transformed CML216 and H614D by all stem borers. This is shown by the large area of leaves consumed and by the low percentage of larvae that were killed on leaves from these plants. The cry1Ab protein was the most active against all species as shown by the least area of leaves consumed and by the high percentage of larvae that were killed. On the other hand, the cry1E protein was not active against any species except for some small effect against Chilo orichalcocliellus.

Among the stem borer species: all cry proteins, except cry1E, affected Chilo partellus. Eldana saccharina was the least affected by any cry protein, although cry1Ab, cry1B and cry1Ab-1B proteins gave some effect against this species. Eldana saccharina was unique in that the larvae did not consume significant amounts of any cry leaves except cry1E. Busseola fusca was affected more than Eldana saccharina, but less than the other species. The cry1Ab protein was the most active against Busseola fusca than all others. Chilo orichalcocliellus was most affected by cry1Ab and cry1B proteins, and moderately by cry1Ab-1B protein. Sesamia calamistis was affected by cry1Ab and cry1Ab-1B proteins.
The event E176 was the best in controlling all insect species overall. Events E5601 and E1835, both with cry1B but driven by actin and ubiquitin promoters, respectively, showed a similar control pattern for all insect species.

DISCUSSION

The cryIE protein is ineffective against any of the insects species tested. This could be due to fact that the cryIE protein does not target the insects, or the event does not

Table 1. Mean area consumed by different species of stem borer larvae after feeding on Bt maize leaves for 5 days

Gene	Event	Area consumed by stemborer larvae (mm^2)				
		Chilo partellus	***Chilo orichalcocliellus***	***Eldana saccharina***	***Sesamia calamistis***	***Busseola fusca***
*cry*IAb-PEPcar	176	0.3	0.3	0.0	1.4	11.7
*cry*1Ac-ubiquitin	5207	11.8	22.2	4.1	32.9	69.2
*cry*1B-actin	5601	0.6	1.0	14.7	44.1	43.9
*cry*1B-ubiquitin	1835	0.5	0.9	4.7	53.8	66.6
*cry*1Ab-1B-actin	7	0.3	0.3	0.4	1.6	35.4
*cry*1E-actin	602	92.0	46.0	75.8	85.7	76.6
CML216	Control1	89.0	56.8	69.1	87.5	79.7
H614D	Control2	52.5	43.5	37.1	44.9	47.7
Significance		**	**	**	**	**

** Significant at the 99% level of probability

Table 2. Mean number of dead stem borer larvae after feeding on Bt maize leaves for 5 days

Gene	Event	Percent Dead larvae				
		Chilo partellus	***Chilo orichalcocliellus***	***Eldana saccharina***	***Sesamia calamistis***	***Busseola fusca***
*cry*IAb-PEPcar	176	97.9	81.0	26.6	95.8	59.2
*cry*1Ac-ubiquitin	5207	84.9	41.4	8.0	30.8	30.4
*cry*1B-actin	5601	100.0	58.8	9.5	19.0	46.4
*cry*1B-ubiquitin	1835	98.8	82.0	23.8	7.5	26.4
*cry*1Ab-1B-actin	7	98.8	51.4	23.8	86.3	34.7
*cry*1E-actin	602	14.1	29.1	6.6	11.3	9.5
CML216	Control1	13.1	20.9	1.2	8.8	10.9
H614D	Control2	7.6	24.4	9.2	4.7	18.5
Significance		**	**	**	**	**

** Significant at the 99% level of probability

produce a large amount of the cryIE protein. Similar results have been obtained using other insect species in Mexico (D. Hoisington, personal communication). Other events of cry1E could be tested to determine their effectiveness.

A prospective control has been identified for the most destructive borer, the spotted stem borer (Chilo partellus), which is the most widely distributed stem borer in Kenya. Similarly, cry proteins to control Chilo orichalcocliellus, Eldana saccharina and Sesamia calamistis were identified. None of the tested Bt proteins were effective in the total control of Busseola fusca. Combinations of two or more cry proteins expressing at high levels need to be tested. Other Bt proteins like cryIC should also be tested.

The control maize line, H614D, suffered less leaf area damage than CML216, but larval mortality was similar in both. This may be due to host plant resistance or hybrid vigor expressed in H614D as opposed to the inbred line CML216. The H614D leaves were also observed to deteriorate rapidly during the bioassay period. H614D was grown in the greenhouses at NARL.

Not all Bt toxins are effective against all lepidopteran pests, and the results obtained support this fact. Therefore, bioassays must be conducted to determine which toxins are active and which ones should be combined to ensure an effective level of pest control for years to come. These results also indicate the specificity of Bt toxins even among lepidopteran stem borer insects. This observation is important as we investigate the effects of Bt genes against other insect and animal species. These bioassays will be very useful as we initiate our product development to deliver an effective and durable level of insect resistance for African maize.

CONCLUSIONS

The importation was successful and demonstrated that transgenic materials can be safely imported and handled in Kenya. The results from the bioassays were excellent and provide critical information regarding the effectiveness of various Bt genes against several important stem borer maize pests. The next steps will be to repeat these tests under field conditions in Kenya.

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GENETIC VARIABILITY OF MAIZE GENOTYPES FOR RESISTANCE TO *EXEROHILIUM TURCICUM* IN KENYA.

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ABSTRACT

Maize (*Zea mays* L) is the most important staple food crop in Kenya. Despite its importance, maize production is limited due to a number of factors, among them diseases and insect pests. Highland leaf blight caused by *Exerohilium turcicum* (Pass.) Leonard & Suggs is one of the most economically important diseases of maize in Kenya. Various maize genotypes were screened for genetic variability for resistance to *E. turcicum* in the greenhouse and the field. Plants were inoculated at the 6-7 leaf stage. Greenhouse test plants were incubated for 24 hrs at 100% relative humidity. Disease severity ratings were recorded two weeks after inoculation on a 0 to 5 scale in the field, and in the greenhouse the lesion lengths and widths were measured. The ratings were significantly different among genotypes and some entries were segregating into groups of resistant, intermediate and susceptible. Mean lesion length ranged from 2.73 cm for POPL 32 to 8.97 cm for M30 while width varied from 0.25 cm for PR98A to 0.57 cm for M30. Mean ratings in the field ranged from 0.5 for three entries to 3.0 for Embu12X CN211. The resistant and/or segregating genotypes appeared adapted and have potential in Embu and other areas with a similar environment. The resistant genotypes identified need to be evaluated against blight and other major diseases under controlled or different environmental conditions at diverse locations. Identification of resistant genotypes is useful in a maize breeding programme where blight is of concern for general varietal improvement.

Key words: Disease, *Exerohilium turcicum,* grain maize, highland (Turcicum) blight, resistance, variability

INTRODUCTION

Maize is the most important staple food crop in Kenya. Maize diseases are one of the major limiting factors in the production of high grain yield and high quality produce in the Kenya highlands. Highland blight is one of the most economically important diseases (Njuguna *et al.* 1990; NARC, 1987; Muriithi, 1990). However, there are limited and/or incomplete reports on breeding for resistance to this important disease in maize production systems. The previous reports showed the commercial varieties and super elite breeders' materials are vulnerable to the highland blight (Muriithi, 1992; Maize Data Base, 1994). However, some genotypes possess some levels of resistance to the blight (Muriithi, 1992).

Turcicum blight, caused by *E. turcicum,* is considered a serious disease where climatic conditions are cool with high relative humidity. Yield losses have approached 50 % when the disease is severe at 2-3 weeks after pollination (Shurtleff, 1980). Observation of near epiphytotic levels of the disease in recent years is an indication that the level of resistance in the commercial varieties is low or the resistance has broken down (NARC, 1987).

Host plant resistance is the cheapest and most effective way to control leaf blight diseases because chemical treatments are expensive, often ineffective, and sanitation practices in crops such as maize are difficult to apply. Breeding for resistance/tolerance to *E. turcicum* is through selection and incorporation of resistance into the existing commercial hybrids and composites with good agronomic characteristics. This can be one of the major components of the leaf blight integrated management.

Since the available reports showed that there is limited information on breeding for resistance to maize diseases and insect pests and that the commercial varieties are vulnerable to the disease (Njuguna, *et al*., 1990; Muriithi, 1990; KARI, 1994; Mutinda, 1997), there is a need to identify new sources of resistance through artificial and natural inoculation, and to determine the type(s) and level(s) of resistance possessed by the available breeders' materials and introduced germplasm. This can be achieved through strengthening the existing identification and utilization of identified resistant genes in the breeding programme.

This information is required in planning future disease management protocols or in the implementation of the existing measures. Hence, the need to identify more sources of resistance through artificial and natural inoculation.

Various maize accessions from the maize breeding programme and established varieties were evaluated for genetic variability in resistance to *E. turcicum.* The objectives were: to determine genetic variability, self and test resistant plants during the tenure of the development of all selections emerging from breeding and pathology programmess; re-evaluate a wide range of germplasm known to have resistance to this important disease; incorporate *E. turcicum* resistance into existing commercial varieties and super elite breeders' lines.

MATERIALS AND METHODS

Field screening. The breeders' lines were planted in October 1999 at KARI-Embu. Dr. C. M. Mutinda of KARI-Embu furnished seeds. Plant spacing was 75 cm between and 25 cm within the rows. Two replications were planted. Each replicate consisted of two-row plots, each row 20 hills per row per entry in a RCBD. Fertiliser was applied pre-plant with 20:20:0 at 50 kg/ha. Two hand weedings controlled the weeds.

Greenhouse screening. The breeders' lines were planted using fertilizer 20:20:0 on 15 cm diameter plastic pots. Three replications were planted in a CRD. Each replicate consisted of pots with four entries, planted clockwise and each entry with six plants. Watering was by can and/or by placing the pots on a plastic tray filled with water.

Inoculum collection and preparation. Diseased leaves were collected from a wide range of cultivars planted in farmers' fields and breeders' plots. The diseased leaves were mixed, washed in running water, refrigerated at 4o C or used directly. The leaves were cut into small pieces, washed in distilled water, put in a plastic tray, covered in a black polythene bag and incubated overnight to sporulate. Conidia were washed off with distilled water by shaking or brushing, the suspension was filtered and the conidia concentration adjusted to about 30,000 / ml.

Inoculation. Plants were inoculated at the 4-6 leaf stage of growth in mid-October 1999 in the field and in May-June 2001 in the greenhouse. Inoculations were made in the evening by pipetting 2-3 drops of the conidia suspension into each plant whorl. All plants in the greenhouse were inoculated and in the field single rows were inoculated and the remaining rows served as controls. After inoculation in the greenhouse, plants were incubated at 100% relative humidity in a plastic chamber.

Disease severity estimation. Highland blight first symptoms were visually noted in the field before inoculation on some entries and 2-3 weeks after inoculation. A scale of 0-5 was used to estimate disease severity following the CIMMYT procedure, i.e. 0 for no lesions and 5 for nearly blighted leaves. Ratings of 0.0-1.4 were considered resistant, 1.5 to 2.4 intermediate, and 2.5-5.0 susceptible. The ratings were based on an average of visual estimates of leaf area covered by the lesions per entry. The severity data estimates were averages for all inoculated plants in the row per entry.

In the greenhouse, the first flecking symptoms were visually observed within one-two days after inoculation and the lesions in about a week. The severity estimates were based on means of the measurements of the lesion length and width two weeks after inoculation.

Data analysis. Analysis of variance of disease severity data was conducted with the SAS Institute, Cary, NC, USA computer package to determine if significant differences were observed between entries. ANOVA and LSD tests were performed.

RESULTS

Disease ratings were significantly different among accessions for the greenhouse (p = 0.0036 for lesion length) and field (p = 0.0001 for severity) observations (Tables 1 & 2). Of the germplasm entries tested in the field, 10 were considered resistant, 16 intermediate, and 4 susceptible (Table 2) with an average disease rating of 1.81. In the greenhouse, no entry was considered resistant, two were moderately resistant, four moderately susceptible and the rest susceptible. No accession was immune to *E. turcicum* under both environments and the testing period.

Disease ratings taken in the field around the flowering stage of growth indicated that susceptible cultivars sustained significantly more disease than intermediate one. The resistant accessions showed only traces of leaf blight on or immediately after flowering. The weather conditions were not conducive for disease development.

Based on the leaf blight disease ratings and lesion length, the germplasm was classified into four groups of resistant, moderately resistant, moderately susceptible and susceptible for greenhouse and three groups of resistant, intermediate, and susceptible for the field materials.

DISCUSSION

Resistance to *Exerohilium turcicum* in maize germplasm was previously reported (Muriithi, 1992; NARC, 1987). Resistance was expressed as reduced percent leaf area affected by the blight, lesion number and size (mainly length). Four accessions from this study were also evaluated in a previous study and had comparable ratings. The

Table 1. Greenhouse disease ratings of the grain maize breeders' lines to *Exerohilium turcicum.*

Accession	Lesion length (cm) [a]	Reaction Type	Lesion width (cm) [a]
216 x CN 99	8.00	S [b]	0.41
TL 98B	5.43	S	0.47
TI 97 B	5.30	S	0.35
PR98A	4.24	MS	0.39
18-2	5.07	S	0.25
E 11	5.07	S	0.41
EM 12	3.63	MR	0.30
Popl 49	4.90	MS	0.30
Popl-32	2.73	MR	0.27
C5051	4.72	MS	0.33
Baby corn	4.46	MS	0.42
12 Mixed	7.68	S	0.33
210	5.77	S	0.40
M7	5.33	S	0.38
H513	5.05	S	0.40
LB3	5.37	S	0.36
M12	5.77	S	0.40
M1	7.10	S	0.50
Mixed (R, P, Y& W)	5.87	S	0.42
M 22	6.30	S	0.50
H622	6.30	S	0.47
C5051	7.07	S	0.43
M 16	7.07	S	0.43
M23	6.03	S	0.34
M17	4.57	S	0.36
H614	5.80	S	0.40
M30	8.96	S	0.57
M5	5.50	S	0.44
M9	6.77	S	0.48
Baby corn	6.47	S	0.44
LSD[c]	2.42		0.1666
Pr > f	0.0036		0.48
CV	26.29		75.5
Overall means	5.16		16

[a]= Means; [b] R = Resistant accession (0.0-2.0); MR = Moderately resistant (2.1-4.0); MS = Moderately susceptible (4.1.0-5.0); S = Susceptible (> 5.0); [c] = LSD individual entries.

injection or dropper inoculation procedure was efficient enough to eliminate chances of escape plants but not good for determining lesion number as a type of resistance.

Significant differences between accessions in the field and in the greenhouse testing are attributable to numerous factors affecting development of leaf blight. Among the factors are climatic conditions, host genotypes, inoculation method, and the disease reading.

The inoculation technique utilizing the dropper was easily performed and reliable unlike the injection technique. This method prevented errors in evaluating resistance due to 'escapes'. The dropper method seemingly would be also useful in screening protocols involving other pathogens of grain maize and also for use in screening other cereal crops.

Most of our commercial hybrids normally have very few but large lesions (personal observation). This is one of several types of resistance expression. The possession of few but large lesions suggests presence of a new but rare strain, if the population is increased, the varieties may become susceptible. The long lesions of tested hybrids indicated this. The means of the width of the lesions did not differ significantly as expected, suggesting that the measurements are not useful in determining resistance. The pathogen grows between the major veins and not across the veins.

Secondary infections in the field of leaf blight were not extensive even on susceptible accessions. However, differences were still notable as the lesions on resistant accessions remained at the point of inoculation and on the intermediate entries, size of lesions was relatively small. By the flowering period, the ratings remained relatively low but constant but the susceptible cultivars still exhibited a moderate increase in diseased leaf tissue. This could be explained by the dry spell, which prevailed during the season.

The resistant accessions reported here appear adapted and to have potential as parental lines, source of resistant gene(s) or germplasm sources in Kenya and other areas with similar environment. Maize genotypes identified as resistant should be screened against pure isolates of *E. turcicum,* under different environmental conditions at diverse locations or under controlled environment. The identification of resistant genotypes is useful in maize breeding programmes where leaf blight is of concern and for general maize improvement. The type of resistance, mechanisms of resistance, and the locations of the gene(s) for resistance of these grain maize accessions remain unknown. The new biotechnology methods available can be used to locate the gene(s) and in incorporating it in the cultivars with desired agronomic characteristics.

Progeny testing and selfing of the individual plants derived from single ears of resistant accessions are being conducted to examine the inheritance of resistance to *E. turcicum*. Selection of less-susceptible individual progenies can result in an accumulation of minor genes, increasing the level of resistance (Ojulong *et a*l., 1996; Pratt, *et a.,* 1997).

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Table 2: Field disease ratings of the grain maize breeders' lines to *Exerohilium turcicum.*

Accession	Score (0-5)	Reaction Type
CN 208 x EMBU 12-210	1.25 [a]	R [b]
PR 98 A- 75 1 B X Embu 12 -210	0.50	R
TL 9790 - 9 X EMBU 12-210	1.00	R
EMBU 12 X EMBU 12 - 210	2.00	I
EMBU 12 - 210 X KBO - 99B - 99A22-16	2.00	I
EMBU- 12 - 210 X TL - 98B - 16760B	1.25	R
CN205 X EMBU12 - 210	1.25	R
EMBU - 12- 210 X TL - 98B - 16760B	1.25	R
BM 98B - 98211 - 66 X EMBU 12 - 210	1.50	I
EMBU 12 - 210 X CN 224	1.50	I
TL 97B - 6790 - 5 X EMBU 12 -210	2.25	I
CN218 X EMBU 12 - 210	0.50	R
CML 202 X EMBU 12 - 210	0.75	R
CN 219 X EMBU 12 - 210	0.75	R
EM 98B - 98211 - 66 X EMBU 12 - 210	2.25	I
EMBU 12 X CN211	3.00	S
EMBU 12- 210 X CN 205	2.00	I
EMBU 12 - 210 X CN222	2.00	I
CN 205 X EMBU 12 - 210	2.00	I
EMBU - 12 - 210 X CN208	2.00	I
EMBU - 12- 210 X CN 211	2.75	S
CN 206 X EMMBU 12 - 210	2.25	I
CN 214 X EMBU 12 - 210	2.00	I
EMBU 12 - 210 X PR 98A7751B	2.00	I
EMBU 12- 210 X EMMBU 98B-98211-66	2.50	S
EMBU - 12 - 210 X POB591 c2f2 BCO Bulk TL 97B - 6790 - 9	1.50	I
KBO - 99B - 99A22- 2 X EMBU 12 - 210	1.50	I
CN226 X EMMBU12- 210	2.75	S
CN 204 - EMBU12 - 210	1.25	R
CN151 - EMBU 12 - 210	1.50	I
LSD	0.90	
P> f	*P* 0.0001	
CV	24.34	
Over all means	1.81	

[a] = Means; [b]R = Resistant accessopm (0.0-1.4); I = Intermediate (105-2.4); S = Susceptible (2.5-5)

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COMBATING HEAD SMUT OF MAIZE CAUSED BY *SPHACELOTHECA REILIANA* THROUGH RESISTANCE BREEDING.

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ABSTRACT

Head smut of maize and sorghum caused by *Sphacelotheca reiliana* was recognized as a constraint to maize and sorghum production in Kenya nearly 50 years ago. However, the only control methods recommended over the years were roguing and crop rotation. With the decreasing size of farms due to population pressure these methods are no longer feasible. Over the last five years, there has been a concerted effort to develop resistant maize types in an effort to control this important disease and to reduce yield losses. Over 580 maize genotypes were screened for head smut resistance at the National Agricultural Research Centre (NARC), Muguga. These entries were mainly inbred lines and populations from CIMMYT Harare and a few entries from the International Institute of Tropical Agriculture (IITA) Nigeria and CIRAD. Most of the 580 entries were susceptible but a few were rated moderately resistant, highly resistant and some rated immune. Some of the lines rated immune and those rated highly resistant were used in the breeding of single crosses, three-way crosses and double cross hybrids. The resulting hybrids are high yielding and have resistance to *S. reiliana*. Further evaluation of these hybrids is being carried out in the farmers' fields in a participatory manner to enhance the rate of adoption by the farmers in the disease prone parts of Kenya.

INTRODUCTION

Head Smut of maize and sorghum has a wide geographical distribution and probably occurs on maize and sorghum wherever they are grown in Europe, North and South America, Mexico, Asia, Australia and New Zealand, West Indies, Palestine, China and many other countries (Tarr, 1962). It appears to occur mainly on maize and sorghum spp. including sorghum, Johnson Grass, Sudan Grass and Teosinte, *Euchlaena mexicana*. The disease is sporadic and disease incidence of 50% or more has been reported from some countries, but in general this is rare. Infected maize plants are often stunted but the general growth habit of infected sorghum plants is little affected. In Russia, infected maize and sorghum plants were reported as somewhat taller than healthy ones, the fungus perhaps stimulating growth of the leafy stem and suppressing that of floral panicles (Bucheim 1935). In maize, *S. reiliana* can be responsible for a variety of symptoms and both tassel (male inflorescence) and cobs (female inflorescence) may be partially or completely smutted. In the tassel only, individual flowers may be attacked, whilst in the cob, smut is usually a single large spore mass with a transient enclosing membrane replacing the whole of the cob. Rudimentary cobs on the lower part of an infected plant may develop into twisted leafy shoots without sori and side shoots may be similarly transformed. In infected maize plants, all the ears are usually smutted if the tassels are smutted or the ears alone may develop smut (Bressman and Brass, 1933).

Description of Fungus

The spore mass, revealed by the rupture of the soral membrane consists of numerous chlamydospores intermixed with sterile cells. The spores themselves tend to form spore-balls of somewhat irregular shape and size (approx. 60-180μ). When mature the individual spores are somewhat opaque, dark brownish, globose to sub-globose.

Physiological Specialization

There is considerable experimental and field evidence that at least two parasitic races of *S. reiliana* exist; one, specialized to attack maize and the second on sorghum (Reeds 1923). For example in Sudan, maize head smut is not common but sorghum head smut is common although both cereals are cultivated throughout the country. However, a low level infection of sorghum with head smut occurs when maize head smut is used to inoculate sorghum. It was found out that head smut could pass from maize to sorghum and vice versa to a limited extent (Tarr, 1962).

MATERIALS AND METHODS

Field screening

Smutted maize ears from the maize breeding nursery provided the inoculum for the subsequent crop. The smutted ears were collected from the field and dried in the oven. Once dry, the smutted ears were crushed by hand to release the chlamydospores. These were separated from the vascular tissue with a sieve. Field inoculation was conducted at planting as described by Njuguna and Odhiambo (1989). The experiment was scored after flowering by visual examination of both the tassel and the ear for head smut symptoms. The plants were scored as smutted if either or both the tassel and the ear were smutted. The total percentage of smutted plants was computed for each entry and the entries classified as either immune, highly resistant, moderately resistant, susceptible or very susceptible according to the following rating scale:

0%	Smutted	-	Immune
1-9%	Smutted	-	Highly resistant
10-29%	Smutted	-	Moderately resistant
30-49%	Smutted	-	Susceptible
50-100%	Smutted	-	Very susceptible

Table 1. Maize germplasm screened for head smut resistance at NARC Muguga during the long rains 2001.

Entry #	Pedigree	Head smut % Incidence	Classification
1.	[P30/P45//Ml62W/MSR]97-269-1-1-3-B	32	S
2.	[P30/P45//Ml62W/MSR]97-240-7-1-1-B	66.7	VS
3.	[P30/P45//Ml62W/MSR]97-240-7-1-5-B	58.3	VS
4.	[P30/P45//Ml62W/MSR]97-312-3-1-3-B	4.5	HR
5.	[P30/P45//Ml62W/MSR]97-388-4-2-1-B	5.2	HR
6.	[P30/P45//Ml62W/MSR]97-388-4-2-1-B	10.5	MR
7.	[P30/P45//Ml62W/MSR]97-110-2-1-1-B	11.1	MR
8.	[P30/P45//Ml62W/MSR]97-269-2-1-1-B	4.6	HR
9.	[EarlyMid2/Gl6SR]-#-128-3-2-B	0	I
10.	[EarlyMid2/Gl6SR]-#-128-3-3-B	17.4	MR
11.	{EarlyMid2/Gl6SR]-#-95-2-2-B	47.6	S
12.	[EarlyMid2/Gl6SR]-#-168-1-2-B	40.9	S
13.	[EarlyMid2/Gl6SR]-#-283-1-1-B	14.3	MR
14.	[EV7992/Gl6SR]#bSlSel-F3-108-1-2-B	26	MR
15.	[TEWDSRDrtTolSyn/[NAW5867/P30SR(S2#)]]-#-160-1-1-B	4.8	HR
16.	[TEWFDrtTolSynl/[K64R/P30SR(S2#)]]-#-84-3-1-B	0	I
17.	Ac8730SR-#-124-1-1-B	35.7	S
18.	P30/P45//M162W/MSR]97-144-3-1-1-B	77	VS
19.	Pl: CML202	37.1	S
20.	P2: CML387	4.8	HR
21.	P3: CML389	34.8	S
22.	P4: CML390	46.2	S
23.	P5: CML393	0	I
24.	P6: CML395	18.8	MR
25.	P7: [MSRXPOOL9]ClF2-l76-4-1-4-X-X-2-B-B-2-l-l-B	5	HR
26.	P8: (87036/87923)-x-800-3-l-X-l-B-B-l-l-l-B-B	100	VS
27.	P9: {MSRXPOOL9)ClF2-205-l(OSU23I)-5-3-X-X-l-B-B-B-l-B-B	0	I
28.	P10: Ac8342/IKENNE{l}8149SR//PL9A]ClFl-500-4-X-l-l-BB-l-BB	45.5	S
29.	P11: FR810/TZMSRW-5-2-l-X-l-B-B-B	3.7	HR
30.	P12: {AC8232/NPPXSC/GWEBI{l}TZMSR-W]#b-144-5-4-1-3-X-X-l-B-B-B-B	55.2	VS

I = Immune
HR = Highly resistant
MR = Moderately resistant
S = Susceptible
VS = Very susceptible

Recommended agronomic practices for this area were followed in the experimental fields. DAP fertilizer was used at planting to provide 50 kg P/Ha and CAN used for top dressing to provide 50 kg N/Ha. Experimental design was a randomised complete block and each entry was replicated twice.

Development of a synthetic

Maize germplasm identified to be immune or highly resistant to *S. reiliana* in 1998 and 1999 was used to generate single crosses, three-way crosses and double crosses in the year 2000. These crosses were made regardless of the heterotic grouping of the parents. The plan was to use 10-12 parents to make a synthetic, which is still in process. These crosses are intermediate products some of which performed very well compared to local hybrids, especially H511. Some of these single crosses were screened for resistance in our nursery at NARC Muguga to assess the level of resistance to *S. reiliana*. One of the best three-way crosses was planted in farmers' fields in Meru where head smut disease incidence is very high. The purpose of this was find out if the resistance established in the centre will hold in a different ecological zone, and also to assess general performance in terms of yield. This work is going on this season.

Table 2. Some of the maize types from different sources rated immune to *S. reiliana* at NARC Muguga 1999.

Maize type/pedigree	**Source**
Pan 6587	Pannar
Pan 6243	Pannar
C 8026	Cargill
C 8001	Cargill
C 8016	Cargill
Sc 627	Seed-Co
Sc 709	Seed-Co
ACD 51	ACFD
ACD 62	ACFD
Inbred A/CML 202	CIMMYT (Harare)
DRB-180-2-1-B-B/CML 206	CIMMYT (Harare)
DRB-F2-60-1-1-1-B/CML 206	CIMMYT (Harare)

RESULTS

Disease incidence in the inoculated field plots ranged from 0% in the immune maize genotypes to 100% in the very susceptible genotypes. Table 1 contains a summary of data generated from a regional nursery 2001. All the entries were from CIMMYT Harare. All the five categories are represented in this data. An important observation in all smutted plants was that if the tassel was smutted then the ears were smutted as well. Occasionally the ear was smutted while the tassel was not.

The ears (cobs) were always fully smutted and no case of partially smutted ear was encountered in our screening nursery. Table 2 has a summary of some of the maize types immune to *S. reiliana* from different breeding programmes. Among six single crosses made in CIMMYT Harare and distributed to participants in the regional nursery in Eastern and Southern Africa during 2001, two entries were scored as immune, three highly resistant and one moderately resistant. When single crosses resulting from a resistant and a susceptible parent were screened the result was intermediate between the two parents.

DISCUSSION AND CONCLUSION

Head smut disease in maize was reported in a local daily as a cause of 30% yield loss of maize in Nyandarua district in the year 2000 (Daily Nation, December 19, 2000). This need not happen again although it probably happens every year but goes unreported. It was reported that there is good potential for developing maize hybrids resistant to head smut in CIMMYT germplasm, Njuguna (1998). This is now being realised from the data presented. The data from the regional nursery coordinated from CIMMYT Harare are circulated to all participants in the region. The single crosses sent to collaborators from CIMMYT Harare, or inbred lines identified, as resistant/immune should be a good starting point towards the desired products.

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WEED MANAGEMENT OPTIONS FOR SEASONAL WETLANDS (*VLEIS*) IN SEMI-ARID AREAS OF MASVINGO PROVINCE, ZIMBABWE.

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ABSTRACT

Discussions with small-scale farmers in semi-arid Masvingo, Zimbabwe indicated that weeds, waterlogging and labour shortages are major constraints in wetland (*vlei*) crop production. Various weed management options chosen by farmers and researchers were tested in four areas on two *vlei* types with maize and rice during the 2000/2001 season. This paper compares the use of traditional hand hoe weeding and post-emergence herbicides (bentazone in rice and maize-rice inter-crops on wet *vleis* and a mixture of atrazine and halisulfuron on maize in wet and dry *vleis*. Herbicides were applied three weeks after crop emergence using additional hoe weeding as required. Gross output was highest in the maize-rice inter-crops in the wet *vleis*. These treatments however required large amounts of labour and net benefits were higher on sole maize crops using herbicides. Farmers particularly liked the herbicide treatment in maize, but remained concerned about cost and their lack of knowledge about herbicides. No overall benefit from herbicide use in rice-maize inter-crops was apparent after one season's trials, which are currently being repeated for a second season.

Keywords: Crop production, herbicides, semi-arid, weed control options, wetlands (*vleis*)

INTRODUCTION

Seasonally inundated lands, variously known as *vleis*, *dambos* or wetlands, cover an estimated 3.5% (1,280,000 ha) of the area of Zimbabwe, 262,000 ha of which are found in communal areas (Mharapara, 1995). There is a general perception that *vlei* cultivation would lead to reduced dry season river flow and general degradation (Rattray *et al.*, 1953; Elwell and Davey, 1972; Bullock, 1992). As a result, *vlei* cultivation is restricted by legislation. namely the Water Act of 1972 (amended 1976), the Natural Resources Act of 1941 and the Public Streambank Protection Regulations of 1952.

Despite legislation, *vleis* are widely cultivated in many small-scale farming areas of Zimbabwe to produce maize, rice and groundnuts. The high water table in *vleis* makes planting of these crops possible in August/September, some two months ahead of the onset of the rains. Winter crops of wheat, beans and vegetables are frequently planted in April/May to benefit from residual moisture in the dry season. Thus *vleis* offer households the opportunity to double crop without using expensive irrigation systems, and in favourable seasons can provide a maize harvest two to three months before the maturity of upland crops which are totally dependent on rainfall. *Vleis* are therefore important for household food security, in many dry areas of Southern Africa (Whitlow, 1983; Faulker and Lambert, 1991, Owen *et al.,* 1995).

In the *vleis* of southern Zimbabwe, weeds, particularly the rhizomatous perennial grasses including *Cynodon dactylon, Leersia hexandea, Panicum repens*, and the tuberous sedge *Cyperus esculentus*, present a serious challenge to farmers because of their ability to re-establish rapidly following land preparation or when hoe weeded or ox-cultivated in wet *vlei* soils. Access to undertake mechanical weed control is difficult because of excessive wetness after the onset of rains and farmers largely rely on hoe weeding. Yield loss from weed competition depends on the wetness of the season, time of planting in relation to the onset of the rains and the duration of continuously wet conditions in the cultivated *vleis*. Maize yield losses of 100% were reported to be common due to waterlogging and excessive weed competition, particularly in seasons when early rainfall leads to standing water by November, and in late planted crops, (Mutambikwa *et al.,* 1999). In these situations only rice, from the commonly planted maize/rice mixture, will be harvested.

In the context of the two major problems (weeds and soil-water management) that prevent optimum utilisation of *vleis*, a research project was initiated in 1999. This aims to identify weed management practices that will increase productivity making maximum utilisation of existing resources particularly animals, implements and labour. This paper reports on the evaluation of weed management technologies by farmers and researchers during the 2000/2001 seasons.

MATERIALS AND METHODS

Experiments were established as a strip plot design with a strip of each treatment measuring from 30m x 5m to 45m x 5.6m depending on the size of a suitable *vlei* available in each field. The strips were replicated in three farmer's fields in each of four areas. Nine treatments were tested in *dhoro* (wet *vlei*) and *dhorobvukwa* (marginal or dry *vlei)* areas (Table 1) including sole maize, sole rice and maize-rice inter-crops with and without herbicides.

Maize and rice were planted before rain in September, germinating on residual moisture. The land was ploughed and harrowed just before planting. A short season Grey Leaf Spot tolerant maize cultivar, SC 513, was planted (2 seeds/station) at all sites at 90cm x 30cm to give a plant density of 37,000 plants ha^{-1}. Planting furrows were immediately closed using harrow, hoes or feet to avoid the

Table 1. Treatments in wet and dry *vleis*. Rice seed rate was 60 kg ha^{-1} unless stated. Herbicides applied 3 weeks after planting.

Treatment	Crop	Herbicide g a.i. ha^{-1}	Other weeding
Dry *vleis*			
T1	Maize	Atrazine 1,250 g Halisulphuron 33.75	Hoe as required
T2	Maize	Nil	Hoe
T3	Maize + rice in same row (farmer practice)	Nil	Hoe from 3 weeks after planting
T4	Maize + rice in rows between maize rows	Bentazon 1,440 g	Hoe as required
Wet *vleis*			
T1	Rice broadcast (120 kg ha^{-1})	Bentazon 1440 g	Hoe as required
T2	Maize + rice in same row (120 kg ha^{-1}) (farmer practice)	Nil	Hoe from 3 weeks after planting
T3	Maize + rice broadcast	Bentazon 1,440 g	Hoe as required
T4	Rice in rows (120 kg ha^{-1})	Bentazon 1,440 g	Hoe as required
T5	Maize	Atrazine 1,250 g Halisulphuron 33.75	Hoe as required

soil around the seed drying out. Maize was thinned to one plant per station 2-3 weeks after emergence (WAE). A local variety of rice, *Muchecheni*, was broadcast, or dribbled into shallow planting furrows opened by cultivator, and covered with a harrow.

Fertiliser (Compound D - 8%N, 14%P and 7%K) was applied at 150 kg ha^{-1}, in planting furrows. Where rice was broadcast between maize rows, half the fertiliser was placed in the planting furrows and half broadcast in the inter-row area. For broadcast rice treatments, the fertiliser was broadcast uniformly. Ammonium nitrate (34.5% N) was side-dressed on maize or rice in rows. In maize-rice intercrop and broadcast rice the fertiliser was at 100kg ha^{-1} at 6 WAE. Herbicides were applied 3 WAE when most of the weeds were at the 2-3 leaf stage. Although emerged weeds were actively growing from residual moisture, surface soil conditions were dry and atmospheric conditions hot and dry. Before weed control at 3 WAE, weeds were counted by species, in three randomly placed 30cm x 30cm quadrats in each treatment. Weeds were also counted in the same marked quadrats at 6-7 WAE, just before the second weeding. Counted weeds were cut at ground level and oven dried to constant weight. At maize physiological maturity, at 12-13 WAE, weeds were counted in three 30cm x 30cm random quadrats in each treatment and biomass determined as before. A third hoe weeding was necessary only for the sole rice treatments in wet *vleis* at 12-13 WAE.

Maize and rice were harvested from three randomly marked quadrats each 4 rows x 8-10 m long for treatments with maize and, 3.6-4m wide x 8-10m long for rice. Maize yield was standardised to 12.5 % moisture content before analysis of variance. Weed density data were square root transformed before analysis of variance.

RESULTS AND DISCUSSION

Weed spectrum and density

The results presented are means for trial sites across the four areas, based on weed counts conducted at 3 WAE. The total weed abundance on wet *vleis* was almost twice that on dry *vleis* (Table 2). The most dominant weeds were *Cyperus esculentus* and *Richardia scabra* on both *vlei* types. Although *C. esculentus* was the most dominant weed on both *vlei* types, it constituted a greater proportion of total weed number (69.15%) on wet *vleis* than on dry *vleis* (45.18%). *R. scabra* was more adapted to dry *vlei* as it constituted a larger proportion (37.29%) of dry *vlei* weed spectrum than on wet *vleis* (12.57%). Other weeds like *Urochloa panicoides* and *Setaria pumila* were also more abundant on wet *vleis* while *Cynodon dactylon* and *Hibscus meeusei* were dominant on dry *vleis* although these weed species were found in low numbers. The difficult-to-control rhizomatous perennial *Panicum repens,* was also a common component of the weed flora.

Effect of weed control treatments on weed density and biomass

The weeding treatments significantly affected ($P<0.001$) weed density but had no effect on weed biomass ($P>0.05$) at the first assessment carried out three weeks after first weed control at 6-7 WAE (Table3) in wet *vleis*. The highest weed density at that stage was recorded where maize and rice were planted in the same row and only hoe weeding was used for weed control (T2, farmer practice). However weed density was similar for the farmer practice treatment (T2), in broadcast rice with bentazone (T1) and in the maize/broadcast rice mixed crop in which bentazone was applied (T3). There was a significantly lower weed density in sole rice planted in rows with bentazone (T4) compared toT2, which had similar weed density to T1 and T3 treatments. The lowest weed density, approximately half of the T1, was recorded where halisulphuron plus atrazine (T5) had been applied at 3 WAE in the sole maize (Table 3). It is noticeable that despite T2 having the highest weed density, it recorded the lowest weed biomass.

Three weeks after the second weed control treatments had been applied in wet *vleis* the weeding treatments significantly ($P<0.05$) influenced weed density but did not have an effect ($P>0.05$) on weed biomass. (Table 3). Weed density was highest in the sole maize with halisuphuron plus atrazine

Table 2. Weed species abundance at trial sites three weeks after crop emergence. Number m^{-2} and % contribution to total.

Weed species	Dry vleis		Weed species	Wet *vleis*	
	No. m^{-2}	%		No. m^{-2}	%
Cyperus esculentus	53.00	45.18	*Cyperus esculentus*	144.20	69.15
Richardia scabra	43.75	37.29	*Richardia scabra*	26.22	12.57
Cynodon dactylon	9.03	7.70	*Urochloa panicoides*	13.54	6.49
Panicum repens	3.58	3.05	*Panicum repens*	8.24	3.95
Hibiscus meeusei	2.63	2.24	*Setaria pumila*	7.14	3.42
Eleusine indica	1.93	1.65	*Eleusine indica*	4.00	1.92
Urochloa panicoides	1.54	1.31	*Hibiscus meeusei*	2.96	1.42
Digitaria milanjiana	0.77	0.66	*Cynodon dactylon*	1.22	0.59
Setaria pumila	0.62	0.53	*Cassia mimosoides*	0.67	0.32
Commelina subulata	0.24	0.20	*Commelina subulata*	0.34	0.16
Alibigardia hispidula	0.23	0.19			
Total	117.32			208.53	

Table 3. Weed density (number m^{-2}) and biomass (g m^{-2}) in wet *vleis* in Masvingo 6-7 and 12-13 weeks after crop emergence (WAE).

Treatment	6-7 WAE, 3 weeks after weed control treatment		12-13 WAE, 3 weeks after weed control treatment	
	Weed density	Weed biomass	Weed density	Weed biomass
T1. Rice + herbicide	608 (22.8 a)	210	198 (13.0 a)	389
T2. Maize and rice in row – herbicide	781 (25.9 ab)	80	234 (14.7 ac)	235
T3. Maize and rice broadcast + herbicide	641 (23.7 a)	153	235 (14.7 ac)	246
T4. Rice + herbicide	504 (20.2 b)	171	181 (12.6 b)	278
T5. Maize + herbicide	305 (15.6 c)	181	269 (15.7 c)	132
Significance	***	NS	*	NS
SED (d.f.)	2.0 (148)	2.7 (40)	1.00 (148)	2.72 (40)
CV%	38	57	28	45

NB. Figures in brackets show the square root transformed data.
* Significant at P< 0.05; *** significant at P< 0.001; NS = not significant

treatment (T5) although this was statistically similar to T2 and T3 (Table 3). The lowest weed density was recorded in the broadcast sole rice with bentazone plus hoe weeding (T1) but this density was similar to T4, T2 and T3. It should be noted that although weed density was highest in T5 (Halisulphuron plus atrazine post emergence at 3-4 WAE), this treatment had the lowest weed biomass at the second assessment in wet *vleis* (Table 3).

In dry *vleis*, weed management treatments had a significant effect (P<0.001) on weed count at both first and second weed assessments (Table 4). Weed density was lowest in T1 (atrazine plus halisulphuron post emergence herbicide) at the first assessment. All the other three treatments had a similar weed density that was higher than T1 at the first assessment. At the second assessment, three weeks after the second weed control, weed numbers were highest in T1, followed by T3 and T2. The lowest weed density was recorded in T4 (Table 4).

Weed biomass was not affected (P>0.05) by the weeding treatments at the first assessment (Table 4). At the second assessment, the dry mass of weeds was highly influenced (P<0.001) by the weeding treatments. The lowest weed biomass was recorded in T1 but was not significantly different from biomass observed in T2 or T3. The highest weed biomass was recorded in T4 (Table 4).

Maize and rice yields in wet *vleis*

Weed control practice had a significant effect (P<0.05) on maize yield in the wet *vleis*. Yield of maize was highest in the herbicide treatment followed by yields in maize/rice planted in the same row. The lowest maize yield was where rice was broadcast between maize rows (Figure 1). Sole maize with herbicide had the highest yield because of reduced competition from weeds and lack of competition from the rice crop. The herbicide treatment had the lowest weed density at 6-7 WAE and the lowest weed biomass at 12-13 WAE. The low weed biomass attained by this treatment at the second weed assessment showed the combined effectiveness of halisulphuron and hoe weeding on *Cyperus esculentus*, the dominant weed species in wet *vleis*. Broadcast rice seemed to provide more competition for resources against maize than when the two crops planted are in the same row as evidenced by the lower maize yield in the maize with broadcast rice mixed crop (Figure 1).

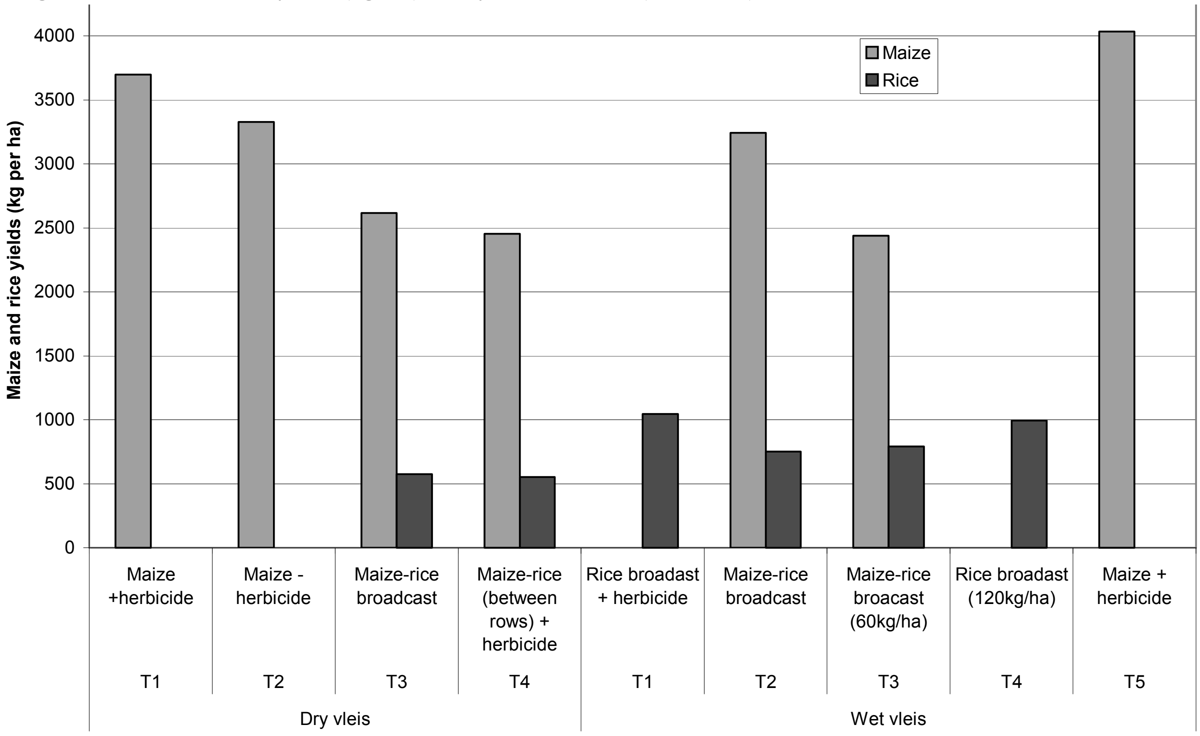
The weed management treatments had a significant influence (P<0.01) on rice yield in wet *vleis*. Rice yield was

Table 4. Weed density (number m^{-2}) and biomass (g m^{-2}) in dry *vleis*.

Treatment	6-7 WAE, 3 weeks after weed control treatment		12-13 WAE, 3 weeks after weed control treatment	
	Weed density	Weed biomass	Weed density	Weed biomass
T1. Maize + herbicide	346 (16.6 a)	273	230 (14.5 a)	90
T2. Maize - herbicide	816 (27.5 b)	88	168 (12.7 b)	124
T3. Maize and rice in row - herbicide	697 (25.7 b)	109	190 (13.4 b)	109
T4. Maize and rice in alternate rows - herbicide	705 (25.6 b)	117	131 (11.0 c)	324
Significance	***	NS	***	***
SED (d.f.)	1.4 (94)	2.93 (30)	0.8 (94)	1.3 (30)
CV%	24	71	27	27

Figures in brackets show the square root transformed data.
* Significant at P< 0.05; *** Significant at P< 0.001; NS = not significant

Figure 1. Maize and rice yields (kgha^{-1}) in dry and wet *vleis*, (2000/2001).



higher in broadcast or row planted sole rice at a higher seed density than the rice maize mixed crops where the rice was seeded at 60 kg ha^{-1} (Figure 1). However there was no significant difference (P<0.05) between rice yields of maize/rice inter-crops whether the rice was broadcast or planted in the same row with maize. Rice yields in sole rice crops at a higher seeding rate, were similar in the two rice spatial arrangements. The higher rice yields obtained in the sole rice crops compared to the rice maize mixed crops are a reflection of the lack of competition from maize in the sole rice crops.

Maize and rice yield in dry *vleis*

Maize yield was significantly influenced (P<0.001) by the weed management treatments in dry *vleis*. The atrazine/halisulphuron herbicide treatment had significantly higher maize yield than sole maize with no herbicide (Figure 1), which had significantly higher yield than the maize rice mixed crops, regardless of the spatial arrangement. There was no significant difference in maize yield due to the intra-row or inter-row spatial placement of rice in the maize rice mixed crops (Figure 1). The higher maize yield obtained where herbicide was used reflects improved weed control over the farmer practice treatment. This is borne out by the mid-season evaluation of the trials when farmers nominated the herbicide treatment as best from both a weed control and crop vigour perspective. In addition the weed density and biomass data from the dry *vleis* clearly confirmed the efficacy of this treatment over either hoe weeding or using bentazone plus supplementary hoe weeding, in agreement with the observations made by farmers during mid-season evaluation.

There was no significant difference (P<0.05) in rice yields on dry *vleis* even though a higher yield was recorded where rice was grown in the same row with maize than where it was planted between the maize rows (Figure 1).

Figure 2. Gross benefits from each treatment ($ per ha).

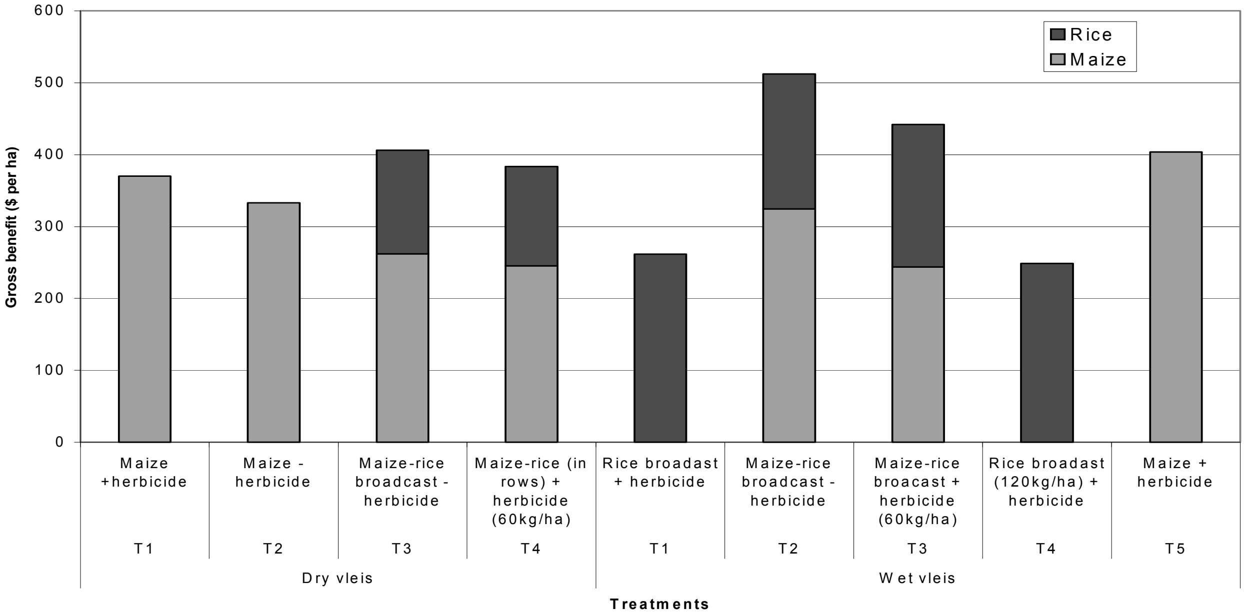


Table 5. Partial budget analysis.

	Treatment	Crop value			Costs that vary			Value less costs	Difference with farmer treatment
		Maize	Rice	Total	Herbicide	Labour	Total		
Dry vleis									
T1	Maize + herbicide	370	0	370	58	340	398	-28	22
T2	Maize - herbicide	333	0	333	0	364	364	-31	18
T3	Maize-rice broadcast - herbicide[1]	262	144	406	0	455	455	-50	0
T4	Maize-rice (in rows) - herbicide	245	138	383	0	442	442	-59	-9
Wet vleis									
T1	Rice broadcast + herbicide	0	262	262	63	246	309	-47	-40
T2	Maize-rice broadcast - herbicide[1]	324	188	512	0	519	519	-7	0
T3	Maize-rice broadcast + herbicide	244	198	442	63	477	540	-98	-91
T4	Rice broadcast (120kg/ha) + herbicide	0	249	249	63	251	313	-65	-58
T5	Maize + herbicide	404	0	404	58	352	410	-7	1

[1] Farmer treatments

Key assumptions: Maize price: $100 per tonne, Rice price: $250 per tonne, Labour price: Z$1.60 per day Herbicide costs: Include cost of herbicide and knapsack sprayer (spread over 5 years, 5 ha each year); US $1=Z$150

Economic analysis

Key variables in determining the highest returns are crop yields, market prices, and the cost of applying herbicide versus savings in labour for each cropping system. Average yields from each of the treatments (Figure 1) and average farm-gate prices have been used to determine the value of the crops produced (Figure 2). Additional herbicide and labour costs for weeding and other operations for each cropping system using either market or opportunity costs have been determined and a partial budget analysis used to determine the most profitable treatment for 2000/2001 season at 2001 prices (Table 5). Differences in net benefit between treatments have been compared showing an increase or decrease over those most commonly used by farmers (Table 5 and Figure 3a and 3b).

Sensitivity analysis on these variables indicates that the price of labour is key. When this is low, traditional farmer systems are the most productive. As labour price increases, due to unavailability or opportunity elsewhere, new systems are more productive. At a labour price of $1.60 per day the growing of maize as a sole crop is the most productive but at $3.20 per day rice or maize as sole crops with herbicide are the most productive systems. This does not however account for the importance of a maize-rice intercrop for risk reduction and for food security in climatically different seasons.

The trials do not reflect the scarcity of labour and the fact that in many seasons the entire crop is lost due to weeds. In such circumstances the use of herbicides is going to be increasingly justified.

Figure 3a. Partial budget comparison with farmer practices (T3 in dry vleis; T2 in wet vleis) at labour rates $1.60 per day.

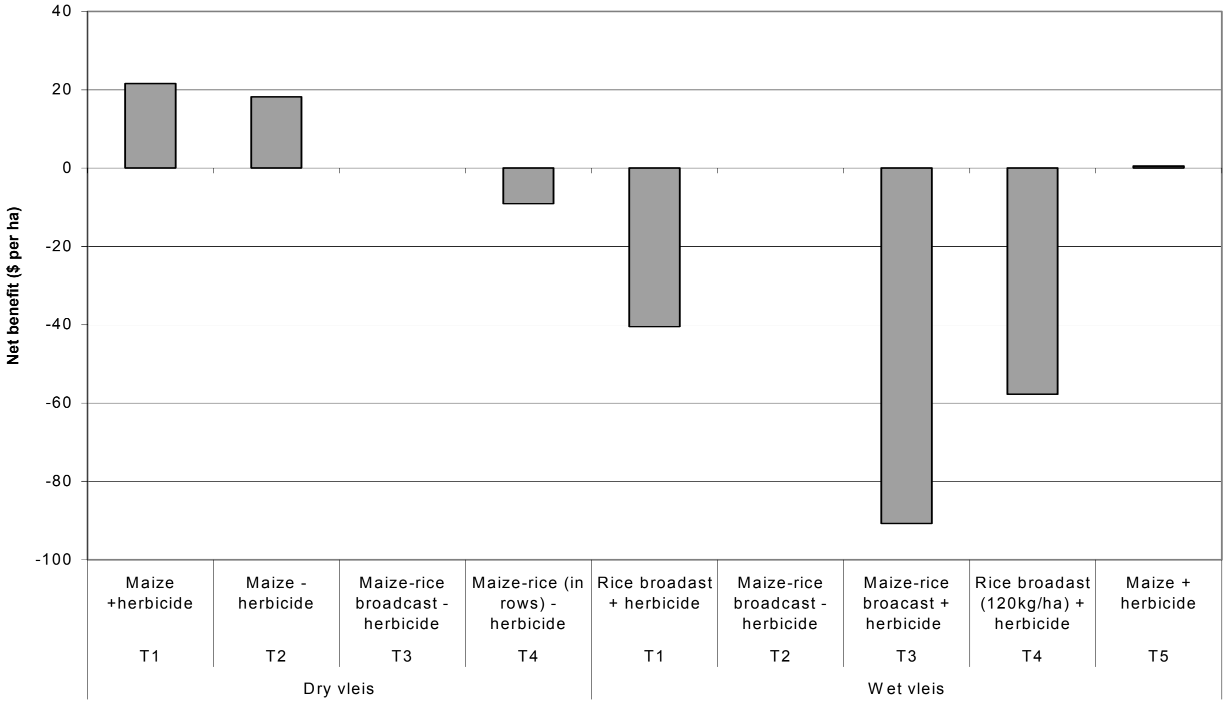
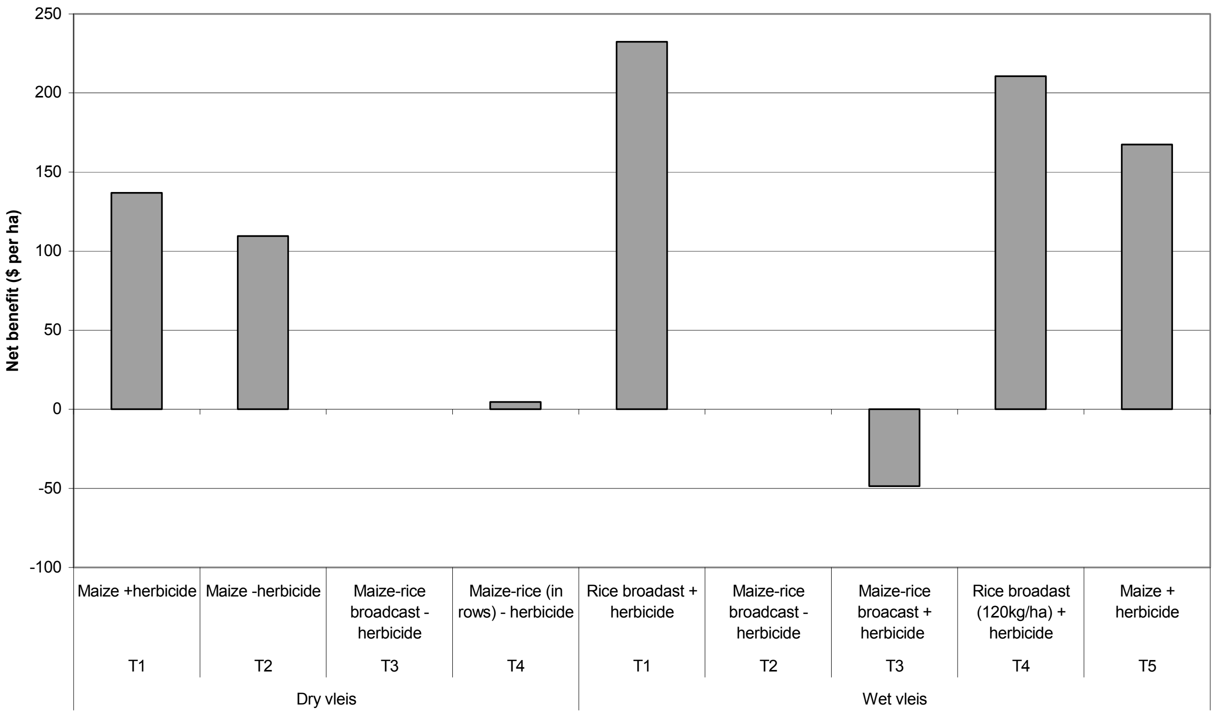


Figure 3b. Partial budget comparison with farmer practices (T3 in dry vleis; T2 in wet vleis) at labour rates $3.20 per day.



DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

These preliminary results indicate that although *Cyperus esculentus* is the dominant weed species in the *vleis*, it tends to be more predominant in the wet *vleis* than in the dry *vleis* followed by *Richardia scabra,* which formed a greater proportion of total weed number in dry rather than wet *vleis*. *Cynodon dactylon* and *Hiibscus meeusei* were more prominent in dry than wet *vleis* and *Urochloa panicoides* and *Setaria pumila* were more in wet *vleis*. *Panicum repens* was present at higher density in wet *vleis*.

The atrazine/halisulphuron treatment in maize gave the highest productivity in both wet and dry *vleis*. This treatment was chosen as the best from a weed control and crop vigour perspective by farmers. Halisulphuron proved particularly effective against *Cyperus esculentus*. Bentazone treatments were not as effective as bentazone is a contact herbicide and only caused a temporary setback to the perennial sedges in both *vlei* types. Maize yields were higher in the wet *vleis* in 2000/2001 season because of the prolonged mid-season drought experienced during January. The wet *vleis* did not suffer from waterlogging until late in the season when maize crops were maturing. Rice yields followed the same trend.

Maize yields were also higher in the sole crops than in the maize-rice inter-crops in both *vlei* types. Rice yields were higher in the sole rice crops seeded at 120kg ha^{-1} than in the maize rice mixed crops where the rice was seeded at 60kg ha^{-1}. Sole crop yields of both maize and rice probably produced higher yields because of the absence of competition from the accompanying crop. It is also likely that the higher rice seed rate in sole rice crops contributed to higher yields.

Economic analysis has shown that in both *vlei* types greatest productivity is achieved growing sole maize crops with herbicides and as the price of labour increases rice as a sole crop with herbicide. However the importance of inter-cropping for food security must be considered. Sensitivity analysis showed that where labour is available at low opportunity cost, maize-rice inter-crops with no herbicide are the most productive options. This does not however take into account declining labour availability in many households due to both the present AIDS epidemic and unwillingness to work in waterlogged and difficult conditions. There remains therefore a need to find a low cost herbicide that will allow effective weed control.

To date the use of halisuphuron in both maize and rice (inter-cropped and sole crops) looks the best-bet option. Although it was only used in sole maize in 2000/2001 it was subsequently learnt that it is selective to both crops. It proved to be more effective for sedge control than bentazone. This will alleviate labour constraints experienced by farmers in the early season when labour is required both to weed early-planted *vlei* crops and prepare and plant topland areas. However a lack of knowledge about herbicides and their application by both extension personnel and farmers make training on their use a priority to widen the weed management options available to farmers.

There remains a need to test the efficacy of other foliar applied translocated herbicides like glyphosate on difficult weed species like *Cyperus esculentus* and *Panicum repens* that are problematic and difficult to control especially under the wet conditions of *vleis*. These herbicides could be directed, using weed wipers or wide-angle flood jet nozzles between the crop rows, or applied after harvest to reduce weed populations. Work is on-going to test these methods of weed control.

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MASS REARING OF THE MAIZE STEM BORERS *CHILO PARTELLUS*, *BUSSEOLA FUSCA*, *SESAMIA CALAMISTIS*, *CHILO ORICHALCOCILIELLUS* AND *ELDANA SACCHARINA* AT KARI, KATUMANI.

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ABSTRACT

An insect rearing facility was established at the Kenya Agricultural Research Institute (KARI) Centre of Katumani in Machakos, Kenya, in 1999, and has to date improved significantly in its scale of operation. The primary purpose of this facility is to provide stem borers for use in resistance screening studies, insect bioassays and for oviposition/feeding preference studies within KARI projects. The stem borers that are reared are: Chilo partellus (Swinhoe), Chilo orichalcocilliellus Strand, Eldana saccharina Walker (Lepidoptera: Pyralidae) Busseola fusca Fuller and Sesamia calamistis Hampson (Lepidoptera: Noctuidae), with the bulk production being for the first two species due to their relative higher demand for use in resistance screening studies. This paper describes the insect rearing facility, procedures used, records taken, problems encountered during rearing and the steps taken to address them. Since initiation of the insectary in 1999, the scale of production has improved significantly, with the seasonal supply of insects increasing from 26,000 in long rains 2000, to 961,689 stem borers in the long rains 2001. There have also been improvements in the quality of production, record keeping and in the supply system in terms of synchrony of the stem borer supply with the various end-uses. As part of the efforts to improve the rearing techniques, a laboratory study was conducted to compare the survival to pupation of B. fusca larvae in large plastic jars (16 x 7.5 cm - 250 ml of diet - 20 larvae) compared to glass vials (7.5 x 2.5 cm - 15ml of diet - 1 larva). There was no significant difference in the survival to pupation of larvae reared in the plastic containers (80.5%) and the glass vials (85.2%) (t= 1.59; d.f = 10; P= 0.143). Since the plastic container saves on the time of infestation (egg batches can be used), is less breakable and is cheaper, it has now been adopted for the rearing of B. fusca at the Katumani insectary.

Keywords: Advanced rearing techniques, mass rearing, stem borers.

INTRODUCTION

Lepidopteran stem borers are one of the major constraints to maize production in Kenya (Warui and Kuria, 1983; Seshu Reddy and Walker, 1990), and the most damaging species are Chilo partellus (Swinhoe), Busseola fusca (Fuller), Chilo orichalcociliellus (Strand), Sesamia calamistis (Hampson) and Eldana saccharina (Walker) (Seshu Reddy, 1983; Warui et al., 1986; Overholt et al., 1997; Songa et al., 1999; Songa et al., 2001). Host plant resistance is one of the preferred methods of controlling stem borers. In an effort to develop stem borer resistant maize varieties, large numbers of stem borers are used in resistance screening studies at the Kenya Agricultural Research Institute (KARI) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT). The unpredictability and seasonal dynamics of field populations of insects necessitate the need for use of artificial infestation in these stem borer resistance screening studies.

As part of the process of introduction of Bt-maize for the control of stem borers in Kenya within the Insect Resistant Maize for Africa (IRMA) project, stem borers are required for several controlled studies including bioassays and field studies on feeding/oviposition preference by the stem borers on maize and other alternate host grasses.

The success of the above-mentioned studies relies on a dependable supply of high quality insects in adequate numbers, at specified times, and at specific stages of development. The purpose of the insectary at KARI, Katumani is therefore to rear and supply stem borers for resistance screening studies, insect bioassays and for baseline studies within the IRMA project.

MASS REARING OF STEM BORERS AT KARI, KATUMANI

Rearing facilities

The rearing facility at KARI, Katumani consists of various rooms which are used for the different rearing activities, and these are: two insectaries for larval and pupal development and for egg incubation, one room for diet preparation and infestation, one for pupal harvesting, one for adult emergence and oviposition, one washing room and a store for the diet ingredients.

The two insectaries are maintained at different environmental conditions. One has the standard rearing conditions (28^{o} C, 60-70%RH, 12:12 light-dark photoperiod), while the other one is maintained at 20^{o} C, 60-70 % RH, 12:12 light-dark photoperiod, and is usually used when insect development needs to be delayed. Sometimes, the rate of development of the larvae or pupae may need to be altered in order to better coordinate the larval supplies or egg supplies of the following generation, with research needs. The environmental conditions within the moth house are maintained at 24 - 25^{o}C and 55-60% RH, with a 12:12 light:dark photoperiod.

Table 1. Diet ingredients for rearing stem borers at KARI - Katumani, Kenya.

Ingredient	Quantity (g or ml) per 3 litre diet
Fraction A	
Maize leaf powder*	75.6
Bean (*Phaseolus vulgaris*) powder**	265.2
Brewer's yeast	68.1
Ascorbic acid	7.5
Sorbic acid	3.9
Methyl-p-hydroxybenzoate	
(Dissolved in 20 ml Ethanol (absolute)	6.0
Vitamin E capsules (200 iu)	6.3
Sucrose	105.9
Distilled water	1209.3
Fraction B	
Agar (Tech. No.3)	37.8
Distilled water	1209.3
Fraction C	
Formaldehyde 40%	6.0

*6-week old leaves washed with tap water, dried at 60^0C for 12 h till brittle and ground using an electric grinding mill.

**Seeds washed with tap water, dried at 60^0C for 24 h and ground to a fine powder.

Colony establishment

The founder stem borer colony was procured from the insectaries at the International Centre of Insect Physiology and Ecology (ICIPE), in order to ensure that it was free from major parasite or pathogen infections. However, in order to avoid genetic decay, to ensure continued adequate heterozygosity among the insects, and maintain the original behavioral characteristics of the species, seasonal gene infusion is used as the main colony maintenance strategy. At the end of every season, field populations of stem borer larvae and pupae are collected from various maize growing regions in Kenya. The field-collected insects are usually reared in isolation for at least one generation in order to prevent contamination of the laboratory colony. Males from the second generation of the field-collected material are then allowed to cross breed with the laboratory colony.

Rearing procedures

Diet preparation: The five stem borer species at the KARI-Katumani insectary are reared using the same type of artificial diet, the composition of which is shown in Table1. The diet ingredients and procedure for diet preparation were adopted from Onyango and Ochieng-Odero (1994). The procedure for diet preparation:

Fraction A: All the powdered ingredients from this fraction including sucrose and vitamin E, are mixed under a fume hood, in a clean container using a plastic spoon. The distilled water is boiled, cooled to 60^{o}C, and then mixed with the above mentioned pre-mixed ingredients using a blender for 1 minute. Methyl-P-hydroxybenzoate that has been dissolved in 20 ml of ethanol absolute is then added into the mixture in the blender and then mixed for a further 2 minutes.

Fraction B: Agar powder is weighed in a separate container and then added to cold distilled water in a separate saucepan, boiled while stirring periodically, and then cooled to 60^{o}C. Ingredients of Fraction B are added to Fraction A in the blender and then mixed for 3 minutes.

Fraction C: Finally, formaldehyde 40% is added to the ingredients of fractions A and B in the blender and then mixed for 3 minutes.

Dispensing of diet: 250 ml of diet is dispensed while warm, into heat-sterilized (65^{o} C for 1.5 h), 1000 ml capacity, wide-mouthed plastic jars (16 x 7.5 cm diameter) using a jug. After the diet is dispensed, the containers are left open for 2hours to allow escape of the excess moisture, after which they are covered using a clean white cloth or paper towel and then left to gel and condition overnight at room temperature on a bench in the laboratory. Each of the five stem borer species is reared using the same type of plastic container described above.

Diet infestation: The surface of the diet in each jar is first punctured in several places using a sterilized plastic rod to facilitate larval penetration. Diet infestation is usually done using surface sterilized black-head-stage eggs, however, sometimes neonate larvae from pre-sterilized eggs are also used. Egg masses containing the following respective number of eggs for each species are introduced into each plastic jar containing diet. For C. partellus, C. orichalcociliellus and E.saccharina - 50 eggs, while for for B. fusca and S. calamistis 25 eggs are used.

The piece of paper bearing the egg mass is usually placed vertically on the edge of the diet within the container. This placement has been observed to reduce chances of infection of the diet. When neonate larvae are used, the same respective number of larvae are introduced into the rearing jar using a sterilized camel-hair brush no. 1., in such a way that the brush does not come into contact with the diet. After infestation, the mouth of the jar is covered with a paper towel and then covered with a screw-cap that is ventilated with very fine wire mesh to prevent larval escape. The paper towel is meant to absorb excess moisture within the rearing jar during larval development.

Colony maintenance

Larval and pupal management: After diet infestation, the larvae are allowed to continue feeding undisturbed within the jars until pupation. Close monitoring for pupal harvesting usually starts at specific respective times for each of the five stem borer species (Table 2). For example, in the case of C. partellus, close monitoring for pupal harvesting starts at 30 days from the time of diet infestation. However, at times, temperatures in the insectary may vary (> 28^{o}C) hence resulting in faster insect development than expected. For this reason, all containers are checked at the end of each day in order to avoid moth emergence within the rearing jars.

Pupation of the five stem borer species is asynchronous, occurring over a period of 5-7 days. However, in order to reduce chances of pupal injury, pupal harvesting from each jar is usually done once, when most (at least 40%) of the larvae in the jars have pupated. The larvae that would not have pupated by this time are kept in sterilized plastic jars containing clean moist paper towel until they pupate. Pupal harvesting is done manually; the diet from each jar is emptied onto a clean tray, and the pupae are sorted and transferred into a plastic container lined with tissue

Table 2. Duration between stem borer life stages at 28^{o}C, 65-70% RH, 12:12 light: dark photoperiod, and the fecundity of the various stem borer species, at the Katumani insectary.

Stem borer species	Duration (days)					Fecundity
	Egg* to Black head egg	Egg* to Neonate	Neonate to Pupa**	Pupa** to Moth***	Pre-oviposition	
Chilo partellus	5	6	30-32	8	1	150
Busseola fusca	5	6	40-45	14	2	250
C.orichalcociliellus	4	5	30-33	10	1	150
Eldana saccharina	5	6	30-33	10	1	250
Sesamia calamistis	5	6	35-36	12	1	250

*Freshly laid egg Neonate - 1st instar larva **Freshly pupated ***Freshly emerged moth Fecundity – Avg. no. of eggs laid per female

paper. When sorting is complete, the pupae are cleaned in batches of about 30 in the hand, by applying a gentle spray of distilled water until they look clean. The pupae are then placed on clean tissue paper to drain the excess water for about five minutes, after which they are transferred in batches of up to 100, to petri dishes (each 9cm diameter x 1.5cm depth) each lined with moist tissue paper. Pairs of petri dishes (containing pupae) are put in each emergence cage, which consists of a plastic container (15 x 22 x 15 cm) ventilated at the top with fine wire mesh. The emergence cages are kept at 28o C, 80-90% RH, 12:12 light:dark photoperiod. A RH of 80-90% is maintained in the emergence cage by placing a plastic cup containing water-soaked cotton wool in the cage at all times.

Maintenance of the moths: The emergence cages are monitored at the beginning of each day, and the emerged moths collected using a glass vial (7.5 x 2.5 cm diameter), and then transferred to an aluminum-frame oviposition cage (45L x 60H x 45W cm), lined with wire mesh on the sides, having a vertically sliding door at the front and an aluminium sheet at the bottom. Each cage holds up to 200 pairs of adults.

Each of the oviposition cages is lined with waxed paper at the bottom. The oviposition substrate for all the five stem borers is waxed paper, however, the paper is moulded into different shapes appropriate for oviposition by each of the species. The shape of oviposition papers for C. partellus and C. orichalcociliellus is the same, and is as follows: the waxed paper is folded to form several pleats, which are then suspended through slits at the top of the cage. The oviposition substrate for B. fusca and S. calamistis is the same and it comprises of wax paper that has been wound to form long 'tubes', that have closely overlapping edges similar to the leaf sheaths in maize plants. The 'tubes' are then placed diagonally within each cage. For E. saccharina, sheets of waxed paper are folded into 4 pleats, on top of each other, and lined at the bottom of the cage. At the same time, strips of tissue paper folded longitudinally, are suspended within the cage from the top. The moths feed on water from a water-soaked cotton wool in a petri-dish placed in each cage.

The cages are serviced daily, and this involves removing and replacing the waxed oviposition paper sheets, putting in newly emerged moths through the sliding front door, replacing the feeder (water-soaked cotton wool in a petri dish) and spraying the cages with water. Also, at the end of each week, the dead moths are removed from the cage after which the cage is cleaned and disinfected. The live moths are transferred to a freshly set cage.

Egg management: Eggs oviposited on the wax papers are collected daily from the cage, and fresh wax paper replaced. Waxed paper sheets (with the attached eggs) are folded, put diagonally in a plastic container, transferred to the insectary, and then allowed to develop at 28^o C . A RH of 80 - 90% is maintained in the container, by putting a wide plastic dish having water-soaked cotton wool at the bottom of the container, below the oviposition papers.

The eggs are allowed to develop in the insectary for at least three days, after which they can either be allowed to continue developing in the insectary for additional days up to black-head stage (Table 2), or their rate of development can be slowed by transferring them to a refrigerator (10^o C) for up to three days. After the 3 days at 10^o C, the eggs have to be brought out to complete development under normal temperature conditions. At 28^o C, the eggs of the different stem borer species develop to black-head stage in 4 - 6 days (Table 2). For the case of E. saccharina, the eggs are glued to the oviposition substrate. For this reason, the wax papers or tissue papers are sprayed with water in order to dislodge the eggs from the glue and thus allow collection of eggs from the papers.

Surface sterilization of eggs: The eggs are usually sterilized at the black-head stage. In preparation for sterilization, the eggs are cut off the butter paper using scissors, into batches (50 eggs per batch). The eggs are then surface-sterilized by dipping them in 10% formaldehyde for 15-20 minutes, rinsing them thoroughly (at least 5 times) using distilled water and then drying them on filter paper.

Records at the insectary:

Two standard sets of records are kept at the insectary:

1. Infestation data: This includes the date of diet preparation and the batch number, the stem borer stage and the number infested into each specific container, date of infestation of the diet, the current generation, a summary form indicating the total number of jars infested and the total number of stem borers infested into the diet on each specific date.
2. Production data: There are two types of production data: pupal and egg production. Pupal production: this includes: the date, number and weight of pupae harvested from each specific container, and a summary form indicating the total number and weight of pupae harvested on each particular date. Egg production: This includes the date and number of eggs laid on each specific oviposition paper, and a summary form indicating the total number of eggs on each date. Simple quick methods are used for estimation of the egg numbers for each of the stem borer species.

Table 3. Stem borers supplied* by the Katumani insectary during each of three seasons.

Stem borer species	Number of stem borers supplied		
	Long rains 2000	Short rains,2000	Long rains, 2001
Chilo partellus	26,000	193,540	712,269
Busseola fusca	-	244,067	236,420
Sesamia calamistis	-	3,300	10,000
Eldana saccharina	-	3,300	3,000
Chilo orichalcociliellus	-	3,300	-
Total	26,000	447,507	961,689

* The total number of stem borers supplied increased by 1621.2% and 114.90 % in the period from the long rains 2000 to the long rains 2001.

Health maintenance of the colony

Various strategies are used to prevent microbial contamination in the insectaries.

i) The floors of the insectary are mopped at the end of each day, using soapy water containing jik (a disinfectant). The bench tops are wiped with 70% ethanol before and after use.
ii) All the plastic rearing containers are sterilized by s.oaking them overnight in jik solution (200ml jik: 60 l of water), and then rinsed with water and dried in an oven at 65^{o} C for 1.5 hours before use.
iii) All insectary personnel maintain high personal hygiene standards.
iv) Entry to the insectary is restricted to only the rearing personnel.
v) A strict quarantine regulation is maintained when using field material for gene infusion.
vi) Any contaminated diet is disposed off including the insects in it.

Quality of the laboratory reared stem borers

Our objective is to rear and supply insects that have traits typical of the particular species and whose behaviour is comparable to that of the wild populations. In order to achieve this objective, regular tests have to be conducted to monitor and compare the behaviour of the laboratory reared insects versus the wild populations. Some of the key performance traits that have been integrated into the rearing system at the Katumani insectary are: fecundity of mated females and fertility of the eggs laid, developmental periods, survival rates, insect weights, morphological abnormalities, host-finding ability, host acceptance and adaptability to the field environment.

Human health hazards in insectaries

There are three main issues of concern to human health for workers at the insectaries, these include: moth scales, toxic fumes and microbial contaminants.

i) Moth scales: Moth scales can cause health problems such as pulmonary diseases and allergic reactions. To prevent these problems, workers at the moth house are required to wear a facemask at all times. In addition to this, all surfaces in the moth house are dusted thoroughly using moist cloths at the end of every week. However, during periods of peak moth production, the moth house is cleaned once every three days.
ii) Toxic fumes: Fumes from formaldehyde, one of the chemicals used during diet preparation, can be harmful to human health. To prevent inhalation of these fumes, it is mandatory that insectary workers wear a face-mask during the process of diet preparation.
iii) Microbial contaminants: There are some microorganisms which contaminate insect diets, and which can also affect human health. Examples are Steptococcus spp. and Aspergillus sp. (Sikorowski, 1984). To avoid such health problems, it is recommended that insectary workers wear facemasks especially when cleaning containers that had infected diet. It is also recommended that a lab. coat be worn by insectary workers.

Progress in mass rearing of stem borers at the KARI, Katumani Insectary

Operations at the Katumani insectaries commenced in 1999. During this year and the year 2000, the activities mainly comprised of trial rearing and standardisation of the protocols for rearing each of the five stem borer species. The first batch of stem borers for field studies (26,000 eggs of C. partellus) were supplied during the long rains 2000. Since then, the scale of insect production at the Katumani insectary has continued to increase, with the greatest one being in the short rains 2000 (1621.2%), after which the production continued to increase at a more stable level (Table 3). There has also been an improvement in the quality of production, record keeping and the supply system in terms of synchrony of the stem borer supply and the end-uses, such as field infestations and other controlled studies. Basic information on the development periods of the stem borer life stages for each species (Table 2) is used together with the timing of the different end-uses in order to synchronise supply with demand.

Advances in rearing Busseola fusca

The time of diet infestation, by B. fusca has been a major constraint since initiation of the Katumani insectary in 1999. This is because larvae of this stem borer had to be reared singly in small glass vials. According to the rearing procedures recommended by ICIPE and which we had adopted, B. fusca larvae should be reared singly due to their cannibalistic nature (Odindo and Onyango, 1998). However, because of the laborious nature of this activity, we found it necessary to explore ways of reducing this problem. We hypothesised that B. fusca larvae only find it necessary to be hypothesised that B. fusca larvae only find it necessary to be cannibalistic when food resources are limited. If these larvae were to be provided with adequate food in a larger container, then cases of cannibalism would be reduced.

An observational study was therefore set up in the short rains 2000, to evaluate the suitability of large plastic jars (capacity = 1000 ml) for rearing B.fusca - 20 larvae per container (diet 250 ml). The objective of the study was to compare the survival to pupation of B. fusca reared in vials (7.5 x 2.5 cm diameter - 15 ml of diet and holding 1 larva per vial) versus rearing them in large plastic containers (1000 ml capacity - 250 ml of diet, and holding 20 larvae per jar).

MATERIALS AND METHODS

Neonate larvae were introduced singly into heat-sterilized (100^{o}C for 1hr) glass vials (2.5 x 7.5 cm) containing 15 ml of diet, using a pre-sterilized camel hair brush that had been dipped in distilled water, to make the transfer of larvae easier. The vials were then plugged using a proper-fitting cotton wool plug. After infestation, the vials were arranged in clean carton containers (27 x 27 x 9 cm), open on one side, (100 vials per carton) and then transferred to the insectary. Three boxes (replications) each containing 100 vials was infested with B. fusca larvae. At the same time, a set of five plastic rearing jars (16 x 7.5 cm - containing 250 ml of diet) were each infested with 20 neonate larvae, giving a total of 100 larvae per set. Two similar sets of jars were infested with larvae in the same way. This gave a total of three replicates (sets) of jars having a total of 300 larvae. The larvae were allowed to feed undisturbed in the insectary at 28^o C, 60-70% RH, 12:12 light:dark photoperiod, up to pupation. The number of pupae harvested from each of the two types of rearing containers per replication, was recorded. This study was repeated twice; data were compared using a t-test (Wilkinson, 1990) and percentage pupation in each type of rearing container calculated.

RESULTS

There was no significant difference in the survival to pupation of larvae reared in the plastic containers (80.5%) and the glass vials (85.2%) ($t= 1.59$; $d.f = 10$; $P= 0.143$). Considering the cost of time incurred during infestation of the glass vials with single larvae, the higher risk of breakage of the vials (while handling and washing them), and their relative higher cost, it was decided that rearing of B. fusca in the jars would be a better method to use, and is what has been used in the Katumani insectary in the past 6 months. The method has been simplified further in that we now infest the diet using batches of surface sterilised blackhead eggs of B. fusca on pieces of oviposition paper. We have also observed that the number of insects infested per jar can be increased to 25 without significant effect on larval survival. We are currently infesting 25 eggs/larvae of B. fusca/250 ml of diet.

CONCLUSIONS AND RECOMMENDATIONS

The basic rearing techniques that are used at the Katumani Insectary were adopted from the ones used at ICIPE. However, various aspects of these techniques have been modified to suit our conditions, and also to make the rearing process less laborious and more efficient. An example is the improved rearing container that we now recommend for rearing of B. fusca. This container has made infestation of diet by B. fusca less laborious, and has also reduced the costs that were formerly incurred in frequent replacement of the glass vials due to breakage. We plan to continue increasing the scale of production, and our target production is 1000 pupae per week during peak production. One of our long term objectives is to install a moth scale extraction system within the moth house in order to improve the working conditions for the insectary personnel.

We plan to continue using the data collected in the laboratory, for close monitoring of the life history of these stem borers. Also, among our medium- to long-term objectives, is to establish a developmental chart indicating various day-temperature combinations that would be required for development of each of the five stem borer species, from egg to adult stage. This chart will improve our efficiency of manipulating developmental time of the various stem borers in order to meet specific insect requests.

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HETEROSIS AND GENETIC DIVERSITY IN CROSSES OF SEVEN EAST AFRICAN MAIZE (*Zea mays* L.) POPULATIONS.

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ABSTRACT

Seven East African maize populations were crossed in a diallel series. The seven parents and 21 crosses (excluding reciprocals) were evaluated at two locations; Jimma and Mettu, in the Southwestern part of Ethiopia in a randomized complete block design with four replications. The objectives were (1) to determine the extent of genetic diversity among the populations based on the level of yield heterosis of their F_1 progenies and (2) to identify heterotic populations that could be used as sources of inbred lines in a hybrid breeding programme. The study indicated wide genetic diversity among some of the populations as indicated by high level of yield heterosis over the mid- and high-parent. Hence, Kitale Composite B (KCB) and Abo-Bako, Ukuruguru Composite A (UCA) and Abo-Bako, and UCA and KCB were found to be the most genetically diverse populations showing high-parent yield heterosis of 55.3, 41.3 and 36.0 %, respectively. On the other hand, A-511 was observed to be genetically closely related with Ukuruguru Composite B (UCB), Kitale Composite C (KCC), Bako Composite and Abo-Bako. Similarly Bako-Composite was closely related with UCB and KCC. Based on the level of their F_1 yield heterosis, KCB and Abo-Bako were identified as heterotic populations to be used in hybrid breeding programme. Further breeding methods through which these populations could be exploited are suggested.

Keywords: Genetic diversity, heterotic maize populations, high-parent heterosis.

INTRODUCTION

Maize (*Zea mays* L.) is not native to Ethiopia. It was first introduced in the late 16th or early 17th century (Haffanagle, 1961). Since then various germplasm has been introduced from different sources. Systematic introduction and evaluation of introduced germplasm was, however, started in the early 1950s. The first batches of varieties were introduced from the USA, Sudan, Kenya, Colombia and other countries. These varieties were evaluated at some experimental stations in comparison with local selections but were not able to exceed the local materials in yield (Benti 1987). Recognizing low yield potential of local materials and poor adaptation of germaplasm introduced from the USA, Europe and Israel to Ethiopian conditions, Ethiopian breeders shifted their attention to germplasm developed in East African tropical highlands having similar production environments to Ethiopia (Benti 1987 and 1988).

In the early 1960s Ethiopia participated in the "East African Co-operative Maize Variety Trial" which included the most promising composites of East African countries. From these trials Ethiopian maize breeders were able to identify and synthesize high yielding composites mostly adapted to potential maize growing environments of Ethiopia. Late maturing composites of East African origin (KCC, KCB, UCA, UCB) and locally synthesized composites of similar maturity group (Bako composite) were mostly recommended for areas above 1,600 meters above sea level (masl) with adequate moisture during the growing period. These composites possess adequate resistance to leaf blight (*H. turcicum*) and rust (*P. sorghi*), which were major limitations of materials from the USA and Europe under Ethiopian conditions. Considering their adaptation to Ethiopian conditions and resistance to major diseases the National Maize Research Program has been using East African germplasm to a large extent in developing improved varieties. Inbred lines directly introduced from East African countries or developed locally from East African germplasm combine very well with CIMMYT materials. This has resulted in developing high yielding hybrids with an acceptable level of tolerance to leaf diseases. In general, most of the successful achievements in hybrid maize production in Ethiopia are ascribed to the desirable characters of East African materials. This has been well observed with the recently released high yielding hybrids which were developed from inbred lines having genetic background with the South and Latin American, and East African heterotic populations, Ecuador-573 (EC-573) and Kitale synthetic II (Ks.II), respectively (Benti *et al*., 1997). Continually reworking these heterotic populations is, however, not likely to substantially surpass the current yield levels. For additional success in the increasing interest in hybrid maize production in Ethiopia there is a need to identify further heterotic populations.

It is an already established fact that the amount of yield heterosis obtained by hybrids depends largely on the genetic divergence of the populations from which the parental lines have been extracted (Moll, *et al*., 1962). Diallel cross analysis for a fixed set of populations provides a basis for preliminary determination of heterotic groups. Thus heterosis information serves as a measure of genetic diversity (Moll, *et al*., 1962; Bridges and Gardner, 1987). Abundant heterosis manifestation by a cross leads to the conclusion that the parents are more genetically diverse than varieties whose crosses show little or no heterosis (Miranda and Vencovsky, 1984; Mungoma and Pollak, 1988).

At present there is limited information of this type available for open pollinated varieties adapted to Ethiopian conditions. Benti, *et al*., (1990) examined genetic diversity among eight locally adapted late maturing maize populations based on high-parent yield heterosis. They reported that most of the populations were genetically related as indicated by very low yield heterosis except KCB and UCA. Dejene and Habtamu (1993) also crossed KCC, KCB, UCA and Alemaya

Table 1. Background information of maize populations used in the study.

No.	Populations	Origin	Country and area of origin of component materials	Maturity	Adaptation Zone (Altitude masl[a].)
1.	UCA	Tanzania	Kenya/Latin America	Late	1700-2000
2.	UCB	Tanzania	Kenya/Latin America	Late	1700-2000
3.	KCC	Kenya	Latin America	Late	1700-2000
4.	KCB	Kenya	Kenya/Latin America	Late	1700-2000
5.	A-511	Kenya	Kenya	Medium	500-1800
6.	Abo-Bako	Nigeria	Nigeria (IITA)	Medium	500-1000
7.	Bako Composite	Ethiopia	Ethiopia/Latin America/East Africa	Late	1700-2000

[a]**masl**: meters above the sea level.

Composite with EC-573 and reported no significant differences among the progenies.

The present study was, therefore, undertaken to (1) determine the extent of genetic diversity among seven East African maize populations based on the level of yield heterosis of their F_1 progenies and (2) to identify heterotic populations that could be used as sources of inbred lines in a hybrid breeding programme.

MATERIALS AND METHODS

Seven East African maize populations were crossed in a diallel series at Jimma Agricultural Research Centre, Ethiopia, in 1996 main season. The populations included were UCA and UCB introduced from Tanzania, and KCB, KCC and A-511 which were introduced from Kenya and Abo-Bako introduced from Nigeria and Bako Composite which was developed locally. Background information of these maize populations is given in Table 1. The diallel crosses were made by using bulk pollen from at least 100 plants to pollinate as many plants in the opposite parent and vice versa. Sib increases of the parental seed were made in the same season using the same number of plants. The seven parental populations and 21 crosses (excluding reciprocals) were evaluated at 2 locations, Jimma and Mettu, in the Southwestern part of Ethiopia in the main season of 1997.

Jimma is located at latitude 7^0 46'N and longitude of 36^0 E at 1,750 masl. It annually receives about 1,500 mm of rainfall about 80% of which is received May to September. The soil is dominantly Nitosol with pH of 5.7. Mettu is located 260 km northwest of Jimma at latitude and longitude of $63.8^0$30' N and 35^0 E, respectively, at an altitude of 1,650 masl. It annually receives rainfall of 1,930 mm. The soil is Utric Nitosol rich in organic matter with a pH of 5.

The entries were arranged in a randomised complete block design with four replications at each location. A plot size of 3 m x 1.5 m was used with 75 cm and 30 cm spacing between rows and plants within the row, respectively.

Data were recorded on days to 50% silking, ear height, plant height and grain yield. All plots were hand harvested and shelled. The weight of shelled grain and moisture content of the grain were determined at harvest. Plot yield was adjusted to 12.5% moisture.

Analysis of variance was done for each location and then combined across locations. Yield data combined across locations were used to compute mid- and high-parent heterosis. The level of mid-and high-parent heterosis was then used to detect genetic diversity between any two populations.

RESULTS AND DISCUSSION

Combined analysis of variance for grain yield, ear and plant height and days to 50% silking indicated highly significant differences among the entries (Table 2).

Mean squares due to genotype x environment (G x E) interaction was also significant at $p < 0.01$ probability level for all characters except grain yield. Across locations, not much difference was observed among the parental populations and the crosses with respect to mean grain yield. They produced 6.1 and 7.5 t ha^{-1}, respectively, at both locations. At Mettu, Bako Composite and UCB were top-yielders with corresponding mean grain yield of 7.2 and 7.0 t ha^{-1} (Table 3). At Jimma; Abo-Bako (7.2 t ha^{-1}), UCB (7.0 t ha $^{-1}$) and Bako Composite (6.9 t ha^{-1}) were the first three best yielders. Bako Composite and UCB were the best yielders across locations. High yielding parents were taller with high ear placement and were also late to come to 50% silking (Tables 3 and 4). The low yielding parent, A-511, was the first to come to 50% silking and was shorter with low ear placement at both locations.

Individual cross mean grain yield combined across locations ranged from 5.9 t ha^{-1} for KCC x A-511 to 9.8 t ha^{-1} for KCB x Abo-Bako (Table 3). UCA, KCB, KCC and Bako Composite with Abo-Bako as a common tester, UCB x KCB and UCA x Bako Composite, UCA X KCB recorded yield advantage of 7.14% (0.5 t ha^{-1}) to 43.5% (2.7 t ha^{-1}) and 9.3% (0.7 t ha^{-1}) to 84.5 (4.9 t ha^{-1}) over the best parent at Jimma and Mettu, respectively. Across locations KCB X Abo-Bako, UCA x Abo-Bako, UCA x Bako-Composite and UCA x KCB gave 18.1%(1.3 t ha^{-1}) - 36.1%(2.6 t ha^{-1}) higher grain yield than Bako Composite which is the best parent.

Table 2. Combined analysis of variance for grain yield, ear and plant height, and days to 50% silking evaluated at two locations.

Sources of variation	Df	Mean squares			
		Grain yield (t ha^{-1})	Ear height (cm)	Plant height (cm)	Days to 50% silking (No.)
Location (E)	1	3.93	311	1292	8452.6**
Treatment (G)	27	5.02**	2926**	3435**	104.4**
G x E	27	1.21	639**	1076**	22.5**
Pooled error	162	0.99	354	124	1.5
CV (%)		20.8	10.5	7.3	2.9

**,* Significant at P< 0.01 and 0.05, respectively.

Table 3. Grain yield (Yld, t ha^{-1}) and days to 50% silking (DTS) of seven parental populations and their crosses evaluated at two locations.

Parents	Site	UCB		UCA		KCC		KCB		Bako Comp.		Abo-Bako		A-511	
		Yld	DTS	Yld	DTS	Yld	DTS	Yld	DTS	Yld	DTS	Yld	DTS	Yld	DTS
UCB	Jimma	7.0	92	8.0	91	8.2	93	8.8	91	7.0	89	7.5	89	7.8	85
	Mettu	7.0	82	5.5	76	8.1	81	7.9	82	6.5	70	8.2	78	6.0	77
	Mean	**7.0**	**87**	**6.7**	**84**	**8.2**	**87**	**8.3**	**87**	**6.7**	**80**	**7.8**	**84**	**6.9**	**81**
UCA	Jimma			6.2	92	8.0	90	8.9	92	8.0	91	8.0	92	7.3	86
	Mettu			6.3	75	6.2	75	8.1	78	9.0	78	9.8	74	7.3	78
	Mean			**6.3**	**84**	**7.1**	**83**	**8.5**	**85**	**8.5**	**85**	**8.9**	**83**	**7.3**	**82**
KCC	Jimma					5.4	91	7.7	92	7.2	94	8.5	89	6.8	85
	Mettu					6.7	78	7.9	76	5.8	79	8.1	76	5.1	76
	Mean					**6.1**	**85**	**7.8**	**84**	**6.5**	**87**	**8.3**	**83**	**5.9**	**81**
KCB	Jimma							5.6	93	8.3	90	8.9	86	6.9	84
	Mettu							5.8	79	6.9	81	10.7	75	5.3	74
	Mean							**5.7**	**86**	**7.7**	**86**	**9.8**	**81**	**6.1**	**79**
Bako Comp.	Jimma									6.9	91	8.4	86	6.8	80
	Mettu									7.5	78	8.2	76	5.1	73
	Mean									**7.2**	**85**	**8.3**	**81**	**6.4**	**77**
Abo-Bako	Jimma											7.2		6.0	76
	Mettu											5.5		6.8	69
	Mean											**6.3**		**6.4**	**73**
A-511	Jimma													4.2	80
	Mettu													4.7	69
	Mean													**4.4**	**75**

Table 4. Ear height (EH, cm) and plant height (PH, cm) of seven parental populations and their crosses evaluated at two locations.

Parents	Site	UCB		UCA		KCC		KCB		Bako Comp.		Abo-Bako		A-511	
		EH	**PH**	**EH**	**PH**	**EH**	**PH**	**EH**	**PH**	**EH**	**PH**	**EH**	**PH**	**EH**	**PH**
UCB	Jimma	187	300	227	332	178	299	199	334	195	304	177	280	153	185
	Mettu	190	278	191	296	171	318	192	295	182	313	160	288	162	307
	Mean	**189**	**289**	**236**	**314**	**175**	**309**	**196**	**315**	**189**	**309**	**169**	**284**	**158**	**286**
UCA	Jimma			184	188	190	297	219	338	215	336	185	297	157	275
	Mettu			192	311	175	298	197	343	193	324	166	312	172	299
	Mean			**188**	**318**	**183**	**298**	**208**	**341**	**204**	**330**	**178**	**305**	**165**	**287**
KCC	Jimma					163	299	187	312	183	305	177	311	168	305
	Mettu					185	314	206	340	190	347	194	343	166	299
	Mean					**174**	**307**	**197**	**326**	**187**	**326**	**186**	**300**	**167**	**302**
KCB	Jimma							194	316	209	327	176	317	149	278
	Mettu							213	320	217	347	158	296	168	296
	Mean							**204**	**318**	**213**	**337**	**167**	**307**	**151**	**287**
Bako Comp.	Jimma									198	235	167	297	150	271
	Mettu									163	306	177	316	161	287
	Mean									**181**	**316**	**172**	**307**	**156**	**279**
Abo-Bako	Jimma											166	304	148	255
	Mettu											136	251	154	287
	Mean											**151**	**278**	**151**	**271**
A-511	Jimma													141	247
	Mettu													148	259
	Mean													**145**	**253**

Table 5. Mid- parent (below diagonal) and high-parent (above diagonal) per cent heterosis grain yield in 21 crosses of maize combined across two locations.

Parents	UCB	UCA	KCC	KCB	Bako Comp.	Abo-Bako	A-511
UCA		-4.3	16.5	36.0	18.1	41.3	15.9
UCB	0.8		17.1	18.6	-6.9	11.4	-1.4
KCC	14.6	25.0		27.9	-9.7	31.7	-3.3
KCB	41.9	30.5	32.2		6.7	55.3	6.8
Bako Composite	25.0	-5.6	-2.2	19.2		15.9	-10.9
Abo-Bako	41.3	17.2	33.9	63.3	22.8		-6.3
A-511	36.1	21.1	12.3	20.6	10.3	10.0	

As opposed to grain yield, environment was found to significantly influence ear and plant height, and days to 50% silking. About 60% of the crosses had higher ear placement and plant height at Jimma and almost all crosses attained 50% silking earlier at Mettu. Nevertheless, both the parents and the crosses recorded almost equal mean number of days to 50% silking at specific location. Hybrids among late x late maturing parents were also late to attain 50% silking and had taller ear placement and plant height. On the other hand, those among late x intermediate maturing parents were intermediate between the parents with respect to days to 50% silking, ear and plant height indicating partial dominance for earliness, low ear placement and short stature (Hallauer, 1985). Short plant height and low ear placement of these crosses is advantageous as it improves tolerance to lodging. Average heterosis relative to the mid- and high-parent was 22.4% and 13.17%, respectively. Mid-parent values ranged from -5.6% for UCB x Bako Composite to 63.3% for KCB x Abo-Bako (Table 5). High-parent heterosis ranged from -10.9 to 55.3 per cent. Seven hybrids recorded negative high-parent heterosis and high-parent heterotic response based on yield data combined across locations was less than 50% almost in all hybrids except in KCB x Abo-Bako which recorded high-parent per cent heterosis of 55.3%. KCC x Abo-Bako, UCA x KCB and UCA x Abo-Bako manifested high-parent heterosis of 31.7, 36.0 and 41.3 per cent, respectively.

It is a common belief in plant breeding that heterosis manifested by a cross of two populations increases with increased genetic diversity (Munguma and Pollak, 1988). Hence, parents whose cross manifested high negative to low positive heterosis lack genetic diversity. On the contrary, parents whose cross showed high positive heterosis are genetically diverse. Based on high-parent yield heterosis, KCB and Abo-Bako, UCA and Abo-Bako, and UCA and KCB are genetically more diverse populations. Benti, *et al*. (1990) also reported similar results for UCA and KCB. On the other hand, A-511 was found to be genetically closely related with UCB, KCC, Bako Composite and Abo-Bako. Similarly, Bako Composite was found to be closely related with UCB and KCC. Hence, UCB, KCC and Bako-Composite could comprise one closely related group. However, KCB and Abo-Bako could be considered as the most genetically diverse germplasm and form one heterotic group.

Higher heterotic response among these populations could be expected on the basis of diverse origin, maturity and zones of adaptation (Moll, *et al*., 1962; Singh, 1987). KCB was introduced from Kenya and was also synthesised from component materials which originated from the same country. It is a long cycle variety adapted to high rainfall areas of the western part of Ethiopia. Abo-Bako is a medium maturing variety which was developed from African and Latin American germplasm sources in Nigeria. In Ethiopia it is adapted to the lowland sub-humid zone at Gambella (Benti, *et al*., 1993). Genetic diversity between KCB and Abo-Bako and genetic resemblance among the rest of the parents could, therefore, be argued on the basis of parental materials included in their early synthesis and the subsequent selection exercised. The poorest crosses (KCC x A-511 and Abo-Bako x A-511) involve closely related parents. A-511, UCB and KCC, though they differ in maturity and origin, might have shared common germplasm. This combined with gene exchange due to inter-pollination might have contributed to lack of heterosis and genetic diversity among them. UCB, KCC and Bako Composite, though they are different in origin, have been grown in the same area for a longer time which probably caused genetic mixing. This might have resulted in loss of genetic diversity and heterosis.

The study indicated wide genetic diversity among some of the populations as indicated by high level of yield heterosis over the mid- and high-parent. High per cent heterosis over mid- and high-parent manifested among parents KCB and Abo-Bako corroborated the fact that wide genetic distances on the basis of origin, adaptation and maturity contribute to genetic diversity and then higher heterosis. Heterotic response among these populations is sufficiently high to justify formation of heterotic groups and commercial exploitation of the hybrid vigour. These parents are the best combinations for a concomitant improvement of grain yield through reciprocal recurrent selection. Inter-population inter-line hybrid development programme is also an effective breeding approach to exploit heterotic potential of these two populations.

Even though maize is not native to Ethiopia, diverse genetic materials have been accumulated through long time introduction. The number of materials included in this study is very small and does not represent the diverse genetic materials available in the country. In the future, similar studies should capitalize on maize germplasm that is diverse with reference to origin, maturity and adaptation.

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USE OF MOLECULAR MARKERS IN MAIZE DIVERSITY STUDIES AT CIMMYT.

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ABSTRACT

Fingerprinting and genetic diversity laboratory protocols have been optimized for high-throughput analysis of maize. Eighty-five SSR markers have been chosen that span the entire genome and can be multiplexed (4-12 SSRs per lane) on an automatic DNA sequencer. Maize populations can also be fingerprinted in a very efficient method by bulking 15 individuals from the same population; this bulk is amplified and run together on the sequencer. This allows the use of peak area from the sequencer output to estimate allele frequencies from each population. Two bulks per population are fingerprinted to have a total of 30 individuals per population in the estimation. Only a limited structure can be deduced in the inbred lines by using molecular markers, reflecting the breeding strategy at CIMMYT of mixing many germplasm pools to increase diversity in tropical and subtropical breeding lines. Origin, and to a lesser extent heterotic groupings, of the populations are reflected in the SSR diversity measurements.

INTRODUCTION

Knowledge of patterns of diversity of genetic resources is of great importance in maize breeding in order to maximize heterosis in hybrid combinations and to maintain diversity of breeding lines. PCR based SSR markers have been widely used in the fingerprinting of maize germplasm (Smith *et al*. 1997; Senior *et al*. 1998), because of their high level of polymorphisms (Saghai Maroof *et al*. 1994) and their ease of detection via automated systems (Sharon *et al*. 1997). The CIMMYT Maize Genetic Resources Center and the CIMMYT Maize Breeding Programme have over 17,000 inbred lines and populations of maize.

The fingerprinting of such a large collection of unique entries will require very high-throughput methodologies in the laboratory and in data collection, storage, and analysis. Populations present a more difficult challenge, as collections of heterogeneous individuals must be characterized. This challenge has been met in the past by laboriously fingerprinting individuals from the population one at a time; a method which precludes the use of large numbers of individuals per population and thus is of limited use in diversity studies. This study aims to optimize the most efficient methods of diversity analysis in maize lines and, particularly, populations using SSR markers.

MATERIALS AND METHODS

Plant materials and DNA extraction

DNA for analysis is extracted with a 'Sap extractor' (MEKU Erich Pollaehne, Germany) using CTAB, according to Applied Biotechnology Center (ABC) standard laboratory techniques (CIMMYT, 2001). Nucleic acid preparations are incubated with RNase A and T1 for 1 hour at room temperature, precipitated with cold 70% ethanol, dried, and resuspended in 200µl of 1xTE for storage at 4°C.

Multiplex PCR and amplification conditions

SSR markers used in diversity studies in the ABC were originally chosen from the MaizeDB database (http:/nucleus.agro.missouri.edu/cgi/bin/ ssr/bin.pl) based on bin location (to maximize genomic coverage) and repeat unit (SSRs with dinucleotide repeats are more difficult to score for allele identities). Fluorescent oligonucleotides are used to label forward primers at the 5' end with either 6-FAM, TET, or HEX. Multiplexed PCR reactions are performed in 10-ul volumes containing 1 µl of template DNA (diluted 5x), 1.2-4.0 pmols of each primer (up to four primers per reaction), 10x PCR buffer, 0.25 mM dNTPs, 1.5-2.5 mM $MgCl_2$ and 0.75 U *Taq* polymerase. Amplifications are done under conditions of 94°C for 2 min.; followed by 30 cycles of: 94°C for 30 sec, X°C for 1 min, and 72°C for 1 min; followed by extension at 72°C for 5 min. X°C refers the annealing temperature, which is specific for each primer (Table 1).

Electrophoresis

Samples containing two PCR reactions (0.5 ul / each), 0.3 ul GeneScan 350 or 500 internal lane standard labeled with TAMRA, and 30% formamide are heated to 95°C for 5 min, placed on ice, and loaded on 4.5% denaturing (6 M urea) acrylamide:bisacrylamide (29:1) gels (36 cm well-to-read). DNA samples are electrophoresed in 1xTBE buffer (PH 8.3) at constant voltage (3.00 KV) for 2.5 hours on an automatic DNA sequencer (Perkin Elmer/ABI Prism™ 377 DNA Sequencer).

Data analyses

Fragment sizes are automatically calculated with GeneScan 3.1 (Perkin Elmer/Applied Biosystems) using the Local Southern sizing method. The GeneScan data are appended to a table with Genotyper 2.1, and then converted to allele frequencies for data storage and analysis.

RESULTS AND DISCUSSION

Genetic Diversity of Inbred Lines

The dendrogram of the analysis of 57 maize inbred lines is shown in Figure 1. Lines do not cluster clearly on pedigree, except for the highly related sister lines (TS lines

Table 1. SSR markers used in the study. Repeat refers to the repeat unit of the simple sequence repeat, and Comp indicates a compound repeat, consisting of more than one repeat type; Bin indicates chromosomal location, PIC is the Polymorphism Information Content, and Ann Temp is the annealing temperature, in degrees centigrade.

Marker	Repeat	Bin	PIC	Ann Temp	Marker	Repeat	Bin	PIC	Ann Temp
nc130	Tri	5.00	0.58	54	phi109275	Tetra	1.00	0.65	54
nc133	Penta	2.05	0.47	54	phi109642	Tetra	2.00	0.54	54
phi002	Tetra	1.08	0.36	60	phi112	Di	7.01	0.46	56
phi006	Tri	4.11	0.77	52	phi114	Tetra	7.02	0.59	54
phi008	Tri	5.03	0.45	60	phi116	Comp	7.06	0.78	56
phi011	Tri	1.09	0.59	60	phi121	Tri	8.04	0.44	56
phi014	Tri	8.04	0.62	52	phi123	Tetra	6.07	0.45	54
phi015	Tetra	8.09	0.65	56	phi127	Tetra	2.08	0.82	52
phi022	Tetra	9.03	0.75	56	phi213984	Tri	4.01	0.17	54
phi024	Tri	5.01	0.48	60	phi227562	Tri	1.12	0.79	54
phi029	Comp	3.04	0.52	56	phi233376	Tri	8.03	0.58	54
phi031	Tetra	6.04	0.59	56	phi299852	Tri	6.08	0.58	58
phi032	Tetra	9.04	0.48	56	phi308707	Tri	1.10	0.67	56
phi034	Tri	7.02	0.84	56	phi328175	Tri	7.04	0.67	54
phi041	Tetra	10.00	0.40	56	phi331888	Tri	5.04	0.53	58
phi046	Tetra	3.08	0.49	54	phi339017	Tri	1.03	0.31	52
phi050	Tetra	10.03	0.12	56	phi374118	Tri	3.03	0.63	54
phi053	Tetra	3.05	0.70	56	phi420701	Tri	8.01	0.56	58
phi056	Tri	1.01	0.73	56	phi423796	Penta	6.02	0.32	54
phi059	Tri	10.02	0.64	60	phi448880	Tri	9.05	0.38	54
phi062	Tri	10.04	0.29	56	phi452693	Tetra	6.06	0.57	52
phi063	Tetra	10.02	0.75	54	phi453121	Tri	3.00	0.69	54
phi064	Tetra	1.11	0.79	56	phi96100	Tetra	2.00	0.75	54
phi065	Penta	9.03	0.57	54	phi96342	Tetra	10.02	0.24	54
phi069	Tri	7.05	0.65	58	umc1061	Tri	10.06	0.62	52
phi070	Penta	6.07	0.49	56	umc1109	Tri	4.10	0.37	54
phi072	Tetra	4.01	0.59	52	umc1122	Tri	1.06	0.34	54
phi073	Tri	3.05	0.64	56	umc1136	Tri	3.10	0.73	52
phi076	Hexa	4.11	0.65	60	umc1143	Penta	6.00	0.62	54
phi078	Tetra	6.05	0.55	56	umc1152	Tetra	10.01	0.74	54
phi079	Penta	4.05	0.44	60	umc1153	Tri	5.09	0.72	54
phi083	Tetra	2.04	0.77	52	umc1161	Hexa	8.06	0.43	54
phi084	Tri	10.04	0.52	54	umc1169	Tri	1.04	0.66	52
phi085	Penta	5.07	0.66	60	umc1196	Hexa	10.07	0.61	54
phi087	Tri	5.06	0.69	54	umc1277	Tetra	9.08	0.48	54
phi089	Tetra	6.08	0.48	54	umc1279	Tri	9.00	0.29	54
phi093	Tetra	4.08	0.64	60	umc1304	Tetra	8.02	0.40	54
phi100175	Tetra	8.06	0.38	54	umc1399	Tetra	3.07	0.62	54
phi101049	Tetra	2.09	0.84	54	umc1545	Tetra	7.00	0.28	54
phi102228	Tetra	3.04	0.35	54	umc1555	Tetra	2.02	0.76	58
phi104127	Tetra	3.01	0.39	54	zcaa391	Tri	6.01	0.85	56
phi108411	Tetra	9.06	0.42	60	zct118	Di	5.07	0.76	60
phi109188	Tetra	5.00	0.71	54					

and LP lines). Nor do they cluster based on mega-environment where grown (tropical, subtropical, highland); nor kernel color or type. This is not entirely unexpected, because CIMMYT inbred lines are generally drawn from a pool, population, or mixture of pools and populations. Pools and populations contain a very broad range of diversity, and may contain more variation within a pool or population than between them. Thus, two lines drawn at random from any given pool or population may not actually contain many alleles in common. Furthermore, lines that have been selected for each environment may have a similar initial pedigree; thus, looking for correlations in allele diversity and pedigree or environment may prove difficult. We would like to suggest for maize breeding of tropical and subtropical hybrids, that markers can be used in future hybrid breeding programmes to create two distinct heterotic groups. Improvement of each heterotic group must be done independently, with no mixing between the groups. Markers can be used to more quickly diverge the groups from each other by choosing the individuals in each group with the

Figure 1. Dendrogram constructed with a Unweighted paird Group Method Using Arithmetic Averages (UPGMA) clustering algorithm form the pairwise matrix of genetic similarity among 57 maize inbred lines. Confidence intervals of the clustering is shown as percentages, as calculated using a bootstrap analysis.

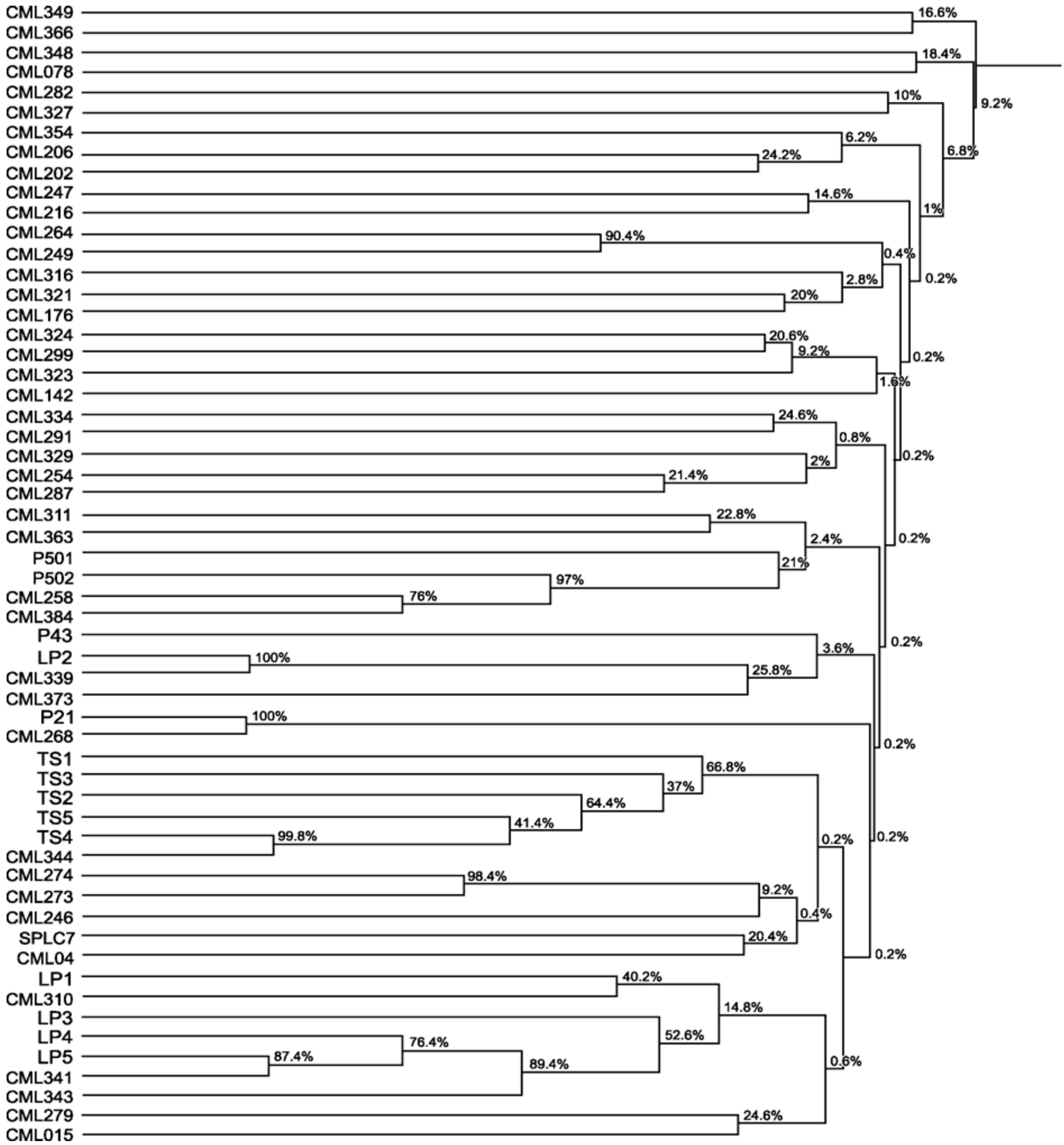
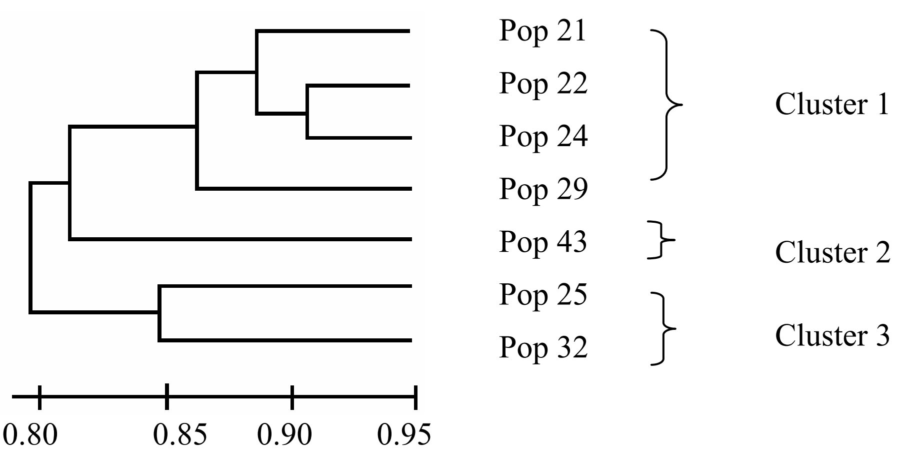


Figure 2. UPGMA dendrogram of 57 inbred lines based on 85 SSRs. The horizontal axis is expressed in genetic distances that were calculated using the Nei and Li coefficient. Bootstrap confidence intervals are included at the junctions of each cluster.



highest genetic distance from the other group. A maximum distance between groups will guarantee the maximum heterotic performance of hybrids formed when parents from the two heterotic groups are crossed.

Genetic Diversity of Populations

The dendrogram of the analysis of 7 CIMMYT maize populations using allele frequency of 30 individuals per population is shown in Figure 2. Populations clearly cluster according to pedigree and heterotic group. Cluster 1 contains Populations 21, 22, 29, and Pool 24. Populations 21 and 22 are tropical, late white dent or semident maize types originated from Pool 24, which is from the Tuxpeño race of maize. All these populations belong to heterotic group A. Population 29 is also a tropical, late white dent maize, with both Tuxpeño and Caribe races in its background, and shows heterosis when crossed to both A and B testers, indicating it belongs to neither group. It is the furthest outlier in Cluster 1. Cluster 2 contains only Population 43, which is a mixture of La Posta elite lines, and is also tropical, late, white, and dent. It also belongs to neither heterotic group A nor B. Cluster 3 contains Populations 25 and 32, which are tropical to subtropical, intermediate to late white flints, and belong to heterotic group B.

Correlations between estimated and actual allele frequencies (calculated by running individuals separately for the purposes of this study) were found to be quite high; over all populations, the correlation was 0.80. The accuracy of the estimated allele frequencies can be further increased by better optimizing the bulked amplifications and data analysis techniques. Two main factors that decreased the correlations were the presence of stutter bands in the gel, which were incorrectly interpreted to be true alleles, and failure of some alleles to amplify in the bulk. In a diploid individual, stutters can be removed based on size in base pairs and decreased peak intensity, but in a bulk, a peak of lower intensity following a peak of high intensity cannot be assumed to be a stutter, rather than a true allele. A method for including a correction factor for stutters in bulked analyses in mammals has been suggested by LeDuc *et al* (1995) and may be applicable to plant species.

Because the PCR reaction is a competitive reaction between template strands of DNA for dNTPs, Taq, and other reagents, bulked amplifications may favour some individual genotypes or alleles over others. Furthermore, in a multiplex reaction, some primers amplify more strongly than others. To avoid so many competing factors in bulked amplifications, it will probably be necessary to avoid multiplexing primers in the same PCR reaction. Furthermore, one must first optimize well the conditions that will allow amplification of all individuals in the bulk.

The work presented in this poster indicates that an efficient and accurate method for the fingerprinting of maize inbred lines and populations using SSR marker has been optimized in the CIMMYT ABC. Routine fingerprinting of maize germplasm will now commence.

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BREEDING FOR RESISTANCE TO THE MAIZE WEEVIL (*SITOPHILUS ZEAMAIS* MOTSCH.): IS IT FEASIBLE?

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ABSTRACT

Maize weevil (*Sitophilus zeamais* Motschulsky) is an important pest of maize in the tropics, particularly where grain is stored on-farm and without chemical protectants. This study was to determine if improvement of weevil resistance of maize is possible through conventional breeding techniques. Selection for weevil resistance was done at CIMMYT-Zimbabwe for two genetically broad-based and four bi-parental maize populations. One hundred or more S1 cobs were selected from each of the populations, they were individually shelled and grain was evaluated for weevil resistance in unreplicated tests at 28±2°C and 70±5% relative humidity in a laboratory at Harare. The number of weevils emerged (F1 progeny) after six weeks of incubation was used as the primary selection criterion. The most resistant 10% and most susceptible 10% of the lines for each population were selected and intercrossed to form two synthetics per population. In addition, all S1 lines from the two genetically broad-based populations were advanced to S2, and three representative S2 cobs were used to evaluate weevil resistance for each family, with grain from each S2 cob constituting a replicate. Divergent selections were then made based on the resistance of the S2 families (replicated) and the S2 individual lines (unreplicated) to form four synthetics per population. Selection using replicated S2 samples was successful for both populations where it was applied, and resulted in 16%, 49% and 20% (all statistically significant) difference between divergently selected synthetics for progeny emerged, weight loss and Dobie index, respectively. S1 unreplicated selection was successful for two of the six populations where it was applied, while S2 unreplicated selection was never successful. Our results confirmed that it is possible to improve maize populations for resistance to maize weevil.

INTRODUCTION

Maize weevil (*Sitophilus zeamais* Motschulsky) is a major pest of stored maize in the tropics. Pesticides for control of weevils are available, but the resource poor farmers of the developing world often cannot afford them. Also, the increasing occurrence of insecticide resistance (Perez-Mendoza, 1999) and increasing environmental concerns about the use of chemical insecticides mean that alternative control methods are required. Varietal resistance to maize weevil would form an important component of an integrated pest management program for storage pests and would help maintain an acceptably low insect population in stored maize.

Most studies on host plant resistance to maize weevil (*Sitophilus zeamais* Motsch.) have focused on grain factors contributing to resistance and inheritance mechanisms of resistance (Widstrom *et al*., 1975; Dobie, 1974; Arnason *et al*., 1992; Derera *et al*., 2001a, 2001b). Additive gene action, dominance gene action and maternal effects are involved in the inheritance of weevil resistance in maize (Derera *et al*., 2001a, 2001b; Kang *et al*., 1995). Factors contributing to weevil resistance have been studied extensively and include concentration of phenolic compounds in pericarp tissue, grain protein content, grain hardness and completeness/tightness of husk cover (Classen *et al*., 1990; Sing and McCain, 1963; Dobie, 1977).

Information on inheritance mechanisms for resistance to maize weevil and factors contributing to resistance is important, but more important is the application of this information in a breeding programme to select for weevil resistance in maize. Despite the growing understanding of the inheritance of weevil resistance and the factors contributing to resistance, there has been very little application of these findings in maize breeding programmes. This paper will discuss findings from divergent selections for resistance to maize weevil in six maize populations. The objectives of the study were to determine if progress could be made in improving maize populations for resistance to maize weevil and to determine the relative importance of replicated and unreplicated experiments when selecting for weevil resistance in maize.

MATERIALS AND METHODS

Germplasm and selection methods. Two synthetic populations and four bi-parental populations were chosen for the study (Table 1). The two synthetic populations, SZSYNA99 (*Sitophilus zeamais* synthetic of heterotic group A, made in 1999) and SZSYNB99 (*Sitophilus zeamais* synthetic of heterotic group B, made in 1999) were populations made from lines of opposite heterotic groups from CIMMYT. The lines were selected based on above average weevil resistance in evaluations of per se weevil resistance of advanced and elite breeding lines at CIMMYT, Zimbabwe, in 1999. The four genetically narrow-based populations were crosses of CML206 (susceptible) and resistant lines. Two of the bi-parental populations were from

Table 1. Name or pedigree, and type of maize populations used for divergent selection studies for weevil resistance.

Pedigree	Type
SZSYNA99	Synthetic (11 lines)
SZSYNB99	Synthetic (9 lines)
[RA87C3108-X-5-1-1-5-X-X-B/CML206]	F2Bi-parental
[RA87C3108-X-5-1-1-5-X-X-B/CML206]	Bi-parental
[CML394/CML206]-F2	Bi-parental
[CML206/CML442]-F2	Bi-parental

reciprocal crosses of the same two lines, which enabled us to investigate whether cytoplasmic genome contributed to weevil resistance.

For the synthetics, 137 S1 cobs for SZSYNA99 (SZA) and 132 ears for SZSYNB99 (SZB) were chosen in May 2000 and evaluated for weevil resistance in the controlled temperature and humidity (CTH) laboratory at CIMMYT, Harare. Each S1 ear was shelled individually and a 50g sample of grain was taken for weevil screening in unreplicated experiments; the remaining seed was kept for future use.

The grain samples were first kept in a freezer at –20°C for 14 days to remove (kill) any field infestations (live insects or eggs) by weevils or any other pests. Each sample was then put in a 500cm^3 glass jar with brass screen lids which allowed adequate ventilation, and then placed in the CTH laboratory that was maintained at 28±2°C and 70±5% relative humidity for a 3-week acclimatization period, to achieve uniform grain temperature and (more importantly) moisture content among all samples. Next, the samples were infested with 32 unsexed weevils aged 7 to 14 days. After an oviposition period of 10 days, the weevils were removed and the number of dead and living weevils recorded. The samples were then left in the laboratory for 45 days (incubation period) after which the number of F1 weevils (progeny) that emerged from each sample was recorded. The number of weevils that emerged from each sample was used as the selection criterion for selecting the best and worst lines for recombining (divergent selection).

The best 14 lines (10% of 137 lines) and the worst 14 lines were selected for SZA; and the best and worst 13 lines (10% of 132 lines) were selected for population SZB. At the same time all the 137 lines for SZA and the 132 for SZB were advanced to S2 by self-pollinating the best plants (based on per se, agronomic aspect) in each row at Muzarabani, Zimbabwe during winter of 2000. After eliminating some families due to failure of pollination, poor plant aspect and/or diseases such as ear rots, there were 106 selected families for SZA and 110 for SZB. Three representative S2 ears (three replicates) were selected for each family (originating from the same S1) for weevil screening, such that there were 318 (106 x 3 cobs) samples for SZA and 330 (110 x 3 cobs) for SZB. The same procedure described above for screening the S1 lines was used for evaluating weevil resistance of the S2's.

For the four bi-parental populations, 100 ears were chosen from each population and screened for weevil resistance using the procedure described for the S1 lines from the two genetically broad-based populations. For each population, the best 10 (10% of 100 lines) and the worst 10 lines were selected for recombination.

Formation of Synthetics. All selected S1 lines from each population were planted at the same time in the summer of 2000/2001. For all synthetic formations, the lines to be recombined were first divided into two arbitrary groups. Pollen was collected from representative plants within each row of each group, bulked and used to pollinate plants of the other group. This resulted in two synthetics per population: 'resistant' and 'susceptible'.

A slightly different procedure was used for S2 lines. All selected S2 lines (three cobs per S2 family) were also planted in the summer of 2000/2001 at the same time that the lines were being screened for weevil resistance. However, the planting dates were set such that weevil resistance data were available prior to flowering time. Using data from the laboratory bioassays of weevil resistance, four synthetics were made from each genetically broad-based population:

- 'SZSYN01BestS2Repl': Made from recombining the best 10% of the families (11 families for each population); based on the mean weevil resistance of the three S2's for each family.
- 'SZSYN01BestS2Unrepl': Made from recombining the best 10% of the lines per se (32 lines for A and 33 for B), irrespective of family, to form a 'resistant' synthetic made from individual selections of the S2's.
- 'SZSYN01WorstS2Repl': Made from recombining the worst 10% of the families; based on the mean weevil resistance of the three S2's for each family.
- 'SZSYN01WorstS2Unrepl': Made from recombining the worst 10% of the lines *per se* as in 2.

All lines selected for recombining into a synthetic were also first divided into two arbitrary groups and recombined as described for S1 lines.

Resistance screening of synthetics. A modification to the original Dobie method (Dobie, 1974) was used in this study. Five hundred grams of grain from each synthetic was weighed into a 1000cm^3 jar with a brass screen lid that allowed adequate ventilation and placed in the CTH for a conditioning period of three weeks. After 3 weeks, moisture content was measured for each synthetic before 10 replicates of 50±0.1g per synthetic were weighed into 500cm^3 jars. Each replicate was then treated as described for S1 lines above. However, after the 10-day oviposition period, the samples were left undisturbed for 14 days before weevil counts were done every second day until no more weevils emerged. From the collected data, the mean development period (the number of days by which 50% of the weevils have emerged) of the weevils was calculated. An index of susceptibility was then calculated for each replicate (Dobie, 1974), where index of susceptibility = 100 x [$\log_e$ (total number of adults emerged) divided by (mean development period)]. Statistical analysis. Progeny data (weevil counts) were transformed using the logarithm transformation prior to analysis using the PROC GLM procedure of SAS (SAS, 1999, 2001). Means were separated using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

A summary of the means for weevil resistance parameters for synthetics made from SZSYNA99 and SZSYNB99 is shown in Table 2. Comparison of the means indicates that we succeeded in separating the two synthetic populations, SZSYNA99 and SZSYNB99 into 'susceptible' and 'resistant' synthetics using S2 replicated selection and to a lesser extent also using S1 unreplicated selection. Unreplicated S2 selection for weevil resistance was not effective.

Combined analysis of variance detected no significant interaction between population and selection direction (i.e. resistant and susceptible selections), indicating that the selection direction effect was similar for the two populations (Table 3). This allowed us to combine the analysis across the two populations (Table4). Our results showed that, on average, S1 unreplicated selection was as effective as S2 replicated selection for progeny emerged and weight loss, but S1 was less effective than replicated S2 selection for mean development period and Dobie index. We expected replicated to be more effective than unreplicated selections because weevil F1 progeny data are often quite variable. Although

Table 2. Weevil resistance parameters for maize synthetics formed by three methods of divergent selection for weevil resistance for two genetically broad-based maize populations.

Selection Method or Description of Reference Entries	Progeny		Log-Transformed No. of Progeny		Parent Mortality		Grain Weight Loss		Mean Development Period		Dobie Index of Susceptibility	
	No.		Log_{10} No.		%		%		d			
	SZA[†]	SZB	SZA	SZB	SZA	SZB	SZA	SZB	SZA	SZB	SZA	SZB
[BestS2Repl]F2	30.3	33.8	1.49	1.53	9.3	13.8	3.4	3.2	38.6	40.6	8.8	8.6
[WorstS2Repl]F2	56.5	54.2	1.74	1.74	9.3	11.6	5.6	4.3	38.1	38.5	10.5	10.4
[BestS2UNRepl]F2	45.6	48.6	1.64	1.66	9.1	6.5	5.1	5.2	38.8	38.7	9.7	9.8
[WorstS2UNRepl]F2	43.6	49.8	1.61	1.67	16.5	14.8	5.6	5.8	38.7	39.0	9.6	9.9
[BestS1UNRepl]F2	35.4	22.7	1.52	1.35	8.6	11.9	3.6	2.0	39.8	41.1	8.7	7.5
[WorstS1UNRepl]F2	43.7	40.2	1.62	1.58	6.2	5.4	4.1	4.8	38.4	40.6	9.7	8.9
Parent Population (cycle 0)	46.9	52.9	1.68	1.72	12.7	12.1	4.5	4.7	40.3	41.3	9.6	9.6
Mexican Composite (resistant)	51.9	51.9	1.70	1.70	12.4	12.4	6.0	6.0	39.2	39.2	10.0	10.0
Popcorn (Susceptible)	88.0	88.0	1.92	1.92	12.6	12.6	10.8	10.8	38.9	38.9	11.3	11.3
Mean			1.64		10.8		4.9		39.4		9.55	
P			***				***		**		***	
LSD(0.05)			0.12				1.4		1.8		1.05	
SED			0.06				0.7		0.9		0.54	
CV%			9.1		96.7		32.2		5.1		12.5	

[†] SZA is the maize population *Sitophilus zeamais* of heterotic type "A"; SZB is the maize population *Sitophilus zeamais* of heterotic type "B"

Table 3. ANOVA table for combined analysis SZSYNA and SZSYNB.

Source	DF	Progeny	Mortality	Weight loss	MDP	Dobie
Rep	9	0.05	152.46	2.71	3.56	2.79
Synthetics	11	0.12***	124.08	13.64***	11.36**	7.33***
Population	1	0.01	20.11	3.43	35.09**	3.19
Selection Method	2	0.20**	153.82	34.28***	15.96*	12.86**
Sel. Direc/method	3	0.25***	276.51	19.49***	10.27*	14.31***
Pop. x Method	2	0.07	75.85	2.32	7.08	4.09
Pop. x Direc/Method	3	0.02	18.64	5.00	4.33	0.22
Error	99	0.03	105.00	2.29	3.78	1.57

*, **, *** = $P \leq 0.05$, $P \leq 0.01$ and $P < 0.001$, respectively

Table 4. Results from divergent selections for SZSYNA99 and SZSYNB99 combined.

Method	Progeny			Weight loss			MDP			Dobie index		
	R	S	RR	R	S	RR	R	S	RR	R	S	RR
S2 rep	1.52	1.74	0.88**	3.3	4.9	0.67**	39.8	38.3	1.04*	8.8	10.5	0.84**
S2 unrep	1.65	1.64	1.01	5.1	5.7	0.89	38.8	38.9	1.00	9.8	9.7	1.01
S1 unrep	1.43	1.60	0.88**	2.8	4.5	0.62**	40.5	39.5	1.03	8.1	9.3	0.87*

*, ** = significant P = 5% and P = 1% respectively
R = Synthetic made from the most weevil resistant lines
S = Synthetic made from the most weevil susceptible lines
MDP = Mean development period
RR = Relative resistance i.e. the resistant synthetic expressed as a fraction of the susceptible one. Values below one mean the synthetic is more resistant than the susceptible one and values above one mean it is more susceptible for all parameters except MDP where the reverse is true

unreplicated S1 selection managed to improve resistance significantly, it was not as effective as S2 replicated selection for separating the populations into susceptible and resistant synthetics. Unreplicated S1 selection succeeded for one population (SZSYNB99), but not the other (SZSYNA99). By contrast, S2 replicated selection succeeded to significantly improve resistance and divergently separate the populations, and did this consistently for the two populations. The relatively good success using S1 unreplicated selection was largely influenced by the value of 22.7 we obtained for progeny emerged from [SZSYNB01BestS1UNRepl]-F2; this value was inexplicably and unbelievably good, but we have found no errors in our data and hence have reported it herein.

We were generally not successful at separating the four bi-parental populations into weevil susceptible and resistant synthetics (Table 5). Although there was a significant (P<0.01) difference between the best and worst synthetics in the combined analysis for all four populations (data not shown), only one population (SZSYNRA/CML206) responded to divergent selection for all four parameters (Table 5). There was also a significant increase in the mean development period for this population, suggesting that antibiosis played a part in the resistance expressed in this

Table 5. Percentage differences between divergently selected synthetics.

Selection Method	Population	Progeny	Weight loss	MDP	Dobie
S2 replicated	SZSYNA	17*	64*	1	19*
	SZSYNB	14*	34	5*	21*
	Average	15.5	49	3	20
S2 unreplicated	SZSYNA	-2	0	0	1
	SZSYNB	1	12	1	1
	Average	-0.5	6	0.5	1
S1 unreplicated	SZSYNA	7	14	4	11
	SZSYNB	17*	140*	1	19*
	Average	12	77	2.5	15
S1 unreplicated	RA/CML206	14*	155*	7*	12*
	CML394/CML206	5	0	0	1
	CML442/CML206	7	0	0	11*
	CML206/CML442	4	15	0	1
	Average	7.5	43	4	6

* significant separation ($DMRT_{0.05)}$

population. SZSYN[M37/CML206 also showed a significant response (P<0.05) for Dobie index of susceptibility. The lack of response to selection in three of the four bi-parental populations confirmed our assessment that S1 unreplicated selection was less effective than S2 replicated selection. It is also possible that these bi-parental populations had little genetic variation for weevil resistance. If this was the case, then differences for weevil resistance observed among the lines would have been due to experimental error, heritability of weevil resistance would have been close to zero, and selection would have been expected to result in little or no response. Weevil resistance of the line ‘RA87C3108-X-5-1-1-5-X-X-B’ has been well documented elsewhere (Arnason *et al*., 1986; Giga and Mazarura, 1991; Giga *et al*., 1999), whereas the other “resistant” parents of our bi-parental populations, ‘CML394’ and ‘CML442’, were classified as moderately resistant only in one unpublished report (Pixley and Kadzere, 1999). Despite the possibility that CML394 and CML442 may not be as resistant to weevil as RA87C3108-X-5-1-1-5-X-X-B, we expect that genetic variation for weevil resistance existed in all of the populations, and that failure to make progress from selection was due to ineffectiveness of the unreplicated S1 evaluation of weevil resistance.

CONCLUSIONS AND RECOMMENDATIONS

Our results indicate that it is possible to improve maize populations for resistance to maize weevil. While S1 unreplicated selection was sometimes as effective as S2 replicated selection, we were successful in separating only two of six populations into ‘resistant’ and ‘susceptible’ synthetics using this method. Replicated S2 selection was successful for both populations for which we applied it. Therefore, we conclude that progress is more likely when selections are based on S2 replicated rather than S1 unreplicated weevil resistance evaluations.

Although we showed that it is possible to improve maize populations for resistance to maize weevil, we still have concerns about the practicality and effectiveness of the weevil resistance screening methodology for use in a breeding programme. There is still need to identify quicker, less tedious and more heritable methods of screening maize samples for resistance to weevil. Finally, although we believe that use of superior cultivars can reduce losses due to weevil infestations in farmers’ stores, it is important to recognize that no maize grain will be immune to attack by weevils.

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YIELD STABILITY OF MAIZE (*Zea mays* L.) GENOTYPES ACROSS LOCATIONS.

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ABSTRACT

Maize genotypes vary in their response to variable environmental conditions. Twenty genotypes were tested at nine locations in Ethiopia (1,100-2,240 masl) in the 1998 cropping season to study their phenotypic yield stability. Analysis of variance and stability analysis were computed. Variances due to genotypes, environments, and G x E interaction were significant. Linear and non-linear components of G x E interactions were also present. Most genotypes had significant deviation mean square (S^2di) implying that they were unstable. None of the top yielding genotypes exhibited general adaptability. Some genotypes had relatively good performance in mid and high altitude areas whereas some had good performance in mid and low altitude areas indicating the possibility to develop specific genotypes adapted to mid and high or low and mid altitude areas. However, the top yielding genotypes were specifically adapted indicating that for high yield potential in each mega-environment, a specific breeding programmme is necessary. Results also showed that understanding of the biophysical limitations within the mega-environment will pave the way for genetic improvement for these limitations.

Keywords: Environment, genotype, interaction, maize, stability, *Zea mays* L.

INTRODUCTION

Changes in relative rankings appear to be an inevitable consequence of growing a set of plant genotypes in even a few locations or seasons. This is especially true in tropical regions where not only are environmental fluctuations greater but also crops lack the protection conferred by purchased inputs; thus for plant breeders, large genotype by environment (G x E) interaction impede progress from selection and have important implications for testing and cultivar release programmes (Smithson and Grisley, 1992). In fact, G x E interactions are as much a function of the genotype as they are of the environment and so are partly heritable (Hill, 1975). Statistically, G x E interactions are detected as a significantly different pattern of response among the genotypes across environments and biologically, this will occur when the contributions (or level of expression) of the genes regulating the trait differ among environments (Basford and Cooper, 1998). It is a common phenomenon in the Eastern Africa (Birhane and Bentayehu, 1989).

Ethiopia is a country of great environmental variation (EMA, 1988). Where environmental differences are greater, it may be expected that the G x E interaction will also be greater. As a result it is not only average performance that is important in genotype evaluation programmes but also the magnitude of the interactions (Fehr, 1992; Gauch and Zobel, 1997). Stability of performance is of special importance in Ethiopia where environmental conditions vary considerably and means of modifying the environment are far from adequate. Thus, this study was intended to study the stability of maize genotypes under different environments in Ethiopia.

MATERIALS AND METHODS

Twenty different maize genotypes of East Africa and CIMMYT origin were tested at nine locations situated between 7^0 09' N and 11^0 16' N latitudes and 36^0 00' E and 42^0 02' E longitudes in the 1998 main cropping season. The altitude and annual rainfall of the locations ranged from 1,100 meter above sea level (masl) to 2,240 masl and 900 mm to 1,595 mm, respectively. The testing locations were Pawe (1,100 masl), Bako (1,650 masl), Awasa (1,700 masl), Hirna (1,800 masl) Jimma (1,750 masl), Areka (1,800 masl), Arsi-negele (1,960 masl), Alemaya (1,980 masl) and Adet (2,240 masl). The locations represent three of the four major maize producing mega-environments in Ethiopia; viz. low altitude sub-humid zone, mid altitude sub-humid zone and high altitude sub-humid zone (Birhane and Bantayehu, 1989).

The genotypes were planted at each location in a randomised complete block design with three replications. The experimental unit was a two-row plot of 5.1 meter long, spaced 75 cm apart and plant-to-plant distance of 30 cm. All trial management practices were based on the recommendation of each location. Grain yield per hectare was calculated using average shelling percentage of 80% and adjusted to 12.5% moisture.

Each location was considered as a macro-environment. Thus each of these nine macro-environments was considered as an independent environment in the statistical analysis. Analysis of variance for each macro-environment and combined analysis of variance were computed for grain yield. Bartlett's test, as cited in Gomez and Gomez (1984), was also computed to assess homogeneity of variances prior to combined analysis. The statistical significance in analysis of variance was determined using the F-test.

The stability of yield performance for each genotype was calculated by regressing the mean yields of individual genotypes on environmental index and calculating the deviations from regression as suggested by Eberhart and Russell (1966). However, regression coefficient (bi) was considered as an indication of the response of the genotype to varying environments while mean square for deviations from regression (S^2di) was used as the criterion of stability as suggested by Becker and Leon, 1988.

Table 1. Combined analysis of variance for grain yield of maize genotypes used to estimate stability parameters.

Source	df	Mean square
Genotype (G)	19	514.96**$^{++}$
Environment (Env.) + G x Env.	160	471.72
Environment (linear)		
G x Env. (Linear)	1	65708.15**$^{++}$
Pooled deviation	19	83.52**
Pooled error	140	58.43**
	342	16.45

**- Significant when tested against pooled error mean sq. at P< 0.01.
$^{++}$- Significant when tested against pooled deviation at P< 0.01.

Table 2. Estimates of environmental index.

No.	Environments	Environmental index (I_j)
1.	Jimma	-0.71873
2.	Adet	3.25752
3.	Alemaya	-1.17122
4.	Hirna	-3.02619
5.	Pawe	0.38069
6.	Awasa	2.71989
7.	Areka	-1.81020
8.	Arsi-negele	-0.20912
9.	Bako	0.57735
	SE (m) ±	0.09074
	CD ±	0.25151

The regression coefficients (bi) were tested for significant difference from unity using t-tests while the significance of the deviations from regression (S^2di) from zero were tested by the F-test. MSTAT-C and Agro-base 1997 computer programmes were used for analysis of variance and stability analysis, respectively.

RESULTS AND DISCUSSION

Analysis of variance for grain yield revealed significant differences (P < 0.01) among the genotypes in each macroenvironment. The combined analysis also revealed significant difference among the testing environments, genotypes, and G x E interaction (Table 1). The presence of significant G x E interaction showed the inconsistency of performance of maize genotypes across the environments. A similar result was reported by Lothrop (1989) in which he indicated an increase in elevation causes G x E interaction.

The partitioning of G x E interaction into linear and non linear portions exhibited that both were important. G x E (linear) and pooled deviations were significant when tested against pooled error mean square indicating that both linear and non-linear portions accounted for G x E interaction. G x E interaction (linear) component was non-significant when tested against pooled deviations from regression indicating the equal importance of both linear and non-linear interaction in these materials. These results are in conformity with the findings of Chaudhary *et al*. (1994) in field pea.

Estimates of environmental index (Table 2) showed that Adet was the most favourable environment for realising the yield potential of the genotypes while Hirna was the poorest yielding environment. This showed that the performance of the genotypes varied from location to location.

The result of this experiment also showed that factors other than the elevation and rainfall distribution during the growing period had great impact on the performance of maize genotypes. For example, Alemaya and Hirna were among the good yielding environments (Dejene and Habtamu, 1993) whereas they were among the poor yielding environments in this experiment. This could be attributed to the continuous moisture stress after emergence due to shortage of rain in Eastern Oromia in 1998. The stress occurred during the vegetative growth while there was good distribution of rain during the grain filling period. This implied that the data obtained from the two locations in the 1998 may not represent the actual yield potential of the normal years. Thus, genotypes may be ranked differently in different years. Similar results were reported by some authors, (Fox and Rosielle, 1982; Becker and Leon, 1988). This also indicated the necessity of testing of elite maize genotypes for at least two years before recommending for commercial production especially in areas where the rainfall distribution is unreliable.

The mean grain yield of the genotypes across the nine environments ranged from 5.175 t/ha for Beletech RC-2 to 8.149 t/ha for BH-660 (Table 3). BH-660 was the top yielding at high altitude and had relatively good performance at mid altitude testing locations. But it was outyielded by BH-530, BH-140 and Gibe-1 at Pawe, low altitude sub-humid zone. Although, BH-530 was the top yielding at Pawe, it was one of the low yielding genotypes at the other testing locations, mid and high altitude sub-humid zones whereas BH-140 and Gibe Comp-1 had relatively good performance at low and mid altitude testing locations (data not presented). This indicated that the rank of the genotypes varied from one testing location to the other testing location confirming the presence of G x E interaction and for high yield potential specific breeding programmes are necessary for tropical low and high altitude maize growing areas of Ethiopia. This is similar to the report of Rathore and Gupta (1994) who stated that the presence of crossover interaction is substantial evidence in favour of breeding for specific adaptation.

The superior performance of BH-660 at high elevations could be attributed to its genetic background as its parental lines are developed from Kitale Synthetic- II and Eucador-573 which are adapted to high altitude transition zones (Benti *et al*., 1993). On the other hand, BH-530 with CIMMYT tropical maize germplasm in its genetic background (Benti *et al*., 1997), had better performance at the lower elevation.

Analysis of responsiveness as measured by regression coefficients (bi) indicated that most of the genotypes had average responsiveness (Table 3). The high yielding genotypes, BH-660 and Gibe Comp-1 were more responsive (bi >1) to improved environmental conditions than the other genotypes. The better response of Gibe Comp-1 as compared

Table 3. Mean grain yield, regression coefficient (bi) and mean square of deviation (S^2di) of maize genotypes tested under 18 environments.

Genotype	Yield (t/ha)	bi	S^2di	r^2
Alemaya Comp. RC-2[3]	6.421	0.8904	35.55**	0.88
Alemaya Comp.[2]	5.919	0.8275	30.16**	0.87
UCB RC-2[3]	6.433	0.8688	14.80	0.92
UCB[2]	6.151	0.8501	15.67	0.91
Beletech RC-2[3]	5.175	0.8721	29.37**	0.87
Beletech S_1C_1 RC-2[3]	5.515	0.9289	16.54	0.93
Beletech[2]	5.480	1.0688	46.08**	0.90
Late RC-5[3]	5.923	1.0659	17.17*	0.94
Synthetic RC-3[3]	6.078	1.1980	103.37**	0.85
BH-660[1]	8.149	1.3178	91.06**	0.88
EAH-75[2]	5.292	1.0080	54.36**	0.87
Bako Comp.[2]	5.518	0.8526	28.35**	0.88
Kuleni[2]	6.336	0.9270	24.85*	0.91
INT-A[3]	5.309	0.9557	-4.51	0.97
INT-B[3]	5.830	1.2910	13.17	0.95
Gibe Comp-1[2]	7.077	1.3230	46.49**	0.93
BH-140[1]	6.502	1.0931	20.20*	0.93
BH-540[1]	6.685	1.0422	55.53**	0.88
A-511[2]	5.375	1.1115	16.62	0.95
BH-530[1]	4.981	0.7459	184.82**	0.56
Mean	6.010			
CV %	11.690			
SE (m) $\pm$	0.2341			
CD $\pm$	0.6490			

*, ** - Significant at P< 0.05 and P< 0.01, respectively.
[1] - hybrids
[2] - open pollinated varieties
[3] - breeding populations

to the other genotypes indicated the possibility of developing responsive open pollinated varieties with high mean grain yield. The old composites, Alemaya Composite and Bako Composite had regression coefficients below unity (bi <1) indicating their average responsiveness to the favourable environmental conditions. In addition, their mean grain yields were less than the grand mean which indicated their inferior performance as compared to Gibe Comp-1.

The coefficient of determination (r^2) ranged from 0.56 to 0.97, which indicated that the large portion of the variation in grain yield could be attributed to linear regression on environmental index (Table 3). The simple correlation coefficient between mean yields and regression coefficients was also calculated and it showed positive relationship (r = 0.537) indicating the possibility to breed responsive varieties along with high grain yield. A similar result was reported by Abebe *et al*. (1984) in sorghum.

Most of the genotypes had a significant deviation mean square from linear regression implying that these genotypes were unstable across environments (Table 3). S^2di was the highest for BH-530. The high yielding genotypes, BH-660 and Gibe Comp-1 had also significant S^2di implying unstable performance across the testing environments. In general, when the adaptability parameters, i.e., mean yield, regression coefficient and deviation mean square from the linear regression were considered none of the genotypes exhibited general adaptability.

However, the good performance of BH-660 in the mid and high altitude areas and good performance of BH-140 and Gibe Comp-1 in the low and mid altitude areas indicated the possibility to develop maize genotypes adapted to mid and high altitude or low and mid altitude areas. Crossa *et al*. (1990) have also reported similar observation about the performance of specific maize genotypes across altitude ranges.

The results of this experiment demonstrated that elevation has great impact on the performance of maize genotypes in the tropical environments. It also showed some specific genotypes which are adapted to mid and high or mid and low altitude areas could be developed. But for high yield potential, a specific breeding programme is necessary for each maize producing mega-environment of Ethiopia.

The result also indicated that, in some areas, distribution of rainfall during the growing period is the determining factor for the performance of maize genotypes. Thus, in these areas, where we have abnormal distribution of rain in some years, testing of maize genotypes across the years may assist to select varieties which give good yield during the years with even distribution of rain and relatively good performance in the year of uneven distribution of rain. This also implied that an understanding of the biophysical limitations within the mega-environment (Basford and Cooper, 1998) will pave the way of genetic improvement for these limitations.

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ANALYSES OF COMBINING ABILITY AND HETEROTIC GROUPS OF YELLOW GRAIN QUALITY PROTEIN MAIZE INBREDS*

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ABSTRACT

Information on the combining ability and heterotic patterns of maize germplasm is of great value to maize breeders. The objective of this study is to determine the heterosis and combining ability of 10 yellow Quality Protein Maize (QPM) inbreds. Among these 10 QPM inbreds, 5 are tropical and subtropical QPM inbreds introduced from CIMMYT, another 5 are from the domestic provinces. These 10 QPM inbreds were used to make up a 10-parent diallel and these 45 crosses were tested in three different environments in Yunnan Province and Guangxi Autonomous region. Highly significant difference was observed among 45 entries and 3 environments for grain yield, while non-significant difference among 3 replications. General combining ability (GCA) was highly significantly different for grain yield, while specific combining ability (SCA) was not significantly different. The highest-yielding cross was CML166 × Qi205 (10,880 kg/ha) and the lowest-yielding cross was Chang631/O2 × Zhongxi096/O2 (5,496 kg/ha). The highest value of GCA for grain yield is CML161 (1,010.53) and CML166 (947.11), while the lowest value is Zhong x i096/O2 (-1,119.98). The highest value of SCA for grain yield is CML194 × Xin9101/O2 (1,813.50) and CML166 × Qi205 (1,272.00), while the lowest value is Xin9101/O2 × Qi205 (-1,670.96). According to the performance of grain yield, these 10 QPM inbreds could be divided into 4 heterotic groups.

Keywords: Combining ability, heterotic groups, inbreds, quality protein maize

INTRODUCTION

Some minority people still use maize as staple food in the remote areas of China as well as direct animal feed, where animal feed industry is not well developed. So there is a great demand for quality protein maize (QPM) due to its much better nutritional value in human consumption as well as feed.

The research on QPM including high lysine maize began in 1973 in China. Great achievements have been made in solving the negative correlation between quality and yield of QPM hybrids through efforts of the Chinese breeders. China has reached international advanced levels in term of QPM hybrid breeding. But in the recent years, the research and promotion of QPM slowed down due to inadequate germplasm resources and the lack of elite QPM lines, which are stress tolerant. In order to solve genetic frangibility of QPM and make yield of QPM hybrids breakthrough quickly, a large number of tropical and subtropical germplasm have been introduced. Those germplasm usually are more stress tolerant (such as disease, insects, high temperature, cloudy weather) than temperate germplasm. The tropical and subtropical germplasm have better root system and stay-green characteristic. The new germplasm of introgression between tropical and subtropical germplasm and temperate germplasm have not only better adaptability but also better stress tolerance. They can broaden the background of QPM germplasm, which will help in developing new hybrids with quality, high yield and multiple tolerances.

Tropical and subtropical lines and hybrids started to be introduced from CIMMYT into Yunnan Province since the 1980s. Domestication and introgression of tropical and temperate germplasm has been improved significantly in adapting tropical and subtropical lines. Wan Yibo et al. (1997) classified the main Chinese normal maize lines into five heterotic groups, but so far there was no reports about the heterotic groups of Chinese key QPM lines and the relationships among CIMMYT tropical, subtropical QPM lines and Chinese QPM lines. So it is very important to classify the QPM lines into different heterotic groups and create new heterotic patterns. The objective of this study is to analyze combining ability of yield characters and determine the heterotic groups of 10 lines through evaluating 45 crosses from a diallel of these 10 lines and provide scientific data for developing new hybrids with good quality, high yield and multiple tolerance in the future.

MATERIALS AND METHODS

The study included 5 tropical and subtropical yellow QPM lines from CIMMYT and 5 domestic key yellow QPM lines (Table 1), where CML refers to tropical and subtropical lines from CIMMYT. The 10 lines were crossed into 45 crosses in a diallel in 1999 summer season. The crosses were planted in Baoshan (subtropical and low altitude area), Dehong (tropical and low altitude area), Yunnan Province and Nanning (subtropical area) Guangxi Autonomous region to evaluate yield in 2000 summer season. The experimental design was a randomized complete block design with three replications for each environment. The plot was one 3-m row spaced 0.6-m apart with 0.25-m between hills, with a density of 66,667 plants/ha. The data of yield were collected with 15% moisture, 80% shelling percentage. At the same time, the data of plant height (PH), the number of rows per ear (R/E), the number of kernels per row (K/R) and thousand-seed weight (TSW) were also collected. Five plants were randomly measured to determine PH and five ears were randomly selected to determine R/E, K/R and TSW.

MSTATC software was used to complete the analyses of variance. Variance of yield was analyzed by using

Table 1. Germplasm resource and characters of 10 QPM inbreds.

Inbred lines	Germplasm resource	Grain color	Grain texture	% Protein in grain	% Tryptophan in protein
CML171	G25QPM	Y	F	10.9	0.90
CML194	S□ Africa	Y	D	8.4	0.88
CML166	P66QPM	Y	D	10.5	0.88
CML161	G25QPM	Y	F	11.2	0.82
Chang631/O2	-	Y	D	-	-
CA339	G32	Y	D	-	-
Zhongxi096/O2	-	Y	D	-	-
CML164	P 65QPM	Y	F	9.0	0.89
Xin9101/O2	-	Y	F	-	-
Qi205	Subtropical germplasm P70QPM introgressed temperate cross (Wei141×Zhongxi017)	Y	D	-	-

(Y: Yellow, F: Flint, D: Dent)

FACTOR model. A character would not be analyzed on combining ability unless the difference of the character was significant. The combining ability of 10 lines was analyzed using SAGA. The value of general combining ability (GCA) and specific combining ability (SCA) effects were automatically calculated in SAGA.

According to hypothesis that yield is higher in inter-groups hybrids than intra-groups hybrids, the 10 QPM lines were divided into different heterotic groups. In other words, the SCA on yield of one cross of which parents were in different heterotic groups is higher than the one of which parents were in the same heterotic group.

RESULTS AND ANALYSES

The data on yield of 45 crosses in Dehong, Baoshan and Nanning were listed in Table 2. In conclusion, the highest-yielding cross was CML166 × Qi205, yielded 10,880 kg/ha; the second highest-yielding cross was CML194 × CML166 yielded 10,452 kg/ha. In Dehong, the highest-yielding cross was CML166 × Qi205 also, yielded 12,220 kg/ha. In Baoshan, the highest-yielding cross was CML166 × Chang631/O2, yielded 12,270 kg/ha. In Nanning, the highest-yielding cross was CML166 × CML161, yielded 9,356 kg/ha. The results of variance analyses were listed in Table 3. The environments and crosses were significantly different, while replications were not significantly different for grain yield. Interaction of environment × cross was highly significantly different. That means the yield of crosses was greatly affected by the environments. Variance analyses of GCA and SCA were obtained from Table 3. The GCA was significantly different in grain yield, while SCA was not significantly different, which indicated that effect of GCA was superior in the yield of crosses and the difference of yield mainly resulted from the difference of the effect of GCA. This indicated that additive gene action was dominant in determining grain yield for hybrid, while non-additive gene effect was not as great as additive gene action. It is said that grain yield for hybrid was mainly governed by additive gene action. The data of other characters such as plant height were not listed here. The results of variance analyses were also presented in Table 3. The difference among 45 crosses was highly significant for PH, R/E, K/R and TSW. The GCA effect for PH, R/E, K/R and TSW was highly different, while SCA effect of them was not significantly different. This indicated that those four traits were mainly governed by additive gene action.

The value of GCA effect is shown in Fig. 1 and Table 4 and SCA effect in Table 5. The line with the highest value of GCA effect for grain yield was CML161 (1,010.53), followed by CML166, CML171, Qi205 and CML194 (947.11, 755.61, 346.40 and 195.94) (Fig. 1). The first five crosses with high grain yield across three locations were Qi205 × CML166, CML194 × CML166, CA339 × CML161, Chang631/O2 × CML166 and CA339 × CML171. The lines with the lowest value of GCA effect for grain yield were Zhongxi096/O2 (-1,119.98), CML164 (-960.47) and Xin9101/O2 (-916.24). The last 9 crosses with low grain yield were all crossed with those three lines. In conclusion, the GCA of parent-lines plays a key role in pedigrees. It is possible to get high-yielding crosses by using CML161, CML166, CML171?Qi205 and CML194 as parents. Inbreds Xing9101/O2 and Zhongxi096/O2 had the lowest value of GCA for plant height. So those two inbreds can be used to improve the plant performance. Inbreds CML161 and CML171 had the highest value of GCA for thousand-seed weight. The two inbreds can be used to breed for big kernels. The first three crosses with highest value of SCA effect for grain yield were CML194 × Xin9101/O2 (1,813.50), CML166 × Qi205 (1,272.00) and CML171 × Zhongxi096/O2 (1,205.20) (Table 4). But their yield only ranked in 10th, first, 16th respectively. That is to say the value of SCA effect

Figure 1. Estimates of GCA among 1 QPM inbreds for grain yield.

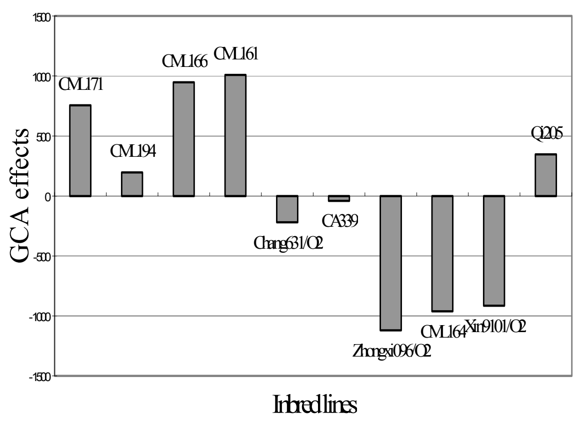

Table 2. Means of these 45 crosses for grain yield across three replications in three locations.

Crosses	Yield (kg/ha)			
	Dehong	Baoshan	Nanning	Mean
CML171×CML194	8333	9911	7467	8570
CML171×CML166	9111	10160	7089	8787
CML171×CML161	10670	11310	7400	9793
CML171×Chang631/O2	10000	10470	7956	9475
CML171×CA339	10000	11960	8067	10009
CML171×Zhongxi096/O2	10000	9289	8178	9156
CML171×CML164	7111	7422	8467	7667
CML171×Xin9101/O2	8222	9622	8511	8785
CML171×Qi205	10220	8733	6956	8636
CML194×CML166	11560	11840	7956	10452
CML194×CML161	11110	9422	7889	9474
CML194×Chang631/O2	9333	7822	7444	8200
CML194×CA339	7778	8400	7111	7763
CML194×Zhongxi096/O2	6222	8800	6067	7030
CML194×CML164	6889	8289	6733	7304
CML194×Xin9101/O2	11110	10270	6844	9408
CML194×Qi205	6222	11270	7111	8201
CML166×CML161	8222	10510	9356	9363
CML166×Chang631/O2	9778	12270	8022	10023
CML166×CA339	9111	10360	8178	9216
CML166×Zhongxi096/O2	6889	8622	6289	7267
CML166×CML164	10000	8578	7067	8548
CML166×Xin9101/O2	6667	9111	7844	7874
CML166×Qi205	12220	11510	8911	10880
CML161×Chang631/O2	11330	10710	7178	9739
CML161×CA339	12000	11180	6911	10030
CML161×Zhonhxi092/O2	10000	7689	8022	8570
CML161×CML164	8222	8511	8289	8341
CML161×Xin9101/O2	8222	8467	8244	8311
CML161×Qi205	9778	9422	8689	9296
Chang631/O2×CA339	4000	8867	8556	7141
Chang631/O2×Zhongxi096/O2	4333	6533	5622	5496
Chang631/O2×CML164	4222	8289	6733	6415
Chang631/O2×Xin9101/O2	7333	9622	5244	7400
Chang631/O2×Qi205	8667	10220	8689	9192
CA339×Zhongxi096/O2	7333	6333	5956	6541
CA339×CML164	5000	10560	7511	7690
CA339×Xin9101/O2	4222	9200	7400	6941
CA339×Qi205	6444	12040	9067	9184
Zhongxi096/O2×CML164	5556	7933	7733	7074
Zhongxi096/O2×Xin9101/O2	6000	7311	6222	6511
Zhongxi096/O2×Qi205	8000	9178	7511	8230
CML164×Xin9101/O2	4667	7200	6733	6200
CML164×Qi205	7778	7667	8289	7911
Xin9101/O2×Qi205	3778	6222	8222	6074

was not correspondent with the yield of crosses, except CML166 × Qi205. The last three crosses with lowest value of SCA effect were Xin9101/O2 × Qi205 (-1,670.96), Chang631/O2 × Zhongxi096/O2 (-1,479.80) and CML171 × CML166 (-1,230.88), their yield ranked in 44th , 45th and 17th. Though one of their parents was CML166, CML171 and Qi205, which have a high value of GCA effect, since SCA effect was a large negative value, which results into the low total effects. So the yield of F1 crosses results from GCA and SCA of their parents, the lines with high GCA and SCA should be selected as parents.

According to the yield performance of 45 crosses, especially SCA of two parents for grain yield, the 10 lines were divided into different heterotic groups. In other words, when two lines possess high SCA, they may be classified into different heterotic groups. Otherwise, they may be in the same group. In this study, the 10 lines were divided into 4 groups: CML171, CML166, CML161 and CML164 were one group, recorded A; CML194 was another group, recorded B; Chang631/O2, CA339, Zhongxi096/O2 and Xin9101/O2 were one group, recorded C; Qi205 was a group, recorded D. Since CML171, CML166, CML161 and CML164 were tropical lines, group A was tropical group; CML194 was subtropical line, group B was subtropical group; group C was temperate group and group D was introgression group. Further analyses on grain yield, heterotic patterns A×D, A×C, A×B, and B×C were obtained. Comparison of the results of heterotic groups with pedigree of the dose CIMMYT lines, inbreds which were extracted from the same population or gene pool mostly belonged to the same heterotic group. CML171 and CML161 were all developed from G25QPM; CML164 was extracted from P65QPM and P65QPM was developed from G25QPM; CML166 was extracted from P66QPM, P66QPM and P65QPM were extracted from the same geographic race Amarillo. In this study, they all belonged in the same heterotic group A.

Table 3. Analyses of variance of these 45 crosses among 10 QPM inbreds for grain yield, plant height (PH), number of rows per ear (R/E), number of kernels per row (K/R), thousand- seed weight (TSW).

Sources	D.F.	MS				
		Grain yield	PH (cm)	R/E	K/R	TSW (g)
Environment	2	110464788 **	39528 **	24.83 **	2790.8 **	11774 **
Replication	2	1039890	42	0.04	1.7	743 *
Cross	44	14765009 **	4501 **	13.07 **	54.5 **	6390 **
GCA	9	5078646 **	2158 **	5.72 **	19.1 **	2529 **
SCA	35	756706	74	0.37	2.7	242
Env.×Cross	88	5875513 **	493 **	2.90 **	19.9 **	2580 **
Error	268	1952104	657	0.36	3.3	231

(** Significant at α= 0.01 levels, * Significant at α=0.05 levels)

Table 4. Estimates of GCA among 10 QPM inbreds for grain yield, plant height (PH), number of rows per ear (R/E), number of kernels per row (K/R), thousand seed weight (TSW).

Inbreds	GCA				
	Grain yield	PH (cm)	R/E	K/R	TSW (g)
CML171	755.61	17.73	-1.59	1.62	11.29
CML194	195.94	7.89	-0.01	0.11	7.09
CML166	947.11	28.42	1.29	1.24	2.00
CML161	1010.53	8.70	-0.77	1.19	37.51
Chang631/O2	-219.06	-7.74	-0.63	0.24	1.26
CA339	-39.81	-6.87	-0.17	-0.45	-0.06
Zhongxi096/O2	-1119.98	-18.09	0.84	-2.62	-21.05
CML164	-960.47	-0.96	0.24	0.15	-27.50
Xin9101/O2	-916.27	-26.99	0.12	-2.70	-5.02
Qi205	346.40	-2.09	0.67	1.22	-5.51

Table 5. Estimates of SCA among 10 QPM inbreds for grain yield.

Inbreds	SCA									
	CML 171	CML 194	CML 166	CML 161	Chang631 /O2	CA339	Zhongxi096/ O2	CML 164	Xin9101/ O2	Qi205
CML171										
CML194	-696.0									
CML166	-1230.8	994.1								
CML161	-287.6	-47.6	-909.8							
Chang631/O2	623.9	-92.0	980.4	633.0						
CA339	978.3	-707.9	-5.8	744.7	-914.9					
Zhongxi096/O2	1205.2	-361.1	-875.3	364.9	-1479.8	-614.3				
CML164	-443.3	-246.6	246.8	-24.2	-720.6	375.7	839.6			
Xin9101/O2	630.8	1813.5	-417.6	-98.0	220.1	-418.0	232.4	-238.0		
Qi205	-780.5	-656.1	1272.0	-375.4	749.8	562.2	688.4	210.5	-1670.9	

DISCUSSION

In this study, the value of the GCA effect of one line was calculated as the sum of one character of crossing with this line minus the sum of the character of all the crosses. So the value depended on all the lines included in this study and the value was just a relative one.

As shown in Fig 1, CML161 was the best general combiner for grain yield. Other inbreds showing significant positive GCA effects for grain yield were CML161, CML171, Qi205 and CML194. Therefore these inbreds would be the ideal lines for initiating a hybrid programme. Our results also indicated that the yield of F1 hybrid relies on not only GCA but also SCA. That suggested the use of high value of GCA and SCA at the same time for the high-yielding breeding.

Based on the data of this experiment, 5 high-yielding crosses CML166 × Qi205, CML194 × CML166, CML161 × CA339, CML166 × Chang 631/O2 and CML171 × CA339 were selected. Those 5 hybrids out-yielded the normal local hybrid Baoshi 2 in the range of 18.55-28.85%, while low-yielded the normal local hybrids Baoyu 7 at range of 6.37-13.86%.

According to the performance of grain yield, especially the value of SCA for grain yield, these 10 QPM inbreds could be divided into 4 heterotic groups. But there was uncertainty of line Xin9101/O2. It was classified into heterotic group C temporarilly.

In this study, we have obtained 4 heterotic patterns: A×D, A×C, A×B and B×C. Among these 4 heterotic patterns, there are 3 patterns " temperate inbreds × tropical and subtropical inbreds ". This has been proved by many other studies (Vasal et al, 1992; Moll et al, 1965; Holland et al, 1995; Beck et al, 1991).

This study has provided useful information for Chinese QPM breeding, the introgression between the tropical, subtropical and temperate materials can be carried out among the same herterotic group, the Chinese QPM genetic background could be broadened in this way.

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SESSION II:

Integrated approaches to Striga control

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RECENT ADVANCES IN BREEDING MAIZE FOR RESISTANCE TO *STRIGA HERMONTHICA* (DEL.) BENTH

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ABSTRACT

***Striga* represents the largest biological threat to cereal production in sub-Saharan Africa. Breeding for resistance to *Striga* has been the focal point of IITA to reduce the impact of this parasite on maize production. The early breeding work at IITA focused on search for tolerance to *Striga*. IITA has made a significant shift in emphasis towards selection of resistant maize genotypes that support a reduced number of *Striga* plants since the early 1990s. Population improvement and the inbred-hybrid method have been used to increase the levels of resistance to *Striga*. An experiment was conducted to evaluate progress from five cycles of recurrent selection in a late-maturing composite, TZL COMP.1-W, at two locations for two years. Selection reduced *Striga* damage symptoms by 3% per cycle and number of emerged *Striga* plants by 10% per cycle. At the same time, grain yield in this population increased by 16% per cycle under *Striga* infestation and by 2% per cycle under non-infested conditions. Furthermore, several open pollinated varieties of different maturity with good levels of resistance to *Striga* were derived from diverse populations. The inbred-hybrid approach has also been effective in identifying inbred lines with high levels of resistance to *Striga* from diverse sources of germplasm. Some of these lines were evaluated in hybrid combinations at two locations with and without *Striga* infestation. Most of the hybrids involving these inbred lines supported fewer *Striga* plants and produced higher yields under infestation with *Striga* than a commercial hybrid. The best hybrids were also more productive than a standard *Striga* resistant hybrid check with much fewer emerged *Striga* plants. These hybrids sustained little or no yield loss under infestation with S. *hermonthica*. In contrast to tolerance, the selection and use of such resistant open-pollinated varieties and hybrids can reduce reproduction of seed of the parasite thereby depleting the soil innoculum in areas where the parasite is endemic.**

INTRODUCTION

Striga is considered to be one of the major biological constraints to food production in sub-Saharan Africa, probably a more serious agricultural problem than insects, birds, or plant diseases (Ejeta and Butler, 1993). The problem of *Striga* is intensifying across regions in Sub-Saharan Africa because of deteriorating soil fertility, shortening of the fallow period, expansion of production into marginal lands with little nutrient input and an increasing trend towards continuous cultivation of one crop in place of traditional rotation and inter-cropping systems. *Striga* severely affects an estimated 40 million hectares of land devoted to cereal production in West Africa alone with additional 70 million hectares having moderate levels of infestation (Lagoke *et al*., 1991). Heavy infestation with *Striga* can render land unfit for crop production and fields have been abandoned in the worst affected areas. The annual yield losses due to *Striga* in the savannas alone are estimated to be worth US$7 billion and are detrimental to the lives of over 100 million people in Africa (Mboob, 1986). The effects are likely to be long lasting as *Striga* plants produce millions of tiny seeds that can stay viable in the soil for many years. Among the numerous species of *Striga* that are endemic to Africa, *Striga hermonthica* (Del.) Benth is the most widespread species affecting cereals, with maize being the most susceptible (Barner *et al*., 1995; Lagoke *et al.,* 1991).

Combating *Striga* has been a focal point for the IITA maize research team since 1982. The advances made in the development of effective artificial field infestation techniques at IITA in the late eighties have made it possible to identify resistance to *Striga* from diverse sources of germplasm (Kim, 1991). The early breeding work at IITA focused on a search for tolerance to *Striga* and sources of tolerance were identified from both temperate and tropical maize germplasm. Working within these sources of germplasm, breeders at IITA made some progress in developing inbred lines and experimental hybrids with some level of tolerance to *Striga hermonthica* (Kim, 1991;Kim and Winslow, 1991). Since the early 1990s, IITA has made a significant shift in emphasis towards selection of maize genotypes that support a reduced number of *Striga* plants. Considerable progress has been made with this approach as excellent sources of resistance have been obtained from *Zea diploperennis*, African landraces and elite tropical germplasm. Intensive screening of these sources of germplasm in the field and in the screenhouse under artificial infestation have yielded inbred lines with high levels of resistance to *Striga* as demonstrated in repeated greenhouse and field tests conducted at IITA.

This paper summarises the recent progress that has been attained at IITA in the development of open-pollinated varieties, inbred lines and hybrids of maize with resistance to *Striga* that are adapted to the major maize growing savannas in Africa.

ACHIEVEMENTS AND PROGRESS

Increasing the levels of resistance to *Striga* through recurrent selection

Recurrent selection has been used as one of the methods at IITA to fix favourable alleles for resistance to *Striga* in maize. A number of populations with diverse genetic backgrounds, maturates and grain colours have been subjected to recurrent selection under artificial *Striga* infestation in at least one location. Full sib and S1 family selection schemes have been used to increase the frequencies of favourable alleles for resistance to *Striga* in these populations. The best *Striga* resistant families selected from family evaluation trials have been used to form the new cycle of selection for further improvement as well as for selfing to generate *Striga* resistant inbred lines.

Periodic evaluation of progress from selection is essential to determine the efficiency of a recurrent selection procedure in changing the target traits in a desired direction.

An experiment was carried out to evaluate progress from five cycles of recurrent selection in a late-maturing composite, TZL COMP.1-W. A full-sib family selection scheme that was used initially was later changed to an S1 family selection scheme to improve resistance to *Striga hermonthica* in this population. In the 1998 dry season, remnant seeds of the five cycles of selection from this composite were increased to evaluate progress from selection. An experiment consisting of these cycles of selection was evaluated at Mokwa and Abuja in 1999 and 2000 with and without *Striga* infestation. As shown in Figure 1, selection reduced *Striga* damage symptoms by 3% per cycle and number of emerged *Striga* plants by 10% per cycle in this population. At the same time, grain yield in TZL COMP.1-W increased by 16% per cycle under *Striga* infestation and by 2% per cycle under non-infested condition (Figure 2). Thus, recurrent selection was effective in concentrating the frequencies of favourable genes for resistance to *Striga hermonthica* in this population.

The various populations under improvement for resistance to *Striga* have also been good sources of open-pollinated varieties for distribution to the national programmes through regional trials. In 2001, a trial consisting of 18 late-maturing open-pollinated varieties derived from the different *Striga* resistant populations along with two check hybrids (9022-13 and 8338-1) was evaluated at Abuja and Mokwa in Nigeria and at Ferke in Côte d'Ivoire. As shown in Table 1, the location x variety interaction mean squares were significant for all parameters, except for grain yield under non-infested condition, plant height and anthesis-silking interval (ASI) under *Striga* infestation. Significant differences were detected among varieties for all traits measured, except for the number of emerged *Striga* plants at eight weeks after planting. The high *Striga* damage score and extremely low grain yield of the susceptible hybrid, 8338-1 is an indicator of the high levels of *Striga* infestation that were present at these locations (Table 1).Almost all the open-pollinated varieties did not differ significantly from a standard resistant hybrid check, 9022-13, for grain yield under *Striga* infestation. More than half of these varieties also supported fewer *Striga* plants than the resistant hybrid.The first four top ranking varieties out-yielded 9022-13 by at least 10% under *Striga* infestation. These varieties did not differ significantly from 9022-13 for grain yield under non-infested condition and had lower *Striga* damage symptoms, good ear aspect scores and reduced anthesis-silking interval. ACR97 TZL COMP.1-W is currently being widely tested on-farm in Nigeria and other countries in West Africa.

A second variety trial composed of 12 early-maturing and *Striga* resistant/tolerant open-pollinated varieties derived from various source populations and three susceptible check varieties (TZE COMP3 C2, TZE COMP4 C3 and ACR94 Pool 16 DT STR) was evaluated at Abuja and Mokwa in Nigeria and at Ferke in Côte d'Ivoire. The location x variety interaction mean squares from the combined analysis of variance were not significant for grain yield under non-infested condition, days to silk under infestation, number of emerged *Striga* plants at 10 weeks after planting and ear aspect score under infestation (Table 2). Significant differences were detected among varieties for all parameters recorded, except for days to silk, plant height and anthesis-silking interval under infestation. Most of the new *Striga* resistant early-maturing varieties produced between 10 to 80% higher grain yield than TZE COMP 4 C3 under *Striga* infestation. Almost all of these varieties also supported fewer *Striga* plants than the three susceptible check varieties. The first four varieties out-yielded TZE COMP3 C2 by at least 10% under *Striga* infestation and had lower *Striga* damage symptoms, fewer emerged *Striga* plants and good ear aspect scores. These varieties also had good yield potential under

Figure 1. Regression of *Striga* damage rating and number of emerged *Striga*/maize plants on cycles of selection evaluated at Abuja and Mokwa for two years

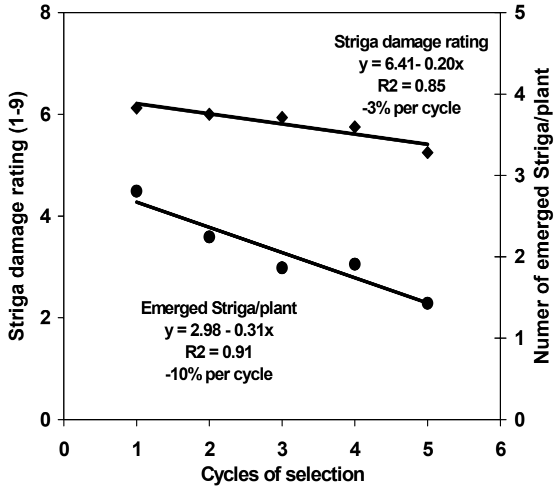


Figure 2. Regression of grain yield under infested and non-infested conditions with *Striga* on cycles of selection evaluated for two years at Abuja and Mokwa

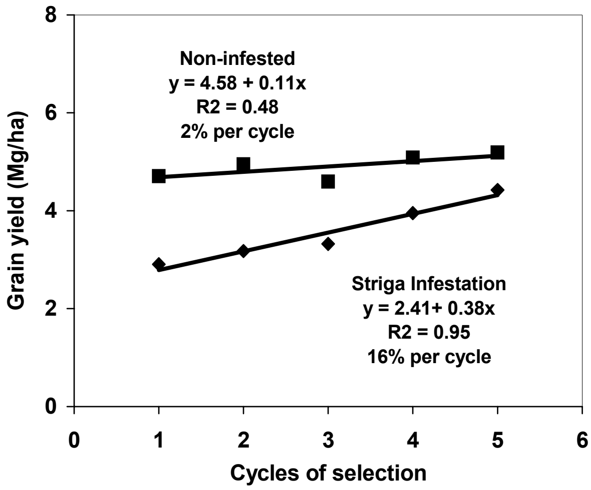


Table 1. Means of late-maturing *Striga* resistant varieties included in an advanced trial evaluated at Abuja and Mokwa in Nigeria and at Ferke in Côte d'Ivoire with and without *Striga* infestation in 2001

Variey	Grain yield		Days to silk	Plant height	*Striga* damage rating		Number of emerged *Striga* plants		Ear aspect	ASI
	Infested	non-infested	Infested	Infested	8 weeks	10 weeks	8 weeks	10 weeks	Infested	Infested
	(kg/ha)			(cm)	(1-9)[1]		(per plot)		(1-9)[2]	(days)
TZL COMP.1 C6 F2	3431	4415	61	207	4.2	4.7	64	86	4.3	3
Z. diplo BC4 C3	3346	4158	59	209	4.1	4.7	74	95	4.7	3
Z. diplo BC4 C2	3119	4438	59	209	4.5	5.2	72	96	5.0	3
ACR97 TZLCOMP.1-W	2909	4263	62	206	4.8	5.3	60	77	4.7	4
TZL Comp.1 C5	2717	4229	61	199	4.9	5.7	77	121	4.9	4
9022-13STR	2638	5159	61	195	5.2	5.7	105	165	5.0	5
STR EV IWD C0	2559	4651	61	198	5.0	5.8	88	130	5.1	5
ACR97 STR Syn-Y	2532	3832	61	192	4.8	5.5	112	163	4.8	5
ACR97 STR Syn-W	2487	3532	62	196	5.1	5.8	75	109	5.2	5
CAM.1 STR-2	2385	3856	60	193	5.3	6.0	135	188	5.1	4
K9350 STR	2357	3549	62	200	5.2	5.8	130	167	5.7	5
EV IWD STR C1	2316	4475	61	190	5.3	5.3	109	159	5.5	5
CAM.1 STR-1	2290	3974	62	192	5.3	6.0	101	150	5.1	4
STR EV IWF C0	2186	4369	62	190	5.6	6.1	97	129	5.2	5
TZB-SR (Susc.)	2055	3975	63	203	5.5	6.2	105	142	5.6	5
Mid-Alt. SYN-W STR	2036	3769	63	188	5.6	6.2	103	147	5.3	4
EV IWF STR C1	1950	4143	58	171	5.9	6.6	106	134	5.6	4
Advanced NCRE STR	1791	4315	63	208	5.8	6.7	120	136	5.9	6
Busseola STR	1676	3787	61	190	5.6	6.7	149	204	5.9	5
8338-1	645	3859	63	194	6.9	7.8	150	175	6.9	7
Mean	2371	4137	61	196	5.2	5.9	102	138	5.3	5
SE	640	428	1	11	0.9	0.9	41	42	0.6	1
CV (%)	27	16	3	9	20	17	46	40	12	37
Prob. of F for variety	**	**	**	**	*	**	ns	**	**	**
Prob. of F for var x loc	***	ns	*	ns	*	**	***	*	***	ns

[1] *Striga* damage rating taken at 8 and 10 weeks after planting, where 1 = no damage symptoms and 9 = severe damage due to *Striga*
[2] Ear aspect rating, where 1 = uniform, well filled and large cobs and 9 = rotten, small and non-uniform cobs

non-infested condition. ACR 94 TZE COMP 5-W is currently being widely tested on-farm in Nigeria and other countries in West Africa.

Increasing the levels of resistance to *Striga* through inbred-hybrid method

IITA uses the inbred-hybrid method as an effective tool to fix alleles for resistance to *Striga*. New inbred, lines derived from improved cycles of selection of *Striga* resistant populations are continually evaluated for vigour, productivity and resistance to Stirga to determine their usefulness as parents of open-pollinated synthetic varieties and hybrids. Several trials that consisted of inbred lines at the various stages of inbreeding were evaluated under *Striga* infested and non-infested conditions at Mokwa and Abuja in 2001. Of these, results from two trials involving inbred lines adapted to the lowland and mid-altitude are presented in Figure 3 and 4, respectively. Principal component analysis was used to define an index (principal component axis) that integrated traits sensitive to *Striga* in the two trials. The PC1 axis accounted for 55% of the total variation in the trial involving lowland inbred lines and 49% of the total variation in the trial involving mid-altitude inbred lines. Grain yields of both the lowland and mid-altitude inbred lines under *Striga* infestation were regressed on the first principal component (PC1) axis scores. As shown in Figure 3, most of the lowland inbred lines combined higher grain yield under *Striga* infestation with smaller PC1 scores than the standard *Striga* tolerant (9030 and 1368STR) and *Striga* susceptible (5057) inbred lines.

In general, low grain yield of the lines under *Striga* infestation was associated with increased *Striga* damage symptoms and number of emerged *Striga* plants, poor ear-aspect scores as well as reduced number of ears per plant under *Striga* infestation. Similarly, the mid-altitude inbred lines combined higher grain yield under *Striga* infestation with smaller PC1 score than a susceptible inbred line, 5057, (Figure 4).

Some of these lines were better than a resistant inbred line, 9450, for grain yield under infestation. In general, low grain yield of the mid-altitude adapted inbred lines under *Striga* infestation was associated with reduced plant height and number of ears per plant as well as with increased *Striga* damage rating and anthesis-silking interval. Several inbred

Table 2. Means of early-maturing *Striga* resistant varieties included in an advanced trial evaluated at Abuja and Mokwa in Nigeria and at Ferke in Côte d'Ivoire with and without *Striga* infestation in 2001

Variey	Grain yield (kg/ha) Infested	Grain yield (kg/ha) Un-infested	Days to silk Infested	Plant height Infested (cm)	*Striga* damage rating 8 weeks (1-9)[1]	*Striga* damage rating 10 weeks (1-9)[1]	Number of emerged *Striga* plants 8 weeks (per plot)	Number of emerged *Striga* plants 10 weeks (per plot)	Ear aspect Infested (1-9)[2]	ASI Infested (days)
TZE Comp.5-W C7	2961	3922	55	178	3.9	4.0	43	90	4.0	2
TZE Comp.5 C6	2723	3857	54	173	3.8	4.2	62	96	4.7	2
ACR94 TZE Comp.5-W	2597	3531	56	177	4.3	4.3	60	100	4.5	3
EV DT 99 STR C0	2421	3525	54	169	4.3	5.3	63	115	4.5	1
ACR94 TZE Comp.5-Y	2344	3262	55	176	5.1	5.2	68	90	5.0	4
2000 Syn WEC	2301	3651	55	169	5.3	6.3	63	108	4.9	2
TZE Comp.3 C2	2143	4186	55	166	5.3	6.1	97	145	5.0	3
EV DT-W 99STR C1	2081	3129	55	167	5.1	6.0	81	121	4.6	1
TZEW-Pop.x1368STR C1	1968	3755	55	172	5.6	6.6	114	166	4.9	3
EV DT-W 2000STR	1961	2670	56	156	4.8	5.6	18	42	4.8	1
99 Syn WEC	1863	3440	55	166	5.3	6.3	50	81	5.2	2
TZEW-Pop.x1368STR C0	1816	3539	55	162	5.5	6.3	74	107	5.1	1
ACR94 Pool16 DT STR	1805	2903	56	163	5.4	6.7	94	129	5.5	2
EV DT 97 STR C1	1709	3462	55	169	5.8	6.5	91	121	5.7	1
TZE Comp.4 C3	1648	3345	56	164	5.7	6.5	117	148	5.2	2
Mean	2156	3478	55	168	5.0	5.7	73	111	4.9	2
SE	495	338	1	11	0.8	1.1	36	42	0.5	1
CV (%)	31	21	3	9	18	18	68	54	16	77
Prob. of F for variety	*	***	ns	ns	**	**	*	*	**	ns
Prob. of F for var x loc	*	ns	ns	*	**	***	*	ns	ns	*

[1] *Striga* damage rating taken at 8 and 10 weeks after planting, where 1 = no damage symptoms and 9 = severe damage due to *Striga*
[2] Ear aspect rating, where 1 = uniform, well filled and large cobs and 9 = rotten, small and non-uniform cobs

lines that combined high grain yield under infestation and good level of resistance to *Striga* were selected for further testing in hybrid combinations.

Promising lines derived from diverse sources of germplasm have also been tested for their performance in hybrid combinations under artificial infestation with *Striga hermonthica*. For example some of the lines derived from *Z. diploperennis* were crossed to testers and evaluated at Abuja and Mokwa in 1999.

Figure 3. Regression of grain yields under *Striga* infestation on the first principal component scores of lowland white inbred lines and a *Striga* susceptible (5057) and tolerant (9030 and 1368STR) inbred checks tested at Abuja and Mokwa in 2001.

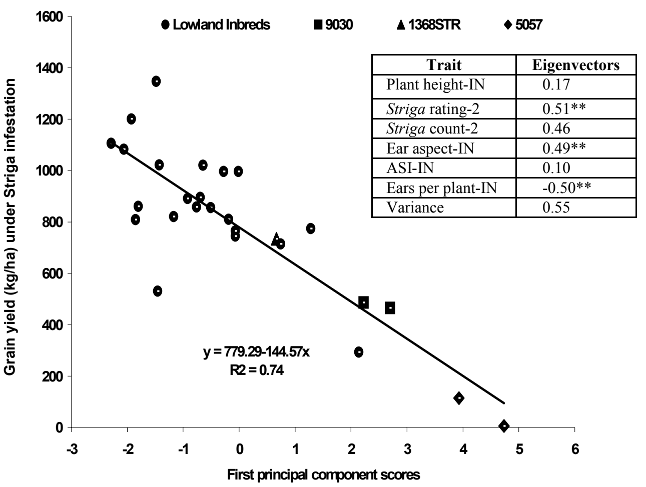


Figure 4. Regression of mean grain yields under *Striga* infestation on the first principal component scores for mid-altitude inbred lines along with a *Striga* susceptible (5057) and a resistant (9450) inbred checks tested at Abuja and Mokwa in 2001.

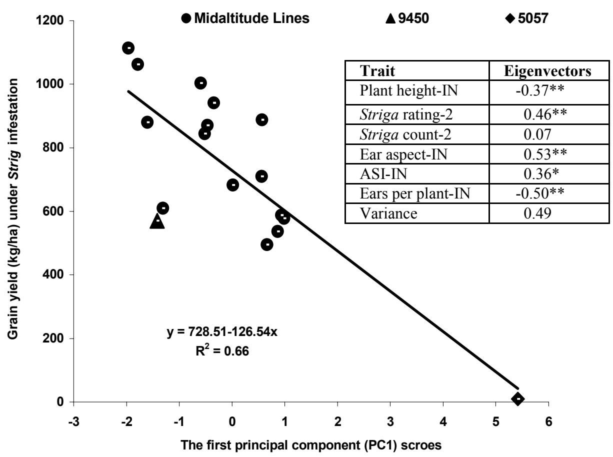


Figure 5. Means of hybrids of inbred lines from *Z.diploperennis* BC4 population tested at Abuja and Mokwa in Nigeria under *Striga* infestation in 1999.

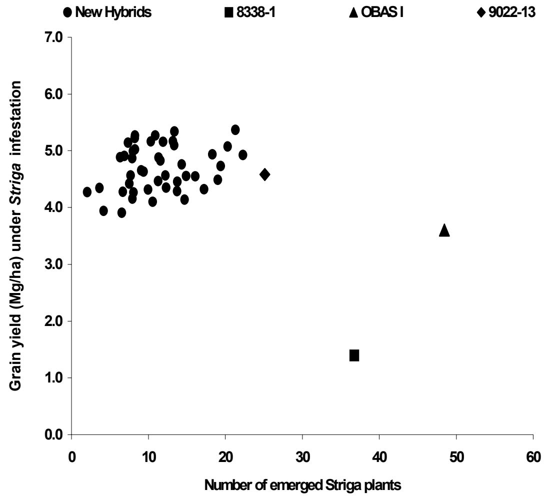
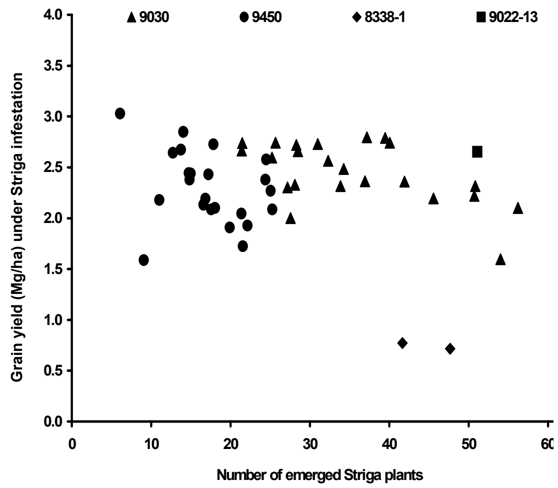


Figure 6. Means of hybrids between lines from STR Syn and two testers evaluated at Abuja and Mokwa in Nigeria under Striga infestation in 1999



Hybrids involving these inbred lines supported fewer *Striga* plants and produced higher yields under *Striga* infestation than a commercial hybrid that is widely grown in the savannas of Nigeria, Oba Super I (Figure 5). Some of these hybrids were also more productive than a resistant hybrid, 9022-13, with much fewer emerged *Striga* plants. The susceptible hybrid, 8338-1, supported a large number of *Striga* plants and produced lower yield under *Striga* infestation in this trial. In another experiment consisting of hybrids involving inbred lines derived from a synthetic variety, most of the hybrids supported fewer *Striga* plants than the resistant hybrid, 9022-13 (Figure 6). Some of these hybrids were also found to be as high yielding as the resistant hybrid. The susceptible hybrid, 8338-1, supported a large number of *Striga* plants and produced low yield under infestation with *Striga*. It is interesting to note that hybrids involving a resistant inbred line, 9450, as a tester supported fewer *Striga* plants than those involving a tolerant line, 9030, as a tester (Figure 6). The best hybrids identified from the two experiments had little or no yield loss under infestation with S. *hermonthica*. In contrast to tolerance, the selection and use of such resistant hybrids can reduce reproduction of seed of the parasite thereby depleting the soil inoculum in areas where the parasite is endemic.

CONCLUSIONS

Results summarised in this report highlight the merits of both recurrent selection and inbred-hybrid method as effective tools to concentrate favourable alleles for resistance to *Striga hermonthica*. Considering the current moderate level of resistance to *Striga* in the available varieties, host plant resistance alone is not expected to be effective to eliminate seed production of the parasite completely. Consequently, the high-yielding and well-adapted open-pollinated varieties that support reduced number of *Striga* plants can contribute significantly to our integrated effort to eradicate the *Striga* menace on-farm in areas where the parasite is endemic. Use of open-pollinated maize varieties and hybrids that support reduced number of *Striga* plants in rotation with legumes selected for their efficiency in causing suicidal germination of S. *hermonthica* will drastically deplete the reservoir of *Striga* seeds from the soil. In conjunction with the West and Central Africa Maize Collaborative Research Network (WECAMAN), efforts are currently underway to promote the adoption of these companion technologies to farmers that grow maize in *Striga* endemic areas of West and Central Africa.

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SCREENING OF MAIZE GERMPLASM UNDER *STRIGA* AND *STRIGA*-FREE ENVIRONMENTS IN KENYA AND SUDAN FOR GRAIN YIELD AND RELATED AGRONOMIC TRAITS.

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ABSTRACT

Forty two germplasm entries were evaluated at Alupe under *Striga* (artificial infestation) and under optimum environments (*Striga*-free) and at Wad Medani in Sudan under a *Striga*-sick environment to identify suitable varieties for *Striga*-prone areas. Data were taken on ear aspect, ears per plant, rotten ears, maize stand at harvest, two *Striga* counts at 60 and 80 days after planting, and grain yield. Seven varieties were identified at Alupe (*Striga*-free) as superior to all checks during long rains of 1999, while only four varieties were superior to the checks under *Striga*-infested conditions. At Wad Medani, there was no significant difference among tested varieties. Wad Medani is a drought-prone site and drought stress affected the expression of variety performance under *Striga*. This suggests that it is more difficult to select germplasm under more than one stress at the same time. *Striga* count and grain yield did not show a strong relationship as some varieties had both low *Striga* count and low grain yield. A further look at three varieties that gave yields of 7.2, 7.6 and 8.7 tonnes per hectare is recommended to verify their performance for utilization in the *Striga* tolerance/resistance breeding programme.

INTRODUCTION

Striga is one of the most serious pests that affect maize production in the tropics. The yield losses due to *Striga* are estimated on average to range between 65 - 100% (Lagoke *et al*., 1991). Among the five major *Striga* species, *Striga hermonthica* is the most important and widely found in Africa (Aggarwal, 1991; Lagoke *et al*., 1991). An estimated 21 million hectares of maize and sorghum are *Striga*-infested in Africa with yield loss of 4.1 million tonnes per year (Sauerborn, 1991). The extent of yield loss is related to the incidence and severity of attack, the host's susceptibility to *Striga*, environmental factors (edaphic and climatic), and the management level at which the crop is produced. A stressed crop is more prone to serious damage. *Striga* damage is caused by parasitism, reduction in photosynthesis and increased partitioning of growth to the roots of a susceptible crop. However, the majority of the yield loss is caused by a potent phytotoxic effect of *Striga* on the host (Ransom et al., 1996).

A number of control measures have been identified and each of them has one or more limitations that has led to low farmer adoption. The screening was conducted to identify suitable varieties for *Striga*-prone areas. A variety resistant or tolerant to *Striga* has in-built protection and hence will not need any extra inputs or training for farmers to use such a variety as a protection measure for *Striga*.

MATERIALS AND METHODS

Forty two varieties were evaluated at Alupe (both *Striga*-free and *Striga*-infested fields) and Wad Medani in Sudan (*Striga*-sick field) (Table 1). The study was carried out for one season in 2000. The varieties were grown in a randomized complete block design with two replications. Each plot consisted of two rows of 3 metre length. The distance between rows was 75 cm and plant to plant spacing within the row was 25 cm. Recommended agronomic practices for maize in the test sites were followed. Data recorded were *Striga* count per plot; ear aspect on 1-5 scale basis where 1 was the ear with most desirable traits such as big size, free from disease and flint while 5 was the ear with undesirable traits such as dent and diseases; ears per plant; rotten ears; and grain yield. Ten varieties were selected based on a combination of grain yield, ear aspect, and ear rot under *Striga* -infested environment.

RESULTS AND DISCUSSION

Striga Count:

There was significant difference in the number of emerged *Striga* shoots among the maize germplasm evaluated. This could be partially explained by differences in resistance to *Striga* emergenceamong varieties. Ten varieties had fewer *Striga* plants per plot compared to other varieties. The mean *Striga* count (80 days after planting) per square metre over two sites ranged from 9 to 19. The selected ten varieties had *Striga* counts ranging from 9 to 16.5 m^{-2} (Table 2).

Ear Aspect:

The ear aspect ranged from 1 to 4.8. Among the selected ten varieties, the variety that was rated poor on ear aspect due to being very dent was TZECOMP5 C6. The other varieties were rated between 1.4 to 3.3 (Table 2).

Ears Per Plant:

The number of ears per plant among the selected ten varieties ranged from 0.7 to 1.2. The variety with less than one ear per plant indicates a degree of susceptibility leading to barrenness. The ten selected varieties had a mean of one ear per plant. The size of the ear was not considered (Table 2).

Table 1. List of Test Varieties at Alupe in Kenya and Wad Medani in SudanDuring 1999 Long Rains Season.

No	Entry Pedigree	Origin
1.	LPSC3-54-1-2-2-3-B-B-B/STGAR-1-SR	KB98B
2.	P43C9-1-1-1-1-1-B*4/STGAR-1-SR	KB98B
3.	P43C9-56-1-1-1-2-B*4/STGAR-1-SR	KB98B
4.	P43C9-56-1-1-2-2-B*4/STGAR-1-SR	KB98B
5.	SPLC7F52-1-3-1-2-1-B*3/STGAR-1-SR	KB98B
6.	POOL PHYLLACORA c0#-11-4-#-1-1-B/STGAR-1-SR	KB98B
7.	POOL PHYLLACORA c0#-11-4-#-4-2-B/STGAR-1-SR	KB98B
8.	POOL PHYLLACORA c0#-15-2-#-3-3-B/STGAR-1-SR	KB98B
9.	P.390C2(SCB)F47-1-2-1-1-#-#-B*4/STGAR-1-SR	KB98B
10.	[MSRXPOOL9]CIF2-2-5-1(OSU23I)-5-3-X-X-1/STGAR-1-SR	KB98B
11.	[AC8342/1KENNE(1)8149SR/2/PL9A]#b-96-3-4/STGAR-1-SR	KB98B
12.	FR810/TZMSR-5-2-3-X/CML202/CML216/STGAR-1-SR	KB98B
13.	FR810/TZMSR-5-2-3-X/CML202/CML216/N3/STGAR-1-SR	KB98B
14.	[EV7992#/EV8449-SR]CIF2-334(OSUi)-8-6(I)-X-X-1-B…/STGAR-1	KB98B
15.	FR810TZMSRW-5-2-1-X-1-B-B/STGAR-1-SR	KB98B
16.	[EV7992#/EV8449-SR]CIF2-334-1(OSU9i)-8-6(I)-X-X-1-B-B/STGA	KB98B
17.	G16BNSEQCOF81-2-1-1-2-B/STGAR-1-SR	KB98B
18.	G16BNSEQCOF228-2-4-2-2-B/STGAR-1-SR	KB98B
19.	G16BSEQC1-15-2-1-2-2-1-B-B/STGAR-1-SR	KB98B
20.	G16BSEQC1-15-2-1-2-2-2-B-B/STGAR-1-SR	KB98B
21.	G16BSEQC1-58-1-1-1-1-1-B-B/STGAR-1-SR	KB98B
22.	G16BSEQC1-58-1-1-1-2-2-B-B/STGAR-1-SR	KB98B
23.	G16BNSEQC-58-1-1-1-2-4-B-B/STGAR-1-SR	KB98B
24.	SPEC6F111-1-3-2-1-B-B/STGAR-1-SR	KB98B
25.	TZECOMP5 C6	IITA
26.	TZECOMP1-WC4	IITA
27.	9022-13STR	IITA
28.	8338-1	IITA
29.	CML247/CML254XCML202/CML206	98103-0
30.	CML202/CML206XCML247/CML254	98103-0
31.	SYNTH STGAR-SR	EMB97P
32.	SYNTH STS SUSCEPTIBLE	EMB97P
33.	PHB3253 CHECK 3	PHB325
34.	HBCG4141 CHECK 4	HBCG41
35.	HB5222SR CHECK 5	HB5222
36.	PHB1 CHECK 6	PHB1 CH
37.	PHB 4 CHECK 7	LOC CH
38.	HB512 CHECK 1	HB512-1
39.	H511 CHECK 2	H511-1
40.	CHECK 8 KSTP94C0	KAKAM
41.	CHECK 9 KSTP94C1	KAKAM
42.	LOCAL CHECK 10 (H513)	LOCAL

Ear Rot

The ear rot was generally low except for KSTP94 C0 which had 26.5% ear rot. The rest of the varieties had ear rot ranging from 0 to 17.5%. The variety P43C9-1-1-1-1-1-B*4/STGAR-1-SR had 0% and had very clean kernels (Table 2).

The criteria used to select the ten varieties was a combination of grain yield, ear aspect, and ear rot at the artificially *Striga*-infested site. It was interesting to note that the three top yielding varieties at optimum level at Alupe (*Striga*-free) were also among the top ten selected varieties. The variety KSTP94 had consistent grain yield at both optimum and *Striga*-infested sites at Alupe. This is a reflection of its ability to tolerate *Striga* attack leading to reduced *Striga* effect despite the fact that it supports a large number of *Striga*.

The performance at Wad Medani is not a good reflection of varieties' reaction to *Striga* as the intensity of *Striga* was higher at Alupe where artificial *Striga* infestation was done compared to natural infestation in Sudan (Table 3). Most varieties performed similarly low, lacking significant differences among them at this site. This site is prone to drought and the low yields are a reflection of drought effect on the varieties as they were not bred for drought tolerance. This suggests that it is not advisable to screen for *Striga* or any other stress unless other stresses are are controlled.

Table 2. Mean *Striga* Count, Ear Aspect, Ears Per Plant, and Ear Rot for Selected Test Varieties at Harvest at Three Sites in Kenya and Sudan During 1999 Long Rain Season.

No	Variety	Striga Count (m^2)	Ear Aspect (1-5)	Ears/Plant	Ear Rot
1.	P43C9-1-1-1-1-1-B*4/STGAR-1-SR	10.3	1.4	1.0	0.0
2.	P390C2(SCB)F47-1-2-1-1-#-#-B*4/STGAR-1-SR	9.8	3.0	0.8	17.5
3.	[AC8342/1KENNE(1)8149SR/2/PL9A]#b-96-3-4/STGAR-1-SR	10.4	1.6	1.0	1.0
4.	G16BNSEQC0F81-2-1-1-2-B/STGAR-1-SR	9.5	2.5	1.0	1.9
5.	G16BNSEQC0F228-2-4-2-2-B/STGAR-1-SR	9.7	2.7	1.0	1.8
6.	G16BNSEQC1-15-2-1-2-2-2-B-B/STGAR-1-SR	15.0	2.6	1.0	3.6
7.	TZECOMP5 C6	9.0	4.8	0.9	10.4
8.	PHB1	15.6	3.3	0.9	2.8
9.	KSTP94 C0	16.0	3.0	0.9	26.5
10.	KSTP94 C1	16.5	3.3	1.0	10.1
11.	H512 (Check)	12.9	3.6	0.9	12.7
	Mean	**9.2**	**2.8**	**1.0**	**8.5**
	LSD 0.05	**15.4**	**1.9**	**0.14**	**16**
	CV %	**30**	**34**	**7**	**98**

Table 3. Grain Yield (t/ha.) of Ten Selected Varieties at Alupe in Kenya (2 fields) and Wad Medani in Sudan.

No	Variety	Alupe		Wad Medani
		Striga Free	Striga Infested	Striga Sick
1	P43C9-1-1-1-1-1-B*4/STGAR-1-SR	8.7	4.7	1.3
2	P390C2(SCB)F47-1-2-1-1-#-#-B*4/STGAR-1-SR	7.6	3.9	0.5
3	[AC8342/1KENNE(1)8149SR/2/PL9A]#b-96-3-4/STGAR-1-SR	7.2	4.2	0.7
4	G16BNSEQC0F81-2-1-1-2-B/STGAR-1-SR	4.3	3.4	0.8
5	G16BNSEQC0F228-2-4-2-2-B/STGAR-1-SR	3.9	3.5	0.8
6	G16BNSEQC1-15-2-1-2-2-2-B-B/STGAR-1-SR	4.2	2.2	0.6
7	TZECOMP5 C6	3.1	2.5	0.9
8	PHB1	3.8	3.2	0.7
9	KSTP94 C0	4.5	4.4	0.5
10	KSTP94 C1	2.8	3.5	0.4
11	H512 (Check)	2.7	2.0	0.7
	Mean	**4.2**	**3.5**	**0.7**
	LSD 0.05	**1.2**	**1.8**	**0.6**
	CV %	**13.6**	**25.7**	**38.6**

CONCLUSIONS

It is suggested that the ten selected varieties be further tested at more Striga-free and natural Striga-infested sites in comparison to the released KSTP94 and commercial hybrids for possible release for use in Striga-prone areas. The selection of varieties that perform well under both Striga and Striga-free conditions is conducive for commercial seed production as such a variety will have a wider market than any variety that is good under Striga and yet does not compare well with commercial hybrids under optimum conditions.

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RELATIVE ROLES OF HERBICIDE, GENOTYPE RESISTANCE AND FERTILIZER IN INTEGRATED MANAGEMENT OF *STRIGA ASIATICA* IN MAIZE IN MALAWI.

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ABSTRACT

The parasitic weed species *Striga asiatica* (L.) Kuntze is one of the major constraints in maize production in Malawi. Studies were conducted in 1999/2000 season to evaluate use of herbicide, resistant varieties and fertilizer application as components for integrated management for *S. asiatica* in Malawi. Two promising open-pollinated varieties from the International Institute of Tropical Agriculture (IITA) were evaluated under *S. asiatica* infection at Chitedze Research Station and 5 farmers' fields at 0 and 59:21:0+4S kgha^{-1} fertilizer rates. Another trial investigated the effects of seed dressing with Imazapyr (an acetolactate synthase [ALS] - inhibiting herbicide) at 0 and 45 gha^{-1} and two fertilizer rates (0 and 59:21:0+4S kgha^{-1}) on maize with ALS target site resistance on *Striga* suppression and grain yield also at Chitedze Research Station and 5 farmers' fields. In the variety trial genotypes did not significantly suppress *Striga* at all sites (P>0.05), while fertilizer use was important at one site only, where it increased emergence from 17 to 36 plants m^{-2} ($P\leq0.05$). Fertilizer increased yields at all sites ($P\leq0.05$). The local OPV (Masika) gave significant yield advantages at most sites. In the herbicide trial, Imazapyr suppressed *Striga* emergence at all sites, but increased yield at only one site. In contrast, fertilizer application had no effect on *Striga* emergence (P>0.05, but significantly increased yield at all sites ($P\leq0.05$). Fertilizer use is found to be the single most important factor in increasing maize yield under *S. asiatica* infection, while herbicide use is important for reducing emergence.

INTRODUCTION

Maize is the staple food crop in Malawi. The parasitic weed *Striga asiatica (L.)* Kuntze.(witchweed) is among the major constraints in its production. Recommended approaches in the control of witchweeed include the use of herbicides, high rates of fertilizer, long term trap cropping and hand pulling. These are usually not feasible for most smallholders who grow maize on over 80 % of the arable land with sub-optimal inputs and minimal rotations. Also, these measures do not offer complete control and may require several seasons for substantial *Striga* reduction (Parker 1984; Kabambe, 1991; Odhiambo and Ransom, 1996; Kabambe *et al.* 2000). The damaging effects of *Striga* spp. on cereals are more pronounced under low fertility conditions (Parker, 1984; Pieterse and Verkleij, 1991). There are only a few reports on maize resistance to *S. asiatica* (e.g. Ransom *et al.*, 1990). Berner *et al.* (1995) reported a 100 % yield advantage of a resistant maize variety over a susceptible one under *S. hermonthica* infection. Delaying *Striga* attachment by 3 weeks gave over 50% and 100% yield gains with resistant and susceptible maize varieties, respectively. One possible way to suppress parasitic weed emergence and prevent damage to the existing crop is through the use of herbicides which inhibit the activity of acetolactate synthase (ALS) (Garcia-Torres and Lopez-Granados, 1991). Examples include Imazapyr (Abayo *et al* 1996; Sulfonylureas (Adu-Tutu and Drennan, 1991) or Imazaquin (Berner *et a.l*, 1997). The herbicide is applied to maize that has target site resistance to the herbicide activity. Since the herbicide is applied to seed, low dosages in the range 10-30 g ha^{-1} (Abayo *et al.*, 1996) or 0.01 mg/g seed are possible (Berner *et al*, 1997). Estimates in Kenya have shown that 30 g a.i. may cost USD 5.00 (personal communication, F. Kanampiu, 1998). Studies were therefore conducted with the following main objectives:- 1). To evaluate the resistance of varieties reported resistant to *S. hermonthica* by IITA for resistance to *S. asiatica* in Malawi and 2) to determine the effect of Imazapyr seed treatment on *Striga asiatica* suppression and maize yield and 3) to determine interaction or relative importance of the two factors on *Striga* suppression and maize yield.

MATERIALS AND METHODS

A herbicide x fertilizer (H x F) and variety x fertilizer (V x F) trials were conducted in 1999/2000 to evaluate the effectiveness of resistant varieties, herbicide use and fertilizer in suppressing the parasitic weed sp *Striga asiatica* (L.) kuntze (witchweed). The main objective was to determine the importance of each of these factors in integrated management of the witchweed in smallholder farming conditions in Malawi.

Trial sites

The V x F trial was conducted at Mbawa, Chitedze Station, Chitedze farmer's field, Mponela, Chitsime and Chiradzulu. For the H x F trial, the same sites were maintained, except that instead of Chiradzulu, Linthipe was used. All sites, except Chitedze station, were on-farm sites and were selected on basis of verified history of notable *Striga* infection. Some of the chemical properties of the sites are given in Table 1. All sites had acceptable pH levels, suggesting potential good responses to nitrogen and phosphate fertilizers. Sites were low in organic matter.

At the Chitedze Research Station, each planting station was infested with 0.035 g (approx 3,500) seeds per station. Plots had four rows, each 4.0 m in length and 90 cm between rows. Maize stations were 50 cm apart, with 2 seeds per station, giving a plant density of 44,444 plants per hectare. The net plot consisted of the two middle rows excluding end-

Table 1. Chemical and physical properties of some of trial sites, V x F and H x F trials.

Site	Trial type	Chemical and physical properties				
		Depth (cm)	% OC	pH	% silt	% clay
Mponela	V x F	0-15	1.83	5.9	5	4
	V x F	15-30	1.91	5.7	6	6
Mponela	H x F	0-15	1.83	6.0	6	8
	H x F	15-30	1.8	6.0	8	8
Chitedze on-farm	H x F	0-15	1.83	5.8	4	16
	H x F	15-30	2.0	5.5	10	8
Linthipe	H x F	0-15	1.07	6.2	10	10
	H x F	15-30	1.27	6.2	8	8
Chiradzulu	V x F	0-15	1.74	6.3	8	12
	V x F	15-30	1.78	6.3	5	14
Chitsime	V x F	0-15	2.05	6.3	8	12
	V x F	15-30	2.13	6.4	6	10
Chitsime	H x F	0-15	1.96	6.0	4	10
	H x F	15-30	2.06	6.3	8	12

of ridge stations (2 x 3.5m x 0.9m = 6.3m^{-2}). Trials were kept free of weeds by hoe weeding at least 2 times within the first 3 weeks. Thereafter weeds (except *Striga*) were controlled by hand pulling.

Variety x fertilizer (V x F) trial

This was a 3 x 2 factotiral experiment conducted at 6 sites namely Chitedze Station, Chitedze farmers' field, Mbawa, Chiradzulu, Chitsime and Mponela. Two of the varieties evaluated were open pollinated varieties (OPV's) TZLComp.1 C4-W and AK94TZEComp5-W, which were amongst outstanding entries evaluated in the1998/99 season from the International Institute of Tropical Agriculture (IITA) (Kabambe *et al.*, 2000). The third variety was Masika, a local check. The fertilizer rates were no fertilizer application or application of 59:21:0+4S kg ha^{-1} N, P_2O_5 K and S,.

The trial design was randomized complete block, with 4 replications at Mbawa, Mponela, Chiradzulu and Chitedze farmer's field, and 3 replications at Chitsime and Chitedze station. In the fertilizer treatments the basal dressing was of 23:21:0+4S kg ha^{-1} N:P:K:S applied in a band made on the side of the ridge at or before planting day. For top dressing 36 kg ha^{-1} N from urea was applied using the point placement method. Planting was done on 14 December 2001 at Chitedze Station, 29th December at Chitedze farmer's field, 12th December at Mponela, 16th December at Chitsime, 31 December at Mbawa, and 16th November at Chiradzulu.

Imazapyr x fertilizer (H x F) study

This was a 2 x 2 factorial experiment conducted at Chitedze Research Station, Chitedze on-farm, Mponela, Mbawa, Chitsime and Linthipe. Levels for the Imazapyr factor were no seed treatment (the control) and Imazapyr seed coating at 45 gha^{-1} rate. The maize hybrid IntA/IntB//Pioneer325irMZ98F2, which bears target site resistance to the ALS inhibiting herbicide was used. All seeds were coated with insecticide (20% Lindane) and fungicide (26% Thiram dust) by mixing a sticker, insecticide and some water. The fertilizer levels were no fertilizer and 59:21:0+4S. Fertilizer application management was the same as in the V x F trial. Planting was done on 17th December 1999 at Mponela, 14th December at Chitedze Research Station , 12th December at Chitedze on-farm, 15th December at Chitsime and Linthipe, and 31st December at Mbawa. A fungicide was applied to prevent fungal disease for which the maize variety was susceptible, being of temperate origin. However, this was not possible at some sites due to inaccessibility.

Maize variables included in this report are grain yield ha-1 adjusted to 12.5% moisture content, and plants harvested. Striga emergence data reported is mainly from the second count, which reflected peak emergence. At some sites, only the first count was available due to inaccessibility of site later in the season. Dates of Striga counts are reported as days after planting (DAP). The analysis of variance was done on all data. Statistical significance is quoted at the 5 % level unless otherwise stated. Mean comparisons were between pertinent treatment means using the least significant difference.

RESULTS AND DISCUSSION

Striga resistant OPV x fertilizer (V x F) trial: maize results

Table 2 presents a summary of statistical significances for maize yield and *Striga* emergence for individual sites. Fertilizer (F) was a significantly important factor for yield at all sites, while varieties (V) were only important at Mbawa. The interaction of V x F was important at Chitsime and Mbawa only.

The results of analysis of variance across sites (S) results for yield and *Striga* emergence are shown in Table 3. The S x V x F factor interaction was not significant at

Table 2. Mean squares and significance levels for maize yield and *Striga* emergence in all 6 sites of V x F trial.

Variable/Factor	Site					
Yield	Chitedze stn	Chitedze farmer	Mponela	Mbawa	Chitsime	Chiradzulu
Variety, V	1017389 ns	336201 ns	1235270 ns	1063112 **	474332 ns	672901 ns
Fertilizer, F	14526050 ***	3423253 ***	17381182 ***	9033174 ***	27123508 ***	14467748 ***
Error	488042	149870	780805	134446	3471094	405741
V x F	659626 ns	31345 ns	1492246 ns	577145 *	897785 *	83497 ns
Striga#						
Variety, V	164.00 **	1320.8 ns	631.7 ns	3.960 ns	16.84 ns	9.949 ns
Fertilizer, F	14.85 ns	595.1 ns	2149.9 *	0.016 ns	25.88 ns	9.675 ns
V x F	7.90 ns	1240.4 ns	687.7 ns	1.546 ns	22.08 ns	14.350 ns
	20.50	576.3	293.1	2.768	15.35	7.140

ns, *,**, and *** = P > 0.05, < 0.05, 0.01 and 0.001 respectively

Striga data used was from second count (which often gave highest) except where only first count was available.

Table 3. Mean squares and significance levels for maize yield and *Striga* emergence, analysis across all 6 sites, V x F trial.

Factors	df	Yield	Striga emergence#
Site (S)	5	13320824 ***	6844 ***
Variety (V)	2	2437289 **	661 *
Fertilizer (F)	1	68646412 ***	117 ns
V* F	2	1820474 **	856 **
S*V	10	581019 ns	327 ns
S*F	5	943823 *	533 *
S*F*V	10	336786 ns	221 ns
Error	80	397834	170

*, **, *** = Significant at $p < 0.05$, 0.01 and 0.001, resp.
Striga data from second count, which was higher than the first.

$P \leq 0.05$. For yield, there were significant S x F and V x F interaction. The simple effects of S x F interaction in Table 4 indicate that at the different sites, yields were significantly different at both the low or high F application, and there was significant positive response to F application at each site except at Chitedze Station. The V*F interaction in Table 5 shows that that the OPV AK94TZEComp5-W did not significantly respond to fertilizer, while the other 2 varieties did. Masika yielded the highest, with the yield difference more pronounced at the elevated F level.

V x F trial: Striga *results*

The individual site anlaysis showed that V had no significant effect on witchweed at all sites. Fertilizer had significant effect only at Mponela, where emergence increased with F application, from 17 to 36 plant m^{-2}. Table 6 gives the mean of *Striga* emergence for each site at the first and second count. The highest *Striga* pressure was at Chitedze on farm, with an average emergence of up to 46 plants m^{-2}. Across the sites, there was significant S x V and S x F interaction effects. The S x V means in. These sites had high pressure of *Striga*. The S x F interaction (Table 7) confirms observations of individual site analysis. The across site V x F interaction (Table 8) indicates that TZL.Comp.1C4-W supported significantly more infection with fertilizer application than without application. Masika responded inversely.

Imazapyr rate x fertilizer (H x F): Maize results

Mean squares and significances for H x F trials for all 6 sites individually are shown in Table 9. Imazapyr use (H) was significantly important for yield at Chitedze on-farm only. Fertilizer (F) and H significantly affected maize harvest count at 3 of the 6 sites (S). Fertilizer was important for yield at all sites. The analysis of variance across sites is.

Table 4. S x F interaction effects on maize grain yield, kg ha^{-1} across all 6 sites, V x F trial.

Fertilizer Rate, kg/ha	Sites					
	Chitedze Stn.	Chitedze on-farm	Mbawa	Mponela	Chiradzulu	Chitsime
0	1778	433	378	578	700	1778
59:21:0+4S	3575	1189	1605	2280	2252	3575
SED S*F	257	297	297	297	297	257

Table 5. V x F interaction effects on maize grain yield across all 6 sites, kg ha^{-1}.

Variety	Fertilizer rate, kg ha^{-1}	
	0	59:21:0+4S
TZLLComp.1C4-W	703	2203
AK94TZEComp5-W	942	1952
Masika	949	2766
SED V*F	630	

Table 6. Mean Striga emergence (m^{-2}) by days after planting at all the sites.

Trial site	1st count (days after planting)	2nd count (days after planting)
Chitedze station	2.04 (66 days)	9.9 (104 days)
Chitedze farmer	2.7 (78 days)	46.0 (98 days)
Mponela	23.0 (61 days)	26.4 (81 days)
Mbawa	1.0 (48 days)	2.8 (70 days)
Chitsime	1.8 (72 days)	-
Chiradzulu	1.5 (DAP days)	2.6 (127 days)

Table 7. S x F interaction effects on Striga emergence, plants m^{-2} .

Fertilizer rate kg ha^{-1}	Sites					
	Chitedze Stn	Chitedze on-farm	Mbawa	Mponela	Chiradzulu	Chitsime
0	8.4	51.0	2.9	16.9	3.2	8.4
59:21:0+4S	10.2	41.0	2.8	35.8	2.0	10.2
SED S x F	6.1	5.3	5.3	5.3	5.3	6.1

Table 8. V x F interaction effects on Striga emergence, plants m^{-2} .

Fertilizer level, kg ha^{-1}	Variety		
	TZL.Comp.1C4-W	AK94TZEComp5-W	Masika
0	12.6	10.7	23.9
59:21:0+4S	22.4	14.2	16.3
SED V x F	3.9	3.9	3.9

Table 9. Mean squares and significance levels for individual H x F trials.

Factor	Chitedze Stn	Chitedze on-farm	Mbawa	Mponela	Linthipe	Chitsime
Maize yield						
H	139968 ns	1770240 **	18564 ns	284622 ns	52212 ns	381909 ns
F	27821076 **	4326002 ***	11814687 ***	10115580 **	17418102 ***	4217558 **
HxF	588 ns	10150 ns	102560 ns	306362 ns	31862 ns	1663363 ***
Error	114984	95364	103036	550658	367288	284970
Harvest count, plant m^{-2}						
H	0.120 ns	0.649 *	0.002 ns	9.348 ***	3.249 ***	0.941 ns
F	0.013 ns	1.159 *	0.183 *	2.038 *	0.005 ns	0.172 ns
H x F	0.001 ns	0.190 ns	0.564 ns	0.701 ns	0.003 ns	1.100 ns
Error	0.065	0.884	0.293	0.321	0.134 ns	0.284
Striga emergence m^{-2}						
HI	65.45 ns	801.80 **	0.2704 **	1893.0 ***	88.78 ns	12.622 *
F	70.71 ns	9.14 ns	0.0144 ns	116.1 ns	18.21 ns	0.911 ns
Hx F	3.60 ns	7.54 ns	0.0250 ns	116.9 ns	18.21 ns	1.815 ns
Error	38.25 ns	0.13	0.0192	82.8	24.18	1.186

*, **, *** = Significant at $p < 0.05$, 0.01 and 0.001, resp.

Table 10. Mean squares and significance levels for maize harvest count, yield and Striga emergence across all 6 sites of H x F trial.

Factor	df	Maize harvest count m^{-2}	Grain yield kg ha^{-1}	*Striga* emergence plants m^{-2}
Site (S)	5	3.53 ***	5003453 ***	326 ***
Imazapyr (H)	1	5.45 ***	136427 ns	1413 ***
Fertilizer (F)	1	1.96 ***	46326174 ***	36 ns
S x H	5	1.77 ***	502218 ns	291 ***
S x F	5	0.32 ns	869573 **	22 ns
Hx F	1	1.10 **	936934 ns	47 ns
S*H*F	5	0.19 ns	235590 ns	20 ns

, * = Significant at $p < 0.01$ and 0.001, respectively

summarised in Table 10. No significant differences were detected for H on yield. There was significant S x F on yield. The interaction is arising from the higher responses to F at some sites, such as 11). Generally harvest count was low in this study. The highest average count was 3.20 plants m^{-2} at Linthipe (data not shown). The expected stand count was 4.44 plants m^{-2}. The across site analysis for harvest count gave significant H x F and S x H effects on harvest count. The interaction indicated that fertilizer use and non-herbicide dressing favored good plant stand (Table 12). The S x H effects showed a decline in plant stand with Imazapyr use at most sites except Chitedze on-farm (data not shown).

H x F trial, *Striga* emergence data

The individual analysis of variance showed that H significantly affected *Striga* emergence at 4 of the 6 sites, while fertilizer had no effect at all sites (Table 9). Across sites there were significant S, H and S x H effects. The S x H effects showed that H suppressed emergence at all sites except at Mbawa, where pressure was very low anyway (Table 13 and 14).

DISCUSSION

The results of the V x F trial shows that fertilizer was more important in increasing yields under *Striga* than varieties. Although in some cases varieties significantly suppressed *Striga* emergence, this did not correspond with yield indicating a low yield for the resistant OPV's. The best yields were obtained by the combination of the high yielding, well-adapted masika and fertilizer use. This is in agreement with the general observation that the damaging effects of witchweed are most pronounced under poor soil fertility conditions (Parker, 1984; Pieterse and Verkleij, 1991). In the H x F trial a similar fact was established, where significant yield increases were recorded with fertilizer and not herbicide use. In other studies, however, Kanampiu *et al.* (2000) and Abayo *et al*. (1996) reported significant yield and *Striga* suppression due to use of Imazapyr. High suppression of witchweed emergence observed with Imazapyr is of great significance to integrated management by small-scale farmers in sub-Saharan Africa as most of the control options such as fertilizer use, rotations with trap crops, resistant varieties or hand pulling, do not offer complete control, particularly in same season (Kabambe, 1991; Odhiambo and Ransom 1996; Parker, 1984; Kabambe *et al.* 2000). Therefore ALS-inhibiting herbicides have an important role to improve yields as well as reduce the amount of seed return to the soil. The reason why the herbicide was not associated with significant yield increases is that the ALS-resistant hybrid used was not locally adapted, and fell prey to grey leaf spot (GLS) (*Cercospora zeae-maydis*) attack at most sites. It was not possible to spray fungicides effectively due to in-accessibility of sites after rains, and incidences of rains washing away sprays soon after application. There are

Table 11. S x F fertilizer effects on maize yield (kg ha-1) across 6 sites.

Fertilizer kg ha^{-1}	Sites					
	Chitsime	Mponela	Chitedze Stn	Chitedze on-farm	Linthipe	Mbawa
0	730	835	2137	1132	1638	680
59:21:0+4S	1793	2425	3100	2332	3725	2399
SED				746		

Table 12. H x F effects on maize stand count at harvest, plants m-2

Imazapyr rate g ha^{-1}	Fertilizer rate, kg ha^{-1}	
	0	59:21:0+4S
0	2.52	3.04
45	2.24	2.32
SED H*F	0.12	

encouraging on-going efforts by CIMMYT to improve the tropical adaptation of these genotypes. The other reason was the negative effect on maize stand associated with the herbicide. The laboratory germination of the seeds were excellent (95%) before and after the experiment. It is therefore possible that the hybrid was simply not able to germinate and establish well under tropical field conditions. Yield gains from ALS herbicides are expected not only due to *Striga* suppression, but also due to delay in emergence. The delay and reduction in *Striga* emergence and numbers flowering was reported by Kanampiu *et al*., 2000. The damaging effects of witchweed are most pronounced before emergence (Kabambe, 1997; Parker and Riches, 1993;

Table 13. S x H effects on Striga emergence, m-2, H x F trial.

Imazapy rate g ha^{-1}	Sites					
	Chitsime	Mponela	Chitedze Station	Chitedze on-farm	Linthipe	Mbawa
0	1.84	21.81	11.80	16.42	4.71	0.39
45	0.00	0.05	6.97	0.08	0.00	0.13
SED S*H	2.8					

Striga emergence data is from second count, which reflected the peak emergence, except for sites where second count was not available.

Table 14. Mean Striga emergence per plant for non-herbicide application at different days after planting.

Site	Count 1	Count 2
Chitsime	1.95 (73 days)	-
Mponela	6.41 (66 days)	16.1 (85 days)
Chitedze Station	11.85 (66 days)	10.5 (85 days)
Chitedze on-farm	16.45 (76 days)	-
Linthipe	4.69 (73 days)	-
Mbawa	0.40 (70 days)	-

Ramaiah and Parker 1982). Berner *et al*. (1985) reported similarly that delaying *S. hermonthica* infection gave high yield gains in maize. The other benefit with reduction of *Striga* emergence is that seed return to soil is reduced hence reducing the drudgery for hand pulling. Even though different sites had different yield levels, there was no close association between soil organic matter (%carbon) and yield. Therefore all farmers have opportunity to increase yields via fertilizer use and good management.

CONCLUSION

Fertilizer use has the highest impact on maize yield even under *Striga*. Therefore avenues to furnish fertilizer by organic or inorganic sources should be encouraged. Imazapyr had the highest impact in suppressing witchweed emergence, therefore, the two factors must be encouraged simultaneously for integrated management which seeks to enhance yields and manage witchweed dynamics. The available *Striga* resistant varieties were of little impact on both yield and *Striga* suppression. There is need for further work to increase yield potential of such genotypes.

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ON-FARM VERIFICATION OF MAIZE/COWPEA INTERCROPPING ON THE CONTROL OF *STRIGA* UNDER SUBSISTENCE FARMING

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ABSTRACT

Witchweed; (*Striga asiatica* (L.) Kuntze, has been identified by Tanzanian farmers as one of the major biotic constraints to Maize and Sorghum production in semi and subtropical regions of the country. The most affected population group is the resource-poor farmers who cannot afford to purchase agricultural inputs such as fertilizer. Average yield losses of 40–90% caused by *Striga* are common on farmers' fields in *Striga*-prone areas. On-farm trials were conducted for two seasons, 1997 and 1998 in Maramba division in Eastern Tanzania to verify on-station results on the control of *Striga* by intercropping of maize with cowpea. Ten farmers were selected to carry out the trial under the criterion that their fields were naturally infested by *Striga*. Plot size was 10m x 10m. *Striga* plants were recorded from the net plot of 6m x 5m at 9 and 12 weeks after planting and grain yield of maize was determined at harvest. Lowest *Striga* numbers were observed from treatments where maize was planted in the same hill with cowpea followed by in alternate hills. Contrary to the *Striga* numbers, highest maize yields were obtained from the sole maize treatment, but the results were not statistically significant. The relatively low number of *Striga* plants in the intercrop indicated a reduced potential for flowering, capsule production and consequently, a reduced capacity of increasing the *Striga* seed bank in the soil. From farmers' evaluation, they preferred intercrop in the same hill because it reduced *Striga* numbers and they were able to harvest two crops from the same field.

Key words: Control, cowpea, intercropping, maize, *Striga asiatica*

INTRODUCTION

Striga has been recognized to be one of the major constraints affecting cereal production in the semi-arid tropical and sub-tropical regions of Tanzania resulting in a serious yield reduction at the field level. *Striga* is particularly important as an endemic pest of crops such as maize, sorghum and upland rice. *Striga* species of economic importance (in term of crop damage) observed on farmers' fields in Tanzania include *Striga asiatica* and *S. forbesii*, the most widely distributed species in the eastern part of the country, followed by *S. hermonthica,* which predominates in the western regions of the country. The economic implication of *Striga* damage is migration of family groups to *Striga*-free areas, shifting cultivation, abandonment of arable land or change of cropping pattern. (Doggett, 1965).

Grain yield losses caused by *Striga* can be significant. Recent studies on maize varieties for reaction to *Striga* infestation on station at Mwele seed farm in Tanga region have shown yield loss of maize due to *Striga* damage to be 25% on maize variety TMV-1, 42% on Katumani and 18% on Staha (Mbwaga *et al.,* 2000 unpublished). In a similar study by Press *et al.,* (1996) in Kenya, yield loss due to *Striga* damage on maize hybrid H 511 was 50% while local Nyamula was 32%. Crop yield losses on farmers' fields due to *Striga* damage could be as high as 100% under high infestation (Obilana 1983, Ransom 1996, Mbwaga *et al.,* 2000).

The present recommended approaches to control witchweed include hand-pulling. This practice is common with farmers. It needs to be done at emergence of *Striga* plants or before flowering, which does not coincide with the ''normal'' weed control practices of farmers. It is tedious and in any case, most damage has been done to the host by the time the parasites reach a size that can be hand weeded. Use of nitrogen fertilizers and animal manure reduces severity of the weed. Urea applied to rice at the rate of 50 kg/ha reduced *Striga* infestation significantly and on the other hand the maize yield was more than doubled. The shortfall of this option is that the access to animal manure is very limited as not all farmers possess cattle and also transportation of manure from homestead to the fields is a problem due to the bulkiness of manure (Mbwaga *et al.,* 2000). Prices for inorganic fertilizers are not readily affordable by most of the subsistence farmers and fertilizers are of limited use in areas prone to prolonged drought.

To date, no reliable maize resistant to *Striga* has been identified. Some success has been achieved at the station in identifying two maize lines, New Syn White–STR and 98 Syn WEC which are tolerant/resistant to *Striga*. Evaluation of these promising lines in farmers' fields is continuing. Fumigation of soils with methyl bromide gas at the rate of 500 kg/ha conducted at research plots, has been found very effective in killing all viable seeds in the soil. The fact is that the costs and availability of the chemical is far beyond the reach of most subsistence farmers. Another approach recommended is crop rotation. Inclusion of trap crops in a rotation system can result in reduction of the *Striga* seed bank in the soil significantly (Riches *et al.,* 1987, Terry, 1988). This method is no longer practicable due to population pressure on available land.

Most of these approaches are usually neither practicable nor economically feasible for subsistence farmers who grow maize on over 80% of the arable land with sub-optimal inputs (Mbwaga, 1996).

Mixed cropping of cereals and cowpea is another common farmers' practice. Intercropping cereals and cowpea in *Striga*-prone areas has been observed to reduce infestation significantly. This is thought to be due to the soil cover of cowpea creating unfavourable conditions for *Striga*

Table 1. Mean grain yield and plant height on the maize/cowpea intercrop at Maramba in 1997 main season.

Treatment	Plant height (cm)	*Striga* counts/30m^2		Yield (t/ha)
		9 WAP	12 WAP	
Sole maize	206	119.3	128.0	5.5
Maize/cowpea (same hill)	177	103.7	115.7	4.5
Maize/cowpea (alternate hill)	167	116.3	124.7	3.2
Mean	183.6	113.1	122.8	4.4
SE	6.2	16.8	16.8	0.4

Source: Research progress report, 1997

Table 2 (a). Mean grain yield and plant height on the maize/cowpea intercrop at Maramba in 1998 main season.

Treatment	Plant height (cm)		Yield (t/ha)	
	H.I	L.I	H.I	L.I
Sole maize	172	191	4.6	3.1
Maize/cowpea (same hill)	164	179	2.5	2.6
Maize/cowpea (alternate hill)	159	183	2.8	2.8
Mean	166	184	3.3	2.9
SE	5.4	3.5	0.5	0.2

Source: Research progress report, 1998
H.I = High infestation; L.I = Low infestation

germination (Mbwaga *et al*., 2000). At present, the emphasis needed is to look on the pattern of intercropping that will be of relative advantage to the farming community. Intercropping cereal with cowpea in the same row gave the highest grain yield (Sign *et al*., 1991) in Cameroon and in Ethiopia (Reda, 1996). This practice can easily be adopted by farmers as they are already mix-cropping cereals with legumes. Another advantage of intercropping in the same row is that it reduces *Striga* growth and makes weeding easier. A particular cropping pattern encourages abortive germination of *Striga* seeds and secondly soil fertility is improved through fixation of atmospheric nitrogen. The association of *Striga* with infertile soils in general and low nitrogen in particular has been well documented. Addition of nitrogen to the soil is generally considered to stimulate crop growth, to alleviate the effects of *Striga* and to lower the amount of *Striga* supported by the host.

The effectiveness of cereal/legume intercropping to influence *Striga* germination depends on the effectiveness of the produced stimulant/inhibitors, root development, fertility improvement, shading effect and its compatibility to *Striga* species because the response of *Striga* to management options is specific (Parker and Riches, 1993). However, it should be noted that the intercropping option has a high potential of being readily adopted by the clients in *Striga*-prone areas for effective *Striga* control in Africa because the practice is not new to them and it has the relative advantage of harvesting two crops from the same field. It is within this background that on-farm trials were conducted;

- To investigate the effectiveness of intercropping maize with cowpea in the control of *Striga* in maize under farmers' conditions.
- To gather farmers' socio-economic aspects related to the maize/cowpea intercrop on controlling *Striga*.

Table 2(b). Striga count at 9 and 12 WAP in the maize/cowpea intercrop at Maramba in 1998 main season.

Treatment	*Striga* count/30m^2 9 WAP		*Striga* count/30m^2 12 WAP	
	H.I	L.I	H.I	L.I
Sole maize	1421	43	1486	134
Maize/cowpea (same hill)	602	41	503	57
Maize/cowpea (alternate hill)	544	90	515	89
Mean	855	58	835	93
SE	206	19	226	36

Source: Research progress report, 1998

Table 3. Farmers' response (%) on effectiveness of intercropping in controlling *Striga*.

Planting method	Very effective	Moderate effective	Not sure	Not effective	Total
Sole maize	0.0	54.5	18.2	27.3	100
Maize/cowpea (same hill)	18.7	72.1	9.1	0.0	100
Maize/cowpea (alternate hill)	0.0	81.8	9.1	9.1	100

Source: Survey results, 1998

MATERIALS AND METHODS

This study was conducted at Maramba division in Muheza district in Tanga region. Two methods of data collection; namely on-farm trials and interviewing were employed. On-farm trials were used to collect agronomic data whereas interviews were used for socio-economic related information.

Ten farmers who participated in on-farm trials were selected on the criterion that they owned fields with high natural *Striga* infestation. Seeds of maize and cowpea were provided by the project. Staha, maize that is susceptible and Tumaini cowpea varieties were used which are both commercial varieties in Tanzania. The trial was carried out for two years, during 1997 and 1998 seasons, respectively.

On-farm trial:
Design were unreplicated plots, each farmer was a replication. Plots consisted of ten meter-long rows with 75-cm spacing between rows. Within the rows, maize was planted at 3 seeds per hill spaced 25-cm apart and thinned to 2 plants per hill at the fourth week after germination. There were three planting patterns; Sole maize, Maize/cowpea planted in the same hill and Maize/cowpea planted in alternate hills in the same row. Plant stand after thinning and at harvesting, plant height, *Striga* count at 9 and 12 weeks after planting, and grain yield at harvesting were recorded. Thionex spray was applied to the maize crop against stem borers. Weeds except *Striga* were removed by hand after the first weeding. Data were subjected to statistical analysis.

Questionnaire:
Structured and unstructured questionnaires were administered to 10 participating farmers at the end of each cropping season. Other socio-economic data were collected at local markets and from non-participating farmers. Farmers

developed criteria for the assessment of the trial with the assistance of the researchers.

RESULTS

Agronomic results on the maize/cowpea intercrop are presented in Tables 1 and 2. Results for 1998 cropping season are divided into two clusters, one with higher *Striga* infestation and the other with low *Striga* infestation, Tables 2a and 2b. *Striga* infestation was not significantly affected by maize treatment; although *Striga* counts were mostly lower on intercropped plots at both stages of counting. Similar results have been reported by Sprich (1994) of annual reduction of the *Striga* seed bank by about 30% through induction of suicidal germination with cotton and soyabean intercropping. In both treatments, the numbers of *Striga* plants was generally increasing from 9 WAP through 12 WAP. This was probably due to the fact that the shading effect of the legumes in the plots was effective. In maize grain yield (Tables 1 and 2a), the sole maize treatment had higher yield than in the intercrop treatments which implies that the higher *Striga* numbers in the sole maize treatment did not have an affect on the grain yield.

Participatory on-farm analysis of the socio-economic aspects with regard to maize/cowpea intercropping was done after harvesting. Results in Table 3 indicate that about 50% of the interviewed clients noted reduction in *Striga* infestation in intercropped plots. The higher proportion was recorded on plots planted in the same hill rather than alternating hills along the row. There was a criticism that maize/cowpea intercropping method requires much labour for planting, thinning, harvesting and insect pest control. It is a practice deemed to be suitable for households with a large number of family members who can work in the farm or with additional capital for labour hiring. However, the importance of cowpea in their farming systems and high producer price throughout the year (mean = TShs 191.10/kg[11]) could act as a catalyst for farmers to adopt maize/cowpea intercropping in the study area.

DISCUSSION AND CONCLUSION

It is possible that *Striga* could spread to additional areas especially with the increasing human population and consequent demand for more land for increased crop production. Since input costs constrain resource-poor, small-scale farmers, it is time to focus on *Striga* control approaches that are viable, low costing and yet effective. This suggests that intercropping could be the most viable method for controlling the *Striga* infestation. The relative lower number of *Striga* emergence in intercropping indicates a reduced potential for flowering and capsule production and consequently a reduced capacity of increasing the *Striga* seed bank in the soil. This cropping pattern is likely to have quick and high adoption because it has been in the farmers' practices.

However, research is required to determine the planting pattern that reduces labour requirement and maize/cowpea competition and at the same time being effective in *Striga* trapping.

[1] 1 kg of maize and cassava is averaged at TShs 68.80 and 26.40 respectively

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CAN WILD RELATIVES OF CEREALS PROVIDE NEW SOURCES OF RESISTANCE TO THE PARASITIC ANGIOSPERM *STRIGA HERMONTHICA*?

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INTRODUCTION

Striga hermonthica is a devastating parasitic weed in sub-Saharan Africa. It infects the root systems of agriculturally important cereals acquiring water and solutes through a specialised organ, the haustorium. Severe infestations can result in total grain failure. Complete resistance to *S. hermonthica* infection has not been identified for cereals, however, there is increasing evidence to suggest that near relatives of cereals may provide new sources of resistance. The aim of this work was to evaluate the susceptibility of a wild relative of maize, *Tripsacum dactyloides*, to *S. hermonthica* infection compared with susceptible maize and to determine the characteristics of a maize *Tripsacum* hybrid in response to infection.

MATERIALS AND METHODS

Plants were grown in a controlled environment growth cabinet operating with a 12 h photoperiod, a photon flux density of 1000 μmol m^{-2} s^{-1} and a 30/20 ^{o}C day/night temperature regime. Plants were grown in root observation chambers (see Frost *et al.*, 1997) in the absence or presence of *S. hermonthica* (collected western Kenya 1997). Specifically, we examined attachment and development of *S. hermonthica* on each host species, haustorial structure and host biomass production.

RESULTS AND DISCUSSION

Tripsacum demonstrated partial resistance to *S. hermonthica* infection which was associated with processes during and post parasite attachment. Germination and subsequent attachment of *S. hermonthica* to *Tripsacum* was low compared with maize. Less than half of the seeds that formed tubercles on the roots of *Tripsacum* developed into *S. hermonthica* plants. In contrast, all germinated seeds that attached to the roots of maize developed into *S. hermonthica* plants resulting in a five-fold increase in the number of parasites supported by maize.

In addition, the growth of *S. hermonthica* on its *Tripsacum* host was arrested at an early stage of development. Vascular continuity was established between parasite and host for all associations even where attached *S. hermonthica* failed to develop. However, histological analysis demonstrated inferior haustorial development on *Tripsacum* compared with maize, in particular poor tissue differentiation. The hyaline body, a metabolically active region of cells surrounding the xylem core, was either absent or poorly developed. Addition of syringic acid, a primary artificial haustorial initiation factor (HIF), did not initiate further tissue differentiation. These results indicate that poor haustorial formation may result from factors other than primary HIFs, either low production or the absence of secondary HIFs or from a subsequent incompatible reaction.

Tripsacum demonstrated tolerance to these low levels of infection with no influence of *S. hermonthica* on growth and biomass allocation in infected plants, in contrast to the devastating impact of *S. hermonthica* on the biomass of maize. Additions of artificial germination and haustorial stimulants (GR-24, and syringic acid, respectively) increased the level of parasite infection, however, this had no further impact on host responses to infection.

Partial resistance to infection was inherited in the maize *Tripsacum* hybrid. Numbers of germinated and attached *S. hermonthica* were at an intermediate level between parental genotypes. Poor haustorial development and seedling growth was observed for some attached *S. hermonthica* but this response was not uniform. Despite a low level of infection by the parasite, growth and biomass allocation of infected plants was severely impaired in a similar manner to the maize parent.

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MULTI-LOCATION TESTING OF HERBICIDE-RESISTANT MAIZE TO CONTROL *STRIGA*

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ABSTRACT

Maize (*Zea mays* L.) carrying acetolactate synthase (ALS) target-site resistance allows application of high herbicide levels, which can be localized on or near the crop seed. Seed coating was tested as a cost-effective procedure for preventing damage from parasitic *Striga hermonthica* (Del.) Benth. (witchweed) and *S. asiatica*. Imazapyr and pyrithiobac at 30 and 21 g a.i.ha^{-1}, respectively, previously proven to be optimal seed coating rates, were used for on-farm trials in 66 farms over a period of five seasons to further evaluate the effectiveness of this technology in several heavily infested farms in Kenya and Tanzania. Seed treatment with imazapyr and pyrithiobac gave season-long *Striga* control. Generally imazapyr had lower *Striga* emerged compared to pyrithiobac in Kenya. However, in Tanzania pyrithiobac rates higher than 11 g a.i. ha^{-1} gave almost total *Striga* control up to 13 weeks after planting. During 2001 long rains, the *Striga* tolerant/resistant hybrid gave highest number of emerged *Striga* by the 12th week after planting in low and high rainfall regimes. Herbicide seed coating increased maize grain yield from 0.75 to 2.75 ton ha^{-1} (average for two seasons) about a 250% increase. These results indicate that seed dressing with imazapyr and pyrithiobac offers good *Striga* control and results in high maize yield benefits to small-scale farmers. This coupled with pulling rare *Striga* escapes can reduce infestation and be used to deplete the *Striga* seed bank as a stopgap until genetic crop resistance becomes available.

Keywords: imazapyr, maize, pyrithiobac, seed coating, *Striga*.

INTRODUCTION

The witchweeds *Striga hermonthica* and *S. asiatica* decimate maize, millet, sorghum, and upland rice throughout sub-Saharan Africa where, according to FAO studies, over 100 million people lose half their crop production to this flowering, root-attaching parasite (Berner *et al*., 1995). From the high plateau of East Africa where peasant farmers struggle to survive on tiny fields of maize, to the arid savannas of northern Nigeria where they rely on sorghum, African farmers today are fighting a losing battle against the *Striga* scourge. *Striga* is nevertheless more than just an unwanted weed growing in fields meant to produce food. In addition to draining photosynthate, minerals and water (Press and Greaves, 1995), *Striga* does most of its damage to its host through phytotoxins before the weed emerges from the soil (Gurney *et al*., 1995). *Striga* is a parasitic plant that survives by literally sucking nutrients out of the crops that African farmers use to feed their families. *Striga* exerts its toll on crops by inserting a sort of underground hypodermic into the roots of growing plants, siphoning off water and nutrients for its own growth. Above-ground, the crop withers, and grain production is reduced.

Much of the *Striga*-infested area of Africa has ultra-high levels of *Striga* seed in the soil due to years of neglect. These seeds have long-term dormancy and continue to germinate for over 30 years. Only a portion of the seed breaks dormancy when stimulated by the exudates of a receptive crop growing in their vicinity. The *Striga* seed density is so great that mechanisms conferring partial tolerance, such as crops with greatly reduced *Striga* germination stimulant production, are overcome by the overwhelming density of *Striga* seed in the soil. Worse, *Striga* thrives on poor soils in areas prone to drought - farming conditions often associated with poverty and poor nutrition. As human populations grow and small, hand-ploughed farms must support more people, soil nutrients are depleted and soils retain less moisture. Under just such conditions, infestation by *Striga* becomes worse; contributing to the downward spiral of poverty that in bad years in Africa can lead to starvation.

Although crop rotation (Berner *et al*., 1995), organic (Combari *et al*., 1990) and inorganic (Mumera and Below, 1993) fertilizers can partially allay the problem, no control measure has been developed that subsistence farmers find within their financial means, or that fit well into their cropping systems. Thus, despite widespread extension efforts, they have not been widely adopted. Moreover, these measures require several seasons of repeated use before they begin to produce yield benefits. Conventional breeding techniques of crossing and testing different varieties for resistance to the pest have so far realized minimal progress. The plant's ability to produce hundreds of thousands of tiny, dust-like seeds means a small problem can lead to devastating levels of infestation in only a couple of seasons. As a result, the problem lingers on, getting worse season by season. In some areas of Africa, farmers are abandoning their fields in search of *Striga*-free land.

In countries such as Kenya, subsistence farmers cultivate maize with judiciously used, small inputs of fungicide and insecticide. For example, they use seed dressings of insecticide and fungicide, and weeks later, put a few granules of insecticide into the funnel formed by the whorl of maize leaves to control stem borers. We reasoned that they would similarly use small affordable amounts of a herbicide if it would control the parasitic *Striga* while it is still underground, before the weed damages the crop. African farmers adopt new maize varieties and technologies when they are released, if they can see value. Many subsistence farmers in *Striga*-free areas even purchase hybrid maize when the cost-benefit ratio renders hybrids superior to saved seed of open pollinated varieties. These practices (seed treatment, whorl pesticide applications, seed purchase) demonstrate that economically viable technologies would be accepted, if they can control the parasite before it damages the crop.

In developing countries and especially in Africa, where average food consumption per person has actually declined over the past decade – agriculture remains both a strategy for survival and the main source of hope for a better life. Among African farmers, the value of technologies which improve harvests is not a subject of much argument. Here, people are literally on the edge of survival. We (Abayo *et al*., 1998) and others (Berner *et al*., 1997) have developed methods of applying herbicide to biotechnologically produced (but in this case, non-transgenic) imidazolinone-resistant (IR) maize seed. These methods considerably lower the amount of herbicide required to control *Striga* on a per hectare basis, rendering it relatively economical to the farmer. Nevertheless, the herbicide concentration is very high in the vicinity of the seed, necessitating the high level of resistance conferred by such mutations. We have tested a model system of *Striga* control, which uses herbicide-resistant maize varieties in combination with traces of imazapyr and pyrithiobac herbicides applied to the seed. Any *Striga* which attaches to the roots of such varieties dies before emerging from the soil. The herbicides dissipate from the soil well before the next planting season, as evidenced by the absence of any residual effect in subsequent crops (data not shown). When *Striga* infestations are moderate, maize yield from treated seed is more than doubled; when the *Striga* infestations are severe, the yield benefit can be almost infinite as there is near total crop loss without seed treatment. This technique, coupled with other control methods like normal weeding could go a long way toward containing the *Striga* problem in small-scale farms in Kenya and most of sub-Saharan Africa. Our objective was to test and verify the herbicide seed coating technology, successful under on-station studies, in farmers' conditions /environments.

MATERIALS AND METHODS

Plant material:
Local commercial hybrid H513 was used as farmers' practice during the short rains 1998. A tropically-adapted open pollinated synthetic maize variety, 'CIMMYT Tropical-IR', was used in all experiments. The variety is an advanced BC0F3 cross of IR donor Pioneer hybrid 3245IR and ZM503 (INTA/INTB) initially made in 1996 in Harare. ZM503 is a full vigour variety cross, developed by CIMMYT in Zimbabwe with good adaptation for Eastern and Southern Africa. The best BC_0F_1's were sprayed with herbicide and selfed to obtain S_1 ears. The S_1s were planted ear-to-row, sprayed with herbicide and resistant plants were self-pollinated to obtain S_2s. The S_2s were planted ear-to-row, sprayed with herbicide and resistant plants were self-pollinated to obtain S_3 ears. The best 151 S_3 ears were planted ear-to-row and recombined by half-sib pollinations to form the F1 generation of 'CIMMYT Tropical-IR' in 1998. The F_2 and subsequent variety maintenance has been by bulking hand-pollinated, full-sib ears. Imazapyr (75 g a.i.ha^{-1}) as Arsenal 25%, was applied over the top to maize plants at the 8-10 leaf stage for selecting homozygous families. During the long rains 2001, the *Striga* tolerant/resistant (STR) hybrid was also tested along with seed coating treatments.

Chemicals:
The magnesium salt of imazapyr used in this study was prepared by reacting solid imazapyr acid (precipitated from a commercial detergent formulation of isopropylamine imazapyr) with a magnesium hydroxide solution, as described by Kanampiu *et al*., (2001). Kumiai Chemicals, USA, kindly supplied unformulated sodium (Na)-pyrithiobac.

Herbicide seed coating:
Seeds were coated with the herbicide by mixing 100 mg of 20% a.i. lindane and 26% a.i. thiram-containing commercial seed-dressing powder (Murtano^{TM}) to bind the imazapyr and pyrithiobac to the maize seed with various amounts of an aqueous solution containing either 22 mg ml^{-1} of aqueous Na-pyrithiobac or 42 mg ml^{-1} of Mg-imazapyr. Maize seeds (144) were added to this slurry and mixed thoroughly to give coatings of 0.21, 0.40 and 0.60 mg a.i. pyrithiobac and 0.57, 0.85 and 1.13 mg a.i. imazapyr seed^{-1}, respectively (i.e. 11, 21 and 32 pyrithiobac and 30, 45 and 60 g a.i. imazapyr ha^{-1}, at 53,300 maize plants ha^{-1}), and dried. The treated seeds were then planted in the field.

Field trials*:*
Field trials were conducted at Kenya Agricultural Research Institute (KARI)- Kibos (0^{o}04'S, 34^{o}48', elevation 1,214 masl), farmers' fields in Western Kenya and at Mwele, Tanzania. Striga hot spots sites were selected earlier in farmers' fields during the previous season. Trials were carried out starting short rains 1998 and 2000 (September-February); and long rains of 1999, 2000 and 2001 (March-August). Treatments during short rains 1998 were H513, IR synthetic coated at 0, 30 and 45 g a.i. imazapyr ha^{-1} and planted in five farms. During the short rains 1999, a control, two imazapyr rates (30 and 45 g a.i. ha^{-1}) and two pyrithiobac rates (21 and 32 g a.i. ha^{-1}) giving five treatments were used in six farms. In both seasons of 2000, the imazapyr rates used were 0, 30 and 45 g a.i. ha^{-1} in a total of 27 farms. During long rains 2001, four treatments, namely 0, 30/45 g a.i. imazapyr ha^{-1}, 21g a.i. pyrithiobac ha^{-1} and a Striga tolerant hybrid (STR) were tested in eight farms situated in low rainfall areas and 18 in high rainfall areas. Imazapyr rate of 30 g a.i. was used in the low rainfall while 45 g a.i. was used in the high rainfall area. All treatments were arranged randomly with each farm being a replication. Experimental plots consisted of 3-m long rows with 75 cm between rows. Maize seeds were planted two seeds per hill within these rows, with hills spaced at 50 cm. Fertilizer was applied at 50 and 128 kg N and P_2O_5 ha^{-1}, respectively, at planting in the form of di-ammonium phosphate (18-46-0) to ensure reasonable maize development. Plots were kept clean by regular hand weeding. Data were collected from the two inside rows excluding the end plants. Striga counts were made every two weeks beginning six or seven weeks after planting when Striga began to emerge and ending at fourteen weeks. A $\log_{10}(X+1)$ transformation was applied to all data to normalize errors before analysis of variance. Means were separated using Least Significant Difference (LSD) at a confidence level of $p < 0.05$.

RESULTS AND DISCUSSION

Short rains 1998: Hybrid H513, a commercial hybrid used as farmers' practice had higher Striga emergence than the herbicide-resistant maize both treated and untreated (Table 1). Being more adapted than the herbicide-resistant maize,

Table 1. Effect of imazapyr coated herbicide-resistant maize on *Striga* control in farmers' fields, short rains 1998 in Kenya.

Imazapyr (g ha^{-1})	*Striga* emergence (m^{-2}) at various weeks after planting				
	6	8	10	12	14
H513	10.5 (1.03) a	15.6 (1.18) a	17.7 (1.23) a	19.5 (1.28) a	19.9 (1.27) a
0	4.0 (0.65) b	6.6 (0.83) b	8.4 (0.93) b	9.8 (0.99) b	10.6 (1.02) ab
30	2.4 (0.49) b	3.7 (0.62) b	4.9 (0.71) b	5.9 (0.78) b	6.5 (0.82) bc
45	2.1 (0.41) b	3.5 (0.54) b	4.4 (0.62) b	5.1 (0.67) b	5.5 (0.70) c
$LSD_{0.05}$	3.6 (0.25)	5.8 (0.28)	6.2 (0.26)	6.5 (0.25)	7.6 (0.27)

Figures in parentheses are transformed means using $\log_{10}(X+1)$. Means followed by the same letter do not differ significantly.

H513 was more vigorous and hence stimulated more Striga to germinate. At 14 weeks after planting 45 g imazapyr ha^{-1} gave low Striga emergence compared to the lower rate of imazapyr.

Short rains 1999: During this season, treated maize gave lower *Striga* emergence at all weeks after planting and higher grain yield than the control (Table 2). Grain

Table 2. Effect of herbicide rate on *Striga* emergence and maize grain, short rains 1999 in Kenya.

Herbicide	Rate (g ha^{-1})	*Striga* emergence (m^{-2}) (weeks after planting)			Grain yield (kg ha^{-1})
		10	12	14	
Control	0	24.3 a	30.7 a	32.4 a	930 a
Imazapyr	30	0.4 b	2.5 c	2.5 cd	3063 b
	45	0.1 b	0.1 c	0.3 d	3390 b
Pyrithiobac	21	4.6 b	19.3 b	18.3 b	3064 b
	32	1.3 b	7.6 c	11.3 bc	2587 b
$LSD_{0.05}$		7.1	9.0	9.2	838

Means followed by the same letter(s) do not differ significantly.

yield increased from about 1 ton to 3 tons ha^{-1} by seed coating only 30 g a.i. imazapyr ha^{-1}; that is, about a 200% yield increase.

Long and short rains 2000:
During these seasons, treated plots gave lower Striga emergence and higher grain yield than the controls (Table 3). The higher imazapyr rate neither gave better Striga control nor increased grain yield than the lower rate. However, both gave season-long control. Maize seed coating resulted in increased grain yield from about 0.5 to 2.5 tons, that is, about a 400% increase.

Long rains 2001:
At 8 and 10 weeks, STR and control had similar *Striga* emergence under both rainfall regimes (Table 4). However, STR had a higher emergence at 12 weeks. The rate of 21 g a.i pyrithiobac and 30/45g a.i. imazapyr ha^{-1} had lower *Striga* emergence than the check at 10 and 12 weeks after planting under both rainfall regimes. Imazapyr and pyrithiobac rates above 30 and 11 g a.i. ha^{-1} gave almost total *Striga* control up to 13 weeks after planting (Table 5). Imazapyr appeared to be more effective than pyrithobac in *Striga* control.

CONCLUSIONS

Results presented indicate that imazapyr and pyrithiobac offer season-long *Striga* control resulting in improvements in maize growth. This is in sharp contrast to the devastating effect of uncontrolled infection on the host crop as exhibited by the controls. These results indicate that seed dressing with imazapyr and pyrithiobac offers good *Striga* control, which would result in high maize yield benefits to small-scale farmers.

The areas badly affected by *Striga* are also the areas where many of the poorest people live with the highest percentage of maize in their diet. Farmers who no longer lose their maize to *Striga* can be expected to put more input into weeding and apply some fertilizer. They will certainly see the benefit of buying coated seed each season, and can easily achieve yields of 3.0 ton/ha. Maize imports can be reduced, and the cost of distribution cut down. This coupled with pulling rare *Striga* escapes can reduce infestation and be used to deplete the *Striga* seed bank as a stopgap measure until genetic crop resistance becomes available.

Table 3. Effect of imazapyr coated herbicide-resistant maize on Striga control in farmers' fields, long and short rains 2000, in Kenya.

Imazapyr (g ha^{-1})	*Striga* emergence (m^{-2}) (weeks after planting)				Yield (kg ha^{-1})
	6	8	10	12	
Long rains					
0	0.1 (0.03) a	1.0 (0.25) a	dnc	14.8 (1.01) a	dnc
30	0.0 (0.00) a	0.1 (0.03) b	dnc	7.6 (0.63) b	dnc
45	0.0 (0.00) a	0.1 (0.02) b	dnc	5.2 (0.54) b	dnc
$LSD_{0.05}$	0.2 (0.05)	0.4 (0.08)		3.7 (0.15)	
Short rains					
0	9.1 (0.64) a	19.4 (1.16) a	28.7 (1.34) a	23.2 (1.21) a	551 (2.71) a
30	0.1 (0.03) b	1.3 (0.23) b	6.5 (0.50) b	4.0 (0.51) b	2498 (3.38) b
45	0.0 (0.00) b	2.8 (0.26) b	6.0 (0.39) b	1.4 (0.32) b	2721 (3.43) b
$LSD_{0.05}$	8.3 (0.38)	9.5 (0.31)	11.5 (0.35)	15.1 (0.38)	609 (0.14)

Figures in parentheses are transformed means using $\log_{10}$ (X+1). Means followed by the same letter do not differ significantly. dnc means data not collected.

Table 4. Effect of imazapyr and pyrithiobac on *Striga* control in farmers' fields, long rains 2001 in Kenya.

Rate/material (g ha^{-1})	*Striga* emergence (m^{-2}) Weeks after planting 8	10	12
Low rainfall			
0	1.3 (0.20) a	12.3 (0.87) ab	23.1 (1.15) b
STR	0.4 (0.13) a	14.2 (1.09) a	32.7 (1.40) a
30-Imazapyr	0.2 (0.05) a	3.5 (0.53) c	8.3 (0.69) c
21-pyrithiobac	0.1 (0.02) a	6.0 (0.72) bc	12.1 (0.98) b
$LSD_{0.05}$	1.5 (0.18)	8.6 (0.23)	13.3 (0.24)
High rainfall			
0	3.1 (0.46) a	18.5 (1.24) a	25.3 (1.35) b
STR	2.4 (0.38) a	23.2 (1.33) a	65.2 (1.68) a
45-Imazapyr	0.3 (0.05) b	2.8 (0.47) c	4.5 (0.64) d
21-pyrithiobac	0.6 (0.14) b	10.2 (0.97) b	18.2 (1.12) c
$LSD_{0.05}$	1.7 (0.18)	6.3 (0.16)	21.2 (0.18)

STR-*Striga* tolerant/resistant hybrid. Figures in parentheses are transformed means $\log_{10}$ (X+1). Means followed by the same letter do not differ significantly.

Table 5. Effect of imazapyr and pyrithiobac on *Striga* control, Mwele Tanzania 2001.

Herbicide	Rate (g ha^{-1})	*Striga* emergence (m^{-2}) Weeks after planting 9	11	13
Control	0	0.0 (0.0)	4.7 (0.6) a	13.3 (1.02) a
Imazapyr	30	0.0 (0.0)	0.0 (0.0) b	0.0 (0.0) b
Imazapyr	45	0.0 (0.0)	0.0 (0.0) b	0.0 (0.0) b
Imazapyr	60	0.0 (0.0)	0.7 (0.16) b	1.3 (0.3) b
Pyrithiobac	11	0.0 (0.0)	3.0 (0.54) c	6.0 (0.81) c
Pyrithiobac	21	0.0 (0.0)	0.0 (0.0) b	0.0 (0.0) b
Pyrithiobac	32	0.0 (0.0)	0.0 (0.0) b	0.0 (0.0) b
	$LSD_{0.05}$	0.0 (0.0)	1.0 (0.31)	2.7 (0.57)

Figures in parentheses are transformed means using $\log_{10}$(X+1).
Means followed by the same letter do not differ significantly.

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TRANSPOSONS AND TOLERANCE; THE IDENTIFICATION OF GENES FOR *STRIGA* TOLERANCE IN MAIZE.

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ABSTRACT

***Striga* is one of the most severe constraints to cereal production in areas of the semi-arid tropics of Africa where subsistence agriculture is predominant. The development of *Striga* tolerant[1] or resistant[2] germplasm has been the goal of many maize breeders. However, to date, no resistant maize has been developed and tolerance, though improved, is still limited.**

Funded by the Rockefeller Foundation, we developed a large population of maize which contained transposable element-induced mutations. The transposon selected was the mutator element system. Mutator elements preferentially insert into coding regions of the genome and are therefore optimal for transposon-tagging. 8000 F_2 families from the transposon-tagged maize population were screened in the field in Kibos during 1998 and 1999. Interesting families were identified as those which had segregating *Striga*-free plants (no emergence) within the family. Twenty three families have been identified which have no/low emergence of *Striga*. All these families displayed 1:3 segregation for the *Striga* free trait (25% *Striga* free, 75% *Striga* emergence), this indicates that a single recessive mutation is responsible for the observed phenotype. The progeny of one of these families has been screened in pot experiments in the laboratory and the phenotype observed in the field has been confirmed. The lack of *Striga* emergence was not due to altered germination stimulant production or perturbed attachment. However, the biomass of the parasite on this transposon-tagged line was much lower than that on susceptible control lines. As such the growth of *Striga* attached to the transposon-tagged plants was severely impaired resulting in a low incidence of emergence.

Work is currently underway to: develop molecular markers to aid in the introgression of this trait into other maize lines; to clone and identify the gene underlying the trait; to investigate the physiological basis of *Striga* growth retardation and to; evaluate other interesting maize families in the laboratory.

Keywords: Maize, mutator, *Striga*, transposable elements, transposon-tagging.

1 Striga attaches but little impact is seen on the host
2 No Striga attachment occurs or attachment fails in early stages

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EVALUATION OF MAIZE CULTIVARS FOR *STRIGA* RESISTANCE IN THE EASTERN ZONE OF TANZANIA.

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ABSTRACT

Early and late intermediate promising *Striga* resistant/tolerant maize materials from IITA were evaluated for *Striga* resistance/tolerance and grain yield in the Eastern Zone of Tanzania during short and long rainy seasons 2000 and 2001. At Mwele site, the maize materials were also compared for yield performance under no and with *Striga* infestation during the short rainy season. From early open pollinated materials, maize entry 98 Syn WEC supported the lowest *Striga* numbers. On yield performance, maize entries EV.DT 97STR C_1 and TMV-1 produced the highest grain yield under *Striga* infestation. There were significant percentage yield loss differences among the maize entries tested and TMV-1 had the lowest yield loss. From late/intermediate open pollinated maize cultivars combined from both short and long season results low *Striga* counts were recorded from maize entries TZ 96 STR Syn.-W, IWF STR CO and Z. diplo. BC4C2 and the highest grain yield was obtained from entry 9022-13 (Res. Hyb.). At Melela site, a hot sport for *S. asiatica* and *S. forbesii*, late/intermediate maize entry TZ96 STR Syn–W supported the lowest *S. forbesii* numbers but the highest grain yield was produced by maize entry STR EV.IWF.

Keywords: maize, resistance/tolerance, *Striga asiatica, S. forbesii,* yield loss.

INTRODUCTION

Maize ranks first of the major cereal grains grown in Tanzania and is a very important staple food for the entire population. The crop is mainly produced by smallholder farmers on 1–3 hectare holdings accounting for about 85% of the total crop production (Moshi *et al*., 1987). Despite the importance of the crop, maize yields under farmers' fields are only 1.2 tons per hectare compared to the estimated potential yields of 4-5 tons per hectare (Kaswende *et al*., 1998). It was identified that the relatively poor yields of maize are due to a range of factors; the major ones include declining soil fertility, lack of high yielding maize cultivars, diseases and the *Striga* problem.

The obligate root hemi-parasite *Striga* (Scrophulariaceae) is one of the most serious constraints to cereal production by smallholder farmers in sub-Saharan Africa. Infestation usually results in substantial yield losses, quite often over 70% (Kim, 1991). *Striga hermonthica* (Del.) Benth and *Striga asiatica* (L.) Kuntze are the most noxious weeds within this genus threatening 44 Mha of agricultural land in Africa (Sauerborn 1991). In Tanzania, *S. forbesii* is also of equal economic importance (Mbwaga and Obilana, 1993; Mbwaga *et al.,* 2000). Maize, sorghum, millets and upland rice are preferred hosts and infection of these crops can result in severe grain losses. It has to be noted that pearl millet is not attacked by any of the *Striga* species found in Tanzania (Mbwaga and Obilana, 1993).

Striga asiatica (L.) has been controlled in the USA with ethylene gas to promote suicidal germination and post-emergence herbicides to prevent reproduction and also strong quarantine on movement of materials from *Striga*-infested to *Striga*-free states (Ransom and Odhiambo, 1995). These practices are expensive and not easily adopted to conditions of African small-scale farmers. Hand weeding, a traditional method of controlling weeds, has no immediate effect on protecting the crop from *Striga* infestation, because a major part of the crop damage leading to yield losses occurs before *Striga* emerges above the ground. Labour costs are also high for heavily infested fields. Growing crop varieties that have resistance or tolerance to *Striga* has long been proposed as a means of reducing losses due to *Striga* and it would be compatible with the low-cost input requirements of small-scale farmers.

Resistant sorghum varieties have already been identified and these include SRN 39 (Ramaiah, 1986), P9405 and P9406 (Mbwaga *et al.,* 2000). Tolerance to *Striga* has also been observed in sorghum cultivar Weijita, a local from Mara region and rice cultivar Mwangulu from Kyela Northern and Southern Highlands of Tanzania respectively (Mbwaga *et al.,* 2000).

The mechanism of *Striga* resistance in sorghum is known and this includes reduced production of *Striga* germination stimulant and post germination barriers to penetration of the *Striga* haustorium (Olivier and Leroux, 1992). Considerable variability in resistance or tolerance has also been reported in maize for *S. hermonthica* (Kim *et al.,* 1987) and for *S. asiatica* (Ransom *et al.,* 1990; Gurney *et al.,* 1999). However, no maize cultivars have specifically been developed with resistance or tolerance to *Striga* species found in Tanzania.

In the Eastern zone of Tanzania, the predominant *Striga* species are *Striga asiatica* and *S. forbesii*, both of which parasitize maize. *Striga* management in farmers' fields in the zone has concentrated mainly on cereal legume rotations, intercropping and nitrogen fertilization, (Mbwaga,1996).

Resistant or tolerant genotypes are a major practical and reliable approach to the management of *Striga* particularly in the context of smallholder farmers. It is a strategy that requires a limited financial outlay and is more likely to be accepted by farmers (Debra, 1994).

In screening studies conducted on-station in Eastern zone by Mbwaga and Kaswende (1998) in collaboration with NRI and Sheffield University, few maize genotypes namely New Sny-W STR, New Sny-W/Y STR, TZE Comp $5C_6$ and 98 Sny WEC, were found promising in terms of *Striga* resistance/tolerance and their yields were observed higher

Table 1. Evaluation of early open pollinated maize lines for *Striga* resistance and grain yield, Mwele seed farm 2000/2001 short rainy season

Entry Name	*Striga* count/7.5m^2		Non *Striga* inoculated Yield (t/ha) (1)	Striga inoculated Yield (t/ha) (2)	Yield loss (%) (1)-(2)
	9 WAP	12 WAP			
Acr, 94 TZE Comp 5-W	349.3	380.7	2.5 a	1.2 ab	52.2 bc
TMV – 1 (check)	**338.7**	**338.0**	**2.5 a**	**2.1 ab**	13.3 a
TZE Comp 4C2 (susc.)	**297.7**	**319.7**	**2.7 ab**	**2.0 ab**	25.2 ab
TZE Comp 3C2	338.7	340.3	3.1 abc	1.8 ab	40.0 abc
Acr. 94 TZE Comp 5-Y	395.0	417.3	3.2 abc	2.0 ab	40.2 abc
98 Syn WEC	89.7	103.0	3.3 abc	1.0 a	68.3 c
EV. DT 94 STR C_1	338.7	144.3	3.3 abc	2.4 b	29.9 ab
Acr. 94 Pool 16 DT (susc.)	204.0	297.3	3.5 bc	1.6 ab	55.3 bc
TZE Comp 5C6	254.0	263.7	3.9 c	1.7 ab	56.9 bc
Mean	**267.9**	**293.2**	**3.11**	**1.76**	42.4
SE ±	**43.4**	**44.8**	**0.12**	**0.13**	4.31

WAP = Weeks after planting, Means followed by different letters are statistically different from each other ($p \leq 0.05$) according to Duncan New Multiple Range Test.

than that of commercial variety TMV – 1 and these are still being evaluated on farmers' fields. From the farmers' point of view, incorporation of host plant resistance in the maize farming system is a potentially important means of *Striga* control as it may be cheap and effective. The study was initiated to evaluate promising *Striga* resistant maize materials obtained from IITA for adaptation. *Striga* resistance and yield at *Striga* hot spots Mwele Seed farm and Melela, a hot spot for *S. asiatica* and *S. forbesii*.

MATERIALS AND METHODS

The trial consisted of 8 early and 12 late/intermediate maturing open pollinated maize materials from IITA bred for *Striga hermonthica* resistance which were evaluated at two locations, Mwele seed farm in Muheza district, an area with natural high *Striga asiatica* infestation and at Melela, a hot spot for *S. asiatica* and *S. forbesii. The* materials were evaluated both during short and long rainy seasons. The site at Mwele was initially fumigated with methyl bromide gas (at a rate of 100g/m^2) to kill all the *Striga* seeds in the soil seed bank. This technique has been used to control *Orobanche ramose* (Emiroglu, Nemli and Kuecuekoezden, 1978) and to eradicate *S. hermonthica* (Gurney *et al*., 1995). In reports from Gurney *et al.,* (1999) methyl bromide has no detrimental effect on a crop grown following soil fumigation.

Maize entries were then planted in two blocks in the fumigated area. One block was artificially inoculated with *Striga* at a rate of about 2000 viable *Striga* seeds per hill before sowing and the other half was not inoculated. The *Striga* seeds were dug to a depth of 10 to 15 cm around the planting hole. The trial was laid out in a Randomized Complete Block Design with three replications. Each plot comprised of four rows, each 5-metre long. Maize was planted at a spacing of 60cm between hills and 75cm between rows. A low dose of 25 kgN/ha in the form of CAN and of 40 kg P_20_5 per hectare was applied to the blocks in a single application.

Data recorded from the trials were plant stand at thinning, plant height at crop maturity, *Striga* counts at 9 and 12 weeks after planting (WAP), grain yield and disease score (Score scale 1-5; where 1 = no disease, 5 = more than 50% leaves severely affected). At second weeding, the plots were hand weeded leaving *Striga* plants unweeded.

The estimated grain yield loss due to *Striga* damage was calculated as follows:

$$\text{Yield loss \%} = \frac{\text{yield (non-inoculated) - yield (inoculated)}}{\text{Yield (non-inoculated)}} \times 100$$

The data were subjected to statistical analysis.

RESULTS AND DISCUSSION

Total rainfall received at Mwele seed farm and Melela are shown in Appendix 1 and 2. It was relatively high but it was not evenly distributed for the maize crop in the season.

The *Striga* infestation at Mwele seed farm during short rains resulting from artificial inoculation was relatively high ranging from 89.7 to 380.7 *Striga* numbers per 7.5m^2 on early maturing maize cultivars (Table 1). The lowest *Striga* count was observed from maize entry 98 syn WEC at both stages of *Striga* counting. The rest of the entries had *Striga* numbers more than 140 per 7.5m^2. The *Striga* counts did not differ significantly among the entries. Grain yield of maize grown under no *Striga* infestation ranged from 2.5 to 3.9 t/ha and the highest yield was obtained from maize entry TZE Comp $5C_6$ and the lowest from maize cultivars TMV-1 and ACR. 94 TZE Comp 5-W (2.5 t/ha). The yield difference among the entries was statistically significant at $p \leq 0.05$. The same maize varieties grown under *Striga* infestation produced relatively very low grain yields ranging from 1 to 2.4 t/ha showing the effect of *Striga* on grain yield. The highest grain yield was obtained from maize variety EV. DT 94 STR C_1 (2.4 t/ha) and the least yield was observed from maize cultivar 98Syn WEC (1.0 t/ha). When these maize grain yields from the non-inoculated plots were compared with those from inoculated plots, the lowest percentage yield loss was observed from variety TMV-1 (13.3%) followed by TZE Comp 4C2 (susc.) (25.2%) showing that these varieties have high tolerance to *Striga* infestation. The highest yield loss of 68.3% was obtained from maize entry 98 Syn WEC, which indicated that the variety was susceptible to *Striga* infestation. When 98 Syn. WEC was tested on farmers' fields

Table 2. Evaluation of late/intermediate open pollinated maize cultivars for *Striga* tolerance/resistance and grain yield under *Striga* infestation, Mwele seed farm 2000/2001 short rainy season

Entry	*Striga* count/7.5m^2		Yield (t/ha) Not *Striga* Inoculated	Yield (t/ha) *Striga* Inoculated	Yield loss (%)
	9 WAP	12WAP			
833-1 (susc. Hyb)	47.0	63.7	2.2 a	1.8	18.8
Staha (check)	130.0	133.0	2.5 ab	1.8	28.8
TZ 96 STR Syn –Y	10.7	22.7	2.5 ab	1.8	28.9
TZL Comp. 1-C4	**30.3**	**35.3**	**2.5 ab**	**2.3**	**3.0**
TZB SR (susc)	9.0	12.0	2.8 ab	2.2	23.3
9022 – 13 (susc.)	**77.0**	**97.0**	**3.2 ab**	**2.8**	**2.4**
STR EV.IWD	**6.7**	**12.0**	**3.3 ab**	**2.8**	**9.7**
TZ 96 STR Syn – W	5.0	14.0	3.4 ab	1.5	56.1
Z. diplo BC4C2	**0.0**	**7.3**	**3.4 ab**	**2.8**	**14.9**
IWF STR CO	41.0	43.3	3.7 ab	2.6	19.6
Acr. 93 TZL Comp 1-W	287.7	295.1	3.7 ab	2.0	39.6
IWD STR CO	24.7	32.7	3.9 ab	2.5	35.0
STR EV. IWF	190.7	139.0	4.1b	3.0	24.0
Mean	**66.2**	**77.5**	**3.18**	**2.3**	**23.4**
SE ±	**25.5**	**27.5**	**0.15**	**0.13**	**4.94**

WAP = Weeks after planting. Means followed by different letters are statistically different from each other ($p \leq 0.05$) according to Duncan New Multiple Range Test

it showed the least *Striga* infestation and this may be due to its extra earliness that it escaped *Striga* infestation. The difference among the maize entries on grain yield loss was statistically significant at $p \leq 0.05$

From late/intermediate open pollinated maize cultivars grown during the short rains (Table 2) and artificially inoculated with *Striga* seeds; *Striga* infestation ranged from 0 to 295.1 *Striga* numbers per 7.5m^2. Maize entry Z. diploBC_4C_2 had the lowest *Striga* numbers at both stages of *Striga* counts 9 weeks and 12 weeks after planting followed by entries STR ED IWD, TZB SR (sus) and TZ 96 STR Syn W. The *Striga* count difference among varieties was not statistically significant.

Yields under no *Striga* infestation were statistically significant between the varieties and it ranged from 2.2 to 4.1 t/ha. The highest grain yield was observed from entry STR EV IWF (4.1 t/ha) and the least was obtained from hybrid 833-1(sus Hyb.) (2.2 t/ha). The same maize materials were grown under *S. asiatica* inoculation and grain yields obtained were not statistically significantly different between the varieties. The relative highest yield was obtained from entry STR EV IWF (3.0t/ha), while the lowest was observed from entry TZ 96 STR Syn - W. When percentage yield loss was computed between non and *Striga* infested plots, there was a percentage yield loss difference among varieties but it was not statistically significant ($p \leq 0.05$). The percentage yield loss ranged from 2.4 % to 39.6 % and the lowest yield loss was observed from hybrid 9022-13 (susc) followed by TZL Comp 1-C4, STR EV IWD, while the highest loss was observed from maize entry TZ 96 STR Syn-W (39.6%).

From combined short and long rain season data of late/intermediate open pollinated maize materials at Mwele site (Table 3), *Striga* numbers at 9 WAP were observed lowest from maize entries TZ 96 STR Syn. – W, IWF STR CO and Z. diplo. BC_4C_2 and the difference between varieties was statistically significant at $p \geq 0.05$. At 12 WAP there was an increase in *Striga* numbers but the difference among the entries at this stage was not statistically significant. At 12th WAP, the three maize entries , TZ 96 STR Syn. – W, IWF STR CO and Z. diplo. BC_4C_2 still maintained relatively lower *Striga* numbers compared to the rest of the entries tested. The combined grain yield was observed highest from maize cultivar 9022-13 (Res. Hyb.) (3.7 t/ha) and the yield difference was statistically significant.

Table 3. Evaluation of Late/Intermediate open pollinated maize cultivars for short and long rainy seasons combined for *Striga asiatica* resistance 2001.

Entry Name	Plant count	*Striga* Count		Yield (t/ha)
		9WAP	12WAP	
TZ96 STR Syn -W	**24**	**2.5 a**	**9.0**	2.3 a
TZ 96 STR Syn – Y	26	65.0 ab	76.5	3.0 ab
Acr. 93 TZL Comp 1-W	**28**	**8.0 ab**	**20.7**	2.7 ab
TZL Comp. 1 C4	29	141.8 c	155.7	3.1 ab
IWD STR CO	30	23.3 ab	44.2	2.8 ab
IWF STR CO	**30**	**12.3 ab**	**22.7**	**3.3 ab**
STR EV. IWD	30	4.5 a	58.3	3.0 ab
STR EV. IWF	31	15.5 ab	92.0	3.3 ab
Z. diplo. BC^{4}C^2	**31**	**1.3 a**	53.8	**3.3 ab**
TZB-SR (susc.) (RE)	**32**	**3.8 a**	25.2	**3.6 ab**
8338-1 (susc. Hyb.)	32	39.0 ab	55.3	3.4 ab
9022-13 (Res. Hyb.)	33	99.0 ab	172.3	3.7 b
STAHA	33	23.3 ab	32.0	3.0 ab
Mean	**30**	**33.82**	**62.90**	**3.10**
S.E.	**0.5**	**13.19**	**15.63**	**0.13**

WAP = Weeks after planting, Means followed by different letters are statistically different from each other ($p \geq 0.05$) according to Duncan New Multiple Range Test

Maize entries, which showed low *Striga* numbers (<54 *Striga* numbers/7.5m^2) but with relatively high grain yield were TZB-SR (susc.) (RE)(3.6 t/ha), IWF STR CO (3.3 t/ha), Z. diplo. BC4C_2 (3.3 t/ha) and Staha (3.0 t/ha). These entries were shown to have partial resistance to *Striga* infestation. Press *et al.,* (2001) reported similar results on Staha and TMV-1.

Table 4. Evaluation of Late/Intermediate open pollinated maize cultivars for *Striga* resistance, Melela 2001.

Entry	Plant count after thinning	9WAP		12 WAP		Leaf blight (score scale 1-5)	Plant height (cm)	Yield t/ha
		S. asiatica	S. forbesii	S. asiatica	S. forbesii			
TZ 96STR SYN-w	28	0.0	0.0 a	0.0	0.0a	4.0 c	167 ab	1.4 abc
TZ96 STR Syn-Y	26	0.3	1.3 a	0.3	1.0a	3.2 ab	169 ab	1.1 abc
Acr93 TZL Comp. 1-W	33	14.3	5.7 ab	25.0	3.3a	3.0 ab	177 ab	1.6 abc
TZL Comp. 1C4	**30**	**0.7**	**3.0 a**	**2.0**	**4.3a**	**3.2 ab**	**147 ab**	**2.2 bc**
IWD STR Co	27	0.0	1.3 a	0.0	3.7a	2.2 a	173 ab	2.1 abc
IWF STR Co	27	0.3	1.3 a	1.7	5.3a	2.2 a	132 a	0.8 a
STR EV. IWD	34	0.3	1.3 a	0.3	4.0a	3.0 ab	163 ab	1.6 abc
STR EV.IWF	**29**	**0.0**	**0.7 a**	**0.7**	**2.3a**	**2.5 a**	**130 a**	**2.5 c**
Z. diplo. BC4C2	**32**	**0.0**	**0.3 a**	**0.3**	**0.3a**	**2.8 ab**	**170 ab**	**2.2 bc**
TZB-SR(Susc.)(RE)	30	13.0	7.7 ab	14.3	14.0ab	3.7 bc	162 ab	0.9 ab
8338-1(Susc. Hyb)	31	0.3	1.3 a	1.3	3.3a	3.2 bc	178 ab	1.7 abc
9022-13(Resist. Hyb)	30	0.0	0.0 a	0.0	1.0a	2.8 ab	172 ab	1.2 abc
STAHA	33	4.3	14.0 b	16.7	23.8b	2.8 ab	200 b	2.0 abc
G. Mean	**30.0**	**2.59**	**2.92**	**4.82**	**5.33**	**2.96**	**164.7**	**1.64**
S.E.	**0.6**	**1.47**	**0.95**	**2.47**	**1.62**	**0.11**	**5.1**	**0.13**

WAP = Weeks after planting, Means followed by different letters are statistically different from each other ($p \leq 0.05$) according to Duncan New Multiple Range Test

Late/intermediate maize materials were planted at Melela, a hot spot for *S. asiatica* and *S. forbesii*, where the *Striga* infestation level during the testing season was relatively low compared to that at Mwele, where artificial inoculation was carried out. At Melela we depended on natural *Striga* infestation. There was statistical significant difference among varieties on *S. forbesii* count; plant count difference among varieties on *S. forbesii* count; plant count, leaf blight score, plant height and grain yield at $p \leq 0.05$ (Table 4). The least *S. forbesii* numbers at both stages of *Striga* count were obtained from maize cultivar TZ 96 STR Syn – W and the highest were observed from maize variety Staha (check) (23.8/7.5m^2 at 12WAP). From *S. asiatica* there was no statistical significant difference among the entries at $p \leq 0.05$.

The grain yields obtained at Melela were relatively low compared to the same materials planted at Mwele site. The highest grain yield was produced by maize entry STR EV.IWF (2.5 t/ha), while the lowest yield was obtained from maize entry IWF STR Co (0.8 t/ha). At Melela site there was very high incidence of *Turcicum* leaf blight, maize cultivars IWD STR CO, IWF STR CO, STR EV.IWF had the lowest disease score (<2.5) showing good resistance to the disease.

CONCLUSION

From early open pollinated maize entries, entry 98 Syn., we recorded the least *Striga* infestation. Highest grain yield under *Striga* infestation was observed from entry EV.DT 94 STR C1. The lowest percentage yield loss was observed from variety TMV-1 (13.3%), showing high tolerance to *Striga* infestation. Late/intermediate open pollinated maize cultivars, Z. diplo. BC4C2 supported the least *Striga* numbers and highest grain yield under *Striga* infestation was produced by maize entry STR. EV IWF. The lowest percentage yield loss was observed from entry hybrid 9022-13. Results of late/intermediate open pollinated maize entries for short and long rains combined, entries TZ 96 STR Syn.-W, IWF STR CO and Z. diplo BC4C2 supported less *Striga* numbers and they also produced relatively high grain yield, showing to have partial resistance to *Striga* infestation.

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Appendix 1: Rainfall data for Mwele seed farm 2001:

Month	1st – 7th	8th – 14th	15th – 21st	22nd – 31st	Total
April	NIL	12.7 (1)	66.6 (2)	49.9 (4)	129.2 (7)
May	14.9 (1)	105.0 (6)	21.74 (3)	41.2 (3)	180. (13)
June	28.4 (2)	NIL	34.8 (2)	88.9 (2)	152.1 (6)
July	NIL	20.32 (1)	NIL	5.8 (1)	26.12 (2)
August	NIL	25.4 (1)	NIL	NIL	NIL

NB: Numbers in brackets represent the rainy days.

Appendix 2: Rainfall data for Melela 2000/2001:

Month	1st – 7th	8th – 14th	15th – 21st	22nd – 31st	Total
November	NIL	NIL	46.2 (2)	NIL	46.2 (2)
December	NIL	29.2(2)	NIL	NIL	29.2 (2)
January	NIL	42.9 (3)	NIL	NIL	42.9 (3)
February	101.3 (2)	NIL	6.5 (1)	NIL	107.8 (3)
March	45.4 (2)	15.4 (1)	10.6 (1)	35.0 (3)	106.4 (7)
April	25.0 (1)	31.0 (3)	30.5 (2)	120.7 (4)	207.2 (10)
May	NIL	5.0 (1)	NIL	NIL	5.0 (1)

NB: Numbers in brackets represent the rainy days.

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SCREENING MAIZE (*ZEA MAYS*) GENOTYPES FOR *STRIGA HERMONTHICA* RESISTANCE IN SUDAN: A THREE -YEAR PROGRESS REPORT

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ABSTRACT

Experiments were conducted in a *Striga*-sick plot for three seasons (1998-2000) in Medani to evaluate maize (Zea mays L.) genotypes for *Striga hermonthica* resistance. A total of 327 genotypes were tested. *Striga* population, grain and straw yield were used to evaluate *Striga* parasitism. Days to 50% silking, *Striga* counts, grain and straw yields were significant (P<0.05). In the first season (1998), the best local variety Kadogli gave straw yield of 6,902 kg/ha; hybrids S-97206-24 (9,816 kg/ha) and S-97206- 30 (9,462 kg/ha) were tolerant to *Striga*. During 1999 season, genotypes KB98B-98203-10 (1,725 kg/ha), TZLCOMPI1-WC4 (1,572 kg/ha) and KBO98B-98204-7 (1,570 kg/ha) showed relative tolerance to *S. hermonthice*. Mugtama-45, a local check, gave grain yield of 1,225 kg/ha. While in the 2000 season, *Striga* infestation was generally low. Genotypes EM99B-99225-5 (3,063 kg/ha), EM99B-99225-7 (3,047 kg/ha), and EM99B-99225-14 (3,032 kg/ha) were identified as high yielders. Mugtama-45 had grain yield of 1,734 kg/ha. Good performance of genotypes during the 2000 season may be attributed to low *Striga* infestation as shown by Mugtama-45 with an increase of 42% in grain yield over the 1999 season. In all the seasons, relative tolerance of some genotypes was evident but *Striga* population was not consistent with grain and straw yields.

Key words: Genotype, maize, resistance, *Striga*, tolerance

INTRODUCTION

Maize (Zea mays L.) is the fourth important cereal in Sudan coming after sorghum, wheat and millet. The parasitic witchweed, *Striga hermonthica* is the greatest biotic stress for maize production particularly to resource-scarce farmers in the central and southern parts of Sudan where the crop is being grown as staple cereal. *S.hermonthica* can cause severe damage and yield loss in maize. Much of the damage occurs before the *Striga* emerges from the ground. The degree of damage depends on the susceptibility of the cultivar, the *Striga* species, the level of infestation, and any additional stress imposed by the environment (Basinski, 1955; Shinde and Kulkarni, 1982; Vasudeva Rao *et al.,*1982). Although hand-pulling is the most common control measure used by the small-scale farmers, it is only effective when the *Striga* population is low (Ransom *et al.,* 1990). *S.hermonthica* currently infests between 21 and 40 million hectares of land in sub-Saharan Africa, causing an estimated grain loss of about 4.1 million tons/year and yield losses of 30 to 50% are common under typical field conditions (Ransom, 1996; Ransom and Odhiambo, 1995). In Sudan, *S.hermonthica* infests most parts of the irrigated central clay plains of the Gezira and large areas in the rainfed sector causing up to 70% yield reduction in maize and sorghum (Basinski, 1955).

Development of and introduction of resistant maize cultivars in maize growing regions of the Sudan would provide an important part of the solution for resource-scarce farmers. Breeding *Striga* resistant maize varieties offers an economical viable option compatible with the low-cost input requirements of the subsistence farmers to control *Striga* (Ramaiah, 1986). Vasudeva Rao *et al*. (1982) reported that genetic resistance lessens the subterranean damage by *Striga*. However, information on genetics of *Striga* resistance is limited. Available data suggest that *Striga* resistance is controlled by relatively few genes with additive effects (Shinde and Kulkarni, 1982; Vasudeva Rao *et al*., 1982). Kim *et al*. (1987) reported that there is considerable variability in resistance in maize *for S. hermonthica*. The early maturing cultivar, "Katumani" in Kenya was found to support less *S. hermonthica* infestation (Ransom, 1996). In Sudan, no maize cultivars specifically developed with resistance to *Striga* are available. Hence, field experiments were conducted in a *Striga*-sick plot at Gezira research station, Medani during 1998-2000 seasons to evaluate maize genotypes for *Striga hermonthica* resistance.

MATERIALS AND METHODS

Experiments were conducted at Gezira research station (14°24'N, 33°28'E and 411 masl elevation) during the

Table 1. Maize genotypes from different sources evaluated for *Striga hermonthica* resistance at Gezira research station, Medani (1998-2000).

Source	Type	1998	1999	2000	Total
CIMMYT, Nairobi	Hybrids	90	45	93	228
CIMMYT, Nairobi	OPVs+	-	04	19	023
CIMMYT, Nairobi	Commercial hybrids (checks)	-	13	09	022
IITA, Ibadan	Hybrids	-	08	04	012
IITA, Ibadan	OPVs	-	08	-	008
Sudan	OPVs	30	-	-	030
Sudan	OPVs (local checks)	01	01	02	004
Total		121	79	127	327

+ Open pollinated varieties provided by CIMMYT- Nairobi, IITA-Ibadan, and from Sudan.

summer seasons of 1998–2000. A total of 327 genotypes obtained from different sources were evaluated (Table 1). In the first season, 30 local varieties and 90 hybrids were tested separately; in the second season 66 hybrids and 12 varieties were tested in two trials, and in the third season 106 hybrids and 19 varieties were evaluated in three trials. These planting materials were mostly lines, bearing only their pedigrees except local checks. Each year, different sets of genotypes were sent for testing. However, the local checks, Geza-2 and Mugtama-45 were included in (1998, 2000) and (1999, 2000) trials, respectively.

The experiment was designed in a randomized complete block with three replications, planted in a *Striga*-sick plot. The soil was heavy cracking clay (calcareous alkaline soil). Planting were done on July 21, 18 and 30 for the three seasons, respectively, at the same site. The plots were of two rows 4 m. long. The spacing was 0.8 m. between rows and 0.3 m. within rows. Two seeds per hill were planted and two weeks after emergence thinned to one plant per hill giving a plant population of 42,000 plants/ha. Basal application of 80 kg/ha N and 40 kg/ha P were made at planting. Two weedings with a hand-hoe were carried out prior to *Striga* emergence, thereafter, weeds were hand-pulled.

Counts of *Striga* were made at 6 and 8 weeks after crop emergence. Days to 50% silking, plant population, grain and straw yields were recorded. Data were subjected to analysis of variance. Each experiment was analysed separately; genotypes with good performance were selected and tabulated for each crop season.

RESULTS

Analyses of variance showed significant differences ($P<0.05$) among genotypes for *Striga* counts, grain and straw yields, days to 50% silking; with no signifiant difference for plant population (Table not shown). During the 1998 season, local varieties Kadogli, Er-Roseires and Dilling were identified as tolerant, with *Striga* population ranging from 2 (Er- Rosieres) to 7 plants/plot (Kadogli) and between 69 (Er-Rosieres) to 177 plants/plot (Kadogli) for the first and second counts, respectively (Table 2). Days to 50% silking ranged between 61 (Dilling) to 68 days (Kadogli). Straw yield for the local varieties ranged between 4,284,kg/ha (Dilling) to 6,902 kg/ha (Kadogli). Although Kadogli supported the highest *Striga* population on both counting dates, it gave the highest straw yield. Among the hybrids, S-97206-24, S-97206-30, S-97205-39, S-97206-31 and S-97205-33 were the best, showing tolerance to *Striga*. The *Striga* population ranged between 2 for S-97205-39 to 13 plants/plot for S-97206-31 and between 9 for S-97206-39 to 25 plants/plot for S-97206-30 during the first and second counts, respectively. Days to 50% silking ranged between 59 for S-97206-30 to 64

Table 2. Performance of selected maize genotypes under Striga stress conditions, Medani, 1998.

Genotype	Days to 50% silking	Plant stand per plot	First Striga count	Second Striga count	Straw yield (kg/ha)
S-97206-24	61	18	12	18	9816
S-97206-30	59	22	8	25	9462
S-97205-39	64	20	4	9	7878
S-97206-31	61	23	13	24	7669
S-97205-33	62	19	2	17	7105
Kadogli	68	24	7	177	6902
Er-Roseires	63	19	2	69	5474
Dilling	61	21	3	71	4284
Geza-2	58	16	1	22	3094
Mean	62	20	5.8	48	6854
Low	58	18	1	9	3094
High	68	24	25	177	9816

Table 3. Performance of selected maize genotypes under Striga stress conditions, Medani, 1999.

Genotype	Days to 50% silking	Plant stand per plot	First Striga count	Second Striga count	Grain yield (kg/ha)
KB98B-98203-10	58	22	07	27	1725
TZLCOMPI1-WC4	60	22	07	20	1572
KB98BO-98204-7	59	24	12	18	1570
KB98BO-98204-1	60	26	09	09	1550
KB99B-98203-3	61	18	07	11	1526
KB99B-98203-16	59	21	10	16	1476
KB98BO-98204-5	60	22	09	09	1408
KB98BO-98204-16	60	22	07	07	1296
KB98BO-98204-20	60	24	04	05	1292
KB98B-98203-12	58	23	07	20	1284
KB98B-98203-17	61	22	11	18	1265
KB98BO-98204-18	60	22	02	02	1212
KB98BO-98204-8	61	22	03	04	1205
KB98BO-98204-13	60	25	08	10	1193
KB98BO-98204-6	60	23	07	10	1188
KB98B-98203-7	64	22	08	10	1158
TZECOMP1-C6	59	20	09	16	1133
9022-13STR (check)	60	21	41	61	0633
Mugtama-45 (local check)	58	20	07	15	1225
Mean	60.21	22.16	9.05	15.16	1311.11
Low	58	18	02	02	0633
High	64	26	41	61	1725

days for S-97205-39 suggesting the similarity of their genetic background. The straw yields of these hybrids were above average (Table 2). While Geza-2, a local check, was susceptible giving the lowest straw yield (3,094 kg/ha), however, it supported a relatively low number of *Striga* (1 and 22 plants/plot) on both dates of counts. In 1999 season, average number of *Striga* per plot ranged between 2 to 12 plants/plot and between 2 to 27 plants/plot for the first and second counts, respectively. The best genotypes showing relative tolerance to *Striga* were KB98B-98203-10, TZLCOMPI1-WC4, KB98BO-98204-7, KB98BO-98204-1 and KB98B-98203-2 gave grain yields ranging between 1,526 kg/ha for KB98B-98203-2 to 1,725 kg/ha for KB98B-98203-10 (Table 3). These genotypes were early maturing, averaging of 60.2 days to 50% silking. The local check, Mugtama-45 showed relative tolerance, supporting less *Striga* population (7 and 15 plants/plot) compared to check, 9022-13STR (41 and 61 plants/plot), on both dates of counts. During the 2000 season, *Striga* population was generally low, ranging from 0 to 3 plants/plot and from 0 to 32 plants/plot for the first and second dates of counts, respectively. Six maize genotypes EM99B-99225-5, EM99B-99225-7, EM99B-99225-14, KBO99A-99A03-11, KBO99A-99A03-12 and KBO99A-99A01-13 were identified as high yielders (Table 4). The local check, Mugtama-45 yielded 1,734 kg/ha, an increase of 42% over the 1999 season. Good performance of the genotypes during the 2000 season may be attributed to low *Striga* infestation.

Considering the overall performance, genotypes EM99B-99225-5, EM99B-99225-7, EM99B-99225-14, KB98B-98302-10, TZLCOMPI1-WC4, KB98BO-98204-7, S-97206-24, S-97206-30, Kadogli and Mugtama-45 were high yielders with average grain yield ranging between 1,392 kg/ha for Mugtama-45 to 3,063 kg/ha for EM99B-99225-5 under *Striga* stress condition. However, there was no consistency in *Striga* population with grain and straw yields. Based on their tolerance to *Striga*, these genotypes may be put in one group.

DISCUSSION AND CONCLUSIONS

For all the seasons (1998 – 2000), *Striga* infestation was very severe only in 1998 season affecting general performance of genotypes, hence low yields. The severity of infestation varied with genotypes. Ransom et al.(1990) observed that maize genotypes differ significantly in amount of *Striga asiatica* supported on counting dates. Mumera and Below (1996) reported that counts of *Striga* emerged plants differ by more than 3 fold between the most and least susceptible genotypes with early maturity types generally being the most resistant. This, however, may not hold as a general rule.

Not all late maturing genotypes supporting high levels of *Striga* infestation are susceptible. In our study, though the late maturing local variety, Kadogli had the highest infestation, it gave high straw yield. This suggests that Kadogli is tolerant to *S. hermonthica*. Early maturing checks like " 9022-13 STR'' and the local check, Geza-2 gave lower yields compared to others. This result is in line with the arguments of Ransom and Odhiambo (1995) that early maturing genotypes generally support fewer *Striga* population but they did not always yield better than intermediate or late-maturing genotypes.

Most of the genotypes included in this study were early maturing with similar number of days to 50% silking, ranging from 58 to 60 days, but varied in number of *Striga* plants supported and grain yield. This suggests that these genotypes vary in tolerance to *Striga.* Ransom and Odhiambo (1995) found that within a maturity group and among maturity groups, there were significant differences among maize genotypes. This result supports the findings of Kim *et al*. (1998) who observed high variation in grain yields

Table 4. Performance of selected maize genotypes under Striga stress conditions, Medani, 2000.

Genotype	Days to 50% silking	Plant stand per plot	First Striga count	Second Striga count	Grain yield (kg/ha)
EM99B-99225-5	60	25	00	06	3063
EM99B-99225-7	61	27	01	10	3047
EM99B-99225-14	61	28	00	08	3032
KBO99A-99A03-11	61	27	00	00	2875
KBO99A-99A03-12	60	26	00	00	2875
KBO99A-99A01-13	62	25	02	03	2860
EM99B-99225-22	61	25	02	05	2813
KBO99A-99A02-6	62	24	00	06	2344
KBO99A-99A08-5	63	26	03	13	2344
KBO99A-99A08-12	62	24	01	13	2250
KBO99A-99A02-11	61	27	01	01	2171
KBO99A-99A02-5	62	26	00	00	2031
KBO99A-99A03-10	63	24	01	12	2016
PAN-567	62	26	01	26	1313
PHB2353	64	23	00	13	1297
TZLCOMPI	64	21	02	17	1297
C5051SR	62	20	01	32	1281
HB513	64	25	00	06	1219
Mugtama-45	56	23	00	04	1734
Geza-2	59	23	02	04	1408
Mean	61.65	24.75	0.85	8.95	2163.40
Low	56	20	00	00	1219
High	64	28	03	32	3063

and host-plant resistance to *S. hermonthica* in synthetic maize genotypes. In our study, relative tolerance of some maize genotypes to *S. hermonthica* was evident in all the seasons. However, our observations did not determine the mechanism for identification of tolerance/resistance. Mumera and Below (1996) suggested that identification of *Striga*-resistant maize genotypes should focus on the ability of ear sink to successfully compete with *Striga* for assimilates.

Maize genotypes included in our study varied from season to season except the local checks (Geza-2 and Mugtama-45) making it difficult to identify a superior genotype. In the three seasons, 10 genotypes with good performance under *Striga* stress were identified, one or more may eventually be recommended for release. Further research is needed to determine the mechanism of and confirm their tolerance/resistance to *S. hermonthica*.

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EFFECT OF INTERCROPPING MAIZE AND BEANS ON *STRIGA* INCIDENCE AND GRAIN YIELD.

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ABSTRACT

Intercrops can smother weeds in cereal crops and improve the overall productivity. Although intercropping with beans has long been practised in the region, a practical bean population and arrangement is required in the management of *Striga*, other weeds and soil fertility to increase maize and bean yields. To study whether parasitic weeds like *Striga hermonthica* can be suppressed and controlled by intercropping, on-farm experiments were conducted in farmers' fields, at Nyadwera, Emabwi, Emuhaya and Kaura in Western Kenya to evaluate maize/bean inter-cropping practices that reduce *Striga* infestation and increase maize and bean yields during the 1999 cropping seasons. Maize was planted simultaneously with beans using different bean planting patterns. The planting system of beans had no influence on *Striga* infestation on maize in Nyadwera and Emuhaya during both seasons. Intercropping significantly influenced the parasite infestation on maize in Emabwi during both seasons. In Kaura, the influence of the intercrop on *Striga* infestation depended on the season. However, in Emabwi and Kaura grain yields were significantly higher under farmers' practices and under intercropping, particularly two rows of beans between two maize rows. During the long rains in Emabwi, intercropping maize with beans with two bean rows between two maize rows increased maize grain yields, significantly, by 51.2% and 61.4% over farmer's practice and intercropping with one row of beans, respectively. Whereas planting arrangements had no significant influence on parasite counts in Kaura, pure maize significantly produced lower grain yield compared to intercropping treatments and farmer's practice. Intercropping maize and beans in the same hole had the highest grain yield, which was 78.6% above yield in pure maize stand. Intercropping maize and beans increased total grain yields in Kaura and Emuhaya during both seasons and in Nyadwera and Emabwi during long rains (LER>1). This shows that cropping practices that can be adopted by farmers to reduce *Striga* incidence and increase maize grain yields are feasible.

Key words: Bean inter-crop, maize, parasitic weed, *Striga*

INTRODUCTION

The major maize production constraints in western Kenya are weeds including *Striga hermonthica* parasitism, labour to control them during peak labour requirement in the season and low soil fertility. The parasite starts emerging 6 weeks after maize planting and therefore evades the first weeding done within the first 4 weeks. Weeding coincides with the period when children are in school while most husbands are also involved in some off-farm activities to supplement family incomes. This leaves women to do most of agricultural activities besides other household duties. Therefore the second weeding to control *Striga* (peak emergence occurs at 12 weeks) is never, in most cases, undertaken. It is also recommended that the parasite plants should be rogued, every 2 weeks, at flowering but before seeding to reduce the parasite seed bank in the soil during the next season (Ransom and Odhiambo, 1994). This is, however, never achieved due to lack of labour.

Intercropping maize and beans is the most common cropping system in *Striga* endemic regions of Kenya. Obilana (1998) explained that intercropping is one of the *Striga* control practices that requires only minor adjustments in the farming systems without any additional inputs. He suggested that the practice should be accompanied by a supplementary hand weeding which would be easier to practice with the few emergent *Striga* plants. Barbiker and Hamdoun (1990) observed that intercropping sorghum with Dolichos bean, cowpea and groundnut invariably reduced *Striga* infestation. This could be due to the shading effect (Oswald *et. al*., 1998). However, a practical bean population and arrangement is required in the management of weeds, *Striga* and soil fertility to increase maize and bean yields. The aim of this study was therefore to evaluate different bean populations and planting arrangements in a maize bean intercropping system on *Striga* infestation, soil fertility, and the overall productivity of maize and bean.

MATERIALS AND METHODS

On-farm experiments were conducted for two seasons during long and short rains of 1999. Six contact farmers were chosen in Western Kenya with the help of the field extension staff in the region. Farmers were selected based on availability of *Striga*-sick plots for intercropping, willingness to grow the crop combinations, availability of labour to carry out treatment operations in time as required and allowing access of demonstration farm to other farmers. The trials targeted farms managed by women who were members of women's groups. Maize (H511) was planted at a spacing of 75 X 50 cm (two seeds per hole) after application of DAP to provide 40 kg P_2O_5 and 18 kg N ha^{-1}. Rosecoco beans (popular in the region) were planted after application of fertilizer at the same rate with maize. Maize was top-dressed with CAN at 40 kg N ha^{-1}. Other recommended agronomic practices were undertaken. One weeding was undertaken 3 weeks after crop germination. The design was a RCBD, with two replications per farmer.

Table 1a. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Nyadwera during the long rains 1999.

Treatment*	*Striga* emergence Plants m^{-2}	Grain Yield (t ha^{-1}) Maize	Beans	LER **	Gross Income **** US $ ha^{-1}
Beans (P)	-	-	2.67	-	2,055
Maize (P	13	0.56	-	-	145
M + B (1)	13	1.56	0.62	3.0	875
M + B (2)	8	1.72	0.69	3.3	970
M + B (S)	9	1.40	0.43	2.7	690
Farmer(P)***	1	1.81	0.25	3.3	655
LSD (0.05)	**NS**	**NS**	**1.00**		

* **Bean (P)** = Beans planted in pure stand; **Maize (P)** = Maize planted in pure stand; **M + B (1)** = Maize intercropped with beans with one bean row between maize rows; **M + B (2)** = Maize intercropped with beans with two bean rows between maize rows; **M + B (S)** = Maize intercropped with beans in the same hole.

** **LER = Land Equivalent Ratio.**

*** **Farmer (P)** = Farmer's practice. The farmer in this season planted pure beans (Rosecoco var.) in one plot while intercropping 2 rows of beans between maize rows in the other plot.

**** **Gross Income =** Sum of the market value of maize at KShs. 20.00 kg^{-1} and that of beans at KShs. 60 kg^{-1} respectively (**Exchange rate of 1 US $ to KShs. 78.00**).

Table 1b. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Nyadwera during the short rains 1999.

Treatment*	*Striga* emergence Plants m^{-2}	Grain Yield (ton ha^{-1}) Maize	Beans	LER**	Gross Income **** US $ ha^{-1}
Beans (P)	-	-	1.85	-	1,420
Maize (P	18	0.72	-	-	185
M + B (1)	22	1.38	0.27	0.7	305
M + B (2)	16	1.37	0.72	30.9	650
M + B (S)	12	1.62	0.62	1.2	635
Farmer(P)***	2	1.66	1.06	1.5	985
LSD (0.05)	**NS**	**NS**	**NS**		

*** **Farmer (P)** = Farmer's practice. The farmer in this season planted pure beans (Rosecoco var.) in one plot while intercropping 2 rows of beans between maize rows in the other plot.

The plot size per farmer varied and depended on the availability of land. Treatments included, 1) Pure maize, 2 seeds per hill, spaced 75 X 50 cm, 2) Pure beans, 1 seed per hill, spaced 50 X 15 cm, 3) Single row of beans between maize rows, 1 bean per hill, spaced 15 cm apart, 4) Double row of beans between maize rows, 1 bean per hill, spaced 15 cm within bean rows, 5) Maize and beans planted in the same hole, 2 and 4 seeds per hill of maize and beans respectively, spaced 75 X 50 cm, 6) Farmer's practice.

Data collected included *Striga* emergence, maize and bean yields. Data was subjected to statistical analysis and means separated by Least Significance Difference (LSD) at $p \leq 0.05$, using General Linear Model of SAS (SAS Institute.1989). The best bean population and arrangement that reduced *Striga* infestation, and increased both maize and bean crop yields were established. Land Equivalent Ratios (LER) were calculated to determine the most beneficial population.

$$LER = \frac{\text{Yield of intercropped maize} + \text{Yield of intercropped beans}}{\text{Yield of monocropped maize} + \text{Yield of monocropped beans}}$$

LER = 1: No advantage of intercropping
LER <1: Intercropping reduces total yield
LER >1: Intercropping increases total yield thus beneficial.

RESULTS AND DISCUSSION

The planting pattern of beans had no significant influence on *Striga* infestation on maize and ultimate grain yield in Nyadwera during both the long and short rains (Table 1a and 1b). However, farmer's practice and intercropping maize with beans with two bean rows between maize rows had low *Striga* emergence which was reflected in high, though non- significant maize grain yield. Beans planted in pure stand had significantly higher yields than beans planted under intercrop with maize. The rest of the intercropping systems produced equivalent bean yield. Intercropping was beneficial to the farmer since it increased total yield as indicated by LER>1 during the long rains.

During the short rains, there was no significant difference between pure beans and those planted under intercrop systems. Yield of pure beans during short rains was half that obtained during the long rains while maize in the intercrop yielded less than half that harvested in the long rains indicating a poor season at this site. Total grain yield was only increased when maize and beans were planted in the same hole and under farmers' practice (Table 1b). Planting M+B (1) and 2 rows of beans between maize rows reduced the total yield during the short rains. Results indicate that the benefit of intercropping maize and beans was more pronounced in the long rains than in the short rains. This was perhaps due to adequate moisture availability to the intercrops that did not result into competitive behaviour during the long rains season. Although intercropping maize and beans was beneficial during the long rains, gross income from pure beans was the highest during both seasons (Table 1a and 1b) due to the higher market value of beans which was 3 times higher than that of maize. *Striga* pressure during both seasons was low and therefore the parasitism did not influence maize yield in any of the treatments. Planting maize and beans in the same hole is still practised by farmers. Farmers reported that it is faster and easier to plant and weed. Although planting up to 4 seeds together with maize in the same hole had no effect on the final yield during both seasons, dumping together of seeds in the same hole should be discouraged to avoid competition for space. Farmers' practice in Nyadwera was similar to the treatments by researchers.

During the short rains, intercropping maize with beans with two bean rows between maize rows and farmer's practice resulted in significantly lower parasite infestation than under intercropping maize with beans with one bean row between maize rows in Emabwi (Table 2a). Intercropping maize with with beans with two bean rows between two maize rows increased maize grain yields, significantly, by 51.2% and 61.4

Table 2a. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Emabwi during the long rains 1999.

Treatment	*Striga* emergence Plants m^{-2}	Grain Yield ($t\ ha^{-1}$)		LER	Gross Income US \$ ha^{-1}
		Maize	Beans		
Beans (P)	-	-	0.32	-	245
Maize (P	6	1.26	-	-	323
M + B (1)	16	0.64	0.18	1.1	300
M + B (2)	2	1.66	0.13	1.7	525
M + B (S)	3	1.42	0.12	1.5	455
Farmer(P)***	2	0.81	1.44	5.1	1,315
LSD (0.05)	**5**	**0.75**	**0.47**		

*** **Farmer (P)** = Farmer's practice. The farmer in this season used a local maize variety while bean (Small type var.) was broadcast between the maize rows.

Table 2b. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Emabwi during the short rains 1999.

Treatment	*Striga* emergence Plants m^{-2}	Grain Yield ($t\ ha^{-1}$)		LER	Gross Income US \$ ha^{-1}
		Maize	Beans		
Beans (P)	-	-	1.30	-	1,000
Maize (P	14	0.52	-	-	130
M + B (1)	16	0.12	0.55	0.7	455
M + B (2)	11	0.60	0.24	1.3	340
M + B (S)	11	0.75	0.08	1.5	255
Farmer(P)***	1	0.47	0.36	1.2	400
LSD (0.05)	**5**	**0.50**	**0.19**		

*** **Farmer (P)** = Farmer's practice. The farmer in both seasons planted local white maize variety while local beans (Punda var.) were broadcast after emergence of maize.

Table 3a. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Emuhaya during the long rains 1999.

Treatment	*Striga* emergence Plants m^{-2}	Grain Yield ($t\ ha^{-1}$)		LER	Gross Income US \$ ha^{-1}
		Maize	Beans		
Beans (P)	-	-	0.28	-	215
Maize (P	8	1.15	-	-	295
M + B (1)	4	1.06	0.26	1.9	470
M + B (2)	9	0.93	0.27	1.8	445
M + B (S)	4	0.73	0.12	1.1	280
Farmer(P)***	0	-	-	-	
LSD (0.05)	**NS**	**NS**	**NS**		

*** **Farmer (P)** = Farmer's practice. The farmer in this season used a local maize variety while bean (Small type var.) was broadcast between the maize rows.

Table 3b. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Emuhaya during short rains 1999.

Treatment	*Striga* emergence Plants m^{-2}	Grain Yield ($t\ ha^{-1}$)		LER	Gross Income US \$ ha^{-1}
		Maize	Beans		
Beans (P)	-	-	0.46	-	350
Maize (P	24	0.19	-	-	50
M + B (1)	20	0.34	0.39	2.6	300
M + B (2)	25	0.16	0.29	1.5	265
M + B (S)	2	0.22	0.13	1.4	155
Farmer(P)***	2	1.00	-	-	255
LSD (0.05)	**NS**	**0.38**	**NS**		

*** **Farmer (P)** = Farmer's practice. The farmer in this seasons planted maize only with farmyard manure then top dressed with calcium ammonium nitrate (CAN).

61.4% over farmer's practice and intercropping with one row of beans respectively. Intercropping increased total yield of maize and beans. However, planting one row of beans between maize rows reduced the total yield during the short rains (LER of 0.70).

During the short rains, farmers' practice had significantly lower *Striga* emergence than all other treatments. This was not, however, reflected in improved yield of the maize crop (Table 2b). Maize planted with beans in the same hole was significantly higher than one row of beans between maize by 6 times. Pure beans was significantly higher than all the intercrops including farmers' practice. Maize yield was 50% higher in the long rains than in the short rains with less *Striga* emergence in the farmers' plots than in the latter. Bean yield was also better in the long rains compared to the short rains.

Farmers' practice resulted in significant reduction of *Striga* infestation in maize during both seasons. However, maize yield was reduced while bean yield was enhanced. The high population of beans could have reduced *Striga* growth and development through shading effect while reducing maize yield through competition. Increase in gross income under farmers' practice during the long rains was due to high yields realised from beans. There was no significant difference in *Striga* emergence although farmer's practice and planting single row of beans between maize rows in Emuhaya resulted in lower *Striga* emergence than the rest of the treatments (Table 3a and 3b). This was reflected in significantly higher maize yield in farmers' practice during short rains only (Table 3b). Maize under farmers' practice outyielded all other cropping systems including monoculture maize during the short rains (Table 3b). Whereas maize yield was better in the long rains than in the short rains, bean yields were comparable in both seasons. Maize yield during the long rains and bean yield during both long and short rains in farmers' practice was not determined. The LER indicated that total yield was enhanced when maize and beans were intercropped irrespective of the method of planting the beans during both the long and short rains. During short rains in Emuhaya, the farmer planted with farmyard manure and top- dressed with CAN. This explains the low *Striga* infestation and

Table 4a. Influence of planting system on *Striga* emergence and maize and bean grain yields at farmer's field in Kaura during the long rains 1999.

Treatment	*Striga* emergence Plants m^{-2}	Grain Yield ($t\ ha^{-1}$) Maize	Beans	LER	Gross Income US \$ ha^{-1}
Beans (P)	-	-	1.20	-	925
Maize (P	13	0.15	-	-	40
M + B (1)	7	0.40	0.17	2.8	230
M + B (2)	7	0.54	0.28	3.8	350
M + B (S)	4	0.70	0.16	4.8	300
Farmer(P)***	2	0.57	0.12	3.9	240
LSD (0.05)	**NS**	**0.24**	**0.27**		

***** Farmer (P)** = Farmer's practice. The farmer in both seasons planted local maize variety then intercropped with a single row of beans (Rosecoco var.) between the maize rows.

Table 4b. Influence of planting system on *Striga* emergence and maize and bean grain yields at farm and field in Kaura during the short rains 1999.

Treatment	*Striga* emergence Plants m^{-2}	Grain Yield ($t\ ha^{-1}$) Maize	Beans	LER	Gross Income US \$ ha^{-1}
Beans (P)	-	-	1.10	-	845
Maize (P	31	0.04	-	-	10
M + B (1)	14	0.29	0.26	7.5	375
M + B (2)	8	0.25	0.36	6.6	340
M + B (S)	7	0.37	0.28	9.5	310
Farmer(P)***	4	0.37	0.40	9.6	400
LSD (0.05)	**20**	**0.26**	**NS**	**-**	

***** Farmer (P)** = Farmer's practice. The farmer in both seasons planted local maize variety then intercropped with a single row of beans (Rosecoco var.) between the maize rows.

significantly higher maize yields (Odhiambo and Ransom, 1997). However, the heavy input failed to increase his gross income due to low market value of maize.

Although planting arrangements had no significant influence on *Striga* emergence in Kaura, pure maize significantly produced lower grain yield than all other treatments including farmer's practice during both seasons (Table 4a and 4b). This was due to higher *Striga* emergence where maize was planted as a pure stand. Maize plus beans in the same hole or one or two rows between maize rows also significantly reduced *Striga* emergence compared to pure maize. Bean yield was significantly higher in pure stand compared to intercrop in the long rains only. Although maize yield was higher in the long rains only, bean yield was, however, comparable in both seasons. Intercropping maize and beans in the same hole had the highest grain yield, which was 78.6% above yield in pure maize stand. Kaura site benefited most in the total yield harvested when maize was intercropped with beans during both seasons.

Striga infestation was low and not significant during the long rains in Kaura. During the short rains, infestation was high and significant in pure maize where yield and gross margin were meagre. *Striga* infestation is serious under low rainfall season. Higher soil moisture content for extended period causes *Striga* seeds to undergo wet dormancy, thereby reducing infestation. High soil moisture content also reduces soil temperature below the optimum requirement for *Striga* germination, growth and development of 23-30^{o}C.

Intercropping maize and beans was beneficial in the region. Although farmers used their own treatments, they also adopted a lot of recommendations from researchers. These included plant population, spacing, planting along contours and fertilizer application.

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PROGRESS IN DEVELOPING DROUGHT AND N STRESS TOLERANT MAIZE CULTIVARS FOR EASTERN AND SOUTHERN AFRICA

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ABSTRACT

Drought and low soil fertility are high priority stresses that impede maize production, food security and economic growth in eastern and southern Africa. Across both regions a close correlation between rainfall and maize production can be observed. In collaboration with National Agricultural Research Programmes and regional organizations (ASARECA, SACCAR), CIMMYT has initiated in 1996 and 1998 two projects that provide NARS with technical and financial support to develop maize germplasm that is more tolerant to drought and N deficiency. Over 100 scientists and technicians have benefited from training opportunities, and capital and recurrent support has been given to stress breeding and testing programmes in ten southern and nine eastern African countries. Several of these breeding programmes have produced stress tolerant experimental OPVs and hybrids that now enter the testing phase. Trials conducted by researchers across the regions, and farmer-participatory trials conducted in collaboration with NGO's, extension and farmer groups have been established to expose the merit of these new varieties under stress conditions that are typical for most smallholder farmers. Even though the breeding approach taken with these two projects seems new to most breeders in Africa, it agrees with research findings from other crop breeding programmes that target stress-prone environments. The fact that farmers as well as private and non-governmental organizations involved in seed dissemination have shown a rapid response to some of the new varieties confirms the merit of these two projects for contributing to food security and economic growth in Africa.

INTRODUCTION

Drought and low soil fertility are among the most important stresses threatening maize production, food security and economic growth in southern and eastern Africa. Across the region, a close relationship between rainfall and maize yields can be observed (Fig 1). Sub-Saharan Africa has by far the largest variability in maize yields in the developing world mainly due to variation in rainfall. As average yields are lower and the agricultural sector of greater importance, this yield variability is of greater socio-economic importance than in any other part of the world (Heisey and Edmeades, 1999). Soils have become depleted due to continuous cropping, removal or burning of crop residues, and lack of fertilizer applied often as a consequence of non-competitive input *versus* product prices (Kumwenda *et al.*, 1997; Smaling and Braun, 1997).

The unprecedented combination of climatic risk, declining soil fertility, the need to expand food production into more marginal areas as population pressure increases, high input costs, extreme poverty, and unavailability of credit systems have resulted in smallholder farmers in southern and eastern Africa producing maize (and other crops) in extremely low-input/low risk systems. Average maize yields are at 1.3 t ha-1 and barely result in self-sufficiency of the region. Below-average production means reduced household incomes and hunger, and, at the regional level, makes maize imports and food aid necessary.

Nevertheless, the choice of growing maize can be shown to be an economically rational one and crop substitution would likely not increase food security (Anderson, Hazell and Evans, 1987; Mudhara and Low, 1990).

Influenced by breeding schemes used in temperate environments and by breeding programs targeted at commercial farming systems, most maize cultivars in eastern and southern Africa have been developed for good performance under optimal, agronomically well-managed conditions i.e., for very different farming circumstances to those faced by the "average", resource-poor smallholder (Fig 2). Up to a few years ago, few variety testing schemes have been in place that systematically evaluated newly developed maize cultivars under conditions representative for resource-poor smallholders. On-farm variety evaluation was being greatly reduced, partly due to resource constraints in the public sector, and partly due to expensive and ineffective on-farm testing and verification approaches. New cultivars were released or promoted largely based on their performance under optimal, researcher-managed conditions, and there was insufficient awareness that this system largely ignores the specific maize variety needs of most farmers. As a consequence, cultivars developed some 30 years ago are still in use by smallholders and some 50-70 % rely on low consequence, cultivars developed some 30 years ago are still in use by smallholders and some 50-70 % rely on low productivity seed from local sources or from recycling grain (Hassan et al, 2001; Phiri *et al.*, 2003). Those farmers either perceive little advantage in growing improved cultivars - because they are not designed for their needs - (e.g. Kamara *et al.*, 1996), or they have insufficient access to seed of improved cultivars and to transparent and objective information based on which they can make an informed choice of variety (Phiri *et al.*, 2003). In return, the market among resource-poor smallholders proves insufficiently attractive to private seed companies and they mainly compete for market share amongst existing purchasers of maize seed, i.e. the commercial farming sector, and focus on breeding goals attractive to that group.

Based on long-term strategic research, CIMMYT and its NARS collaborators introduced in 1996 and 1998 a new breeding approach to southern and eastern Africa, respectively, using two projects, the Southern Africa Drought and Low Soil Fertility Project (SADLF), and the Africa Maize Stress Project (AMS). Maize germplasm is being improved under carefully managed stress conditions relevant to resource-poor farmers' conditions, specifically drought and low nitrogen stress, then tested through a scheme that considers smallholder farmers' conditions and preferences in an effective manner. The projects contributed to establishing and maintaining regional drought and N stress screening sites with several National Programs and CIMMYT stations in Kenya and Zimbabwe, training of National Program scientists, and a better characterization of the target environment using geographic information systems (GIS). This paper summarizes the results achieved within these projects in regard to developing drought and N stress tolerant maize cultivars that are adapted to eastern and southern Africa.

Figure 1. Relationship between rainfall and average maize yields across eastern and southern Africa.

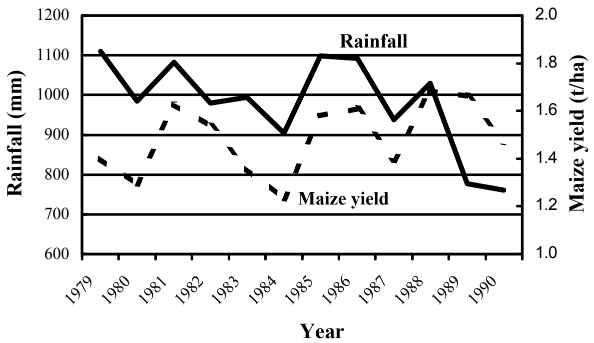
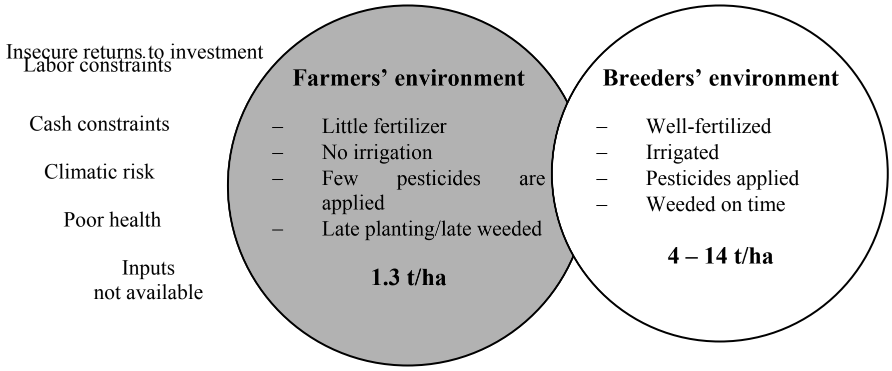


Figure. 2. Divergence of breeders' and farmers' environment in traditional breeding approaches.



Rationale for a different breeding strategy

There is ample evidence that breeding under optimally managed agronomic conditions does not do justice to the type of conditions under which the majority of African farmers grow their crops, in particular when considering the prevalence and important of stress factors such as drought and low soil fertility those impact on crops is often exuberated by late planting, late weeding and the inability of farmers to access inputs and credits. Spill-over effects from selection gains achieved under agronomically well-managed conditions have been shown to decrease along with the yield level of the environment where the variety is deployed (Bänziger *et al.* 1997; Castleberry *et al.*, 1984; Duvick, 1984). In the case of maize, no breeding gains may be achieved under severe N stress - that reduces grain yield by more than 75% as compared to well-fertilized conditions - when maize is selected under well-fertilized conditions (Bänziger *et al.* 1997). Similarly traditional breeding approaches under well-watered conditions and using multi-environment testing contribute little to improving maize yields under drought conditions (Byrne et al, 1995; Edmeades *et al.*, 1999).

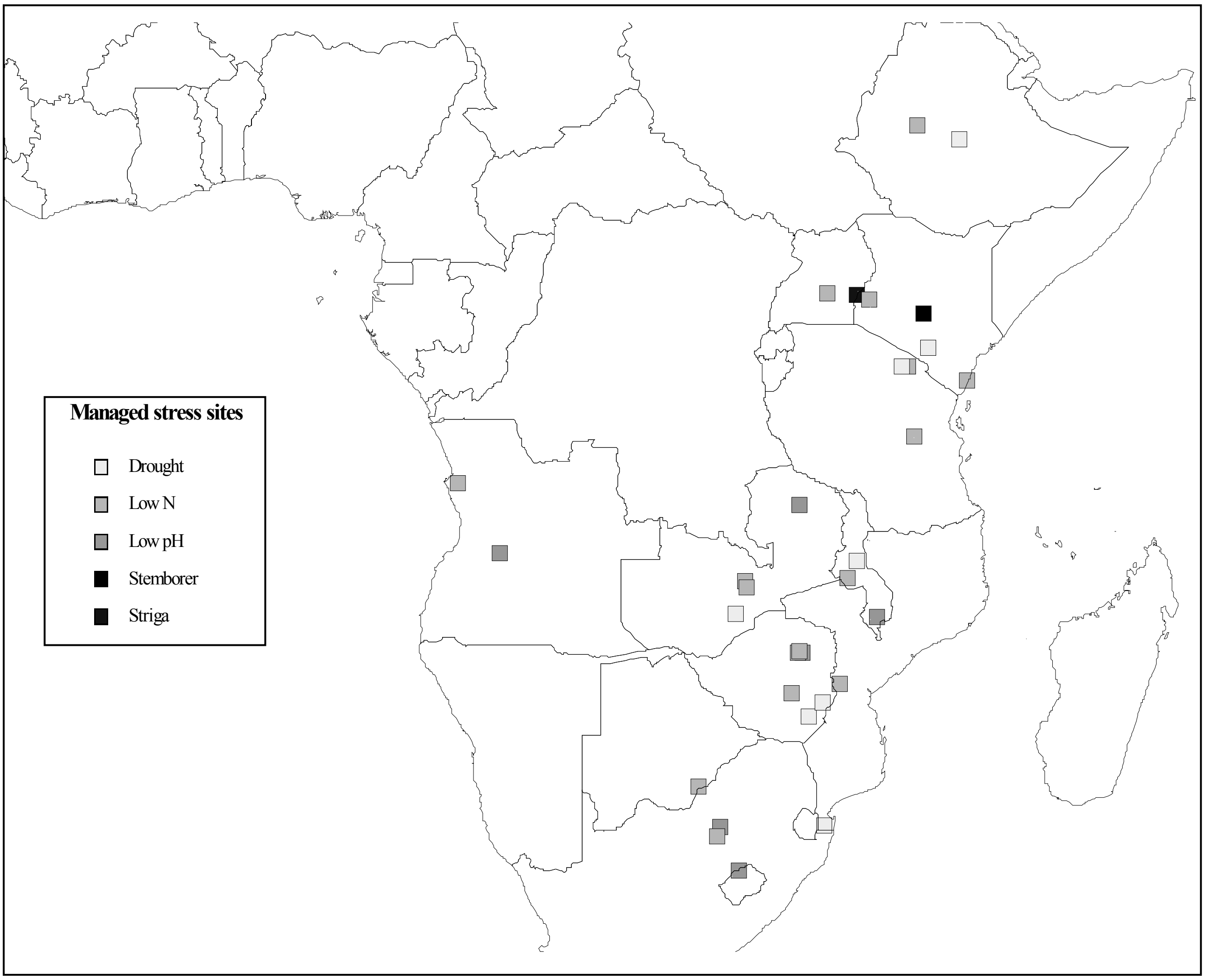
Many studies concluded that selection under stress conditions is more effective than selection under non-stress conditions for improving grain yield in environments where that specific abiotic stress occurs (Atlin and Frey, 1990; Bänziger et al., 1997; Ceccarelli et al., 1992; Edmeades et al., 1999; Pederson and Rathjen, 1981). However, the difficulty of choosing appropriate selection environments that would lead to consistent gains and resource constraints impeded the application of this concept in Sub-Saharan Africa. The approach introduced by SADLF and AMS was therefore based on a cost-effective breeding methodology developed by CIMMYT during the eighties and nineties (Bänziger *et al.*, 2000a), for which substantial selection gains have been documented (Bolaños and Edmeades, 1993; Edmeades *et al.*, 1999; Lafitte and Edmeades, 1994; Pandey *et al.*, 1994).

Germplasm screening and testing

SADLF and AMS established sites on research stations in Angola, Botswana, Ethiopia, Kenya, Malawi, Mozambique, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe where maize breeding materials can be screened under managed drought or N stress (Fig 3) following methods described in in detail by Bänziger *et al.* (2000a). In contrast to farmers' fields, it is possible to screen large numbers of breeding materials (lines, testcrosses, hybrids, open-pollinated varieties etc.) at these sites while managing the target stress uniformly. Results from these sites give information about the tolerance of the genetic material being evaluated to a specific abiotic stress factor. This information is combined with other selection criteria such as performance under good conditions, disease resistance and known preferences of farmers (hard endosperm, earliness) for selecting those varieties that are likely more suitable to farmers' real conditions. Bänziger and Cooper (2001) recently reviewed the rationale for this stress breeding approach. In essence, it considers the fundamental elements of breeding progress by ensuring adequate genetic variation, a high selection pressure for priority traits, and an evaluation strategy that permits retention of high heritability while ensuring better genetic correlations between selection and target environment.

Financial, human resource and logistical constraints dictate that individual breeding programs and countries in Africa may select their germplasm only for a few but not all

Figure 3. Location of managed stress screening sites established through SADLF and AMS in southern and eastern Africa.



not all stress factors that are relevant in farmers' fields and using only a few sites. SADLF and AMS therefore established regional testing networks that evaluate common sets of trials for drought, N stress and low pH tolerance, responsiveness to good conditions, and resistance to several important diseases and insects at several sites. Any breeder (from national and international breeding programs, private sector) can submit maize germplasm for evaluation. Within one year, the trials deliver reliable information on the tolerance and resistance of germplasm for traits that are important for a cultivar's performance under smallholder farmer conditions (see for example Bänziger et al., 2000b; Vivek et al., 2001; Vivek et al., 2002).

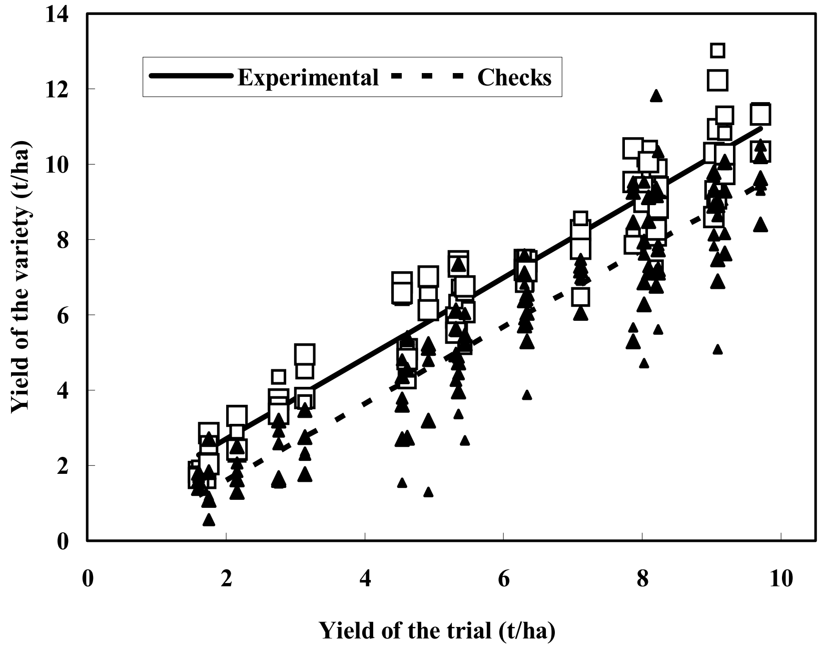
SADLF and AMS identified several released cultivars with potential value to smallholders as they are significantly higher yielding under drought and/or N stress - characteristics that have so far not been used when promoting those cultivars (Bänziger et al., 2000b; Vivek et al., 2001; Vivek et al., 2002). In addition, experimental maize germplasm with more than 50% higher grain yields under drought and N stress, at a yield level of about 1-2 t/ha, was identified (Fig 4).

Verification with farmers – the Mother-Baby Trial approach

Selection and evaluation under managed stress conditions increase the frequency and number of varieties that supposedly better met farmers' needs. However, collaboration with farmers is essential for assessing the performance and acceptance of such pre-selected varieties under farmers' real conditions as the breeder's perception may not be completely accurate about what stresses are important in farmers' fields. Also farmers have their own perception of what variety they like and deem suitable, and such feed-back needs to be captured if varieties with a high adoption potential should be identified.

Researchers and NGOs have been using farmer-participatory variety evaluation in southern and eastern African countries. Inadequate human and financial resources, high transport costs, and poor road infrastructure, however, often limited such efforts to a relatively small sample of sites and farmers in each country. Thus, SADLF and AMS were challenged to develop a verification system that evaluates the performance and acceptance of new maize varieties under farmers' conditions, and also creates a cost-effective and

Figure 4. Performance of four experimental stress tolerant hybrids as compared to five private company check hybrids of similar maturity when evaluated across 23 locations in southern and eastern Africa.



simple flow of information between breeders, extension staff and farmers.

The resulting testing scheme, the Mother-Baby Trial Scheme, was based on two concepts: (i) an innovative experimental design - the 'Mother-Baby Trial Design' (Snapp, 1999) – that was adapted for variety evaluation and linked to regional trials, and (ii) wide-ranging and organized partnerships with farmers and farmer organizations interested in variety testing.

A Mother-Baby Trial Scheme involves sets of experiments grown by researchers, NGO and extension staff and farmers under both researcher- and farmer-managed conditions (Fig. 4; Bänziger and de Meyer, 2002). The Mother Trial is a replicated researcher-managed trial, planted in the center of a farming community, typically with a school or a progressive farmer. It evaluates new maize varieties, maybe 9 to 25, under (i) recommended input application and (ii) using the amount of inputs that is representative for farmers' practice in the area, often none at all. From the breeding perspective, the two input levels create two environments per site, each representing relevant growing conditions. Baby Trials, each with three or four of the varieties in the Mother Trial, are grown under completely farmer-managed conditions by at least six farmers in a community that hosts a Mother Trial. Local partners, such as a local research, extension or NGO staff or an agricultural teacher, supervise individual Mother-Baby Trial sets. This method allows up to 30 farming communities in a country to assess most promising new maize varieties. Information on farmers' opinions of the varieties and data on their performance flow back to researchers, NGOs, extension and seed companies.

The approach was a great success. Today, the Mother-Baby Trail concept is used by National Progarams in Angola, Botswana, Kenya, Lesotho, Malawi, Mozambique, South Africa, Tanzania, Uganda and Zambia, with over 60 institutions and 1500 farmers involved. Researchers have adopted the same methodology for maize and rice in Asia.

One advantage of the Mother-Baby Trial concept is that it involves both farmers and stakeholders that are responsible for technology transfer in the verification process. This greatly increases the chances that farmers will get access to seed of selected varieties in the shortest time-frame possible.

Many of the varieties that farmers (and breeders) selected through the Mother-Baby Trial approach originated from the stress breeding approach initiated by SADLF and AMS. As an example, ZM421, ZM521 and ZM621, three drought and N stress tolerant maize OPVs were selected from among more than 2000 maize breeding materials evaluated during 1997, using results combined across managed stress and non-stress screening sites. The OPVs were composed in 1998, evaluated in regional trials during 1999 and 2000, and in Mother-Baby Trials during 2000 and 2001. By the beginning of the 2001 season, these OPVs had been evaluated in 86 regional trials and 54 Mother and Baby Trials – likely a much more thorough, appropriate and faster evaluation than conducted in the past for new varieties in this region. By 2002, they have been released in several eastern and southern African countries.

Conclusions and challenges for the future

Stress breeding approaches, as introduced by SADLF and AMS through managed stress screening sites and Mother-Baby Trials, have led to farmers getting access to more drought and N stress tolerant maize varieties. Over 250 researchers, technicians, extension and NGO staff have been exposed to these new methodologies in eastern and southern Africa, and many new breeding materials are in the pipeline. However, the challenge is large. There are 250 million people depending on agriculture in eastern and southern Africa.

Many of these farmers do not grow improved varieties or grow maize varieties developed 20-40 years ago. They could benefit greatly from these stress-tolerant varieties.

For the future, it is imperative that National Agricultural Research Systems institutionalize stress breeding approaches but also sustain the highly collaborative approaches that are intrinsic to SADLF and AMS. Given that average maize yields are below 2-3 t/ha in all Sub-Saharan African countries, evaluation and selection of maize varieties exclusively under high yielding conditions must be a thing of the past – unless breeding should exclusively target commercial farmers. Such changes must also affect release and registration systems that evaluate new crop varieties typically under optimally managed conditions. Experience tells us that for reliably assessing the merit of a new variety, results from > 30 sites are needed and they must be representative for a wide range of stress conditions. No institution can achieve this alone, or only at great expense, making collaboration imperative as promoted by collaborative regional trials or Mother-Baby Trials. Thus, institutional policies must provide incentives to support such collaboration.

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SESSION III:

Breeding approaches to abiotic stress – nitrogen stress

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DEVELOPING LOW-N TOLERANT MAIZE VARIETIES FOR MID-ALTITUDE SUB-HUMID AGRO-ECOLOGY OF ETHIOPIA

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ABSTRACT

Soil fertility condition is among the factors influencing maize production in mid-altitude sub-humid areas of Ethiopia. Farmers are constrained by cash shortage that keeps them from using inorganic fertilizers. Different maize varieties in different sets of trials were evaluated under low-N and optimum conditions at Bako during 1999 and 2000 cropping seasons in alpha lattice design in collaboration with CIMMYT AMS project to identify varieties (hybrids and OPVs) which can give reasonable yield under both conditions. Grain yield, selection index, ears per plant, leaf senescence, anthesis-silking interval, disease reaction were considered in selecting the varieties. Separate analysis of variance for grain yield was done for each trial and it showed significant differences ($P \leq 0.05$) among the varieties. The results showed that, when the top yielding genotype under optimum conditions in each trial was selected, the mean yield loss across the trials and years under the low-N condition was high (64.56%) and when the best materials under low-N condition were selected, most of them were less responsive under the optimum condition. But when the selection was based on the performance under both fertility conditions the mean yield loss across trials and years under low-N was 47.34%, without or with mean loss of 6.52% under the optimum condition. These varieties also significantly out yielded the local checks under both fertility conditions. This indicated the existence of genetic variation among the tested materials for the efficiency of nutrient utilization and the possibility of releasing nutrient-use-efficient commercial varieties in Ethiopia. Thus, better performing varieties under both fertility conditions were selected for further evaluation across locations.

Key words: Low-N, maize, optimum, stress, tolerance, variety

INTRODUCTION

Mid-altitude sub-humid zone is the most important maize producing environment in Ethiopia (Birhane Gebrekidan and Bentayehu Gelaw, 1989; Kebede *et al.*, 1993). However, nutrient deficiencies are the most widespread problem influencing maize production in the zone due to the low use of purchased inputs and the lack of soil fertility enriching rotations or fallow (Ransom *et al.*, 1993). Farmers are also constrained by cash shortage to use inorganic fertilizers (Asfaw *et al.*, 1997)

Nitrogen is the most limiting nutrient as it is the most mobile in the soil and the nutrient needed in the largest quantities by the crop (Ransom *et al.*, 1993; Tolessa *et al.*, 1997). Research results also indicated that maize varieties vary in performance across soil fertility levels and nitrogen use efficiency (Laffitte and Edmeades, 1994).

The high yielding commercial maize varieties released for the mid-altitude sub-humid areas of Ethiopia were selected under optimum soil fertility conditions. These varieties may not serve the interests of resource-poor farmers who cannot apply inorganic fertilizers. This necessitated the development of low–N stress-tolerant varieties in Ethiopia.

Thus, in this paper the results of the trials which have been conducted to identify low-N stress-tolerant varieties in Ethiopia in collaboration with CIMMYT Africa Maize Stress (AMS) Project have been presented.

MATERIALS AND METHODS

Different maize varieties (hybrids and open pollinated varieties) in different sets of trials (Table 1-6) were evaluated under low-N (no fertilizer application) and optimum (100/100 kg N/P_2O_5 ha^1) conditions at Bako during 1999 and 2000 cropping seasons. Bako (1,650 meters above sea level) represents the mid-altitude sub-humid areas of Ethiopia with annual rainfall of 1,200 mm. The soil is nitosol.

The varieties were planted in alpha lattice design in different sets of trials. The row length was 5.1 meter and spaced 75 cm apart and plant to plant distance was 30 cm. All trial management practices were based on the recommendation of the center except soil fertility levels.

The data were recorded for days from emergence to tasseling (50% pollen shading), silking (50% silk emergence), grain yield, ear and stand count per plot, leaf senescence, disease reaction and other important agronomic traits. Grain yield (t/ha), selection index, ears per plant and anthesis-silking interval were also calculated (Banziger *et al.*, 2000). Analysis of variance for each trial was made using alpha computer programme at CIMMYT-Nairobi. Then the best performing varieties were selected (Table 1-6).

RESULTS AND DISCUSSION

The analysis of variance for grain yield at each fertility environment demonstrated significant ($P \leq 0.05$) differences among the genotypes in both years indicating the difference in the yield potential among the genotypes (Table 1-6). Ranking of the genotypes was also not constant across the fertility environments implying that the different genotypes performed differently in the different fertility environments. Similarly Oikeh *et al.*, (1997) reported that different

Table 1. Mean grain yield and some other agronomic traits of the top yielding hybrids tested under Low-N and optimum-N at Bako-1999, Trial-99101.

Pedigree	Ent	Rank		Grain Yield (t/ha)		Index		EPP		LS		ASI		GLS	
		Stress	Opt	Stress	Opt.	Stress	Opt	Stress	Opt	Stress	Opt	Stress	Opt	Stress	Opt
LAPOSTA SEC3-H1-2-2-3-2-1-1-#-#-B-B XCML-258XCML-202	2	2	4	3.6	8.9	0.04	0.16	0.9	1.6	2.1		5	2	1.7	1.8
TS6C2-2-1-1-2-2-B-BXCML-271XCML-202	12	3	5	3.6	8.8	0.02	0.30	0.9	1.4	2.3		6	2	2.3	1.5
P43C9-56-1-1-2-2-B-B-X-CML--254XCML-202	1	4	3	3.1	9.0	0.11	0.04	0.8	1.6	2.6		7	1	1.7	2.0
LPSC3-36-2-2-1-1-B-BXCML-258XCML-202	8	5	14	2.8	8.1	0.05	0.43	0.9	1.4	2.2		4	1	1.6	2.0
LPSC3-40-1-1-1-1-B-B-CML-258XCML-206	33	6	41	2.7	6.8	0.09	0.68	0.9	1.3	2.6		6	4	1.7	1.8
CML-202XCML-206XCML-247XCML-254	48	7	18	2.7	7.9	0.13	0.09	0.7	1.3	2.2		7	6	1.6	1.8
LPSC3-36-2-1-1-2-B-BXCML-258XCML-202	6	8	8	2.6	8.5	0.55	0.13	0.6	1.4	2.9		5	2	1.4	1.8
LAPOSTASEQC3-H17-11-2-3-1-4-#-#-B-BXCML-258XCML-202	3	9	25	2.6	7.4	0.16	0.54	0.8	1.5	2.4		6	5	1.8	1.8
LPSC3-36-1-1-2-1-B-BXSPL254-1-2-3-2-2-BXCML-206	41	17	1	2.1	9.2	0.27	0.02	0.8	1.7	2.7		6	2	2.0	2.3
P443C9-56-1-1-1-4-B-BXCML-258XCML-202	5	19	2	2.1	9.0	0.41	0.14	0.7	1.6	2.6		6	2	1.4	1.8
BH-540	56	54	54	0.8	5.9	0.89	0.91	0.6	0.9	3.1		4	4	2.2	1.8
Mean (Trial)				1.9	7.4										
LSD				1.8	1.4										
CV %				46.4	9.8										

Table 2. Mean grain yield and some other agronomic traits of the top yielding hybrids tested under Low-N and optimum N at Bako-1999, Trial-99102.

Pedigree	Ent	Rank		Grain Yield (t/ha)		Index		EPP		LS		ASI		GLS	
		Stress	Opt	Stress	Opt	Stress	Opt.	Stress	Opt	Stress	Opt	Stress	Opt	Stress	Opt.
CML-254xCML-340xCML-206	17	24	1	2.49	9.7	0.33	0.03	1	1.7	2.0		3.0	1	1.5	2.0
Lpsc3-54-1-2-2-3-B-BXCML-264 BXCML-202	1	28	2	2.33	9.4	0.45	0.13	1	1.7	2.0		4.0	1	1.5	1.9
lpc3-36-2-1-1-2-B-BxTS6C1-F-118-1-1-3-1-2-#-#-B-BXCML-202	7	9	3	3.28	9.3	0.63	0.05	1	1.7	2.3		4.5	2	1.5	1.9
P43C9-1-1-1-1-1-B-BXCML-254xCML-206	24	3	4	3.72	9.1	0.05	0.25	1	1.6	1.8		4.5	3	2.0	2.0
POOL P11YLLACORACO#15-2-#-3-3XCML254XCML-202	9	7	5	3.35	9.1	0.13	0.10	1	1.8	1.5		6.5	2	1.5	2.2
LAPOSTASEQC3-H297 -2-1-1-1-2-#_#-B-BX CML- 254XCML-206	19	1	17	3.87	8.4	0.03	0.23	1	1.6	1.5		4.0	2	1.5	2.1
T56C1-F208-2-3-2-2-2-#-#-B-BXCML-273XCML-202	3	2	13	3.85	8.5	0.10	0.4	1	1.6	1.5		4.5	-1	1.5	2.0
P43C9-1-1-1-1-1-B-BXCML-264XCML-206	13	4	21	3.69	8.1	0.28	0.53	0.9	1.4	1.8		5.0	2	2.2	2.3
T56C2-32-1-1-1-1-B-BXCML-271XCML-206	27	5	35	3.41	7.2	0.08	0.80	1	1.4	2.0		5.5	3	1.5	2.0
BH540	40	25	38	2.40	7.1	0.85	0.98	0.8	1.1	2.0		6.0	4	1.5	1.9
Mean (Trial)				2.7	8.0										
LSD				1.2	1.0										
CV %				21.8	7.0										

genotypes performed differently across soil fertility levels.

The mean yield under low-N conditions was less in all the trials as compared to the mean yield under the optimum fertility conditions (Table 1-6). This indicated appreciable variation of the testing soil fertility environments and assisted to select maize genotypes under different soil fertility conditions. Banziger and Edmeades (1997) also stated that selection under low nitrogen was predicted to be about twice as efficient as selection under high nitrogen when yield reduction in the target environment was 50%. They further stated that selection under high nitrogen did not lead to any predicted response under low nitrogen when yield reduction in the target environment exceeded 75%.

The top yielding hybrids outyielded the local commercial hybrids by over 20% under low-N and optimum conditions. This implied the superiority of these hybrids to the local commercial hybrids under the different soil fertility conditions of Ethiopia (Table 1-5). Banziger et al. (2000) also stated that the pattern of low-N stress is very similar among low-N fields. In addition, they indicated when relatively severe low-N stress is combined with grain yield data from trials under high-N, it allows prediction of genotype performance across a range of nitrogen levels. Kuleni, the

Table 3. Mean grain yield and some other agronomic traits of the top yielding hybrids tested under Low-N and optimum-N at Bako-2000, Trial-001-16.

Pedigree	Ent	Rank		Grain Yield (t/ha)		Index		EPP		ASI		GLS	
		Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt	Stress	Opt.
99102X99101	9	1	13	6.96	8.44	0.26	0.33	0.9	1.5	2	2	1.5	2.5
99106X99101	3	2	10	6.69	9.13	0.11	0.19	1.0	1.6	2	2	2	1.8
99106X99104	7	3	6	6.54	9.61	0.52	0.26	1.0	1.5	2	2	1.3	1.5
99101X99104	13	4	5	6.11	9.69	0.04	0.11	1.2	1.5	2	2	1.7	1.8
99105X99102	2	5	7	5.91	9.59	0.59	0.37	0.9	1.3	2	3	1.5	1.5
PAW567	14	14	1	5.37	12.08	0.19	0.04	1.0	1.6	2	2	1.7	2.3
99106X99102	11	18	2	5.23	10.23	0.70	0.15	0.9	1.5	2	2	1.8	2.0
HB513	23	17	3	5.26	10.06	0.44	0.07	0.9	1.4	3	3	1.4	2.4
DCHB-1XDCHB-2	16	8	4	5.77	9.92	0.81	0.30	1.7	1.4	2	2	1.5	2.0
99101X99104	13	4	5	6.11	9.69	0.04	0.11	1.2	1.5	2	2	1.7	1.8
BH-540	27	12	17	5.43	7.94	0.56	0.89	1.1	1.1	2	2	1.5	2.3
Mean (Trial)				5.4	8.5								
LSD				2.0	3.2								
CV%				15.8	18.0								

Table-4. Mean grain yield and some other agronomic traits of the top yielding hybrids tested under Low-N and optimum-N at Bako-2000, Trial-001-11.

Pedigree	Ent	Rank		Grain Yield (t/ha)		Index		EPP		ASI		GLS	
		Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt	Stress	Opt.
CML-202/CML-216/[MSRXPL9]C1F2-176-4XCML-312	75	1	73	6.36	6.38	0.01	0.88	0.9	0.8	4	2	1.5	1.9
CML-258/CML-202/[MSRXPL9]C1F2-176-4XCML-312	60	2	13	6.36	8.87	0.02	0.31	0.9	1.4	3	2	1.5	2.3
LPSC4F273-2-2-1-B-B-B/CML-202/P501C1#303-1-1-1-2-1-1-BXCML389	22	3	8	6.34	9.17	0.06	0.72	1	1.4	3	2	1.5	2.3
90323(B)-1-B-6-B-B/CML-312/CML-391/CML-384	35	4	26	5.76	8.38	0.04	0.73	1	1.4	3	2	1.5	1.6
M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-B-B-B/P43C9-1-1-1-1-1-B-B-BXCML-395XCML-312	46	5	4	5.75	9.57	0.23	0.54	0.9	1.1	2	1	1.5	1.4
M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-B-B-B/CML-202XCML-395XCML-312	38	56	1	3.83	9.73	0.59	0.80	0.8	1.1	4	2	1.5	2.3
CML-312/CML-202/CML-391/CML-384	21	68	2	3.51	9.70	0.80	0.02	1	1.3	3	2	1.5	2.2
M37W/ZM607#-bF37sr-2-3sr-6-2-X]-8-2-X-1-B-B-B/P43C9-1-1-1-1-1-B-BX(MSRSPL9)C1-F2-176-4XCML-312	64	64	3	3.66	9.63	0.83	0.09	0.9	1.3	4	2	1.5	1.8
[(TUXPSEQ)C1F2/P49-SR]F245-5-1-2-B/CML-202/CML-312	44	5	5	5.75	9.52	0.44	0.28	0.9	1.1	2	3	1.5	1.8
M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-B-B-B/P43C9-1-1-1-1-1-B-BXP501C1#303-1-1-1-2-1-1-BXCML-389	10	48	6	4.32	9.28	0.58	0.47	1	1.4	4	2	1.5	1.9
DTP2WC4H255-1-2-2-B-B-B/CML-202/CML-391/CML-384	23	79	7	2.67	9.25	0.93	0.07	1	1.5	3	2	1.5	2.0
[(TUXPSEQ)C1F2/P49-SR]F2-45-5-1-2-B/CML-202/[MSRXPL9C1F2-176-4XCML-312	62	58	9	3.82	9.02	0.47	0.05	0.9	1.2	5	2	1.5	1.8
THG-B-76/EV8725SR-3-2-#-B1-8-B1/CML-258/CML-391/CML-384	34	17	10	5.12	9.02	0.09	0.22	1	1.3	5	2	1.5	2.0
LPSC4F273-2-2-3-B-B-B/CML-202/CML-391/CML-384	20	22	11	4.82	9.0	0.14	0.37	1	1.6	3	1	1.5	2.4
BH-540	81	61	56	3.77	7.47	0.88	0.99	0.9	1.0	5	2	1.5	2.1
Mean (Trial)				4.3	7.91								
LSD				1.9	1.9								
CV%				21.9	12.4								

the locally adapted open pollinated variety had reasonable yield under low-N conditions but some of the tested populations significantly out-yielded it under the optimum conditions (Table 6). This showed the importance of improving Kuleni for low-N stress tolerance and the work is already in progress.

The genotypes had longer days to silking under the low -N conditions than under the optimum soil fertility conditions implying that, days to silking was influenced by soil fertility conditions. The top yielding genotypes under both fertility environments had relatively reduced anthesis-silking interval (ASI). Variation was also observed for ears per plant, selection index, leaf senescence and disease reaction (Table 1-6).

Table 5. Mean grain yield and some other agronomic traits of the top yielding hybrids tested under Low-N and optimum-N at Bako-1999, Trial-99105.

Pedigree	Ent	Rank		Grain Yield (t/ha)		Index		EPP		LS		ASI		GLS	
		Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt	Stress	Opt	Stress	Opt	Stress	Opt.
(AC8342/IKENNE{1}8149SR//PL9A)C1F1-500-4-X-1-1-B-B-1-B/TASEQ	16	1	1	3.76	8.91	0.03	0.05	1	1.8	2		6	1	1.7	1.8
TS6C2-2-1-1-1-1-B-B-B/TASEQ	5	3	23	3.45	7.20	0.10	0.67	1	1.2	2		5	3	1.5	1.5
P43C9-1-1-1-1-1-B-B-B/TASEQ	21	4	21	3.45	7.22	0.08	0.72	1	1.3	2		3	1	1.5	2.3
LPSC3-65-1-1-1-B-B-B/TASEQ	17	5	28	3.35	7.13	0.18	0.54	0.9	1.4	1.8		4	1	1.5	1.8
CML-202/CML-206XCML-247/CML-254	33	34	2	2.10	8.66	0.92	0.03	0.8	1.7	1.6		3	1	1.6	2
DRB-F2-60-1-1-1-B/TSEQ	22	8	4	3.10	8.03	0.46	0.23	0.9	1.3	2.3		5	1	1.5	1.5
P21MRRSC2-19-1-2-2-3-B-B-B/TASEQ	9	14	5	2.82	7.95	0.54	0.10	0.9	1.4	2.5		7	1	2.3	2
DRB-F2-180-2-1-B-B/TSEQ	27	19	6	2.56	7.86	0.36	0.21	1	1.4	2.5		5	1	1.5	2
(EV7992#/EV8449-SR)C1F2-334-1(OSU8i)-10-7(I)-X-X-X-2-B-B-1-B/TASEQ	11	22	7	3.20	7.69	0.31	0.46	1.2	1.4	2.4		2	2	1.7	1.8
BH-140	39	37	20	1.81	7.25	1.0	0.51	0.7	1.1	1.8		5	2	1.5	1.5
Mean (Trial)				2.60	7.30										
LSD				1.10	1.1										
CV%				21.5	7.6										

Table 6. Mean grain yield and some other agronomic traits of the top yielding populations tested under Low-N and optimum-N at Bako-2000, Trial-001-13.

Pedigree	Ent	Rank		Grain Yield (t/ha)		Index		EPP		ASI		GLS	
		Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt.	Stress	Opt	Stress	Opt.
Staha-msv-#	2	1	25	5.40	4.87	0.04	1.0	1.0	1.1	3	3	1.9	2.9
KULENI-#	10	2	18	5.21	6.04	0.08	0.56	1.1	1.2	3	2	2.0	2.2
ECAVL-1	14	3	9	5.07	6.50	0.12	0.40	0.9	1.2	4	2	1.5	2.0
TUXPENOSEQUIA6(TS6)-#	16	4	12	4.98	6.42	0.16	0.52	1.0	1.2	2	2	1.9	2.5
Coast composite-#	8	25	1	2.96	7.76	1.0	0.04	0.9	1.1	3	2	2.4	2.0
KSTP94	11	13	2	4.38	7.23	0.52	0.28	1.0	1.1	4	4	2.0	2.4
SADVALB-#-#	5	8	3	4.61	7.17	0.32	0.08	1.1	1.3	3	3	1.6	1.5
ECAVL-2	15	15	4	4.21	6.96	0.60	0.44	1.0	1.1	3	3	1.8	2.6
Mean (Trial)				4.30	6.3								
LSD				1.90	2.3								
CV %				26.6	22.1								

low-N conditions than under the optimum soil fertility conditions implying that, days to silking was influenced by soil fertility conditions. The top yielding genotypes under both fertility environments had relatively reduced anthesis-silking interval (ASI). Variation was also observed for ears per plant, selection index, leaf senescence and disease reaction (Table 1-6).

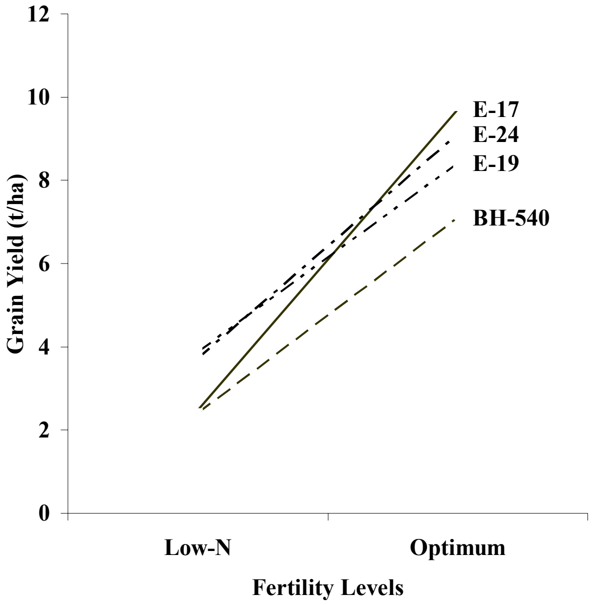
The results of these experiments showed that when the top yielding genotype under optimum soil fertility conditions in each trial was selected, the mean yield loss across the trials and years under low-N conditions was high, 64.56% (Table 1-6). These implied that these genotypes are inefficient in nitrogen utilization. Ransom *et al*. (1993) also indicated that inefficient genotypes are those genotyes which have high yield at high-N but greatly reduced yield in the low-N environments.

However, some genotypes had reasonable yield under both fertility conditions. Thus, when the selection was based on the performance under both fertility conditions, the mean yield loss across trials and years under low-N was reduced to 47.34% without or with mean loss of 6.52% under optimum conditions. These varieties also significantly out yielded the local checks under both fertility conditions. These results were in agreement with the reports of Ransom *et al*. (1993) who stated that N use efficient genotypes are those genotypes, which have high yield *per se* at both high and low-N levels. Some varieties had good performance under the low-N but less responsive to the improved fertility condition. This indicated the existence of genetic variation for efficiency in nutrient utilization among the tested materials. Typical examples of nitrogen use inefficient, nitrogen use efficient and less responsive varieties are shown in Figure 1.

The results also implied that the alleles controlling high grain yield in low-N conditions were at least partially different from those alleles controlling high grain yield in high-N conditions. This may result in low yield in one of the fertility environments if only one of the fertility environments is used for screening purposes. This indicated the possibility of selecting varieties with high grain yield under a range of soil fertility levels when the data from low-N is combined with grain yield data from high-N. Ceccarelli (1989,1992) also stated that differences for grain yield observed in the absence of stress are largely unrelated with differences observed in presence of severe stress.

In general, the better performance of some of this varieties under both fertility conditions as compared to the local checks indicated the existence of genetic variation

Figure 1. Performance of three hybrids (Entry 17, 24 & 19) as compared to the check (BH-540) under two soil fertility levels in trial 99102 at Bako - 1999



among the tested materials for the efficiency of nutrient utilization and possibility of releasing nutrient use efficient commercial varieties in Ethiopia. But the selected varieties should also be tested at different locations in the mid-altitude sub-humid agro-ecology of Ethiopia to select the varieties with wide adaptation.

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IDENTIFICATION OF MAIZE CULTIVARS TOLERANT TO LOW SOIL FERTILITY IN SOUTH AFRICA

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ABSTRACT

In Southern Africa maize is usually grown by resource-poor farmers under poor soil fertility conditions such as low N, low P and soil acidity. This leads to unstable maize production and thus to low income and food security. The aim of this project is to improve the livelihoods of resource-poor farmers through sustainable maize production. The objectives are: (1) Identification of test sites. (2) Identification of cultivars and genotypes that are tolerant to low soil fertility. (3) Identification of the best 20 cultivars to be made available to other Southern African Developing Countries (SADC) countries and resource-poor farmers. During 1999/2000, materials from CIMMYT-Zimbabwe and the South African National Cultivar Trials were tested under low nitrogen conditions with good results. The low N trials were replicated in three localities in South Africa afterwards. A low phosphorus (P) and a high soil acid trial were also planted at Potchefstroom during 2000/2001 to identify tolerant genotypes. The yield ranged from 0.2 to 3.9 t ha^{-1} under low P conditions and from 0.5 to 2.1 t ha^{-1} under acid conditions. These results would raise yields and stabilize maize production, which will lead to food and income security for the resource poor farmer in South Africa.

Keywords: Cultivar evaluation, low soil fertility, maize, resource-poor farmers.

INTRODUCTION

In the past, little effort was made in breeding maize (*Zea mays L.*) cultivars that suit the needs of small-scale farming systems. Small-scale farmers do not always have the financial resources or available technology to exploit their environmental potential, or to rectify production constraints such as soil acidity or nutrient deficiencies. This leads to low and unstable maize production, and consequently to reduced income and food security (Anon, 2001; Du Toit *et al*., 1999).

Cultivars chosen by farmers are not always those best adapted or with the highest yield potential. For small-scale farmers, factors such as ear size and appearance of the kernel (shape, size and colour) are often more important than yield potential, since main interest focuses on utilization as corn-on-the-cob, basic food supply or selling in small markets. Most maize cultivar trials are being conducted under optimum managed conditions. This implies optimum fertilization and effective weed, pest and disease control. Little support or information is currently available to small-scale farmers on the availability or type of cultivars to be planted in order to be sustainable under resource limiting constraints. Small-scale farmers are currently using any cultivar based on availablity (Ahmed *et al.*, 1997).

This study includes a farm-like, resource limiting evaluation of cultivars to be identified for use in different regions that will meet the needs of sustainable maize production. (Anon, 2001; Shao, 1996). This project will not only disseminate important information on cultivar selection to extension officers and farmers, but will also help in making an informed cultivar choice based on a particular constraint. Ultimately this will lead to enhanced sustainability in the long term.

MATERIALS AND METHODS

Execution of stress trials in this study includes four stages: (1) Identification of localities associated with yield loss due to low soil fertility. (To qualify as a nutritional stress site the locality had to provide at least a 50 % yield loss due to low soil fertility). (2) Evaluation of cultivars from the National Cultivar Trials and other partners e.g. CIMMYT-Zimbabwe at localities identified under the previous objective. (3) Identification of the best 20 cultivars to be provided to other SADC countries as well as to small-scale farmers. (4) Replicated trials to identify the best five cultivars that could tolerate soil fertility restrictions in different regions.

A factorial design was used with 49 cultivars and two fertiliser treatments and three replicates. A fertilised cultivar trial was planted adjacent to a trial that had a particular nutrient deficiency. One cultivar was chosen as a control and was planted every fourth row as a covariant to take spatial variation into account. The low Nitrogen (N) trials received no N, while the *N*-fertilized trials were planted with 71 K LAN (28) ha^{-1} (20 kg N ha^{-1}) and 357 LAN (28) ha^{-1} (100 kg N ha^{-1}), as a side-dressing four to six weeks after planting. The low phosphorus (P) trials received no P, while the P-fertilized trials were planted with 100 kg Maxifos ha^{-1} (50 kg P ha^{-1}). The high soil acidity trial received no lime, while the trial with neutralised soil acidity received enough lime to reduce the acid saturation of the soil below 20% during the first year. All the other nutritional elements were measured and applied according to needs. The seed were treated with fungicide and insecticide (Curaterr) and total weed control was applied.

Data of the South African National Cultivar Trials for nitrogen stress in 1999/2000 at Viljoenskroon, Free State Province of South Africa will be presented. Two trials from CIMMYT-Zimbabwe, an Early to Intermediate Hybrid Trial (EIHYB) and an Early Maturing Experimental Population Trial (EPOP), at Viljoenskroon during 1999/2000 were also used. These CIMMYT-trials (EPOP and EIHYB) are a collection of material from the Southern African Developing Community (SADC) countries maize breeding programmes.

During 2000/2001 low N trials were also planted at

Table 1. Yield of the Early Maturing Experimental Population Trial (EPOP) under low N conditions at Viljoenskroon for 1999/2000

Pedigree	Rank	Yield ($kg\ ha^{-1}$)
LOCAL CHECK 2	28	0
POP 25 (Zambia)	27	579
LOCAL CHECK 1	26	836
POOL 16 SR (Zambia)	25	865
POP 10 (Zambia)	24	1020
POP 101 (Zambia)	23	1111
MMV 400 (Zambia)	22	1135
[Z98EDRSYN] F2-bal breeder bulk-#	21	1204
MATUBA (Mozambique)	20	1209
[TEWD-SRDRTOLSYN /[NAW5867/ P30-SR(S2#)]]##-#	19	1210
KATUMAI-ST (Tanzania)	18	1265
SADVI2 F1	17	1276
KEP (Botswana)	16	1342
SADVI2 F2	15	1440
SADVI1 F1	14	1455
MATINDIRI (Malawi)	13	1495
POOL 16 SEQ (Zambia)	12	1515
SADVE F2	11	1553
POP 101 x KATUMANI (Zambia)	10	1682
ZM 521 = SADVI F1	9	1740
[EARLY-MID-1/KATUMANI-SR1]-#	8	1750
KITO-ST (Tanzania)	7	1813
CCD (Malawi)	6	1913
ZM 301	5	1920
SADVI1 F2	4	1942
ZM 421 = SADVE F1	3	1951
SEMOCI (Mozambique)	2	2009
[EARLY-MID-2/PL16-SR]-#-#	1	2157
LSD(0.05)		624

Viljoenskroon, Potchefstroom and Bethlehem, Free State Province, but the data are not yet available. A low phosphorus (P) trial and a high soil acidity trial were planted at Potchefstroom, in 2000/2001. Preliminary data of the low P and high soil acidity trials will be given.

Grain yield was measured at physiological maturity. The average yield of each cultivar at Bethlehem and Viljoenskroon were plotted against the average yield of the corresponding cultivar at Potchefstroom to indicated yield response over localities. It also provided a measurement of the extent of tolerance, according to the method of Hadzistevic *et al*., (1973).

RESULTS AND DISCUSSION

Tables 1 and 2 represent data of the EPOP and EIHYB trials under low N-conditions ranked according to yield obtained for the 1999/2000 season at Viljoenskroon. Yields of the EPOP trial ranged from 0 to 2,157 kg ha^{-1} and the EIHYB from 632 to 1,977 kg ha^{-1} under low N conditions. Table 3 presents data of the South African National Cultivar Trial under low N and fertilised N conditions at

Table 2. Yield data of the Early to Intermediate Hybrid Trial (EIHYB) under low N conditions at Viljoenskroon for 1999/2000

Pedigree	Rank	Yield ($kg\ ha^{-1}$)
CZH99002	32	632
CZH99016	31	729
CZH99016	30	835
SC5201	29	1081
CZH99010	28	1106
CZH99004	27	1106
CZH99001	26	1107
CZH99015	25	1154
PAN31	24	1166
CZH99012	23	1198
LOCAL CHECK 2	22	1241
SC407	21	1257
LOCAL CHECK 1	20	1268
CZH99014	19	1307
SC515	18	1379
CZH99017	17	1383
CZH99018	16	1408
CZH99009	15	1434
SC405	14	1437
GV512	13	1454
PHB30R93	12	1456
CZ99013	11	1494
SC513	10	1501
CZH99008	9	1532
CZH99011	8	1578
SC401	7	1602
CZH99007	6	1644
C8031	5	1677
CZH99003	4	1847
CZH99006	3	1910
SC501	2	1948
SC403	1	1977
LSD(0.05)		519

Viljoenskroon for the 1999/2000 season. Yields range from 647 to 3,853 kg ha^{-1} under low N conditions and from 4,170 to 6,930 kg ha^{-1} under N fertilised conditions. The South African cultivars gave better yield under nitrogen stress conditions than the EPOP and EIHYB, because these cultivars were developed in the South African conditions. Analyses of variance for the above trials, are presented in Table 4.

Yield potential of cultivars also differed from optimum fertilized to stressed conditions. As an example, SNK2340Bt, of the South African National Trial, gave the best yield under optimum N fertilized conditions (6,930 kg ha^{-1}), but just 976 kg ha^{-1} under low N. The ideal is to identify a cultivar that will give good yield under both optimum and stress conditions.

During the 2000/2001 season, a trial for low phosphorus (P) and an acid soil trial were both planted for the first year at Potchefstroom to identify tolerant genotypes. The mean yields of the National Cultivar Trial entries range from 0.2 to 3.9 t ha^{-1} under low P conditions, and from 0.5 to 2.1 t ha^{-1} under acid soil conditions. It is recommended that for maize production, on acid soils, the acid saturation should be below 20 %. The average soil acidity of the trial area was 50% which is well above acceptable levels. Some cultivars had almost no tolerance towards soil acidity while others performed fairly well. With an incorrect cultivar choice there would not have been any harvest, but with the correct choice a yield of 2.1 t ha^{-1} could have been obtained.

Table 3. The South Africa National Cultivar Trial under low N and fertilised N conditions at Viljoenskroon for 1999/2000

Cultivars	Low N		Fertilised N	
	Rank	Yield (kg ha^{-1})	Rank	Yield (kg ha^{-1})
PAN6243	49	647	15	6230
PAN6823	48	647	21	6020
PHB33A14	47	786	42	4870
SNK2340BT	46	976	1	6930
LS8503	45	978	39	5200
CRN7821BT	44	1088	46	4600
NS9100	43	1189	10	6510
SNK2021	42	1216	29	5720
PAN6734	41	1266	6	6620
PAN6561	40	1322	43	4790
PAN6710	39	1341	47	4510
PAN6332	38	1377	34	5480
SNK2721	37	1422	22	6010
CRN3818	36	1440	30	5610
OS7608	35	1500	13	6330
SNK2147	34	1546	28	5740
SNK2975	33	1559	40	5020
SNK2782	32	1583	27	5760
CRN3549	31	1606	19	6090
PAN6479	30	1611	24	5880
SNK2778	29	1664	5	6730
SNK2659	28	1708	48	4460
CRN3414	27	1723	20	6030
PAN6573	26	1733	9	6520
PAN6568	25	1743	31	5610
SNK2626	24	1919	7	6550
SNK2945	23	1936	17	6200
LS8502	22	1970	38	5260
PHB3203	21	1971	49	4170
CRN1598	20	1975	33	5510
PAN6335	19	2004	11	6430
CRN3604	18	2086	8	6530
PAN6615	17	2148	36	5300
CRN3815	16	2387	41	4950
PAN6364	15	2458	18	6100
SNK2969	14	2468	32	5600
PAN6242	13	2496	25	5880
PHB3442	12	2565	35	5400
PAN6043	11	2566	45	4680
PAN6164	10	2640	2	6870
PAN6256	9	2643	4	6750
CRN3524	8	2707	37	5290
SNK2472	7	2788	14	6240
PAN6633	6	2896	26	5890
SNK2682	5	3043	16	6220
CRN3853	4	3116	12	6390
PHB30H22	3	3135	23	5960
SNK2911	2	3707	44	4700
CRN3760	1	3853	3	6820
LSD(0.05)		741		617

Table 4. Analyses of variance (ANOVA) for yield for the EPOP, EIHYB and South African National Cultivar Trial (low N and N fertilized)

Trial	Source	Df	F-Ratio	P-Value
EPOP	Cultivar	27	1.56	0.0824
	Error	53		
EIHYB	Cultivar	31	1.04	0.4397
	Replications	58		
National Cultivar Trial	Cultivar	48	2.66	0.0005
Low N	Error	48		
National Cultivar Trial	Cultivar	48	1.23	0.1947
N fertilised	Error	96		

CONCLUSION

It is generally accepted that maize cultivars yield differently in a specific environment due to genetic differences. Data of Viljoenskroon showed that yield potential of cultivars differed from optimum fertilized to stressed conditions, and also indicated that yield differences were maize cultivar response specific for a specific environment.

Very little support or information is currently available to small-scale farmers on the availability or the type of cultivars that could be planted in order to be sustainable under certain production constraints such as soil acidity and nutrient deficiency. These kinds of research will not only disseminate important information on cultivar selection to extension officers and farmers but will ultimately lead to enhanced sustainability in the long term.

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DROUGHT AND LOW NITROGEN TOLERANT HYBRIDS FOR THE MOIST MID-ALTITUDE ECOLOGY OF EASTERN AFRICA

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ABSTRACT

Maize is the principal food staple of the rural and urban poor of eastern and central Africa, constituting > 50% of the caloric intake derived from cereals in the region. Drought and low soil fertility are among the most important constraints to maize production even in the high potential moist mid-altitude eco-zone. This zone, generally falling within the altitudinal range of 1000-1800 masl and characterized by rainfall of >500 mm and mean temperature of 21.5°C, comprises a total area of approximately 500,000 hectares in Kenya alone, and is among the most densely populated regions on the continent. Though of high potential productivity, fertilizer use is constrained by high costs and lack of credit for small holders. Maize productivity in maize-based cropping systems could be greatly improved using varieties that utilize nitrogen (N) from fertilizers and other sources more efficiently as well as tolerating the periodic moisture stress. Farmers in this region have shown a preference for hybrid maize varieties. The objective of the research described here was to develop hybrid maize varieties adapted this ecology that are tolerant of low soil fertility and drought. Drought and low N tolerant inbred lines developed by CIMMYT-Harare in collaboration with CIMMYT Mexico were crossed with two streak resistant testers (CML202 and CML206) during the 1997-98minor season. In 1999, the resulting crosses were evaluated across 7 sites and compared with local checks under both stressed (managed drought and low N) and unstressed conditions. The selected best single cross hybrids were crossed with 2 other testers (CML78 and CML384) in 2000 and the resulting 3 way-hybrids were evaluated as in 1999. Grain yield and secondary traits such as Anthesis-Silking Interval (ASI), leaf senescence, and number of ears per plant were used to select the most promising materials. Eight drought and low N tolerant 3-way hybrids were identified which yield 24, 15 and 64% more than the best commercial hybrid checks under optimum, low N and drought stress conditions, respectively. These hybrids have the potential to increase yields, reduce input requirements and improve yield stability for resource-poor farmers in densely populated high potential eco-zones of Eastern and Southern Africa.

INTRODUCTION

Maize is the principal food staple of the rural and urban poor of eastern and central Africa, constituting more than 50% of the caloric intake derived from cereals in the region. Drought and low soil fertility are among the most important constraints to maize production. In areas where the probability of drought stress is high, farmers often respond by reducing the application of N fertilizer (McCown et al. 1992). In seasons when rainfall is plentiful, maize crops are often severely N deficient (Bänziger *et al.,* 2000). Use of fertilizers is constrained by high costs and lack of credit faced by small holders even in the high potential moist mid-altitude eco-zone. This zone, generally falling within the altitudinal range of 1000-1800 masl and characterized by rainfall of >500 mm and mean temperature of 21.5°C, comprises a total area of approximately 500,000 hectares in Kenya alone, and is among the most densely populated regions on the continent.

Maize productivity in maize-based cropping systems could be greatly improved using cultivars that utilize nitrogen (N) from fertilizers and other sources more efficiently as well as tolerating the periodic droughts which befall the region, hence the African Maize Stress (AMS) project whose the development objective is to increase food security and income generation of African farm families by increasing the productivity and sustainability of maize-based cropping systems subject to drought, low and declining soil fertility, *Striga*, and insect attack. Farmers in the eastern Africa region have shown a preference for hybrid maize. The objective of the research described here is to develop hybrid maize hybrids adapted to the moist mid-altitude ecology that are tolerant to low soil fertility and drought and resistant to the main diseases prevalent in the region.

MATERIALS AND METHODS

Inbred lines from CIMMYT-Mexico, -Zimbabwe and the former CIMMYT station in Ivory Coast with mid-altitude and/or tropical adaptation were used in this study.

Screening and testing sites.

In order to permit efficient breeding for drought and low N tolerance, screening sites where the timing and intensity of stresses (drought, low N) could be reliably managed were developed in the region. For drought screening, a relatively rain free environment is needed where uniform irrigation can be applied to provide relief from stress at the appropriate plant growth stage. Screening for tolerance to low N is best accomplished at sites with a uniformly low level of native soil fertility, but which are otherwise representative of the target environment. Nitrogen levels were reduced where necessary by densely cropping the area with maize or sorghum and cutting and removing the green biomass for several seasons until yields fell to less than 25-35% of those in neighbouring well-fertilized control plots. Screening is done during the normal rainy growing season (Bänziger et al., 2000).

In addition to the key screening sites, national testing sites distributed through the region in NARS experimental fields were used for their reliability in presenting the particular targeted stresses normally encountered in the maize growing season in that area of the country. This strategy allowed screening the materials under both managed stressed, random-stressed and unstressed environments, hence enhancing their broad adaptation and stability. This ensured selection of germplasm that is well buffered against environmental stress, a prerequisite for minimizing yield losses under farming conditions. Final release for use by farmers depended on stress tolerance, yield potential, and agronomic qualities.

During the minor season of 1997-98, selected drought and low N tolerant inbred lines developed at CIMMYT-Harare and Mexico were crossed with two streak resistant testers (CML202 and CML206) under the auspices of the Southern Africa Drought and Low Soil Fertility (SADLF). In 1999, the resulting 63 single cross hybrids along with 7 checks (commercial hybrids grown in the region) were evaluated across 11 sites including 5 rain-fed, 4 managed low N, and 2 managed drought.

The following season, the selected best single cross hybrids were crossed with 3 other testers (CML78, CML384, and CML373) and the resulting 3-way hybrids along with 4 local checks (commercial hybrids grown in the region) were evaluated across 7 sites including one drought, 3 low N, and 3 optimum conditions. In 2001, the selected hybrids were grouped by maturity and were evaluated in 2 trials of 27 entries (late maturing hybrids from the crosses with CML384) and 32 entries (early hybrids from crosses with CML78) across 23 sites.

An alpha (0,1) lattice design (Patterson and Williams, 1976) with 2 or 3 replications was used. The entries were planted on 1 or 2 row plots of 5 m long with spacing of 0.75 m between rows and 0.25 m between hills. Two seeds were planted per hill and thinned to one plant per hill after full establishment immediately before or after an irrigation to give a population density of 53,333 plants ha^{-1}.

Screening for drought tolerance.

Screening experiments were conducted to identify germplasm that is more drought tolerant at flowering, which is the growth stage in maize that is most sensitive moisture stress. Extreme sensitivity seems confined to the period –2 to 22 days after silking, with a peak at 7 days, and almost complete barrenness can occur if maize plants are stressed in the interval from just before tassel emergence to the beginning of gain fill (Grant et al., 1989)

The trials were planted during the rain-free dry season and were irrigated from planting until 10-15 days before male flowering after which watering was withheld until 10-15 days after male flowering when an additional irrigation was applied if necessary to prevent zero-yield (Bänziger et al., 2000). The irrigation is timed so that there is severe drought at flowering stage.

Sufficient fertilizer, including N topdressing, was applied to avoid any confounding effect of N and/or P deficiency. The experiments were maintained free of weeds, and Regent® (500 ml ha^{-1}) was applied at planting in the open furrow to prevent termite damage during the entire season. The crop was periodically controlled for stem borers and other pests. Irrigations were applied in a timely manner with the last targeted so that severe drought stress would occur at flowering time. Care is taken so that irrigation, and hence stress, were as uniform as possible and the drought blocks were not contaminated with irrigation water from neighboring blocks or leaking pipes and wind drift.

The following data were taken: (1) Anthesis date (date when 50% of the plants per plot shed pollen); (2) Silking date (date when 50% of the plants per plot show silks); (3) Anthesis-Silking Interval (ASI) (number of days between date of 50% silking and date of 50% pollen shed); (4) Leaf senescence score (at three dates after flowering when differences between genotypes were visible on a scale 0 to 10 corresponding to the percentage of dead leaf area divided by 10 (Bänziger et al., 2000)); (5) Plant number (number of plants per plot at harvest discarding the plants of the first hill on each end of the row); (6) Number of ears harvested (number of ears per plot, discarding end hills as above, where an ear is defined as a cob with at least one grain); (7) Number of ear per plant (computed as number of ears per plot divided by the number of harvested plants); (8) Field weight (weight of harvested ears per plot taken directly after harvest); (9) Shelled grain weight (weight of shelled grain per plot); (10) Grain moisture (measured at harvest); (11) Grain yield (computed at 15% moisture in t ha^{-1}); and (12) other important agronomic traits (plant and ear height, husk cover, root and stem lodging) and diseases scored and used in the selection indices.

Screening for low N tolerance.

The screening for low N tolerance was done during the normal rainy growing season. The trials were planted on N-depleted blocks with normal application of P_2O_5 and insecticides as recommended. All normal husbandries are carried as recommended except that no N fertilizer was applied. The various measurements as described for the drought screening trials were made with special care to the senescence score on 3 occasions during grain filling using a scale from 0 to 3 (Bänziger et al., 2000).

Data analysis.

Data in Tables 1-4 are only for the best 10-20% of entries in each trial, plus hybrid checks. The best entries were selected using data of various traits to create a simple selection index (CIMMYT Maize Program, 1999). Each table presents data columns referred to as “selection index” for “YP” (yield potential), “Drt” (drought) and “Low N”. The selection indices are constructed by assigning a pertinent weight (importance) to each trait measured (e.g. grain yield, lodging, etc). Only sites where significant differences were obtained were taken into account in selection indices; the secondary traits like ASI, date to anthesis etc, are presented

Table 1. Means of grain yield (t/ha) and other important agronomic characters of 16 selected single cross hybrids compared to 7 checks across 11 sites in East Africa, 1999

Entry	Pedigree	Selection Index				Across	Grain Yield Averages			Ear Aspect	Anth date	ASI	Ears/ plant	Ear rot	GLS	E. turc	Leaf senesc
		Avg	YP	Drt	Low N	Rel GY	OPT*	LN**	Drought								
		0-1	0-1	0-1	0-1	%	t/ha	t/ha	t/ha		d	d	#	%	1-5	1-5	1-10
5	P21MRRSC2-19-1-2-2-3-B-B-B/CML202	0.06	0.10	0.01	0.06	117	5.5	3.1	2.2	2.6	80	1	0.9	2	1.9	2.4	4.2
51	[[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202	0.08	0.06	0.16	0.01	135	6.7	2.8	2.1	2.1	74	2	1.0	4	1.6	1.7	4.5
61	CML202/CML206XCML247/CML254	0.11	0.01	0.19	0.13	125	6.1	2.5	2.6	2.4	81	3	0.9	3	2.1	2.9	3.0
48	DTP2WC4H255-1-2-2-B-B-B/CML202	0.15	0.13	0.09	0.23	120	5.7	3.1	2.3	2.5	77	3	1.0	3	1.7	1.8	4.3
14	LPSC3H144-1-2-2-2-4-#-B-B-B/CML202	0.17	0.11	0.24	0.16	108	5.4	2.7	1.4	2.4	77	3	0.9	7	1.6	1.8	4.0
12	LPSC4F273-2-2-1-B-B-B/CML202	0.19	0.20	0.10	0.26	116	5.7	2.9	1.8	2.5	78	1	0.9	2	1.9	2.2	4.2
19	CML-312/CML202	0.19	0.33	0.11	0.11	121	6.3	3.0	1.5	2.2	78	3	0.9	14	1.7	1.6	4.2
15	CML444/CML202	0.22	0.17	0.41	0.07	137	7.3	2.6	1.6	2.1	80	1	0.9	0	1.7	2.1	4.2
4	P21MRRSC2-19-1-2-2-2-B-B-B/CML202	0.26	0.54	0.06	0.19	112	5.4	2.7	1.8	2.5	78	2	0.9	7	1.8	2.3	4.3
52	CML445/CML202	0.27	0.27	0.31	0.21	130	6.3	3.1	1.7	2.2	76	3	0.9	8	1.8	1.9	3.7
63	CML202/CML206XCML247/CML254	0.28	0.19	0.37	0.27	125	5.9	3.0	2.4	2.6	81	3	0.9	5	2.2	3.0	3.3
16	CML388/CML202	0.29	0.37	0.14	0.34	113	5.4	3.0	1.9	2.3	77	4	0.9	3	1.6	2.0	4.6
13	LPSC3H144-1-2-2-2-2-#-B-B-B/CML202	0.31	0.04	0.56	0.33	111	5.7	3.3	0.9	2.4	77	4	0.9	2	1.6	1.8	3.9
60	CML442/CML444	0.31	0.09	0.43	0.43	134	7.4	2.8	1.6	2.6	79	1	0.9	17	1.8	2.6	3.9
6	CML442/CML202	0.50	0.24	0.44	0.81	128	6.4	2.5	2.3	2.6	76	6	0.8	6	2.2	2.2	3.9
49	SPLC7F182-1-2-2-B-B-B/CML202	0.65	0.67	0.81	0.47	129	5.9	3.5	1.7	2.7	76	2	1.0	4	1.9	1.8	4.3
64	HB512 CHECK 1	1.00	1.00	1.00	1.00	64	4.4	1.8	0.7	3.4	77	10	0.6	48	2.0	2.2	4.7
65	H511 CHECK 2	0.98	0.99	0.99	0.97	81	4.3	2.8	0.9	3.4	73	5	0.8	41	2.4	2.6	5.5
66	PHB3253 CHECK 3	0.87	0.87	0.84	0.89	103	4.9	3.5	1.6	3.1	75	5	0.9	31	2.6	1.9	4.7
67	HBCG4141 CHECK 4	0.96	0.97	0.97	0.93	67	3.2	2.8	0.8	3.8	73	3	0.8	38	2.6	2.5	4.5
68	HB5222SR CHECK 5	0.95	0.96	0.94	0.94	72	3.7	2.7	0.9	3.4	77	6	0.8	15	2.4	2.9	4.2
69	PHB 1 CHECK 6	0.87	0.93	0.90	0.79	70	3.3	1.9	1.2	3.3	74	4	0.9	21	2.3	3.0	4.9
70	LOCAL CHECK 7	0.88	0.86	0.93	0.84	117	5.4	3.3	1.4	2.9	77	5	0.9	0	1.7	2.0	3.9
	Means of selected fraction						**6.1**	**2.9**	**1.9**	**2.4**	**77.8**	**2.6**	**0.9**	**5.5**	**1.8**	**2.1**	**4.0**
	Checks Means						**4.2**	**2.7**	**1.1**	**3.3**	**75.1**	**4.4**	**0.9**	**21.0**	**2.3**	**2.5**	**4.4**
	Grand Means						**4.8**	**2.2**	**2.2**	**2.6**	**78.3**	**4.4**	**0.9**	**9.2**	**1.9**	**2.4**	**4.0**
	Min						**2.9**	**0.7**	**1.1**	**2.1**	**72.5**	**0.7**	**0.6**	**0.0**	**1.4**	**1.6**	**3.0**
	Max						**6.7**	**3.2**	**3.3**	**3.8**	**83.7**	**10.4**	**1.1**	**48.3**	**2.6**	**3.5**	**5.5**

OPT*= Optimum
LN** = Low Nitrogen
Rel GY= Relative grain yield

as averages across sites where the differences were significant. The values of selection indices in the columns are percentile ranking for each entry, relative to all entries in that particular trial. The selection index "across" is an average of the percentile rankings for the all selection indices (CIMMYT-Zimbabwe, 1998). For example, relative to the 16 entries (Table 1) selected in the 1999 trial, entry 5 was among the best 1% at the drought site and among the top 6% at the low N site.

The tables list entries in descending rank according to their combined performance judged by selection indices at high yield potential, drought-stressed, and low-N sites. Thus the best entries are those that performed well under all three environmental conditions. The relative grain yield, referred as "RelGY" in the tables, represents the performance of the entry compared to the mean of all entries in the trial across sites.

RESULTS AND DISCUSSIONS

In 1999, evaluation for drought stress tolerance was done at Kiboko in Kenya, and Selian in Tanzania. Evaluation for low N tolerance was done at Kiboko and Mtwapa in Kenya, Namulonge in Uganda, and Bako in Ethiopia. Table 1 presents the yield performance and other agronomic traits of 16 selected single cross hybrids out of 70 genotypes evaluated across 8 sites where statistical yield differences were recorded.

The average of selection indices for the 16 selected hybrids varied from 0.06 to 0.65 compared to the checks for

Table 2. Means of grain yield (t/ha) and other important agronomic characters of 9 three-way hybrids selected across 7 environments (3 Optimum, 3 low nitrogen and one drought) in East Africa 2000.

Entry	Pedigree	Selection Index Avg	Selection Index YP	Selection Index Low N	Across Rel GY	Mean Grain Yield OPT	Mean Grain Yield LN	Mean Grain Yield DR	Ear Aspect	Anth date	ASI	Ears/ plant	Husk cover	Ear rot	GLS	E.turc
		0-1	0-1	0-1	%	t/ha	t/ha	t/ha		d	d	#	%	%	1-5	1-5
11	CML445/CML202/CML78	0.14	0.20	0.08	117	9.1	7.2	0.8	2.7	70	3	0.9	11	1	2.1	2.2
31	[[TUXPSEQ]C1F2/P49-SR]F2-45-7-5-1-B/CML202/CML384	0.16	0.18	0.14	105	8.7	6.1	1.1	2.8	75	2	1.0	11	0	1.7	1.8
30	[[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202/CML384	0.22	0.17	0.28	107	8.0	6.0	1.2	2.9	75	3	1.1	12	0	1.7	1.6
40	[EV7992#/EV8449-SR]C1F2-334-1(OSU9i)-8-2(I)-X-1-2-B-./CML202/CML384	0.28	0.39	0.18	106	8.1	6.6	1.4	2.8	75	3	1.0	13	0	1.6	1.6
4	CML444/CML202/CML78	0.29	0.26	0.32	107	8.2	6.7	1.3	2.4	73	2	1.0	14	5	2.1	2.1
10	[[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202/CML78	0.38	0.67	0.09	113	9.1	6.8	1.1	2.3	71	4	0.9	13	3	2.1	1.9
5	CML388./CML202/CML78	0.41	0.43	0.38	103	8.2	6.4	1.1	2.4	71	5	0.9	12	1	1.9	2.4
25	LPSC4F273-2-2-1-B-B-B/CML202/CML384	0.55	0.51	0.60	108	8.0	6.9	1.8	2.9	78	2	1.2	10	0	2.0	2.1
23	CML442/CML202/CML384	0.57	0.68	0.46	96	7.3	5.5	1.7	2.9	77	4	1.1	13	1	1.7	1.8
57	HB513 CHECK1	0.58	0.63	0.53	83	6.6	5.1	0.8	3.1	74	4	0.9	25	9	2.3	2.3
58	PHB3253 CHECK 2	0.60	0.61	0.58	81	6.1	5.1	0.5	2.8	73	6	0.8	24	16	2.8	1.7
59	PAN5195 CHECK3	0.55	0.60	0.50	93	6.9	5.9	0.4	3.3	75	4	0.9	15	9	1.9	2.2
60	Local Check	0.72	0.83	0.61	80	6.2	5.1	1.0	2.7	72	6	0.9	11	3	1.8	2.4
	Means of selected fraction					**8.3**	**6.5**	**1.3**	**2.7**	**74.0**	**3.1**	**1.0**	**12.1**	**1.3**	**1.9**	**1.9**
	Checks Means					**6.4**	**5.3**	**0.7**	**3.0**	**73.6**	**5.0**	**0.9**	**18.5**	**9.3**	**2.2**	**2.2**
	Grand Means					**7.3**	**5.8**	**0.9**	**2.8**	**73.9**	**3.7**	**1.0**	**14.1**	**3.8**	**2.0**	**2.0**
	Min					**5.0**	**3.3**	**-0.1**	**2.3**	**70.0**	**1.6**	**0.8**	**9.6**	**0.0**	**1.6**	**1.6**
	Max					**9.1**	**7.2**	**1.8**	**3.3**	**78.1**	**5.8**	**1.2**	**25.3**	**16.1**	**2.8**	**2.4**

OPT = Optimum
DR= Drought
Rel GY= Relative grain yield

which the same parameter varied from 0.87 to 1.0. The average ranks of the 7 checks across environments were 32, 33, 49, 51, 52, 56 and 56 (results not shown). Under managed drought conditions in Kiboko, significant differences ($p<0.05$) were obtained for grain yield and number of ears per plant, whereas the differences among genotypes were highly significant ($p<0.01$) for Anthesis-Silking Interval (ASI). The best entry (61) yielded 2.6 t ha^{-1} vs. 1.6 t ha^{-1} for the best check (Phb3253). Six entries out-yielded the checks by 31 to 62%. The ASI of the selected entries varied from 1 to 6 days whereas the ASI of the checks varied from 4 to 10 days; the number of ear per plant ranged from 0.8 to 1.1 for the selected hybrids and from 0.6 to 0.9 for the checks.

Under low N conditions, significant and highly significant differences in grain yield were obtained at Mtwapa, Kenya, and Bako-1, Ethiopia, respectively (data not shown). The average yield across the two low N sites varied from 1.2 to 3.5 t ha^{-1}. Eight entries gave yields similar to the best check, Pioneer Phb3253 (3-3.5 t ha^{-1}). Highly significant differences were observed for ASI and ears per plant at Mtwapa whereas, at Bako-1, only number of ears per plant differed significantly. Like under drought conditions, the highest grain yielding genotypes under low N tended to have lower ASI and higher numbers of ears per plant (Table 1). These data showed that the evaluated maize genotypes performed differently under drought and low N conditions, in agreement with many findings related to the existence of genetic variability for tolerance to drought and low N in maize (Bolaños and Edmeades, 1993; Lafitte and Edmeades, 1994; Edmeades *et al*., 1995; Vasal et al., 1997;Banziger *et al*., 2000)

Results of these trials also confirmed that the high grain yield performance of the tested hybrids under drought is associated with smaller Anthesis-Silking Interval (ASI) and higher number of ears/plant. This agrees with many earlier findings (Bolaños and Edmeades, 1993; Kosmos and Kevin Pixley, 1997; Edmeades et al, 2000). Anthesis-Silking Interval and number of ears per plant are very easy variables to use for selection for drought and low N tolerance provided the stress level is sufficiently high for their expression. However, correlation between ASI and grain yield among progenies are typically no larger than –0.5 to –0.6 in trials where stress coincided with flowering. This implies that two-thirds or more of the variation in grain yield within a breeding population is not accounted for by variation in ASI. Efforts to identify the secondary traits that account for this residual variation must continue (Edmeades et al., 2000).

Under optimal conditions, highly significant differences in grain yield among hybrids were obtained at 5 sites. The grain yield across 5 optimal sites varied from 3.1 to

Table 3. Means of grain yield (t/ha) and other important agronomic characters of 8 early 3W hybrids compared to 2 local checks across 23 sites in East Africa 2001.

Entry	Pedigree	Selection Index				Across	Grain Yield Averages				Anth Date	ASI	Ears/ Plant	Husk Cover	Ear Rot	GLS	P. sorg	E. turc
		Av	OPT	LN	STR	Rel GY	OPT	DR	LN	*STR*								
		0-1	0-1	0-1	0-1	%	t/ha	t/ha	t/ha	t/ha	d	d	#	%	%	1-5	1-5	1-5
1	[[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202//CML78	0.29	0.24	0.20	0.44	109	7.2	0.9	3.8	2.1	72	2	1.1	15	18	2.1	2.1	1.9
2	CML445/CML202//CML78	0.25	0.25	0.40	0.09	108	6.7	1.1	3.8	3.1	71	3	0.9	27	14	2.3	1.6	1.9
6	LPSC3H144-1-2-2-2-4-#-B-B-B/CML202//CML78	0.29	0.38	0.42	0.06	105	6.6	0.6	3.7	3.1	73	2	1.0	16	11	2.0	2.1	2.0
10	CML444/CML202//CML78	0.30	0.51	0.35	0.03	106	6.8	0.6	3.8	3.7	74	2	1.0	9	9	2.0	1.7	2.4
11	SPLC7F182-1-2-2-B-B-B/CML202//CML78	0.52	0.49	0.31	0.75	108	6.5	0.6	4.2	2.5	73	3	1.1	17	20	2.4	2.5	2.3
14	CML216/CML202//CML78	0.54	0.41	0.54	0.66	110	7.2	0.4	3.9	2.9	73	2	1.0	18	17	2.2	2.0	2.1
19	CML312/CML444//CML78	0.40	0.53	0.32	0.34	105	6.6	0.5	4.2	2.6	74	3	1.0	8	16	2.1	2.7	2.3
26	CML197/CML247//CML78	0.27	0.31	0.36	0.13	113	7.1	0.9	3.9	3.8	72	2	1.0	11	20	2.1	2.6	2.1
31	LOCAL CHECK 1 Pioneer 3253	0.85	0.87	0.71	0.97	79	6.0	0.0	2.6	1.0	74	4	0.7	7	10	2.8	1.5	2.7
32	LOCAL CHECK 2: Best Adapted entry	0.80	0.67	0.73	1.00	90	6.0	0.5	3.3	1.1	76	5	0.9	9	8	2.2	1.5	2.3
Means of selected fraction							**6.8**	**0.7**	**3.9**	**3.0**	**72.8**	**2.5**	**1.0**	**15.2**	**15.7**	**2.1**	**2.2**	**2.1**
Check Means							**6.0**	**0.2**	**3.0**	**1.1**	**75.0**	**4.7**	**0.8**	**8.0**	**9.1**	**2.5**	**1.5**	**2.5**
GrandMean							**6.4**	**0.64**	**3.6**	**2.3**	**73.2**	**2.8**	**0.99**	**15.1**	**14.8**	**2.1**	**2.1**	**2.3**
Min							**5.7**	**0.04**	**2.6**	**1.0**	**71.2**	**1.5**	**0.72**	**7.2**	**8.3**	**1.9**	**1.5**	**1.9**
Max							**7.2**	**1.33**	**4.2**	**3.8**	**76.1**	**5.2**	**1.13**	**33.3**	**23.4**	**2.8**	**2.9**	**2.8**

OPT= Optimum
LN= Low Nitrogen
DR= Drought
STR=Striga
Rel GY= Relative grain yield

7.4 t ha^{-1}. The average yield of the best-adapted check was 5.4 t ha^{-1} vs. 7.4 t ha^{-1} for the best entry (entry 60: CML442/CML444). Seven entries out-yielded the best-adapted checks by 13 to 37% across 5 optimal environments. All selected entries except one were slightly later than the checks in terms of number of days from planting to 50% anthesis. Entry 60 (CML442/CML444), which outperformed all others across environments in the SADC region in the 1998 growing season (CIMMYT-Zimbabwe, 1997), tasseled 3 days later than the earliest local check, but out-yielded the best check by 37% under optimum conditions, and much more under low N, drought and *Striga* infested conditions. The new stress tolerant hybrids are as and/or more resistant than the commercial checks to the prevalent diseases in the region (ear rot, *Turcicum* blight and GLS) (Table 1).

The higher performance of the new hybrids compared to the checks can be partially attributed to the fact that single cross hybrids are normally higher yielding than 3-way and double-cross hybrids. Generally, most of the commercial hybrids used as checks in this experiment were 3-way and/or double-crosses. Nevertheless, one new stress tolerant double-cross hybrid (entry 63: CML202/CML206/CML247/CML254) gave a yield similar to the checks under optimum conditions but out-yielded them by 32, 39 and 33% under low N, drought and *Striga* infested conditions, respectively. In the mid-altitude ecologies of Eastern Africa, earliness is important particularly when farmers want to plant 2 crops per year. Otherwise, they would be better off with late/intermediate maturing drought resistant cultivars. Late drought susceptible maize genotypes are more stressed and lower yielding than early genotypes if stress increases over time after flowering (Bänziger et al., 2000).

In 2000, the best single-cross hybrids identified in 1999 were selected and crossed with appropriate testers (CML78, CML384 and CML373) to develop stress tolerant 3-way and double-cross hybrids, which were then evaluated regionally across 7 sites including one drought, 3 low N, and 3 optimum environments. Results related to the selected entries are presented on the Table 2. Highly significant differences ($p<0.01$) in grain yield were obtained under optimum conditions at 2 sites (Embu-1, and Namulonge-1). Under low N conditions, significant yield differences ($p<0.05$) were also obtained at 2 sites (Kakamega-2 and Embu-2), whereas the yield differences under drought at Kiboko were not significant, although differences in the number of ears per plant under drought were ($p<0.05$). The average of selection indices of the 9 best entries varied from 0.14 to 0.57, whereas the averages of the selection indices for the checks were from 0.55 to 0.72. The 9 best entries out-yielded the best check by 6-32% under optimum, 3-22% under low N, and 10-80% under drought conditions. The ASI varied from 2 to 5 days for the 9 best entries and from 4 to 6 days for the checks. The number of ear per plant varied from 0.9 to 1.2 for the selected entries and 0.8 to 0.9 for the checks. Four selected entries were later maturing than the checks and 4 were of the same maturity as the checks. The selected entries were tolerant to the main prevalent diseases (ear rot, GLS and *Turcicum*) (Table 2).

In 2001, the selected early and intermediate/late 3-way hybrids (crosses with CML78 and CML384 as males, respectively) were grouped by maturity and evaluated across

Table 4. Means of grain yield (t/ha) and other important agronomic characters of 5 intermediate 3W hybrids compared to 2 local checks across 25 sites in East Africa 2001.

Entry	Pedigree	INDEX				Across	GY Averages				Anth Date	ASI	Ears/ Plant	Husk Cover	Ear Rot	GLS	E.turc	Ear Aspect
		AV	OPT	LN	STR	Rel GY	OPT	DR	LN	STR								
		0-1	0-1	0-1	0-1	%	t/ha	t/ha	t/ha	t/ha	d	d	#	%	%	1-5	1-5	1-5
1	[[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202//CML384	0.45	0.24	0.41	0.70	107	7.2	0.7	4.7	1.5	76	1	1.4	3	6	2.3	2.4	2.9
5	LPSC3H144-1-2-2-2-2-#-B-B-B//CML202/CML384	0.20	0.31	0.15	0.15	103	7.0	0.6	5.4	2.1	78	1	1.1	9	5	3.4	2.2	2.6
7	LPSC4F273-2-2-1-B-B-B/CML202//CML384	0.16	0.18	0.28	0.04	107	7.4	0.7	4.5	3.1	77	2	1.0	4	5	2.1	2.3	2.3
8	CML442/CML202//CML384	0.33	0.41	0.41	0.19	103	7.0	0.4	4.8	1.9	77	2	1.1	8	8	2.5	2.6	2.6
16	CML442/CML444//[MSRXPL9]C1F2-205-1(OSU23i)-1-1-X-X-1-X-B-B	0.35	0.47	0.48	0.11	112	7.6	0.2	4.5	2.3	76	3	0.8	19	13	4.7	2.3	3.2
26	PHB3253	0.87	0.91	0.89	0.81	67	4.6	0.0	3.1	0.5	73	3	0.8	13	17	3.1	3.0	3.3
27	Local check2	0.82	0.68	0.94	0.85	90	6.4	0.3	3.0	1.3	76	3	0.9	12	9	2.9	2.8	3.1
Means of selected fraction							**7.2**	**0.5**	**4.8**	**2.2**	**76.8**	**1.9**	**1.1**	**8.6**	**7.4**	**3.0**	**2.3**	**2.7**
Check Mean							**5.5**	**0.2**	**3.0**	**0.9**	**74.7**	**3.0**	**0.9**	**12.1**	**13.2**	**3.0**	**2.9**	**3.2**
Mean							**6.44**	**0.51**	**4.30**	**1.54**	**77.0**	**1.9**	**1.06**	**8.4**	**9.0**	**2.9**	**2.5**	**2.8**
Min							**4.43**	**0.04**	**2.09**	**0.50**	**73.5**	**0.71**	**0.81**	**3.0**	**4.17**	**1.9**	**2.1**	**2.3**
Max							**7.63**	**1.24**	**5.75**	**3.05**	**79.8**	**3.71**	**1.35**	**21.1**	**17.14**	**4.7**	**3.6**	**3.5**

OPT= Optimum
LN= Low Nitrogen
DR= Drought
STR=Striga
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23 sites for the early and 25 sites for the intermediate/late. The early hybrids were tested in 13 optimum, 8 low N, one drought and one *Striga* sites, whereas the intermediate/late hybrids were tested across 15 optimum, 8 low N, one drought and one *Striga* infested sites in east Africa. For grain yield, the early hybrids differed significantly, and sometimes highly significantly, in 9 optimum, 5 low N, and one *Striga* infested environments. Under managed drought conditions, only the number of ears per plant were significant ($p<0.05$) among entries. Table 3 presents the means of grain yield and other important characters of 8 best entries across sites where significant and highly significant differences were observed. The averages of selection indices for the selected group of entries varied from 0.29 to 0.54 and, for the checks, from 0.80 to 0.85. Under optimum conditions, the 8 best entries out-yielded the best check by 8-20%; 3 entries yielded more than 7 t ha^{-1} across 9 sites while the best check yielded 6 t ha^{-1} (Table 3). Under low N conditions, the yield of the best entries varied from 3.7 to 4.2 t ha^{-1} and the checks from 2.6 to 3.3 t ha^{-1}. These entries out-yielded the best check by 12 to 27%; 2 entries yielded 4.2 t ha^{-1} compared to 3.3 t ha^{-1} for the best check across 5 low N sites. Under drought conditions at Kiboko, the best entries yielded from 0.4 to 1.1 t ha^{-1} compared to 0.0 to 0.5 t ha^{-1} for the check. Under *Striga* infested conditions at Alupe, these entries yielded 2 to 3 times more than the checks. The best entries was of the same maturity as the checks and had lower ASI and higher number of ears per plant across all stresses (Table 3). moreover, the performance of the new stress tolerant hybrids under disease pressure (GLS, *Turcicum* and ear rot) was also as good and sometimes better than that of the checks.

Means of grain yield and other important agronomic characters of the 5 best intermediate /late 3-way hybrids compared to 2 local checks across 25 sites in East Africa in 2001 are presented in Table 4. The hybrids differed significantly in grain yield at 12 optimum and 2 low N sites. The yields were not significantly different under managed drought. The differences in ASI were not computed since some entries did no flower; however, differences in number of ears/plant were significant.

CONCLUSIONS

Using a breeding strategy of managed drought and low N stress coupled with regional testing under random stressed and stressed conditions, biotic and abiotic stress tolerant hybrids adapted to the mid-altitude ecology of East Africa have been successfully developed within a space of less than 4 years beginning with drought and low N tolerant inbred lines developed by CIMMYT-Harare. These hybrids yield significantly more than the best commercial hybrid checks under optimum, low N and drought stress conditions (for the 8 best 3-way hybrids, 24, 15 and 64% more, respectively), and also have resistance to the common biotic stresses in the region. These hybrids have the potential to increase yields, reduce input requirements and improve yield stability for resource-poor farmers in densely populated high potential eco-zones of Eastern and Southern Africa.

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SELECTION OF SUITABLE MAIZE GENOTYPES IN BOTSWANA

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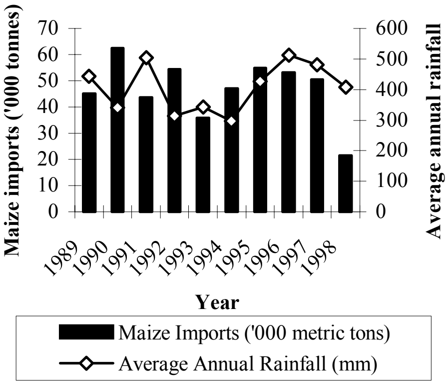
ABSTRACT

Maize [Zea mays L.] provides a high percentage of daily calories in most diets of Botswana. As in other semi-arid regions, rainfall and soil fertility are the major environmental factors affecting maize productivity. Even in seasons of above average rainfall, dry spells lasting up to 30 days or more are common, therefore dry land crops usually experience periods of moisture stress during their growth cycle. The Department of Agricultural Research is faced with a challenge of developing and improving genotypes that are drought tolerant and adapted to low fertility conditions. The cereal improvement program of Botswana has embarked on strategies to address the situation. Genotypes are tested under moisture and low soil fertility stress as well as under optimal conditions. Due to limited resources in terms of germplasm and testing sites, the department collaborates with CIMMYT and other countries in the SADC region. Collaboration with CIMMYT has resulted in selection of materials from its nurseries that are undergoing improvement. S1 lines are extracted from the promising populations for further screening and recombination. The generated populations are put in national and regional trials for evaluation under the different stress conditions. Farmers are involved at an early stage of variety screening in the hope of identifying relevant drought and low fertility tolerant materials for the country.

INTRODUCTION

Maize is the most important cereal in Botswana. It provides a high percentage of the daily calories in most of the diets of Botswana. A survey conducted on maize imports shows that imports rose from 45,070 metric tons in 1989 to 50,520 metric tons in 1998 (Botswana Trade Statistics, 1998). The imports fluctuate on a yearly basis due to fluctuations in climatic conditions (Figure 1). Several factors are responsible for these fluctuations. These include poor rainfall, low fertility, low water holding capacity and high prices of inorganic fertilizers (National Development Plan 8., 1997). Some soils have unfavourable physical properties such as crusting; surface sealing and high bulk densities that make rooting and seedling emergence difficult (Gakale and Tibi, 1990). Maize is grown in all regions of Botswana, the main cropping areas receive between 400 to 600 mm annual rainfall (Gakale and Tibi, 1990).

Figure 1. Maize imports versus rainfall from 1989 to 1998.



Sources: Department of Meteorological Services, Gaborone Botswana, and Botswana Trade Statistics, 1998

The area under production has increased since 1979. By 1993, 85,257 ha were planted. Ninety-eight percent (83,956 ha) of this area is under subsistence farming and only 2% (1,301 ha) is under commercial farming (Agric. Census Report, 1993). Subsistence farmers harvested 22,185 ha of the planted land with total yield of 2,979 tonnes, while commercial farmers harvested 1,197 ha producing total yield of 1,778 tonnes (Agric. Census report, 1993).

The objectives of this paper are to review present activities and progress made through breeding schemes employed to address the effects of drought and low fertility on maize production in Botswana.

BREEDING STRATEGIES FOR LOW MOISTURE

The Cereal Improvement Program in Botswana has been carrying out drought screening for several years and the main strategy was breeding for earliness. In addition to earliness, the maize program has adopted other strategies that include testing genotypes under random drought, using anthesis-silking interval (ASI) for selection and collaborating with the CIMMYT which has a well established drought breeding program. The experiment is conducted under random moisture stress (dry land) conditions where there is no control as to when the stress is implemented. The genotypes with short ASI tend to be more tolerant to stress (CIMMYT Int. Annual Report, 1994). Aother trial is put under irrigation to establish the full potential of the genotypes used.

Data collected include flowering, plant height, ASI, and grain yield. The data from the locations including irrigated plots were compared after being subjected to analysis of variance using PROC GLM (SAS, 1990) and ranked to establish the good performers across environments (Table 1). The genotypes had relatively short ASI and yields of above a tonne. Three populations have been selected for further improvement using the recurrent selection scheme. The experiments consist of open pollinated genotypes

Table 1. Mean grain yield (t/ha) and ASI (days) of some genotypes across sites under random drought stress.

Pedigree/Genotypes	Grain yield (t/ha)			ASI		
	1999	2000	2001	1999	2000	2001
[TEWD-SRDRTOLSYN/NAW5867/P30-SR(S2)]]##	1.75	3.37	2.79	2.5	1.4	4.5
[EARLY-MID-2/PL16-SR]-#	1.60	3.47	2.97	3.5	1.6	4.0
DTP-W C6 Sel. PRECOZ	1.89	3.15	3.16	1.0	1.4	4.0
Pool 16 BNSEQ C1 HC	1.78	3.40	2.72	2.0	1.5	3.0
[P32-SR/R201]F3-S1-F3	1.55	3.00	3.05	2.5	2.1	4.5
ZM 301	2.20	2.88	3.53	2.5	1.4	5.0
[ZS225/[POOL16-SR]]F2-S1-F3	1.53	2.63	2.88	2.0	2.2	3.5
[TSEQZIM]C2F2	-	3.44	3.98	-	2.8	3.0
ZM 521	-	3.90	3.31	-	1.6	5.5
ZM 621	-	3.24	3.49	-	1.8	4.0
ZM 421	-	3.06	3.24	-	2.1	4.5
Kalahari Early Pearl	1.92	2.93	3.29	2.5	1.8	5.5
Mean	**1.86**	**3.11**	**3.24**	**2.0**	**1.9**	**4.1**
LSD (0.05)	**0.77**	**0.89**	**1.04**	**1.1**	**1.5**	**2.6**
P < 0.05	**ns**	**	***	**ns**	*	**ns**

Table 2. Mean grain yield (t/ha) and ASI (days) of some genotypes across sites planted under low soil fertility.

Pedigree/genotypes	Grain yield (t/ha)			ASI		
	1999	2000	2001	1999	2000	2001
[TEWD-SRDRTOLSYN/NAW5867/P30-SR(S2)]]##	2.54	1.55	3.25	3.2	3.0	3.0
[EARLY-MID-2/PL16-SR]-#	1.76	1.32	4.00	3.0	4.6	2.5
DTP-W C6 Sel. PRECOZ	1.95	1.24	3.45	3.3	2.1	3.0
Pool 16 BNSEQ C1 HC	1.77	1.48	3.66	3.5	3.7	3.0
[P32-SR/R201]F3-S1-F3	1.59	1.68	4.03	3.4	3.3	3.0
ZM 301	1.76	1.26	4.31	2.2	3.7	3.0
[ZS225/[POOL16-SR]]F2-S1-F3	1.92	2.14	3.98	3.0	4.2	2.5
[TSEQZIM]C2F2	-	1.41	4.25	-	2.9	2.5
ZM 521	-	1.57	4.25	-	3.0	3.0
ZM 621	-	2.04	4.89	-	2.8	2.5
ZM 421	-	1.88	4.33	-	3.4	3.0
Kalahari Early Pearl	1.45	1.84	3.68	4.3	3.7	3.0
Mean	**1.80**	**1.53**	**4.11**	**3.0**	**3.3**	**2.7**
LSD (0.05)	**1.19**	**0.80**	**1.22**	**2.5**	**3.7**	**1.4**

obtained from the region. S1 lines are extracted from selected populations for further screening under controlled moisture stress, thus starting a new cycle of population improvement and selection.

BREEDING STRATEGIES FOR LOW SOIL FERTILITY

The program is involved in evaluating some maize varieties/populations under recommended fertilizer and no fertilizer management. A nursery includes some S1s that are put in an area which has been depleted of nitrogen for some years. The populations used have been selected from regional trials (provided by CIMMYT–Zimbabwe) and have been exposed to similar conditions during their development. The other strategy is through collaboration with CIMMYT on the Southern African Drought and Low Fertility (SADLF) Project. Data collected include flowering, plant height, anthesis-silking interval, senescence score and grain yield. The data were subjected to analysis of variance using PROC GLM (SAS, 1990), and compared across locations to establish good performers (Table 2). The short ASI for the genotypes shows the progress made during the selection and development of these varieties. Data from the nursery has been used in selecting populations mentioned under drought.

COLLABORATION WITH CIMMYT

The collaboration started in 1997 with the initiation of the SADLF project conducting trials from the region. Some genotypes are selected for inclusion in the national maize cultivar evaluation trials and planted in more locations. The seed is supplied by CIMMYT. The S1 progenies formed from the promising varieties that performed well are recombined to form the country's version, and are currently undergoing population improvement. This helps in building a base for the maize breeding program as some materials will be recommended for release in the country.

ON FARM TRIALS

Unlike the conventional method of on farm testing and variety release, the maize program has adopted a different strategy. Genotypes selected for advanced testing are put in a new testing scheme. The process involves the farmers at the early stages of variety development and release. The genotypes are at the same time tested under the farmer-managed conditions. The farmers within a locality act as blocks in a trial replication, and several locations and farmers are used. This helps to get feedback at an earlier stage and to compare results with the on station trials.

DISCUSSION

The Department of Agricultural Research has embarked on an exotic germplasm screening, testing and recurrent selection scheme for improved maize populations for about five years under drought and low nitrogen. The programme is carried out in conjunction with the SADC regional NARS and CIMMYT through the drought and low fertility project.

The recombination method could increase the effective use of non-elite source materials, where the greater opportunities for recombination could break the linkages between genes and unfavourable agronomic characteristics (Rattunde et. al., 1997).

S1 lines are extracted from the promising populations for further screening and recombination. The generated populations are put in national and regional trials for evaluation under the different stresses. The number of genotypes in the national trial increase yearly as new materials are being identified from the regional trials.

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SCREENING OF KENYAN MAIZE GERMPLASM FOR TOLERANCE TO LOW pH AND ALUMINIUM FOR USE IN ACID SOILS OF KENYA

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ABSTRACT

Low soil pH is a major constraint to maize (*Zea mays* L.) production on tropical soils due to toxic levels of aluminium (Al) and the concomitant phosphorus (P) deficiency that hinders plant root growth. A preliminary laboratory screening was conducted to test 75 Kenyan landrace maize accessions and 12 commercial varieties for response to low soil pH and Al toxicity in solution culture. The landrace maize accessions were screened under different levels of Al concentration (0, 100, 200, and 300 µ*M*) at pH 4.0. A standard acid-tolerant variety (CIMCALI 97Balopia SA4 subsequently referred to as 97BASA4) and an Al-sensitive variety (CIMCALI 97BSA3-1) from CIMMYT were included as controls. Preliminary classification of the 75 randomly chosen landrace accessions into tolerant/sensitive phenotypic classes was based on the FRL, Rti and haematoxylin staining of seedlings grown in a solution culture containing 200 µM Al at pH 4.0, but the final screening of commercial hybrids/synthetics/composites was done in similar medium at 220 µM Al. The most consistently tolerant accessions based on FRL and Rti were, 1X1, 5A, 203B, and 4D, and the most consistently sensitive accessions were 306A, 306B and 7B2, while the rest of landrace accessions had intermediate tolerance or sensitivity when compared with 97BASA4 and 97BSA3-1. Interesting observations were made when four selected tolerant landrace accessions (203B, 5A, 4D and 1X1) and two susceptible accessions (306A and 306B) were tested against 13 commercial hybrids, synthetics and composites at 220 µM Al. The most tolerant commercial varieties were DH02 and H513 while the most sensitive were H623 and H625 and the rest were of intermediate tolerance or sensitivity. It is interesting to note that some of the commercial varieties and landrace accessions were sensitive to Al concentrations as low as 140 µM typically found in some high potential maize producing areas of Kenya indicating that Al toxicity could be one of the major causes for the low maize yields in acid soils of Kenya. Secondly, there is high variability in tolerance to Al toxicity among Kenyan commercial varieties and landrace maize populations that may be useful in selection for Al-tolerant materials for use in acid soils in Kenya..

Keywords: Aluminium toxicity, commercial seed maize, landraces, soil acidity, *Zea mays*.

INTRODUCTION

Maize is the second largest food and commodity crop in the world after wheat, although in the developing countries of Latin America and Africa, it ranks first (Dowswell *et al*., 1996). In Kenya, 90% of the population depends on maize as a staple food. It does well on a variety of soils although its growth is inhibited by acidic soil. Low soil pH commonly occurs in the tropical and subtropical areas of the world where it occupies about 40% of the arable land. Acidity is a major constraint to production of maize and other crops on tropical soils. At low pH (pH<5), toxic Al^{3+} ions hinder plant root growth, are released into the soil solution, thus affecting the development of the entire plant (Kidd and Proctor, 2000; Kochian, 1995). Al toxicity causes short, thick and underdeveloped roots and plants, thus reducing nutrient uptake and increasing susceptibility to drought (Sasaki *et al*., 1996). In Kenya, acid soils cover over half a million ha of maize growing areas (Okalebo *et al*., 1997) and in these areas maize yields are low (1.0 – 1.5 t/ha) compared to the research potential (5.0 t/ha) (Oluoch-Kosura, 1999).

More than 8 million hectares of acid soils are planted with maize in the tropics (Pandey *et al*., 1994) and soil acidity reduces yield on about 10% of the maize produced in developing countries (Borrelo *et al*., 1995). The problem of low soil pH can be solved by use of soil amendments such as liming, although most farmers in developing countries cannot afford such amendments (Pandey *et al*., 1994). A more sustainable solution would be to select Al-tolerant maize genotypes for use in acid soils, which in the long run, is less expensive, sustainable and more environmentally friendly. Considerable genetic tolerance to soil acidity is shown by maize (Khan and McNeilly, 1998; Duque-Vargas *et al*., 1994) and other crops (Pinto-Carnide and Guedes-Pinto, 1999; Heim *et al*., 2001; Kochian, 2001). Further, extensive genetic variability with respect to Al tolerance exists in plants both at inter- and intraspecific levels (Ishikawa and Wagatsuma, 1998). In maize, the majority of commercial genotypes are sensitive to Al toxicity, such that breeding for more adapted cultivars seems to be the best strategy to improve farming of this crop in regions with acid soils.

Testing of maize for Al tolerance can be done in the field, but this is expensive and time-consuming considering the number of genotypes that need to be tested. Other efficient and less time consuming methods include screening in nutrient solutions (Magnavaca *et al.,* 1987; Urrea-Gomez *et al*., 1996; Cancado *et al*., 1999), potted soil (Ahlrichs *et al*., 1990) and root staining with haematoxylin (Ruiz-Torres *et al*., 1992; Cancado *et al*., 1999). Among these methods, nutrient solution screening is attractive since it is less expensive and provides adequate Al stress thereby allowing preliminary screening of a large number of genotypes in a small area and consequently reduces the number of promising genotypes to be analysed in the field (Polle *et al*., 1978; Ruiz-Torrez and Carver, 1992; Magnavaca *et al.,* 1987). In addition, the results obtained with solution culture screening method, correlate positively with those obtained using field screening (Urrea-Gomez *et al.*, 1996) showing that this method could be representative of what happens in the field.

The effect of Al ions on plants in solution culture could be quantified in terms of root length measurements, root biomass, total plant length and biomass or mineral uptake. Early symptoms of Al toxicity occur in the roots because roots are in direct contact with toxic Al^{3+}ions. In addition to the solution culture method, haematoxylin staining has also been found to be an early indicator of Al toxicity effects on the apices of young developing roots grown in nutrient solution (Polle *et al.*, 1978; Cancado *et al.*, 1999). Haematoxylin turns blue when it forms a complex with aluminium so that the penetration and retention of this ion in the roots can be assessed (Polle *et al.*, 1978; Delhaize *et al.*, 1993). The reaction between haematoxylin and Al is specific such that other stress factors exert minimal effect (Cancado *et al.*, 1999). This technique has been observed to show a high capacity to discriminate among tolerant and sensitive genotypes and displays significant correlation coefficient with root length and root growth measurements (Cancado *et al.*, 1999).

Sensitive genotypes tend to accumulate higher amounts of Al in their root tissues (Polle *et al.*, 1978; Carver *et al* 1988). Solution culture and hematoxylin staining methods have been recommended for identifying Al-tolerant maize genotypes (Cancado *et al.*, 1999; Magnavaca *et al.*, 1987). The level of tolerance/sensitivity of the Kenyan Maize germplasm is not known and this could be determined by any of these methods. The objective of this study is to determine the level of tolerance of the Kenyan maize germplasm to low pH and aluminium toxicity.

MATERIALS AND METHODS

Over 300 landrace maize accessions were collected from farmers in February and March 2000. The accessions were obtained from thirteen districts representing maize growing regions of Kenya and some with documented low soil pH. These include; Rift Valley and Western region (Vihiga, Butere-Mumias, Siaya, Kisii, Nandi), Coast (Kilifi, Taita-Taveta Mombasa, Malindi), Central and Eastern region (Muranga, Machakos and Kitui). Seed of 12 commercial maize cultivars which comprise hybrids, composites and synthetics popularly grown in these districts were purchased from the Kenya Seed Company and also used in the study to determine their level of tolerance/sensitivity to Al toxicity. In this preliminary trial, only 75 landrace accessions that had enough seed for replications were included in the study and the rest are still being multiplied and will be screened later.

Twenty-five (25) seeds of each accession were washed with distilled water and surface-sterilized in 1% sodium hypochlorite solution for five minutes and rinsed two times with excess distilled water.

Sterilized seeds were placed in petri dishes lined with absorbent paper and moistened with distilled water. These were placed in plastic trays and more absorbent paper spread on top. The trays were covered with aluminium foil and incubated for 3 days at 27^0C. Maize seedlings were transferred into nutrient solution on perforated Styrofoam such that only the roots were immersed in solution. In all cases, four seedlings were used per treatment. The nutrient solution was prepared according to Magnavaca *et al*. (1987).

The initial landrace screening trial, was set up in a completely randomized design with four replications and four aluminium treatments (0, 100, 200 and 300 μM Al), added in the form of $Al (SO_4)_3.16H_2O$. Five litre solutions were prepared and used for each level of aluminium and the pH was adjusted to 4.0 using 0.1*M* HCl.. The Al-sensitive and Al-tolerant varieties from CIMMYT were included as checks. Measurements of the seminal root lengths (RL) of seedlings grown in nutrient solution containing different concentrations of Al were taken and designated as the final root length (FRL). Other parameters including root tolerance index (RTi) and % response to Al treatments were derived from the root length measurements according to the following equations:

$$RTi = \frac{\text{RL (Al-treated plants)}}{\text{RL (Al-control plants)}}$$

$$\% \text{ response} = \frac{\text{RL (Al-treated plants)} - \text{RL (Al-control)} \times 100}{\text{RL (Al-control plants)}}$$

After the preliminary experiment, 6 selected tolerant and 4 sensitive landrace maize genotypes were exposed to 0 Al and then transferred to 220 μM Al for seven days together with 12 commercial maize varieties and in addition to the RTi and FRL, the net seminal root length (NSRL) was calculated as described by Cancado *et al* (1999) as follows:

$$NSRL = \frac{\text{Final root length (FRL) (after transfer)}}{\text{Initial root length (IRL) (before transfer)}}$$

In a separate experiment, the seedlings of the 75 landrace accessions were subjected to the hematoxylin staining as described by Cancado *et al* (1999). A 0.2% haematoxylin solution containing 0.02% potassium iodide was prepared in distilled water. This stain turns blue in the presence of aluminium ions and was therefore used to identify roots that absorbed aluminium from solution.

Maize seedlings (suspended on Styrofoam trays as described before) were transferred from the nutrient solution after 72 hours following transfer into distilled water and subjected to gentle shaking (at 20 rpm) in a mechanical shaker for 15 minutes. The seedlings were then transferred into the haematoxylin solution and shaken gently as above for 20 minutes after which the seedlings were placed in distilled water and shaken for another 15 minutes. All the four seedlings in the treatment were visually scored for root staining intensity on a scale of 1-5 as follows: seedlings with non-stained roots were classified as very tolerant (scale 1), faintly stained roots, as tolerant (scale 2), moderately stained, as moderately tolerant (scale 3), well stained roots, as sensitive (scale 4) and those with deeply stained roots, as very sensitive (scale 5).

RESULTS

Increasing Al concentration from 0 to 200 μM or 0 - 220μM in nutrient growth medium, had a differential negative effect on the seedling root growth depending on genotype (Tables 1 and 2). The effect of 200 μM Al concentration on root growth and hematoxylin staining of the 26 out of 75 randomly chosen Kenyan landrace maize accessions is presented in Table 1. Control plants (grown on zero μM Al) did not show any staining with haematoxylin. In the preliminary screening, separation of the maize accessions into tolerant/sensitive phenotypic classes based on haematoxylin staining intensity of roots was carried out at

200 μM Al and on this basis one accession was classified as tolerant, 12 out of 26 landraces, as moderately tolerant and 12 as sensitive when compared to the CIMMYT tolerant and sensitive standards, respectively. Overall, with regard to the level of haematoxylin staining, a smaller proportion of the maize accessions including the standard acid-tolerant accession, 97BASA4 fell at level 3 indicating the presence of reasonable degree of tolerance to Al toxicity among the Kenyan landrace populations. The most susceptible accessions were 306A, 306B and 7B2. These accessions showed a haematoxylin staining value of 4 just like the susceptible standard, showing that they were indeed sensitive to Al toxicity. Based on the effect of 200 μM Al concentration on the final root length (FRL), the most consistently tolerant accessions were 1X1, 5A, 203B, 6D and 4D. The 1X1 and 5A were the only two accessions that showed increase in FRL, compared to the rest that showed a reduction in FRL. Few landraces performed better in terms of root growth, than the standard tolerant CIMMYT material (97BASA4), while a good number performed worse than this standard check variety. Slightly more than half of the tested landrace populations showed sensitivity to 140 μM Al concentration found in some acid soils in Kenya (data not shown) indicating that Al toxicity could be one of the causes of low yield in acid soils of the country. For example, accessions such as 306A and 306B from Kilifi and 7B2 from Nandi manifested relatively high reduction in root length as compared to the Al susceptible standard, 97BSA3-1. Accession 306B had the highest reduction in root length of 66 %, which compared well with the 63 % observed in the susceptible standard.

In terms of root tolerance index (RTi) values at 200 μM Al concentration, 1X1 showed the highest tolerance value (1.1), followed by 4D and 203B, both of which had an RTi value of 1.0. The tolerant accessions compared well with the acid-tolerant accession (97BASA4) that had an RTi value of 0.9. However, the sensitive accessions also showed low RTi, comparable to that of the Al-sensitive standard. The rest of the accessions were of intermediate RTi.

When the selected Al-tolerant and Al-sensitive landrace accessions together with commercial hybrids/synthetics and composites were subjected to 220 μ*M* Al concentration in the growth medium for seven days, interesting observations were made (Table 2). Some of the tolerant landraces (203B, 5A and 4D) still manifested a high degree of tolerance to Al toxicity although one, initially tolerant accession (eg 1X1), succumbed for reasons not immediately known. The selected Al-sensitive accessions (306A and 306B) remained sensitive to the relatively high Al concentration. Out of 12 hybrids, synthetics and composites, DH02 had the lowest root growth reduction to Al toxicity, followed by H513 and PH1. The H623 hybrid showed the highest negative response in terms of root growth to high level Al concentration and could be regarded as the most sensitive. Other hybrids sensitive to Al included H625, H614, H626 and H627.

Table 1. Effect of 200-μM aluminium concentration on root length and haematoxylin staining intensity of selected Kenyan landrace maize accessions grown in solution culture.

Collection No.	Collection area	Level of haematoxylin staining	FRL at 0 μ*M* Al (mm)	FRL at 200 μ*M* Al (mm)	% FRL respone at 200 μ*M* Al	Root tolerance index (RTi)
5A	Nandi	3	60	72	20	0.9
1X1	Vihiga	2	80	83	4	1.1
4D	Butere-Mumias	4	72	72	0	1.0
203B	Muranga	3	65	62	-5	1.0
6D	Nandi	3	74	67	-9	0.9
2B4	Vihiga	4	91	80	-12	0.9
401	Kilifi	4	47	41	-13	0.9
2A1	Vihiga	4	85	73	-14	0.9
4C3	Butere-Mumias	3	72	60	-17	0.9
1C4I	Vihiga	3	95	79	-17	0.8
6EI	Nandi	3	49	36	-27	0.8
3C1	Siaya	3	64	47	-27	0.7
6D1	Nandi	4	48	31	-35	0.7
97BASA4	CIMMYT	3	105	67	-36	0.9
105A	Machakos	4	71	44	-38	0.6
7A1	Nandi	4	83	50	-40	0.7
6A	Nandi	4	66	39	-41	0.6
102A1	Machakos	4	91	53	-42	0.5
104A	Machakos	3	111	63	-43	0.6
301I	Taita-Taveta	3	95	44	-52	0.5
102C	Machakos	4	115	50	-57	0.5
104B	Machakos	3	95	40	-58	0.4
7B2	Nandi	4	81	33	-59	0.4
97BSA3-1	CIMMYT	4	87	32	-63	0.4
306A	Kilifi	3	87	31	-64	0.4
306B	Kilifi	4	96	33	-66	0.4

Key: FRL = Final root length

DISCUSSION

Although the results presented here are preliminary, a few useful observations have been made. First, the landrace accessions that showed greater tolerance to Al toxicity in this study, were those initially obtained from western and central parts of Kenya (Vihiga, Nandi, Butere-Mumias and Muranga districts), these are areas known to contain acid soils. These landrace accessions could probably have been maintained by farmers owing to their capacity to grow and perform well in acidic soils. Crop plants growing in acid soils have been found to have greater tolerance to low pH and Al toxicity (Kidd and Proctor, 2000). This preliminary observation indicates that searching for Al-tolerant maize germplasm in areas containing low soil pH could be fruitful.

Secondly, there is wide variability for tolerance to Al-toxicity among the Kenyan landrace populations. Some of the landrace accessions had higher tolerance level than the CIMMYT standard material. This is an indication that breeding for Al-tolerance using local landrace populations adapted to different agro-ecological zones is possible, particularly if the genetic basis of their tolerance could be established. Tolerance of Al-toxicity is genetically controlled by a single or multiple genes (Pandey *et al*, 1994; Doque-Vargas *et al*, 1994; Magnavaca *et al*., 1987). However, the genetics of the tolerance to Al-toxicity among the Kenyan landrace populations is yet to be determined. Variation of the maize accessions in the level of haematoxylin staining or root growth is an indication of differential ability of maize genotypes to take in toxic Al. Large differences in Al tolerance exist within a given crop species (Marschner, 1995) and this genetic variability appears to have been introduced unintentionally by breeding the same species in different regions with high or low pH (Foy *et al*., 1974). Al tolerance is the most important individual factor required for adaptation of species and cultivars to acid mineral soils (Marschner, 1995). Inter- and intra-cultivar differences in tolerance to Al have been reported in maize (Urrea-Gomez *et al*.,1996; Khan and McNeilly, 1998).

Thirdly, a good number of landrace maize populations including commercial hybrids, synthetics and composites showed sensitivity to Al-toxicity even as low as 140 µM commonly found in some soils (Muok, 1997) located in the maize growing areas of Kenya. This shows that Al-toxicity could be one of the major contributing factors to low maize yields in Kenya. It is probably time that serious consideration is given to liming as an alternative (Pandey *et al*., 1994) or the use of tolerant maize germplasm as has been done in Brazil and USA (Dowswell *et al*., 1996). A more thorough screening of maize germplasm, which includes inbred lines, should be conducted in order to address the problem of Al-toxicity in maize.

Fourthly, different parameters used in the assessment of maize for tolerance to Al-toxicity could give conflicting results and consequently, tolerant materials should be selected using several methods. In this report, the variable results in terms of tolerance classification could have come from the low number of maize seedlings used in measurement of root growth parameters in each treatment given the open pollinated nature of maize. A similar observation has been reported by Cancado *et al.* (1999) and Pandey *et al.* (1994). In our hands, percentage reduction in the FRL emerged as the best root length parameter for separating the maize accessions for tolerance to Al in solution. This parameter indicates clearly that Al had a significant effect on root growth, as this is a measure of root elongation and has been adopted by several maize breeders (Magnavaca *et al.*., 1987; Marschner, 1995). Inhibition of root growth as a result of Al could be due to the fact that Al inhibits cell division as has been reported earlier (Kidd *et al*., 2001; Sivaguru *et al.*,2001; Sivaguru *et al*., 1999; Foy, 1996; Kidd and Proctor, 2000).

Adaptation to Al stress can be achieved by tolerating the stress or avoidance of the same or both of these mechanisms. Both strategies are probably required

Table 2. Effect of 220 µ*M* Al concentration on root elongation of selected Kenyan landraces, hybrids, composites and synthetic maize germplasm grown in solution culture.

Accession No	Source	Description	NSRL at 7 days after transfer	% Response to Al	Root Tolerance Index
DH02	Kenya Seed Co.		7.3	-8.58	0.91
203B	Muranga	Landrace	12.9	-12.9	0.87
H513	Kenya Seed Co.	Hybrid	7.4	-21.9	0.78
5A	Nandi	Landrace	7.4	-30.2	0.7
4D	Butere-Mumias	Landrace	6.3	-32.0	0.68
PH1	Kenya Seed Co.		3.2	-32.4	0.68
H511	Kenya Seed Co.	Hybrid	5.9	-37.2	0.63
H622	Kenya Seed Co.	Hybrid	6.1	-48.5	0.51
KATUMANI	Kenya Seed Co.	Composite	5.2	-49.3	0.51
PH4	Kenya Seed Co.		6.2	-52.0	0.48
306B	Kilifi	Landrace	4.8	-52.2	0.48
6D	Nandi	Landrace	5.5	-52.4	0.48
H627	Kenya Seed Co.	Hybrid	6.1	-53.0	0.47
H626	Kenya Seed Co.	Hybrid	6.1	-54.2	0.46
H614	Kenya Seed Co.	Hybrid	4.3	-56.1	0.44
H625	Kenya Seed Co.	Hybrid	5.4	-56.2	0.44
306A	Kilifi	Landrace	5.3	-56.7	0.43
1X1	Vihiga	Landrace	6.4	-57.6	0.42
H623	Kenya Seed Co.	Hybrid	4.6	-58.0	0.42

Key: NSRL = Net Seminal Root Length.

simultaneously for plants exposed to acidic conditions, although to varying degrees (Marschner, 1995). Sometimes, tolerance to Al is manifested within the plant cells. Some plants are able to absorb Al, but have cell mechanisms that are able to tolerate given amounts of Al in the cell. It is possible that some accessions were able to withstand low levels of Al even when the Al had been absorbed into the cells.

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MAIZE GRAIN YIELD CORRELATED RESPONSES TO CHANGE IN ACID SOIL CHARACTERISTICS AFTER 3 YEARS OF SOIL AMENDMENTS

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ABSTRACT

A long-term agronomic experiment was conducted from 1996 to 2000 in Cameroon, on acid soil with low pH (4.63), high Al supply, low Mg and low P. The objective was to assess the relative advantages of the use of acid tolerant maize (*Zea mays L.*) cultivars compared to the use of fertilizers and organic manure to correct soil acidity. On acid soil, maize grain yield of the soil acidity-tolerant cultivar ATP-SR-Y was 61% higher compared to the sensitive cultivar Tuxpeño Sequia. The application of 60 kgha^{-1} of P yearly for 3 consecutive years did not significantly increase the grain yield of the acidity-tolerant cultivar. Lime except in the first year resulted in a significant increase in grain yield of both the tolerant (82%) and particularly the susceptible cultivar (208%). This corresponded to a significant decrease in exchangeable Al and to a significant increase in pH and available Ca and Mg contents of the soil. The application of chicken manure or green manure (*Senna septabilis* leaves) significantly increased maize grain yield. These increases were partly attributed to an increase of available Ca and P of the soil for chicken manure application and to a decrease of exchangeable Al and a small increase in pH and Mg for *Senna septabilis* leaves application. It was concluded that the best correction factor was lime. However, organic amendments which are within reach of small farmers can at least substitute for lime application particularly for soil acidity-sensitive maize cultivars. Furthermore, the use of soil acidity-tolerant cultivars can greatly reduce the need for lime application and thus contribute to overall sustainability.

Keywords: Acid soil, aluminium toxicity, calcium, chicken manure, lime, magnesium, phosphorus, *Senna Septabilis*, susceptible, tolerant, *Zea mays L.*

INTRODUCTION

Maize (*Zea Mays L.*) is grown on approximately 8 million hectares of acidic soils (Brewbaker, 1985; Pandey and Gardner, 1992). On these soils, maize yield is reduced due to Al or Mn toxicity, and Ca, Mg, P and Mo deficiencies (Aldrich *et al.,* 1975 Clark, 1977 and Granados *et al*., 1993). Tropical African acid soil covers 29% of the continent (Eswaran *et al.,* 1997). To achieve sub-Saharan Africa food security by the year 2050, Jacques du Guerny, 1997, estimated that food production should be multiplied by seven as compared to the 1995 level. This implies the development of strategies for advanced resource-friendly sustainable and economic production systems on acid soils including the introduction of improved acid soil-tolerant germplasm and the amelioration of soil acidity using phosphorus, lime and/or organic amendments.

A long-term agronomic experiment was conducted from 1996 to 2000 in Ebolowa, Cameroon with the objective of assessing the relative advantages of the use of acid soil-tolerant maize cultivars compared to the use of fertilizers and organic manure to correct soil acidity. Furthermore, this experiment aimed at determining the grain yield correlated response to change in acid soil characteristics after 4 consecutive years of soil amendments.

MATERIALS AND METHODS

The test site is Ebolowa, located in the humid forest zone of Cameroon. Its altitude is 615 m above sea level. The average rainfall is 1,800 mm with bimodal distribution. The soil is a typic kandiudox type (USDA 1992 classification), with low pH (4.10), low nutrient status and high exchangeable Al (Yemefack and Moukam, 1995). ATP-SR-Y, an acid soil-tolerant maize cultivar, developed by maize breeders of Cameroon, and the sensitive cultivar Tuxpeño Sequia from CIMMYT Mexico, were used from the 1997 to 2000 cropping seasons.

From 1997 to 2000, soil amendments were per year as follows: 2 phosphorus rates (0 and 60 kg ha^{-1}), 2 dolimitic lime rates (0 and 2 tons ha^{-1}), 3 organic manure types (0, chicken manure at 4 tons ha^{-1}, and *Senna septabilis* leaves at 4 tons ha^{-1}). The design was a factorial 2 x 2 x 3 x 2 with treatments arranged in a RCBD with 6 replications. Each replication consisted of 2 blocks of 7 treatments with a local maize check treatment (CMS 8501) augmented in each block. Plot size was 6m x 6m, consisting of 8 maize rows per plot, 6 m long. The spacing between rows was 0.75 m. The spacing between hills in the same row was 0.50 m. Two seeds were

Table 1. Chemical soil analysis at the beginning of the Experiment in 1997.

$cmol_{(+)}\,kg^{-1}$	0-10 cm	10-20 cm	Means
Ca	0.83	0.70	0.76
Mg	0.31	0.12	0.21
K^+	0.18	0.09	0.14
Na	0.08	0.09	0.09
Mn	0.03	0.01	0.02
Al	1.66	2.15	1.91
H^+	0.22	0.19	0.21
CEC	3.85	3.52	3.69
pH Water	4.67	4.89	4.76

planted per hill with no thinning. The total plant density was 53,333 plants ha^{-1}.

Additional fertilization was applied in all the plots as follows: 100 N 24 P_20_5 and 14 K_20 ha^{-1} according to local recommendations. This fertilizer was applied in 2 doses at 15 and 35 days after planting. The first doses consisted of 40 N, 24 P_2O_5 and 14 K_20. The second dose was made of 60 N.

Soil data at the depth 0-20 cm, were collected at the beginning of the experiment in 1997 and in each plot after 3 consecutive years of soil amendment in 1999. Soil samples were analysed at CIRAD, Montpellier, France. Field data collection consisted of plot weight from which grain yield expressed at 150 g H_20 kg^{-1} (15% moisture) were calculated assuming a shelling percentage of 80%.

Analysis of variance was performed for each year and for combined years using SAS GLM procedure. (SAS Institute, Inc., 1988), treatment was considered as fixed effects and years random.

General effects of each soil amendment on grainyield were estimated using orthogonal contrasts. Finally, correlation values were computed between grain yield and some soil characteristics (pH, exchangeable Al and Ca).

RESULTS

Ebolowa soil analysis at the beginning of the experiment in 1997 is presented in Table 1. Means over 0-10 cm and 10-20 cm showed that:

- pH (H_2O) ranged from 4.63 to 4.89.
- exchangeable Al ranged from 1.66 to 2.47 cmol(+) kg^{-1}.
- Ca content of the soil varied from 0.70 to 0.83 cmol(+) kg^{-1}.
- Mg content was between 0.12 to 0.31 cmol(+) kg^{-1}
- CEC content ranged from 3.52 to 3.85.

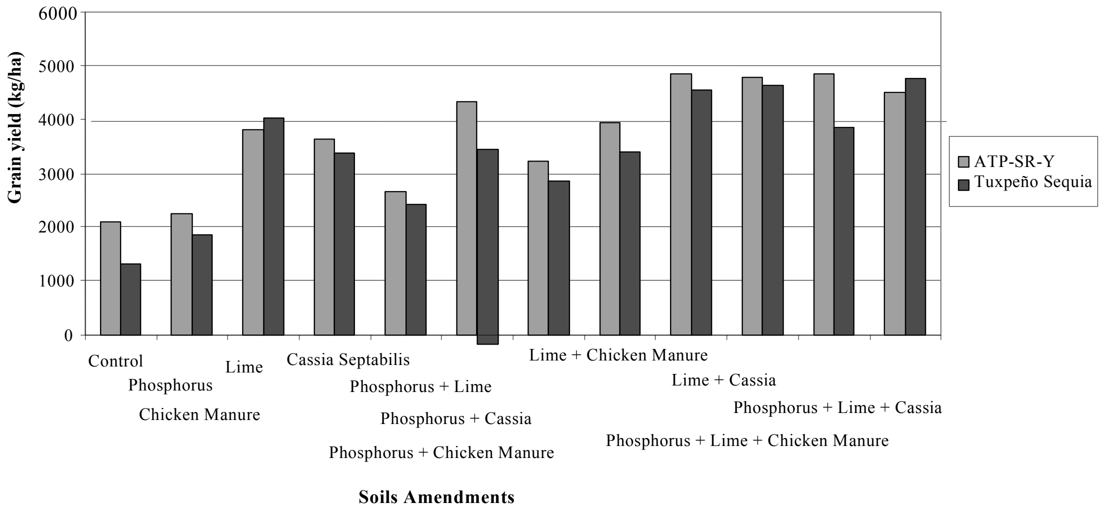
The analysis of variance over years revealed no significant treatment by year interaction. This suggested that the treatment effect had the same relative ranking from one year to the other. However, significant treatment differences ($P<0.01$) were detected for grain yield.

Treatment means obtained on acid soil and on amended acid soil as well as yearly means obtained from 1977 to 2000 are presented in Table 2 and Figure 1.

Table 2 : Treatment on acid soils and on amended acid soil obtained from 1977 to 2000.

TREATMENTS	1997		1998		1999		2000		MEANS			
	ATP-SR-Y	Tuxpeño	ATP-SR-Y	Tuxpeño	ATP-SR-Y	Tuxpeño	ATP-SR-Y	Tuxpeño	ATP-SR-Y	%C	Tuxpeño	%C
Control (Acid soil)	2288	1863	2384	1617	2918	1282	790	459	2095	100	1305	100
Phosphorus (P) alone	2582	1998	2238	1764	2895	2420	1267	1214	2246	107	1849	142
Lime alone	2513	3147	4215	4081	4720	5410	3820	3484	3817	182	4031	309
Chicken manure alone	3329	3468	3332	2656	5245	5080	2602	2314	3627	173	3380	259
Senna Septabilis alone	3249	2578	2578	2770	3164	3333	1620	1028	2653	127	2427	186
P + Lime	3038	2935	4465	3265	6181	5145	3558	3128	4331	206	3618	277
P + Chicken Manure	3607	3168	2630	2482	6115	4415	3376	3482	3932	188	3387	260
P + Senna Septabilis	3420	3133	3069	2799	4661	3409	2276	2080	3236	154	2855	219
Lime + Chicken Manure	3861	3674	4670	3403	5298	5586	5593	5531	4856	232	4549	349
Lime + Senna Septabilis	3163	3580	5269	5199	5583	4915	5181	4862	4799	229	4639	355
P + Lime + Chicken Manure	3797	3141	4530	4050	6103	4411	4988	3807	4855	232	3852	295
P + Lime + Senna Septabilis	3197	4056	4382	4617	5859	5551	4555	4870	4498	215	4774	366
Local Maize CMS 8501	2077		1892		2550		888		1852		142	
Means of amended treatments	3250	3171	3762	3371	5075	4516	3531	3255	3905	186	3578	274
L.S.D. (0.05)	890	890	1140	1140	1100	1100	1251	1251	952		952	

Figure 1. Four-year (1997-2000) treatment means for ATP-SR-Y (Tolerant) and Tuxpeño sequia (Susceptible) maize varieties



Performances on acid soil (Control plots and local check plots)

On acid soil (control plots and local check plots), ATP-SR-Y (2,095 kgha^{-1}) outyielded the susceptible Tuxpeño Sequia (1,305 kg ha^{-1}) by 61%. ATP-SR-Y, also outyielded the local CMS 8501 (1,852 kg ha^{-1}) by 13%. The local CMS 8501 was better than the susceptible control Tuxpeño Sequia by 42%. This was partly due to better adaptation of the local variety CMS 8501 than the introduced Tuxpeño Sequia.

On acid soil, except for year 2000, the acid-tolerant cultivar ATP-SR-Y grain yield increased over years while the susceptible cultivar Tuxpeño Sequia grain yield decreased over time. The ATP-SR-Y year 2000 performance was less than in 1999. This was probably due to the drought stress experienced during the 2000 cropping season at the flowering stage. These results suggested that a farmer could increase his production by 13% just by replacing his widely grown local variety by the tolerant cultivar ATP-SR-Y. In addition, the farmer would lose 61% and 42% of his production by planting the susceptible cultivar on acid soil instead of a tolerant variety or his local cultivar, respectively.

Performance on amended acid soil

Except for year 2000, grain yield on amended acid soil increased over the years for both the tolerant and the susceptible cultivars. ATP-SR-Y grain yield averaged 3,905 kg ha^{-1} over four years which represented a 86% production increase over its grain yield obtained on acid soil. The susceptible cultivar Tuxpeño Sequia grain yield mean was 3,578 kg ha^{-1} over the four years, which represented 174% production increase over its grain yield observed on acid soil. It was also noted that even on amended acid soil, the tolerant cultivar generally outyielded the susceptible cultivar by 9%. These results suggested that breeding for soil acidity tolerance did not lead to a loss in productivity at the high input level. Furthermore, the susceptible cultivar generally responded more to soil amendments than the tolerant suggesting that it was more dependent on soil amendment for better productivity.

The best soil correction factor for the tolerant variety ATP-SR-Y was Lime plus Chicken Manure. This treatment yielded 4,856 kg ha^{-1}, which represented a 32% grain yield increase over its control. Similar grain yield and grain yield increase over the control were obtained for ATP-SR-Y when phosphorus was added to lime and chicken manure. These results suggested that the addition of phosphorus to lime and or chicken manure was expensive and useless.

The addition of chicken manure to lime produced an additional 27% and 13% grain yield for ATP-SR-Y and Tuxpeño Sequia, respectively.

The best soil correction factor for the susceptible cultivar Tuxpeño Sequia was Phosphorus + Lime + Cassia. This treatment yielded 4,774 kg ha^{-1}, which represented a 266% grain yield increase over the control plot. This treatment yielded only 135 kg ha^{-1} and 225 kg ha^{-1} more than treatment involving Cassia added to Lime and/or to chicken manure, respectively. These yield increases represented only non-significant 3% and 5% grain yield differences, suggesting that the addition of phosphorus to Lime and Cassia, and its addition to Lime and Chicken manure was expensive and useless.

The best single soil amendment factor was Lime for both the tolerant and the susceptible cultivars. ATP-SR-Y and Tuxpeño Sequia yielded with Lime application alone 82% and 209% more grain yield over their performances on acid soil.

Soil amendment effects and changes in soil characteristics

The effects of soil amendment factors estimated for grain yield using orthogonal contrasts are presented in Table 3, and the contribution of phosphorus application to the performance of the two maize cultivars is presented on Table 4. The correlated responses between soil amendment and change in soil characteristics are shown in Table 5. The comparison between soil characteristics at the beginning of the experiment (Table 1) and soil characteristics of the control plot and of the plot planted to local maize after 3 years (Table 5) showed a slight decrease in soil pH and an increase in exchangeable Al with continuous maize cultivation on acid soil. These findings suggested that maize cultivation on acid soil without soil acidity correction would lead to an increase of soil acidity.

Phosphorus Effect: Effects of phosphorus amendments on maize grain yield are presented in Table 3. The mean grain yield obtained from the contribution of phosphorus to the performance of the two cultivars is presented in Table 4.

Except for 1999 on ATP-SR-Y, the effects of phosphorus application were not significant on both cultivars. The effects were negative in 1998 on both varieties. As compared to their respective controls, the application of phosphorus alone yielded after four years 7% and 42% more grain yield for ATP-SR-Y and Tuxpeño Sequia, respectively (Table 2). However, the application of phosphorus alone or in combination with other soil amendment factors produced after 4 years 2.5% more grain yield for ATP-SR-Y and Tuxpeño Sequia (5% and 0%

Table 3. Estimated effects of soil amendments on grain yield using orthogonal contrast.

Years	Effects							
	Phosphorus		Lime		Chicken Manure		Cassia Septabilis Manure	
	ATP-SR-Y	Tuxpeño seq.	ATP-SR-Y	Tuxpeño seq.	ATP-SR-Y	Tuxpeño seq.	ATP-SR-Y	Tuxpeño seq.
1997	0.127 ns	0.002 ns	0.099 ns	0.369**	2.015**	1.237*	0.442ns	1.133ns
1998	0.048 ns	-0.1 ns	0.812**	0.867**	1.206*	0.947ns	1.61**	1.281*
1999	0.486*	-0.086 ns	0.807**	0.989**	2.552*	2.766*	0.00**	-0.301ns
2000	-0.048 ns	0.079 ns	1.425**	1.263**	4.098**	3.065**	0.233**	0.771 ns

* ** Significant at 0.05 and 0.01 probability level, respectively.

Table 4. The cumulative effect of soil correction factors on the performance of two maize cultivars from 1997 to 2000

Cultivars	Soil correction Factor	1997		1998		1999		2000		Means		Percentage yield increase
		With	With-out	With	With-out	With	With-out	With	With-out	With	With-out	With/ without
ATP-SR-Y	Phosphorus	3274	3105	3552	3741	5302	4488	3337	3434	3846	3651	5
	Lime	3262	3079	4589	2705	5624	4250	4616	2155	4523	2963	53
	Chicken Manure	3649	2931	3909	3575	5724	4498	4223	4555	4354	3458	26
	Senna septabilis	3257	3127	3825	3558	4817	4997	3408	3249	3797	3719	2
TUXPEÑO SEQUIA	Phosphorus	3072	3052	3163	3288	4225	4268	3097	2946	3389	3389	0
	Lime	3422	2701	4103	2348	5170	3323	4280	1763	4244	2534	67
	Chicken Manure	3363	2911	3442	3264	5009	3933	4001	2641	3988	3187	26
	Senna septabilis	3337	2924	3846	2915	4302	4219	3210	2927	3674	3246	13
MEAN	Phosphorus	3173	3079	3358	3515	4764	4378	3217	3190	3618	3520	3
	Lime	3342	2890	4346	2527	5397	3787	4448	1959	4384	2749	59
	Chicken Manure	3506	2921	3676	3420	5367	4216	4112	3598	4171	3323	26
	Senna septabilis	3297	3026	3835	3237	4560	4608	3309	3088	3736	3483	7

Table 5. Chemical soil analysis at Ebolowa 2000.

Amendments	Grain (1) Yield (kg ha$^{-1)}$	ATP-SR-Y						
		SOIL CHARACTERISTICS (cmol$_{(+)}$ kg^{-1})						
		pH (H_2O)	Al Exch.	H^+ Exch.	Ca Exch.	Mg Exch.	P (mg kg^{-1})	CEC
Local Variety	1852	4.67	2.16	0.21	0.53	0.20	23.22	3.92
Control	2918	4.54	2.32	0.14	0.6	0.13	24.06	4.04
Phosphorus (Phosphorus)	2895	4.45	2.47	0.19	0.43	0.14	21.2	3.90
Lime (Lime)	4720	4.77	1.30	0.11	1.21	0.73	18.52	4.12
Lime + Phosphorus	6181	4.90	1.08	0.08	1.33	0.85	20.13	4.16
Chicken Manure	5245	4.78	1.60	0.18	0.78	0.21	31.39	4.02
Chicken. M + Phosphorus	6115	4.76	1.55	0.21	0.96	0.20	43.26	3.94
Chicken M. + Lime	5298	4.96	0.80	0.12	1.38	0.80	29.65	4.02
Chick. M.+ Lime + Phosphorus	6103	5.09	0.70	0.10	1.62	1.01	32.60	4.55
Cassia	3164	4.75	1.96	0.24	0.57	0.18	22.15	3.08
Cassia + Phosphorus	4661	4.68	2.12	0.20	0.61	0.15	25.77	3.47
Cassia + Lime	5583	4.76	1.35	0.16	1.16	0.77	16.23	4.04
Cassia + Lime + Phosphorus	5859	4.94	1.07	0.16	1.28	0.79	23.10	4.02

(1) Mean grain yield obtained after 3 years.

Table 5. Chemical soil analysis at Ebolowa 2000 (Cont.).

AMENDMENTS	Grain Yield kg ha^{-1}	TUXPEÑO SEQUIA						
		SOIL CHARAC TERISTICS (cmol$_{(+)}$ kg^{-1})						
		pH (H_2O)	Al Exch.	H^+ Exch.	Ca Exch.	Mg Exch.	P (mg kg^{-1})	CEC
Local Variety	1852	4.67	2.16	0.21	0.53	0.20	23.22	3.92
Control	1282	4.51	2.25	0.17	0.64	0.14	17.66	3.82
Phosphorus (Phosphorus)	2420	4.47	2.45	0.19	0.54	0.12	27.16	3.88
Lime (Lime)	5410	5.38	0.70	0.05	1.49	0.84	21.25	5.24
Lime + Phosphorus	5145	4.80	1.14	0.05	1.21	0.84	25.13	4.10
Chicken Manure	5080	4.54	2.20	0.11	0.72	0.16	29.45	4.19
Chicken Manure Chicken + Phos	4415	4.86	1.68	0.20	0.94	0.25	32.32	4.08
Chicken Manure + Lime	5586	4.88	0.92	0.11	1.30	0.88	26.48	4.38
Chicken M. + Lim + Phosphorus	3409	4.87	1.23	0.18	1.40	0.84	28.85	4.07
Cassia	3333	4.90	1.76	0.19	0.61	0.18	22.50	3.57
Cassia + Phosphorus	4411	4.68	1.92	0.22	0.62	0.20	34.5	3.62
Cassia + Lime	4915	5.10	0.63	0.12	1.61	1.03	20.5	4.49
Cassia + Lime + Phosphorus	5551	4.98	1.13	0.13	1.13	0.70	26.5	3.75

respectively). These yield increases were negligible, suggesting that it was of no value to apply phosphorus as an acid soil correction factor especially when an acidity-tolerant cultivar was cultivated. The susceptible cultivar responded better to the application of phosphorus alone (42% vs. 7%). This was partially due to the fact that Tuxpeño Sequia was Al sensitive but phosphorus efficient (EMBRAPA personal communication).

Soil analysis of plots amended with phosphorus alone (Table 5) revealed that the application of 60 kg ha^{-1} of phosphorus alone for 3 consecutive years did not induce any significant change on soil characteristics, especially on pH and Mg. Exchangeable Al and H^+ tended to increase and the available P (Olsen) content of the soil tended to increase only on plots planted with the Al sensitive but P efficient cultivar Tuxpeño Sequia. The small but not significant pH and Ca decrease suggested that phosphorus application alone tended to increase soil acidity. This was probably due to DAP (Diammonium phosphate) application known to release NH^+_4 in the soil. Finally, it was observed that the addition of other correction factors (lime, chicken manure, *Senna septabilis* leaves) to phosphorus lead to an increase in grain yield, pH, Ca, Mg and P and also a decrease in exchangeable Al and H^+.

Lime Effects: The effects of lime application are presented in Table 3, the mean grain yield of maize due to lime application is shown in Table 4 and the induced soil characteristic change due to 3 years of dolomite lime application is presented on Table 5.

Except for the first year of application on ATP-SR-Y in 1997, the effect of lime was significant and increases with time on both the tolerant and the susceptible cultivar as compared to their respective controls. Lime application alone (Table 2) yielded 82% and 208% more grain yield for ATP-SR-Y and Tuxpeño Sequia, respectively. The susceptible cultivar responses were superior to that of the tolerant cultivar. The general effect of four years of lime application on maize cultivar (Table 4) revealed that, lime induced 60% more grain yield (53% and 67% for ATP-SR-Y and Tuxpeño Sequia, respectively).

Soil characteristics data taken after 3 years of dolomitic lime application revealed that grain yield increase could be attributed to the significant decrease in exchangeable Al and H^+ and to the increase in Ca, Mg, CEC and pH of the soil. The observed differential response of the two cultivars was partially explained by the higher decrease in Al and H^+ and the higher increase in Ca, Mg, CEC and pH observed in plots planted to the susceptible cultivar, Tuxpeño Sequia than in plots planted to the tolerant cultivar ATP-SR-Y.

The addition of other amendment factors to lime (phosphorus, chicken manure and Senna septabilis leaves), generally increased grain yield. This was related to additional decrease in Al and H+ and to additional increase in Ca, Mg, P, CEC and pH of the soil. The best treatment was obtained with the addition of chicken manure to lime. This addition when compared to lime application alone induced an additional 27% and 13% more grain yield for ATP-SR-Y and Tuxpeño Sequia, respectively. The differential responses of the 2 maize cultivars were attributed to lesser exchangeable Al, and more exchangeable Ca, Mg, available P and better pH obtained in plots planted to the tolerant cultivar.

Chicken Manure Effects: The general effect of chicken manure application from 1997 to 2000 was positive and significant except in 1988 on the sensitive cultivar (Table 3). The performance of the two maize cultivars fertilized with chicken manure alone and compared to their respective performance on control plot (Table 2), revealed a 74% and a 159% grain yield increase for ATP-SR-Y and Tuxpeño Sequia. The cumulative effect of chicken manure application yielded after 4 years, 26% more grain yield on maize cultivar. The response of the 2 cultivars to chicken manure application was then similar.

Soil chemical analysis (Table 5) revealed that these yield increases over the control plot were partly attributed to the decrease in exchangeable Al and the increase in exchangeable Ca, Mg and pH, for the tolerant cultivar ATP-SR-Y. However, for the susceptible cultivar, Tuxpeño Sequia, the yield increase was mainly due to increased availability of Ca, P and to better CEC, as the exchangeable Al and the pH of the soil were not significantly affected. Additional grain yield increase obtained by the addition of phosphorus and/or lime was explained by additional decrease in exchangeable Al and the important increase in Ca, Mg, P and pH obtained on those plots as compared to plots which received only chicken manure.

Senna Septabilis **Leaves Effects:** The effects of the application of *Senna septabilis* leaves presented in Table 3 were positive and significant on ATP-SR-Y except in 1997 cropping season. This effect was positive and significant on the susceptible cultivar only in 1998. The effects were positive but not significant on the susceptible cultivar in 1997 and 2000 and were significantly negative on this cultivar during the 1999 cropping season.

The cumulative effect of the application of *Senna septabilis* leaves alone (Table 1) produced 27% and 86% more grain yield than did their control for the tolerant cultivar ATP-SR-Y and for the susceptible cultivar Tuxpeño Sequia, respectively. Thus the effect was more beneficial to the susceptible cultivar than to the tolerant cultivar.

The overall effect of *Senna septabilis* leaves on the performance of the two cultivars presented in Table 4 showed a 7% grain yield increase due to this amendment. This grain increase resulted from 2% and 13% grain yield increase obtained with ATP-SR-Y and Tuxpeño Sequia, respectively. Soil characteristics analysis (Table 5) revealed that compared to control plot, green manure application resulted in a small increase in pH and Mg, and a decrease in exchangeable Al on plots planted with the 2 cultivars. These plots planted with the 2 varieties also showed an increase in H^+ and a decrease in CEC. The Ca content of the soil was unaffected. The grain yield differential response of the two cultivars (2% vs. 13%) resulted from lesser increase in H^+ and more availability of P in plots planted with the susceptible cultivar Tuxpeño Sequia.

The addition of lime to *Senna septabilis* leaves resulted in an additional 81% and 91% grain yield increase over *Senna septabilis* leaves alone. These results were attributed to additional increase in pH, Ca, Mg, and CEC, especially on the susceptible cultivar.

The general effect of *Senna septabilis* leaves on the performance of the two cultivars presented in Table 4 showed a 7% grain yield increase due to this amendment. This grain increase resulted from 2% and 13% grain yield increase obtained with ATP-SR-Y and Tuxpeño Sequia, respectively.

Relation of Grain Yield to Soil pH, Al, and Ca.: The relation between grain yield and some soil characteristics after 3 consecutive years of soil acidity correction is shown on Fig. 2, 3, 4 and 5. Grain yield changes were more correlated to changes in Al (r^2=0.59) and Ca (r^2=0.55), than to pH (r^2=0.36) of the soil. The soil pH was very much affected by lime application, which generally increases this element in the soil. *Senna septabilis* leaves permitted a small increase in pH on plots planted to both cultivars while chicken manure seems to affect the pH on plots planted only to the tolerant cultivar ATP-SR-Y.

Grain yield was also highly correlated to Ca content of the soil. This element was also more affected by lime application. Chicken manure did not significantly affect this element in the soil. No significant trend was detected between grain yield and P and between grain yield and Mg.

DISCUSSION AND CONCLUSION

Grain yield of both the tolerant and especially the susceptible cultivars were affected by soil acidity. Compared to the control plot, grain yield losses ranged from 3% to 67%. These grain yield losses were higher than those reported by Borrero *et al.,* (1995), who obtained a 10% grain yield loss due to acid soil. On acid soil, the tolerant cultivar ATP-SR-Y out performed the susceptible cultivar Tuxpeño Sequia by 61% and it was demonstrated also that the susceptible cultivar relied more on soil amendment to achieve good productivity. These results suggested that the use of an acidity-tolerant cultivar would greatly reduce the need for soil amendment.

Soil amendment with phosphorus tended to increase soil acidity and soil fertility (an increase in Al and H^+ and a decrease in CEC). These findings were not in agreement with Ritchey and Sousa (1997) who obtained with the application of gypsum a reduction in exchangeable Al and increase in Ca. Different sources of P used in this study might explain the differential response obtained. Diammonium phosphate used in this study might have contributed NH_4^+ known to have negative effect on soil pH. In addition, the rate of 60 kg ha^{-1} of phosphorus, used alone might have been small on Ebolowa high P fixing acid soil.

The best soil acidity correction factor was lime which resulted in a significant reduction of exchangeable Al allowing more efficient uptake of N and P absorption, particularly for the sensitive cultivar. This observation is in agreement with findings of Raij and Quaggia (1997). Change in Al was more correlated to grain yield than change in Ca content and pH (r^2=0.59 vs. r^2 = 0.55 and r^2=0.36). Al and pH were highly inversely related (Fig 5; r^2=0.82) and were both similarly affected by lime and *Senna septabilis* leaves application. These results suggested that *Senna septabilis* leaves which is within the reach of the small farmers could at least partly substitute for lime application that most of the farmers cannot afford.

Manure application generally resulted in a small Al decrease in the soil. This result is in agreement with the findings of Keltjens (1997). With chicken manure the pH of the soil was affected only on plots planted to the tolerant cultivar. The lack of corresponding pH increase obtained in plots with the susceptible cultivar was also noted by Zekeng (1992). In addition, the observed slow rate of change in soil characteristics after manuring as compared to lime application suggested that soil acidity correction with manure might take a longer time than the present 3 years of application. In this site in Cameroon, lime application was necessary and highest grain yields were only achieved in a short period when both lime and manure were applied.

Finally, on acid soil and on amended acid soil, grain yield of the tolerant cultivar was greater than that of the susceptible cultivar, which relied more on soil amendment to achieve better productivity. Therefore, the use of soil acidity tolerant cultivars could partially substitute for soil amendment and its contribution to sustainability is demonstrated to be more advantageous.

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VERTICAL ROOT-PULLING RESISTANCE IN MAIZE IS RELATED TO NITROGEN UPTAKE AND YIELD

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ABSTRACT

Poor soil fertility and recurrent drought are major constraints to maize production in the West African savanna. The development of maize cultivars with superior rooting system to absorb nitrogen and water efficiently from the soil is desirable. However, direct measurement of root characteristics for rapid selection of maize lines having tolerance to the two stresses is difficult. Vertical root-pulling strength, which has been shown to relate well to the rooting characteristics of the maize plant could be an alternative trait that can be used in improving the efficiency of selection of maize lines for tolerance to low-N stress and drought. This trait has effectively been used to select maize lines for resistance to corn root rot and lodging. Field evaluations were conducted during 2000 and 2001 to determine the root-pulling strength, yield, N-uptake and N-use of maize S1 lines derived from selected full-sib families from a Low-N tolerant population. There were significant differences in vertical root-pulling strength, N-uptake, N-use efficiency and yield among the maize breeding lines. Root-pulling strength positively correlated with N-uptake and maize yield. However, some S1 lines gave a higher grain yield despite low root-pulling strength. Other factors such as high numbers of ears per plant and high N-utilization efficiency were responsible for these yield increases. Because of the magnitude of the differences between S1 lines in root-pulling strength and the positive correlation of this trait with N-uptake, it can be used in selecting lines for variations in the rooting system and for high N uptake efficiency.

INTRODUCTION

A decline in soil fertility particularly in nitrogen levels, and recurrent droughts are widespread in sub-Saharan Africa, especially as agricultural populations increase. In consequence, crop yields are falling to very low levels and food insecurity is widespread amongst agricultural communities. Nitrogen (N) is the most limiting nutrient in maize production in the humid and sub-humid tropics. Inorganic fertilizer use in sub-Saharan Africa is limited since it is expensive and often not available. Drought is also common early and sometimes late in the growing season in the West African savannas. Drought stress at the beginning of the season will severely affect plant establishment and at the seedling and flowering stages of maize (*Zea mays* L.) it is estimated to cause annual yield losses of about 12% in the West African sub-region (Waddington *et al*., 1995).

The effects of low N and drought make cultivars desirable that are able to perform well under such stresses and also when conditions are optimal. One approach to reducing the impact of N deficiency and water stress on maize production may be to select cultivars that are superior in their capacity to take up N and water from the soil and utilize them efficiently. Tolerance of maize to stress from drought and low N is related to the development of the root system, which in turn influences water and nutrient uptake by the crop plant. A number of studies have shown that water uptake from a given volume of soil depends on the rooting density and soil-water properties (Allmaras *et al*., 1975; Taylor and Klepper, 1973; Nimah and Hanks, 1973). In addition to lodging resistance, a vigorous root system could also provide better tolerance to drought and nutrient stress, thereby stabilizing maize yield under stressed conditions. Early proliferation of roots in the topsoil would allow maize cultivars to make efficient use of the soil inorganic N while a deep, dense root system would be able to extract nitrate leached to deeper soil layers. Furthermore, the response of maize to drought is related to the development of the root system, which influences water uptake (Taylor and Klepper, 1973; Aina and Fapohunda, 1986). Thus, maize cultivars with a rapid and large rooting density in the topsoil early in the growing season may be more drought-tolerant and better able to use available water. Because of the importance of the root system for the acquisition of nutrients and water and for resistance to lodging, extensive studies have measured the rooting pattern of maize and its relationship to nutrient uptake and yield. However, root measurements, particularly root length density, specific root length, and root mass density, are not only laborious but also error-prone. Thus, these traits cannot easily be used in rapid selection for tolerance to low N and drought. Also the size of the root system alone does not always relate well with grain yield among cultivars. Heuberger (1998) and Oikeh *et al*. (1999) did not find a relationship between the root density of maize cultivars and yield or between root density and N-uptake.

Vertical root-pulling resistance has been studied and used to select for root strength and lodging resistance in maize (Fincher *et al*., 1985). It is one method used by breeders to measure plant resistance to lodging. Spencer (1940) found significant correlations within a set of genotypes between vertical root-pulling resistance and root dry weight. Zuber (1968) found a significant positive correlation in different environments between vertical root-pulling resistance and root clump weight. He also found that a rating for the amount of fibrous roots was significantly correlated with vertical root-pulling resistance. Beck *et al.* (1988) found significant positive correlations between vertical root-pulling resistance, root volume and the total number of brace roots. Although vertical root-pulling resistance has been shown to relate well to the root system in plants, little research has been done to study the relationship between this resistance and N-uptake and drought tolerance in maize, particularly in the tropics. Since vertical root-pulling resistance can be measured more rapidly than other rooting characteristics, it will be helpful to breeders in the selection of breeding lines for high N-uptake and yield.

This study was conducted to evaluate the root-pulling strength of some S1 progenies from a maize population developed for tolerance to low-N stress and to relate it to maize N-uptake, N-use efficiency and yield.

MATERIALS AND METHODS

Field evaluations were conducted during 2000 and 2001 on clayey sand at the experimental farm of the International Institute of Tropical Agriculture, in Mokwa, Northern Nigeria. A total of 18 S1 lines with diverging root-pulling resistance and derived from selected full-sib families from a Low N-tolerant population and 2 inbred checks were screened for root-pulling strength as well as yield and N-uptake at 60 kg N/ha. Nine families were selected with high root-pulling strength and another 9 were selected with low root-pulling strength. These lines were evaluated to determine whether root-pulling measurements obtained during selection were repeatable and if so, whether there was any relationship between high root-pulling strength and N-uptake and other growth and yield parameters. Two separate experiments were carried out in both years to evaluate root-pulling resistance on the one hand and N-uptake and agronomic and yield characteristics on the other hand.

In both years, the 18 maize lines and 2 inbred checks were laid out in a randomized complete block design (RCBD) with four replications. Planting distance was 0.75 m between rows and 0.25 m between plants (arranged in single rows for the root-pulling experiments and in four rows for the experiment meant for agronomic data collection) to give a plant population of 53,333 plants/ha. Root-pulling resistance was measured as kilograms of force required to lift a plant vertically from the soil. Stalks were cut off 30 cm above the ground just prior to pulling. Force was exerted by a tractor through a bar attached from a bipod through a dynamometer (Rogers *et. al*., 1976; Peters *et. al.,* 1982) to a clamp secured just above the soil around the base of the cut plants. Other studies indicate that maximum root-pulling resistance is achieved after mid-silking (Fincher *et. al*., 1985). Based on this information, root-pulling resistance was determined 2 weeks after the average mid-silking date of the maize lines in the test. Ten plants were pulled in each plot. Only non-consecutive plants were used to obtain root-pulling resistance data. Plants adjacent to a wider space or another pulled plant were not used. In the second experiment, data were collected on plant height, ear height, lodging frequency, days to flowering, ear leaf area, and grain yield. The above-ground biomass and grain at harvest were dried, milled and analysed for total N content. N-uptake, utilization and use efficiencies were calculated according to Moll *et al*, (1982).

Analysis of variance procedure (ANOVA) was used to detect differences between the maize lines for all variables with Statistical Analysis Systems Package (SAS version 6.04) (SAS Institute Inc., 1989). Significant differences between lines were compared using Standard Error of the Means. Root-pulling resistance data were log-transformed before analysis.

RESULTS AND DISCUSSION

Vertical root-pulling strength

The 20 maize lines differed significantly in vertical root-pulling resistance in both years (Tables 1 and 2). The magnitude of resistance for individual S1 lines differed strikingly. This indicates that it is possible to select for differences in this trait. S1-14, S1-22, S1-24, S1-25, S1-37, and S1-67 showed consist

Table 1. Root-pulling strength, yield, N-uptake and N-use efficiency of maize lines at Mokwa, Nigeria in 2000

Variety	Grain yield (Kg/ha)	Root Pulling strength (kg)	Total-N g/plant	N-uptake efficiency	N-utilization efficiency	N-use efficiency	Days to 50% silking	Days to 50% Tasseling	ASI (Days)
S1-25	5176	2.05	3.53	2.19	39.73	86.28	62.33	58.00	4.33
S1-52	4085	2.00	3.31	1.72	39.66	68.09	62.33	58.00	4.33
S1-67	4279	2.00	3.75	1.78	39.90	71.33	65.00	60.33	4.67
S1-22	4041	1.99	4.58	1.72	39.11	67.36	64.33	60.33	4.00
S1-61	1879	1.99	3.43	1.51	19.97	31.32	69.00	61.33	7.67
S1-74	2782	1.95	3.42	1.46	31.76	46.38	64.67	58.67	6.00
S1-24	4151	1.94	3.92	1.74	39.58	69.18	64.67	59.00	5.67
S1-14	4018	1.94	3.43	1.96	34.45	66.98	68.33	63.67	4.67
S1-37	4244	1.93	4.28	1.90	37.19	70.75	65.33	59.33	6.00
S1-58	3845	1.93	3.46	1.91	33.65	64.09	63.67	59.67	4.00
S1-55	2685	1.91	3.77	1.65	27.12	44.75	62.33	58.67	3.67
S1-64	4365	1.90	3.35	1.81	40.17	72.77	64.00	61.00	3.00
S1-31	2439	1.86	2.37	1.24	32.89	40.65	65.33	59.33	6.00
S1-10	4351	1.86	4.22	2.25	32.55	72.53	62.67	57.00	5.67
S1-32	2935	1.86	2.60	1.38	35.40	48.92	66.00	61.67	4.33
S1-45	3884	1.85	3.25	1.99	32.64	64.74	67.33	61.00	6.33
S1-72	4527	1.84	3.53	1.84	41.97	75.46	64.33	62.00	2.33
S1-39	3701	1.80	3.35	1.82	33.96	61.68	66.67	62.67	4.00
Checks									
9071	2285	1.68	2.63	1.20	31.77	38.09	67.33	62.33	5.00
9450	1170	1.68	1.72	0.74	26.06	19.51	64.67	61.67	3.00
Mean	**3542**	**1.90**	**1.90**	**1.69**	**34.48**	**59.04**	**65.02**	**60.28**	**4.73**
S.E	**230**	**0.02**	**0.09**	**0.08**	**1.24**	**3.85**	**0.44**	**0.40**	**0.29**

Table 2. Root-pulling strength, yield, N-uptake and N-use efficiency of maize lines at Mokwa, Nigeria in 2001

Variety	Grain yield (Kg/ha)	Root Pulling Strength (kg)	Total-N g/plant	N-uptake efficiency	N-utilization efficiency	N-use efficiency	Days to 50% silking	Days to 50% Tasseling	ASI (Days)
S1-25	4736	3.07	1.66	1.47	56	83	55	55	0
S1-24	4592	3.02	1.54	1.36	57	77	58	58	0
S1-67	4248	2.98	1.17	1.04	62	65	58	58	0
S1-14	4096	3.09	1.60	1.42	56	79	62	60	2
S1-72	3961	2.99	1.09	0.96	61	58	58	57	1
S1-74	3915	2.95	1.74	1.54	44	68	57	55	2
S1-22	3805	3.03	1.23	1.08	50	54	59	58	1
S1-55	3703	2.94	1.47	1.31	44	57	55	55	0
S1-45	3543	2.75	1.36	1.20	53	63	58	57	1
S1-10	3236	2.72	1.24	1.09	40	44	59	57	2
S1-31	3139	2.81	1.13	1.00	52	52	59	58	1
S1-58	3122	2.96	1.30	1.15	47	55	58	58	0
S1-64	3111	2.87	1.26	1.11	54	61	58	57	1
S1-52	2872	2.74	1.03	0.91	58	53	58	57	1
S1-37	2768	2.97	1.11	0.98	49	48	58	57	1
S1-61	2352	2.92	1.03	0.91	45	42	60	56	4
S1-39	2290	2.67	0.93	0.83	47	38	60	60	0
S1-32	2288	2.80	0.73	0.64	53	34	60	58	2
Checks									
S1-9450	1795	2.71	0.49	0.44	56	24	59	56	3
S1-9071	1739	2.67	0.72	0.64	33	22	63	60	3
Mean	**3265**	**2.88**	**1.19**	**1.06**	**51**	**54**	**58**	**57**	**1.23**
SE	**196**	**0.03**	**0.07**	**0.06**	**1.62**	**3.73**	**0.42**	**0.33**	**0.25**

RESULTS AND DISCUSSION

Vertical root-pulling strength

The 20 maize lines differed significantly in vertical root-pulling resistance in both years (Tables 1 and 2). The magnitude of resistance for individual S1 lines differed strikingly. This indicates that it is possible to select for differences in this trait. S1-14, S1-22, S1-24, S1-25, S1-37, and S1-67 showed consistently high root-pulling strength in both years. Root-pulling strength in S1-10, S1-31, S1-32, S1-45 and S1- 39 was lower than in the other lines in both years. S1-52, S1-58, S1-72 and S1-74 showed variable results and rankings between the 2 years. Peters et al. (1982) found that the root-pulling resistance value for a given line was valid for comparisons to be made only with other lines in the same test. Their work indicated that maize lines ranked somewhat differently in the 2 years of their experiments. This suggested that year-to- year environmental changes significantly influence root-pulling resistance of maize lines relative to each other. There were also year-to-year differences in the average root-pulling strength of the maize lines in this study. Mean value of root-pulling strength in 2001 was 34% higher than that in 2000. Factors such as soil type and soil moisture content strongly influence root-pulling resistance obtained in a given day, year, and location (Peters et al., 1982; Kevern and Hallauer, 1983; Beck et al., 1988).

Grain yield

Considerable differences in yield were observed amongst the maize breeding lines. There was a significant positive correlation between vertical root-pulling resistance and yield (r = 0.53 in 2000; r = 0.77 in 2001). Most of the maize lines that had high root-pulling resistance gave higher yields than those with lower root-pulling resistance. Selection of maize lines exhibiting large root systems through root-pulling resistance and other methods has been successful in recent years. However, as larger root systems are developed, a question arises concerning how large a root system the plant can produce without reducing grain yield, particularly under stressed conditions (Peters *et. al*, 1982). However, the sets of correlation coefficients in our study indicate that a large, profuse root system may be selected without causing serious reductions in yield potential. This correlation however, reflected the relationship existing in favourable seasons as observed by plant conditions and field means for the breeding lines. Selection for superior root system characteristics with little or no concern for yield affects the usefulness of such breeding lines. There is, therefore, a need to evaluate the breeding lines identified to have high root-pulling resistance under conditions of both low N and drought-stress.

Although, higher root-pulling resistance generally gave higher yields, there were a few exceptions. S1-61, which was, for example, among the lines with higher root-pulling resistance, gave consistently low yields in both years. This was attributed to its relatively high anthesis-silking interval (ASI) and low number of ears per plant. Delayed silking has been associated with barrenness (Herrero and Johnson, 1981) and appears to reflect reduced partitioning of assimilates to the developing ear at flowering (Edmeades *et al*., 1993). This was true for S1-61, which had days to silking above the overall average of the population in both years. S1-39 and S1-72, though having consistently low root-pulling strength, gave yields as high as those of some breeding lines which had higher root-pulling strength. S1-39 showed a high reduction in yield only in 2001 because of lodging of over 90% during the grain-filling period. These high yields of S1 lines with low root-pulling resistance could be explained by differences in the number of ears per plant. S1-39 and S1-72 gave over 1 ear per plant in both years. Nitrogen use efficiency, high N-uptake and utilization efficiency and high yield are strongly associated with number of ears per plant. (Moll *et al*, 1987).

N-accumulation, N-Uptake and N-Use efficiency (NUE)

Differences occurred among cultivars for N-accumulation and for efficiency in N-use, N-uptake and N-utilization. N-accumulation, efficiency in N-Use and N-uptake were significantly and positively correlated with vertical root-pulling strength in both years (P>0.01). Correlation values for total N taken up in the above-ground biomass at maturity and vertical root-pulling strength were 0.56 in 2000 and 0.68 in 2001. In both years S1-14, S1-22, S1-24, S1-25, and S1-37 absorbed higher amounts of N and this translated into high yield and subsequently high N-use efficiency. These breeding lines gave consistently higher vertical root-pulling strength. Nitrogen utilization efficiency was, however, independent of vertical root-pulling strength. S1-64, for example, with relatively low vertical root-pulling strength in both years, utilized N very efficiently, and this translated into high yield independent of vertical root-pulling strength. The efficiency with which maize plants utilize N fertilizer is affected by several factors including root morphology and extension and biochemical and physiological mechanisms in nitrate assimilation and use (Jackson *et al*., 1986). Efficiency of uptake and utilization of N in the production of grain require that those processes associated with absorption, translocation, assimilation and redistribution of N operate efficiently (Moll *et al*., 1982). Significant and consistent differences in the accumulation and distribution of N to various plant parts have been reported among maize lines (Chevalier and Schrader, 1977; Pollmer *et al*., 1979, Muruli and Paulsen, 1981). In this study, differences were observed for grain yield and N-accumulation. Also, several of the S1 lines demonstrated outstanding root development as expressed by resistance to pulling. This development translated into high nutrient uptake and subsequently high yields. These suggest the possibility of selecting for high N-uptake using vertical root-pulling strength of the maize lines. Chevalier and Schrader (1977) found nitrate absorption by maize inbred lines to be related to root dry weight. Although vertical root-pulling strength values were higher in 2001 than in 2000, total N accumulated in the above-ground biomass was higher in 2000. The different fertility levels at the two different sites where experiments were conducted explain these differences. In 2000, the plot used for the root-pulling experiment was previously cropped to a nitrogen-fixing herbaceous legume, which apparently returned more N into the soil thereby making more N available to the maize crops. In 2001, the plot used was previously cropped to cassava.

CONCLUSION

There were significant variations in vertical root-pulling strength, N-uptake, and yield among maize S1 breeding lines. Root-pulling strength positively correlated with maize yield and N-uptake. However, some S1 lines gave a higher grain yield despite low root-pulling strength. Other factors such as high numbers of ears per plant and high N utilization efficiency were responsible for these yield increases. Because of the magnitude of the differences between S1 lines in root-pulling strength, this trait can be used in selecting lines for variations in the rooting system. The positive and significant correlation between N-uptake and vertical root-pulling strength suggests that selection for high N-uptake can be achieved through selection for high vertical root-pulling strength. It is, however, not clear how maize lines selected for high root-pulling strength will perform under low N levels and drought stress. Further research is therefore needed to determine whether selecting for high root-pulling strength will improve maize performance under low N and drought conditions.

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RESPONSE OF MAIZE VARIETIES TO NITROGEN: SELECTION FOR N-USE EFFICIENCY IN UGANDA

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ABSTRACT

Nitrogen is the most limiting factor in the production of maize in Uganda. The small-scale farmers who produce the bulk of the maize cannot afford the cost of mineral fertilizer and production of organic manure is inefficient. Breeding for nitrogen use efficiency is a viable alternative. In a study to select for N efficiency, 10 trials involving hybrids, synthetics and open pollinated varieties were screened under low and high nitrogen sites at Namulonge Research Institute. A number of entries ranked high under both nitrogen levels in each of the trials. The synthetics and open pollinated varieties seemed to be more stable than the hybrids. The varieties that performed well under both conditions should be considered for further testing for eventual release.

Keywords: Hybrids, low N efficiency, maize varieties, open pollinated varieties, synthetics, Uganda.

INTRODUCTION

Most soils in Uganda are low in soil fertility. Nitrogen is the most limiting nutrient. There are several ways in which the low nitrogen factor can be mitigated: inorganic nitrogen can be applied, organic manure such as the use of compost, or legumes that can fix atmospheric nitrogen. Alternatively, it is possible to breed for genotypes that can use the available nitrogen efficiently. Inorganic nitrogen is too expensive for the resource-poor smallholder farmers who produce 85% of the maize in the country. The fertilizers are not affordable and are not always available in the correct quantities at the right time. Farmers are encouraged to use compost and green manure to increase the nitrogen supply in the soil. Compost making is very demanding and it requires the addition of some nitrogen source if it is going to be rich in the element. Very few farmers can afford to make good manure. The option of using nitrogen fixing legumes in rotation is a possibility, although it might require a season to grow the legumes as an improved fallow which may not be possible in the highly populated areas where all the land is used all the time. Nitrogen fixation is also dependent on other factors such as the right species and *Rhizobia* and climatic conditions that favour fixation. Perhaps the most attractive option is to lower crop demand for nitrogen through breeding for maize varieties that are efficient in utilising N at both low and high nitrogen levels. One other approach is to lower crop demand for nitrogen through breeding (Smith *et al*, 1994). It is possible that through breeding one can get varieties that perform well under both low and high nitrogen levels (Short, 1991, Banziger *et al*, 2000) thus Producing a nitrogen-stable variety. Such a variety would benefit farmers who cannot afford to buy fertilizer and those who normally use it. Evaluating 15 Malawi hybrids under both low and high nitrogen levels, Zambezi and co-workers (Zambezi *et al*, 1994) found that four of the hybrids were outstanding at both fertility levels.

In its international breeding and testing, CIMMYT has developed varieties that are considered to be able to yield well under both low and high nitrogen conditions. They could be used to improve maize production in the country. They, however, must be adapted to the local biotic and abiotic factors if they are to be adopted. When using hybrids, it is possible to identify lines that contribute most to efficiency to low N that can be used in further breeding. Lines with good combining ability could also be used to produce synthetics. The objective of this study was to evaluate genotypes for their adaptability to the local conditions and their efficiency in utilising low nitrogen. The superior ones would be recommended for release to farmers. The national breeders could also take advantage of the germplasm to continue breeding.

The expected output was varieties that would be able to perform well under low and high nitrogen conditions. Varieties that would perform well under both conditions would be considered nitrogen use efficient.

MATERIALS AND METHODS

Sets of genotypes were tested at Namulonge Research Institute during the first seasons of 1999, 2000 and 2001. The genotypes were open pollinated varieties, and hybrids. Among the open pollinated varieties were also synthetics. Among the hybrids were: top-cross hybrids, three-way hybrids and double-cross hybrids. The hybrids were made up of both experimental lines and inbreds that were already used in hybrid production. The number of entries and the type of sets are indicated in Table 1.

The trials were supplied by the CIMMYT regional programme in two sets; one for the low nitrogen site and another for the high nitrogen site. The two sites were two adjacent strips at Namulonge Agricultural Research Institute. The low nitrogen site was established in 1998. This was done by growing maize at a very high population for two seasons. All the maize was cut and removed from the field at the end of the season. Soil tests at the end of the depletion process indicated that the nitrogen had been depleted to levels acceptable for the study.

Both fields received 60 kg of P_2O_5/ha and 30 kg K_2O/ha at the beginning of each season. The phosphorus was applied as Triple Super Phosphate and the potassium was in the form of Muriate of Potash. The high nitrogen plot

Table 1. Brief description of Nitrogen use efficiency trials conducted at Namulonge 1999-2001.

Year	Trial No.	No. of entries	Description
1999	99101	56	3-way crosses involving CML202 and CML206 as male parents
	99102	40	3-way crosses of lines with CML202 and CML206 as male parents
	99105	39	Top-crosses of inbreds with TASEQ
	99108	33	Top-crosses of single crosses with Katumani
	99110	70	Test crosses of inbred lines using CML 202 and CML206 as testers
2000	ECA-DN001-11H	81	Double cross hybrids
	ECA-DN001-12H	60	3-way hybrids involving lines that combine well for low N efficiency
	ECA-DN001-13P	25	Open pollinated varieties, composites and synthetics. Intermediate
	ECA-DN001-14P	20	Open pollinated varieties, composites and synthetics. – early maturity
2001	ECA-DTLN-HTB-	32	3-way hybrids with CML78 as the male parent

received 80 kg N/ha each season; half the nitrogen applied at planting and the rest at 7 weeks after crop emergence as side-dressing. The nitrogen was applied as urea and incorporated into the soil after application.

The trials were planted at a spacing of 75 cm between rows and 30 cm between hills in a row at one plant per hill. Each plot comprised of two rows 5 m long. The design was a balanced lattice. The entries were replicated three times if the trial was small and two times for those with many entries. Both the low and high N sites were planted the same day.

Data collected included establishment, days to tassel and pollen shed, plant and ear height, scores for diseases especially maize streak virus (MSV) disease, northern leaf blight and gray leaf spot (GLS) and grain yield. Genotypes were also checked for ear rot and ear tip cover. Diseases were scored at the scale of 1-5 whereby a score below 3 was considered acceptable under the local conditions. The two rows were harvested for yield determination. Grain yield was adjusted to 15% moisture content.

Data analysis was carried out using MSTAT-C software. Yield was used as the main determinant of performance. Entries were ranked on the basis of yield and the top 10 entries used to establish nitrogen use efficiency. An entry was considered efficient if it was among the top 10 under both low and high nitrogen conditions. The discussion of the results will therefore be on these.

RESULTS AND DISCUSSION

The soil analysis results indicated that the level of nitrogen was low enough for a nitrogen study. The organic matter content was 2.22% compared to the normal range of 3.0-6.0% and the percentage nitrogen in the soil was 0.2%. It was low in potassium and phosphorus but within good pH range for maize. The low percentage organic matter indicates that the soil has limited capacity for nitrogen mineralization. The analysis also indicates that phosphorus and potassium needed supplementation. The recommendation from the soil scientist indicated that the land was ready for nitrogen studies.

In the Trial 99101 only entry 11 was in the top 10 entries for both low and high N (Table 2). It had an average rank of 3. It had good reaction to diseases under both low and high nitrogen conditions. It also had the highest number of ears per plant under both nitrogen levels.

In Trial 99102 involving 3-way crosses of lines with CML 202 and CML 206 as male parents, entries 11 and 24 were among the top 10 highest yielding under both nitrogen conditions (Table 3). Both had CML 206 as the male parent. They both had a low ASI and had good reaction to diseases.

In Trial 99108, the local check, Longe 1, had the highest yield under both low and high nitrogen levels (Table 4). Also, entries 25 and 21 ranked high under both low and high nitrogen conditions.

In the Trial 99108 three entries were among the top 10 yielders. These were 33. 25 and 21. Entry 33 which yielded the highest under both N levels was the local check, which has some genes of pool 16 (Table 4). The yields were similar. It also had good MSV and GLS rating compared with the other entries. In the 99108 trial there was no difference between the low and high N sites suggesting that other factors such as the drought and termite damage had a stronger influence on yield than the nitrogen factor.

In the Trial 99110 four entries ranked higher than 10 under both low and high nitrogen conditions (Table 5). These were 6, 15, 52 and 60. Entry 15 had the highest average ranking of 1.5 followed by entry 60 with an average rank of 2.5; entries 6 and 52 had similar ranks (5 and 5.5, respectively). Entry 15 is a single cross of CML 202 and a line derived from P43CQ, entry 52 had TuxPSEQ while entries 6 and 60 had lines derived from M37W/ZM607.

In the Trial DN00l-11H which had double cross hybrids, two out of 70 entries ranked higher than 10 under both low and high nitrogen conditions (Table 6). These were entries 10 which had M37W/ZM607 germplasm and 55, LPSC4 and CML202 as one of the single crosses. Entry 10 ranked 5 and entry 55 ranked 10 under both conditions. Thus entry 10 could be considered quite sufficient compared with the rest. Among three-way hybrids planted in trial DN001-12H, three of them ranked high under both low and high N (Table 7). These were entries 10, 11 and 54. Entry 54 ranked highest under both high and Low N. It is made up of a line from 90323 crossed to CML 312 and then CML 373. Entries 10 and 11 are products of sister lines of P49SR with TUXPSEQ then crossed to CML 202 and CML 78 highest under both high and Low N. It is made up of a line from 90323 crossed to CML 312 and then CML 373. Entries 10 and 11 are products of sister lines of P49SR with TUXPSEQ then crossed to CML 202 and CML 78.

In the intermediate maturity open pollinated varieties (Trial DN001-13P), 4 entries showed stability over nitrogen levels (Table 8). The highest ranking was Longe 1, a local check, followed by another check PAN 5195 (entry 23) which is a hybrid. Entries 2 and 7 also ranked higher than 10

Table 2. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial 99101

LOW N						RANK	HIGH N					
Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)		Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)
23	76	0	196	1.1	5203	1	18	72	1	209	1.4	5401
41	73	3	181	1.1	5001	2	40	73	2	207	1.2	4210
11	76	1	200	1.3	4962	3	11	73	4	208	1.6	4155
50	78	1	170	1.0	4819	4	15	73	2	198	1.3	4101
10	78	1	174	1.3	4819	5	2	73	1	192	1.1	4093
24	75	3	148	1.1	4808	6	14	73	0	198	1.0	4042
1	77	1	181	1.0	4627	7	30	75	2	198	1.1	3950
5	75	1	179	0.9	4511	8	6	75	1	218	1.1	3887
49	80	1	159	1.0	4495	9	4	75	1	195	1.1	383
9	75	2	181	1.0	4307	10	26	74	1	186	1.1	3775
Trial Mean	77		170		3467			75		181		2999
LSD	2.0		6.7		413			4.2		5.4		277

Pedigrees of the entries ranking higher than 10 in either nitrogen level:

1. P43C9-56-1-1-1-4-B-BXCML254/CML202
2. LA POSTASEQC3-HI-2-2-3-2-1-#-#-B-BXCML258/CML202
4. LA POSTASEQC3-H17-1-2-3-2-1-#-#-B-BXCML258/CML202
5. P43C9-56-1-1-1-4-B-BXCML258/CML202
6. LPSC3-36-2-1-1-2-B-BXCML258/CML202
9. LPSC3-40-1-1-1-1-B-BXCML258/CML202
10. LA POSTASEQC3-HI-2-2-2-1-1=#-#-B-BXCML254/CML202
11. LPSC3-36-2-1-1-2-B-BXCML254/CML202
14. SPLC7F52-1-3-1-1-3-B-BXCML258/CML202
15. SPLC7F275-1-1-1-1-2-B-BXCML258/CML202
18. POOL OHYLLACORAC0#-4-3-#-1-1XCML254/CML202
23. TASEQ-SR/CML202
24. [CML247/CML254/CML202
25. LA POSTASEQC3-HI-2-2-3-2-1-#-#-B-BXCML258/CML206
30. LPSC3-36-2-1-1-2-B-BXCML258/CML206
40. LA POSTA SEQC3-H297-2-1-1-1-2-#-#-B-BXSPL254-1-2-3-2-2-B/CML206
41. LPSC3-36-1-1-2-1-B-BXSPL254-1-2-3-2-2-B/CML206
49. CML247/CML254/CML202/CML206
50. CML202/CML206XCML247/CML254

Table 3. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial 99102

LOW N						RANK	HIGH N					
Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)		Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)
13	77	0	199	1.4	5532	1	35	75	-9	201	0.9	4027
7	76	0	201	1.3	5081	2	36	74	5	188	1.1	3629
11	74	3	187	0.9	4704	3	37	72	1	196	1.0	3596
27	77	1	177	1.2	4624	4	15	73	2	175	1.0	2990
28	78	-2	192	1.3	4421	5	2	72	1	179	1.0	2904
26	77	1	205	1.1	4343	6	17	76	0	177	1.0	2900
24	77	2	190	1.2	4343	7	24	73	1	190	1.1	2841
34	76	0	182	1.1	4182	8	10	78	1	171	0.9	2744
23	78	0	179	1.4	4127	9	32	75	4	186	1.0	2717
12	75	2	193	1.1	4116	10	11	74	1	168	0.8	2696
Trial mean	76		176	1.1	3556			74		178		2458
LSD	6		32	0.2	2225			4		24		748

Pedigrees of the entries ranking higher than 10 in either nitrogen level.

2. CML339XTS6C1-F228-2-2-3-1-2-#-#-B/202
7. LPSC3-36-2-1-1-2-B-B/TS6C1-F118-1-3-1-2-#-#-B-B/CML202
10. LPSC3-71-1-2-1-1-B-B/CML258/CML206
11. LA POSTA SEQC3-HI-2-2-3-2-1-#-#-B-BXCML264/CML206
12. P43C9-1-1-1-1-1-B-BXCML264/CML206
15. LPSC3-36-1-1-2-1-B-BXCML264/CML206
17. CML254XCML340/CML206
23. LPSC3-36-1-1-2-1-B-BXCML254/CM206
24. P43C9-1-1-1-1-1-B-BXCML254/CML206
26. TS6C1-F62-2-1-3-1-2-3-3-B-BXCML271/CML206
27. TS6C2-32-1-1-1-1-B-BXCML271/CML206
28. LA POSTA SEQC3 HI-2-2-1-2-1-#-3-B-BXTS6C1-F118-1-1-3-1-2-3-#-B-B/CML206
32. SYNTHETIC-DR-SR/CML206
34. CML202/CML206XCML247/CML254
35. HB512 CHECK1
36. H511 CHECK 2
37. PH3253 CHECK 3

Table 4. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial 99108

LOW N					RANK	HIGH N				
Entry No.	Days to anthesis	ASI	Ears/plant	Yield (kg/ha)		Entry No.	Days to anthesis	ASI	Ears/plant	Yield (kg/ha)
33	73	1	1.1	4618	1	33	72	1	1.0	4535
25	63	1	1.0	3088	2	18	61	1	1.0	3172
16	63	6	1.1	2902	3	4	64	5	0.9	3071
28	65	2	1.0	2865	4	25	65	0	1.1	3006
6	61	1	1.1	2830	5	12	64	3	1.0	2819
15	64	2	1.4	2822	6	26	64	1	0.9	2803
21	63	0	1.0	2762	7	21	61	3	1.1	2727
17	63	2	1.2	2580	8	27	65	1	1.0	2619
7	67	1	1.2	2540	9	10	62	0	0.9	2345
32	60	1	1.0	2473	10	22	63	2	1.0	2302
Trial mear	64			1701			63			2059
LSD $_{0.05}$	4			1888			5			1394

Pedigrees of the entries ranking higher than 10 in either nitrogen level:
4 G16SeqC1-15-2-1-2-2-2-BXG15C22#13#-1-3-4-1-1-BB/KATUMANI
6. G16SeqC1-58-1-1-1-2-4-BXG15C22H13#-1-3-4-1-1-B-B/KATUMANI
7. SPEC6F74-1-4-1-1-2-B-BXG15C22H12#-1-3-4-1-1-B-B/KATUMANI
10. G16SeqC1-58-1-1-1-1-1-BXG16C19F219-5-1-13-2-B-#-B/KATUMANI
12. SPEC7F60-1-2-1-1-1-B-BXG16C19F219-5-1-1-3-2-B-#/KATUMANI
15 [K64R/P30-SR]-82-2/[K64R/P30-SR-87-4-7-3-4-B-B-B-B/KATUMANI
16. [P30/945//M162W/MSR]97-TRIALS SEED/KATUMANI
17. [VAR/TEMP.HILANDPOP]-##/KATUMANI
18. TEWF-DRTOLSYN1/K64R/P30-SR(S2#)]##/KATUMANI
21. AC8730-SR-#-#/KATUMANI
22. DMSREW96-F2-3/KATUMANI
25. [EARLY-MID-2/PL16-SR]-#/KATUMANI
26. [EV7992/POOL16-SR]#BSISEL-F3/KATUMANI
27. [ZS225/[POOL16-SR]]F2-SI-F3/KATUMANI
28. [DMRESR-W]#b9EARLY SEL]-#/KATUMANI
32. DILC1 CHECK 3
33. LOCAL CHECK LONGE 1

Table 5. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial 99110

LOW N						RANK	HIGH N					
Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)		Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)
15	77	1	199	1.0	6860	1	6	71	-3	182	1.0	6027
60	78	0	177	1.0	5767	2	15	79	-4	185	0.9	6019
13	74	-1	185	1.4	5427	3	60	76	0	178	1.1	5670
61	78	-1	158	1.1	5338	4	51	71	0	169	1.0	5284
49	75	0	179	1.1	5299	5	52	77	-2	165	1.0	4959
52	74	-1	191	1.1	5221	6	3	72	-1	171	0.9	4808
20	75	-3	169	1.2	5116	7	48	72	0	176	0.9	4796
63	77	-1	154	1.1	5064	8	59	72	0	167	1.0	4780
6	74	-1	169	1.1	4854	9	10	75	-2	147	1.0	4523
19	78	0	177	1.0	4760	10	57	72	-1	165	0.9	4510
Trial Mean	77		164		3652			76		157		3416
LSD	4		26.4		2192			5		25.5		1672

Pedigrees of the entries ranking higher than 10 in either nitrogen level.
3. IKENE8149SR-68-2-BBB-6-BB-B-B-B/CML202
6. M37W/ZM607#bf37SR-2-3SR-6-2-X]-8-2-X-1-B-B-B/CML202
10. LATA-F2-138-1-3-1-B-B/CML202
13. .LPSC3H144-1-2-2-2-2-#-B-B-B/CML202
15. P43C9-1-1-1-1-1-B-B-B/CML202
19. CML312/CML202
20. CML258/CML202
48. DTP2WC4H255-1-2-2-B-B-B/CML202
49. SPLC2F182-1-2-2-B-B-B/CML202
51. [[TUXPSEQ] C1F2/P49-SR]F2-45-5-1-2-B/CML202
52. [[TUXPSEQ]C1F2/P49-SR]F2-45-7-5-1-B/CML202
57. INTB-91-1-2-2-1-B-B/CML206
59. [[TUXPSEQ]C1F2/P49-SR]F2-45-5-5-1-B/CML206
60. M37W/ZM607#bf37SR-2-3SR-6-2x]-8-2-x-1-B-B-B/P49C3-1-1-1-1-1-B-B-B
61. CML202/CML206XCML247/CML254
63.. CML202/CML206XCML247/CML254

Table 6. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial DN001-11

LOW N							HIGH N					
Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)	RANK	Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)
8	64	3	176	1.1	9246	1	3	67	2	164	1.1	10178
19	65	4	155	1.0	8982	2	45	66	3	168	1.1	10055
37	66	3	170	1.1	6965	3	39	66	3	180	1.1	10050
10	66	3	181	1.1	6952	4	46	65	4	169	1.3	9946
79	67	3	152	1.1	6825	5	58	65	1	158	1.1	9925
1	66	3	174	1.2	6808	6	10	65	3	173	1.2	9440
64	65	3	158	1.1	6677	7	2	66	2	178	1.3	9364
18	67	3	140	1.1	6501	8	38	65	4	161	1.1	9109
20	65	3	150	1.0	6466	9	13	65	4	166	1.1	8966
55	65	5	145	1.0	6564	10	55	65	3	152	1.1	8950
Trial Mean	70		151		5328			65		151		7124
LSD	3		20.5		2637			0.4		3.4		443

Pedigrees of the entries ranking higher than 10 in either nitrogen level:

1. M37W/ZM607#Bf37SR-2-3-SR-6-2X]-8-2-X1-B-B-B/CML202/P501C1#303-1-1-1-2-1-1-B/CML389
2. LPSC4F273-2-2-1-B-B-B/CML202/P501C1#303-1-1-1-2-1-1/CML389
3. P43C9-1-1-1-1-1-B-B-B/CML202/P501C1#303-1-1-1-2-1-1B/CML389
8. [[TUXPSEQ]C1F1/P49-SR]F2-45-5-1-2-B/CML202/P501C1#303-1-1-12-1-1-B/CML389
10. M37W/ZM607#Bf37SR-2-3SR-6-2—X]-8-2-X-1-B-B-BB/P43C9-1-1-1-1-1-B-B-B/P501C1#303-1-1-12-1-1
13. 90323(B)-1B-6-B-B/CML312/P501C1#303-1-1-1-2-1-1-B/CML389
19. ZM605C3F1-17-1-B-1-B/CML202/CML391/CML384
20. LPSC4F273-2-2-3-B-B-/CML202/CML391/CML384
37. CML202/CML216.CML391/CML384
38. M37W/ZM607#6f37SR-2-3SR-6-2-X]-8-2-X-1-B-B-B/CML202/CML395/CML312
39. P43C9-1-1-1-1-1-B-B-B/CML202/CML395/CML312
45. [[TUSPSEQ]C1F2/P49-SR]F2-45-7-5-1-B/CML202/CML395/CML312
46. M37W/ZM607#Bf37-SR-2-3SR-6-2X]-8-2-X-1-B-B-B/P43C9-1-1-1-1-1-B-B-B/CML395/CML312
55. LPSC4F273-2-2-1-B-B-B/CML202/[MSRXPL9]C1F2-176-4XCML312
58. LPSC4F273-2-2-3-B-B-B/CML202/MSRXPL9/C1F2-176-4XCML312
64. M37W/ZM607#Bf37SR-2-3-SR-6-2-X]-8-2-X-1-B-B-B/P43C9-1-1-1-1-1-B-B-B/[MSRXPL9]C1F2-176-4
79. PAN5195 CHECK 3
81. LONGE 2H

Table 7. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial DN001-12H

LOW N							HIGH N					
Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)	RANK	Entry No.	Days to anthesis	ASI	Plant height	Ears/plant	Yield (kg/ha)
54	64	4	142	1.0	7272	1	54	65	2	149	1.1	10599
4	67	2	137	1.0	6619	2	21	63	4	153	1.1	9705
10	59	7	144	1.1	6558	3	43	63	5	135	1.1	9637
51	60	3	152	1.1	6431	4	13	63	2	153	1.0	9519
50	65	3	133	1.0	6290	5	11	61	4	150	1.1	9433
11	60	3	148	1.0	6287	6	53	64	3	140	1.1	9429
25	68	1	152	1.1	6278	7	44	65	4	141	1.1	9428
27	65	3	145	1.4	6272	8	10	61	3	145	1.0	9307
40	67	2	154	0.8	6248	9	45	66	3	141	1.1	9246
14	64	2	141	1.0	6139	10	31	65	2	153	1.5	9146
Trial mean	64		140		4945			64		144		7462
LSD	5.2		23.2		2745			0.6		3.1		398

4. P43C9-1-1-1-1-1-B-B-B/CML202/CML78
10. [[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202/CML78
11. [[TUXPSEQ]C1F2/P49-SR]F2-45-7-5-1-B/CML202/CML78
13. [EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-10-7(I)-X-X-X-2-B-B-1-B/CML202/CML78
14. P43SR-4-1-1-2-3-1-3-B/CML265/CML78
21. CML202/CML216/CML78
25. LPSC4F273-2-2-1-B-B-B/CML202/CML384
27. LPSC4F273-2-2-3-B-B-B/CML202/CML384
31. [[TUXPSEQ]C1F2/P49-SR]F2-45-7-5-1-B/CML202/CML384
40. [EV7992#/EV8449-SR]C1F2-334-1(OSU9i)-8-2)(I)-1-2-B-/CML202/CML384
43. CML-312/CML202/CML373
44. CML-258/CML202/CML373
45. LPSC4F273-2-2-1-B-B-B/CML206/CML373
50. P502C1#-771-2-2-1-3-1-3-B/P501C1#-886-3-1-1-B-B-B/CML373
51. THG-B-76/EV8725SR-3-2-#-B1-2-B1/CML258/CML373
53. P502C1#-771-2-2-1-3-1-3-B/CML258/CML373
54. 90323(B)-1-B-6-B-B/CML312/CML373

Table 8. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial DN001-13P

LOW N							HIGH N					
Entry No.	**Days to anthesis**	**ASI**	**Plant height**	**Ears/plant**	**Yield (kg/ha)**	**RANK**	**Entry No.**	**Days to anthesis**	**ASI**	**Plant height**	**Ears/plant**	**Yield (kg/ha)**
25	65	5	132	1.1	5936	1	16	66	1	128	1.1	11291
5	63	3	157	0.9	5043	2	25	67	3	133	1.0	6889
14	64	5	134	0.9	4639	3	20	66	3	144	1.0	6866
17	67	1	161	0.9	4606	4	23	66	3	163	1.0	6729
2	67	4	158	0.9	4537	5	3	66	3	159	1.0	6488
4	65	3	135	0.9	4405	6	7	63	3	129	1.0	6424
23	68	4	132	1.0	4365	7	4	62	2	143	1.1	6340
20	65	4	132	0.9	4148	8	17	66	1	171	1.0	6201
6	63	5	146	0.9	3951	9	24	63	3	139	0.9	6114
7	62	4	118	0.9	3901	10	2	66	3	164	1.0	5962
Trial means	66		1.36		3529			66		149		5651
$LSD_{0.05}$	1.5		8.7		550			0.8		6.2		1717

Pedigrees of the entries ranking higher than 10 in either nitrogen level:
2. Staha-msv-#
3. Kilima-st-msv-#
4. SADVILA-#-#
5. SADVILB-#-#
6. Pop32srC1F2-#
7. Nip 25-#
14. ECAVL-1
16. TUXPENO SEQUIA 6(TS6)-#
17. LA POSTA SEQUIA(LPS)SYNTHETIC-#
20. SYNTHETIC-NUE-SR-#
23. PAN5195 CHECK
24. C5051SR
25. LONGE 1 LOCAL CHECK

Table 9. Performance of maize varieties ranking higher than 10 when grown under low and high nitrogen levels.
Trial DN001-14P

LOW N							HIGH N					
Entry No.	**Days to anthesis**	**ASI**	**Plant height**	**Ears/plant**	**Yield (kg/ha)**	**RANK**	**Entry No.**	**Days to anthesis**	**ASI**	**Plant height**	**Ears/plant**	**Yield (kg/ha)**
20	68	4	132	0.9	5526	1	16	61	4	150	1.2	7092
9	61	6	146	1.1	4857	2	4	57	3	152	1.0	6103
7	59	5	151	1.1	4781	3	8	58	5	153	1.0	6002
18	65	4	143	0.9	4761	4	20	64	5	140	0.9	5973
6	60	4	135	1.0	3957	5	9	61	4	165	0.9	5619
16	61	7	153	0.9	3920	6	7	58	5	159	0.9	5433
4	60	3	143	1.0	3754	7	10	60	5	139	1.0	5403
11	59	1	132	1.0	3741	8	6	59	3	149	0.8	5335
8	62	3	142	1.0	3333	9	11	56	6	146	1.0	5230
5	59	4	131	1.2	3316	10	17	62	4	154	0.9	4856
Trial mean	61		140		3318			60		148		4357
$LSD_{0.05}$	1.0		8.7		522			0.9		7.3		607

Pedigrees of the entries ranking higher than 10 in either nitrogen level:
4. SADVEA-#-#
5. SADVEB-#-#
6. SADVIA-#-#
7. SADVIB-#-#
8. EARLY/SADVILA-#-#
9. EARLY/SADVILB-#-#
10. Pop49srC1F2-#
11. Senematiali94EW(1)#1#1#
16. Longe 1
17. EMCO Check
18. HB513 Check 2
20. Longe 2H

(Trial DN001-13P), 4 entries showed stability over nitrogen levels (Table 8). The highest ranking was Longe 1, a local check, followed by another check PAN 5195 (entry 23) which is a hybrid. Entries 2 and 7 also ranked higher than 10 under both nitrogen conditions.

In the early group of open pollinated varieties comprised of 20 entries, seven ranked above 10 under both low and high nitrogen levels (Table 9). These were entries 4, 6, 8, 9, 11, 16, and 20 which was the highest ranking (averaged over the two nitrogen levels. The highest average ranking was Longe 2H with the average rank of 2.5. It ranked higher under low N than when grown under high N conditions. This is contrary to the common belief that hybrids will not yield well under low fertility conditions. It was followed by Longe 1 and SADVILB-H-H which are open pollinated varieties.

Among the three–way hybrids planted in the Drought Tolerant Low Nitrogen trial (ECA-DTLN-HTB-15), 4 hybrids were found to be low nitrogen use efficient (Table 10). These were entries 5, 22, 24 and 26. Entry 26 was the

Table 10. Performance of Three-Way hybrids with CML 78 as the male parent evaluated under low and high nitrogen levels

Trial ECA-DTLN-HTB-15

LOW N							HIGH N					
Entry No.	**Days to antheis**	**ASI**	**Plant ht(cm)**	**Ears /plant**	**Yield kg/ha**	**RANK**	**Entry No.**	**Days to antheis**	**ASI**	**Plant ht(cm)**	**Ears /plant**	**Yield kg/ha**
26	64	4	158	1.1	3420	1	26	62	3	191	1.0	7766
27	65	3	151	1.0	3251	2	10	64	1	206	1.0	7411
1	64	4	165	1.0	3224	3	15	60	1	184	1.0	6841
5	63	6	156	1.0	3100	4	22	61	2	210	1.1	6790
21	65	4	147	1.0	3008	5	24	63	2	205	0.94	6708
6	64	4	150	1.4	2981	6	23	60	0	199	1.0	6687
29	68	1	143	1.0	2927	7	9	63	1	214	0.97	6558
3	65	6	156	1.1	2851	8	13	62	2	196	1.0	6556
24	67	3	161	1.0	2800	9	5	61	0	201	0.9	6428
22	65	3	160	0.9	2775	10	25	61	2	197	1.0	6429
Trial mean	64	7	145	1.0	2880			62				6104
LSD	2.87		26.7		1436			2.91				1165
CV	2.57		11.3		37.6			2.79				11.7

Pedigree of the entries:
1. [[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202/CML78
3. CML388/CML202/CML78
5. LPSC3H144-1-2-2-2-2-#-B-B-B/CML202/CML78
6. LPSC3H144-1-2-2-4-#-B-B-B/CML202//CML78
9. P21MRRSC2-19-1-2-2-2-B-B-B/CML202//CML78
10. CML444/CML202//CML78
13. CML373/CML202//CML78
15. CML442/CML444//CML78
21. CML312/CML373//CML78
22. CML312/CML247//CML78
23. CML395/CML247//CML78
24. CML197/CML216/CML78
26. CML197/CML247//CML78
27. CML197/CML254//CML78
29. CML216/CML373//CML78

highest ranking with average of 1. It was the highest yielding under both low and high Nitrogen conditions followed by entry 5 and entries 22 and 24. Entry 5 had the highest ASI under Low N conditions and yet ranked 5 suggesting that ASI was not important under the conditions of the trial. The yield under high nitrogen conditions was more than twice that obtained under low nitrogen both for the highest ranking entry and the overall trial mean. The four entries had good disease rating and their maturity range judged from days to anthesis would be within the reasonable range for the local conditions. The plant height under both low and high nitrogen condition was acceptable.

A lot of entries were tested over the three years. Out of the 411 hybrids and 45 open pollinated varieties that were evaluated for low nitrogen use efficiency, fifteen hybrids and 9 open pollinated varieties were nitrogen use efficient if the criterion of ranking above 10 is discriminating enough. Among the hybrids, a number of lines were common. These included lines derived from TUXPSEQ P43C9, M37W, LPSC2 and to some extent Pool 16, CML 202 and CML 206. These lines excelled in most of the combinations they were involved in. The local varieties, Longe 1 and Longe 2H were among the top performers in some of the trials. At group level the open pollinated variety selections were more efficient than the hybrids. This could relate to the selection that went into constituting them but it could also relate to the inherent stability of the open pollinated varieties.

CONCLUSION

A number of lines have shown the potential for being nitrogen use efficient. The lines that contributed towards the efficiency could be used directly in the hybrid combinations in which they were involved. The hybrids could be further tested to verify the results obtained, evaluated with farmers to identify those that would be suitable to the production domains and released as commercial varieties. The scope could be extended by using the same lines to form new combinations or to cross them with other proven lines to form new hybrids. It is suggested that the 15 hybrids that were found to be efficient be grown in a single trial and be evaluated in larger plots in order to determine the best which should be further evaluated using the mother and baby methodology and National Performance Trials for eventual release. The open pollinated varieties could also be evaluated for eventual release. They would have to be tested for acceptability for both the local and export market.

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DEVELOPING LOW-N TOLERANT MAIZE VARIETIES FOR LOW AND MID-ALTITUDE SUB-HUMID AGRO-ECOLOGIES OF BURUNDI

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ABSTRACT

During the last two decades, the Burundi maize breeding programme concentrated its efforts on developing open pollinated varieties that are high yielding, early and streak resistant. For this reason, only OPVs have been recommended to Burundian farmers until today. With the current agricultural development and the need for intensification of the maize crop, the national programme has started a hybrid testing project taking into consideration the major stresses such as low N, stem borers and drought. During the 2000/2001 growing season, a trial composed of East and Central Africa drought and low N hybrids was carried out under medium stressed conditions at Moso research station; with the aim of evaluating the grain yield potential of good top crosses, three-way cross and double cross hybrids. Five commercial hybrids widely grown in East Africa together with the locally recommended variety served as checks. The results indicated that the best hybrids were: LPSC3-36-2-2-1-1-B-B X CML 258/CML202, LPSC3-36-2-1-1-3-B-B- X CML258/CML206, P.72 reformed-s2-#-s2-##-1-1-2-2-B XCML258/CML202, LA POSTA SEQC3-H1-2-2-2-1-1-#-#-B-B X CML254/CML202, LA POSTA SEQC3-H297-2-1-1-1-2-#-#-B-B X SPL254-1-2-3-2-2-B/CML202. These hybrids have potential for future use in the low and mid-altitude sub-humid agro-ecological zone of Burundi.

INTRODUCTION

In Burundi, maize is the most important cereal as well as one of the most important crops in terms of total production and total area under cultivation (Rufyikiri, 1989).

One of the big problems farmers complain about is the low soil fertility. Very few farmers apply enough farmyard manure or inorganic fertilizers (Nijimbere, 1998). Stem borers are thought to be responsible for 30 % of yield loss. Drought is a serious problem in the ecologies between 800 masl and 1,400 masl, covering the natural regions of Bugesera, Bweru, Buyogoma, Moso, Buragane and Imbo.

The genetic improvement of maize started in Burundi since the 1950s. The breeding work of the programme has aimed at improving populations rather than developing hybrids. This was in conformity with the level of agricultural development in the country where open-pollinated varieties of maize were recommended because of the ease of seed production, the maize breeding programme is embarking on a hybrid testing project using the drought and low-N tolerant germplasm developed from the East and Central Africa Regional Programme. This particular experiment was conducted in order to find a suitable substitute for the varieties SNSYNF3 (89, Elite) and EV32SRBC2F2. The first variety is susceptible to *H. turcicum* whereas the second is not high yielding; both are released in the marginal rainfall low- and mid-altitude ecologies.

MATERIALS AND METHODS

Maize germplasm listed below was supplied by CIMMYT office Kenya in order to be evaluated for grain yield and adaptation in Burundi. This trial was composed of 56 entries including 45 three-way cross hybrids made of drought and low N tolerant tropical hybrids crossed with 2 mid-altitude testers (CML202 and CML206), 2 topcross hybrids (cross between drought tolerant synthetics and CML202 and CML206), 3 double cross hybrids (cross between one lowland single cross and one mid-altitude single cross), 5 checks (commercial hybrids grown in East Africa), and one local check SNSYNF3 (89, Elite) (Table 1).

The trial was planted mid-December in a fairly uniform field located in Moso research station, with a poor red clay loam soil. Ten tonnes of farmyard manure were applied without any inorganic fertilizer in order to raise the fertility a bit but still maintain a medium stressed soil. The experimental design was a lattice (alpha 0,1) with 7 plots (14 rows) per block with 2 replications. Although designed as an alpha-lattice, the trial has been analysed as a randomized complete block design without violating any of the assumptions of the model. The plot size was 1.6 m wide by 5 m long (2 row plot) with a spacing of 80 cm between the rows and 50 cm between the hills of 2 plants after thinning.

The trial was hoe weeded and no measures were taken against pests. Data were recorded on plants from the entire 2 row plot leaving out the plants of the first hill on each end of the row for the following characters: Plant stand count, number of days from planting to 50 % anthesis, total number of plants at harvest, plant height, ear height, number of ears harvested, number of rotten ears, ear aspect, score of disease, field weight and moisture content. Plot yields were transformed to tonnes per hectare (t/ha) adjusted to a uniform 14 % moisture content and a coefficient of 0.8 was used as a shelling percentage. Plant stand was done for each plot after thinning. The anthesis date was determined by writing the number of plants on the row tag first; and then by determining the date when 50% of the plants had shed pollen. The plant height was determined by measuring representative plants from the ground to the insertion of the top ear. The plant number at harvest was determined by counting all the plants just before harvest leaving out the plants of the first hill on each end of the row. The number of stem lodging was also counted before harvest. The number of ears was counted discarding the ears from the first hill on each end of the row; an ear being defined as a cob with at least one grain. Ear rot was scored on a scale from 1 (clean, no rot) to 5 (completely

Table 1. Pedigrees of East and Central Africa Hybrids in Evaluations

Variety name	Entry number
P43C9-56-1-1-2-2-B X CML254/	1
LAPOSTA SEQC3-H1-2-2-3-2-1-#-#-B-B X CML258/CML202	2
LAPOSTA SEQC3-H17-1-2-3-1-4-#-#-B-B X CML258/CML202	3
LAPOSTA SEQC3-H17--1-2-3-2-1-#-#-B-B X CML/CML202	4
P43C3-56-1-1-1-4-B-B X CML258/CML202	5
LPSC3-36-2-1-1-2-B-B X CML258/CML202	6
LPSC3-36-2-1-1-3-B-B X CML258/CML202	7
LPSC3-36-2-2-1-1-B-B X CML258/CML202	8
LPSC3-36-1-1-1-1- B-B X CML258/CML202	9
LAPOSTA SEQC3-H1-2-2-2-1-1-#-#-B-B X CML254/CML202	10
LPSC3-36-2-1-1-2- B-B X CML254/CML202	11
TS6C2-2-1-1-2-2-B-B X CML271/CML202	12
SPLC7F183-1-2-1-2-1-2-B-B X CML254/CML202	13
SPLC7F52-1-3-1-1-3-B-B X CML258/CML202	14
SPLC7F275-1-1-1-1-2-B-B X CML258/CML202	15
LAPOSTA SEQC3-H297-2-1-1-1-2-#-#-B-B X SPL254-1-2-3-2-2-B/CML202	16
LPSC3-36-1-1-2-1- B-B X SPL254-1-2-3-2-2-B/CML202	17
POOL PHYLLACORAcO#-4-3-#-1-1 CML254/CML202	18
P.22 DMR-s2-F1-#-s2-##-1-1-3-1-B X CML254/CML202	19
P.72 Reformed-s2-#-s2-##-1-1-1-3-B X CML258/CML202	20
P.72 Reformed-s2-#-s2-##-1-1-2-2-B X CML258/CML202	21
La posta Sequia (LPS) Synthetic /CML202	22
TASEQ-SR/CML202	23
[CML247/CML254]/CML202	24
P43C9-56-1-1-2-2-B X CML254/CML206	25
LAPOSTA SEQC3-H1-2-2-3-2-1-#-#-B-B X CML258/CML206	26
LAPOSTA SEQC3-H17-1-2-3-1-4-#-#-B-B X CML258/CML206	27
LAPOSTA SEQC3-H17--1-2-3-2-1-#-#-B-B X CML/CML206	28
P43C9-56-1-1-1-4-B-B X CML258/CML206	29
LPSC3-36-2-1-1-2-B-B X CML258/CML206	30
LPSC3-36-2-1-1-3-B-B X CML258/CML206	31
LPSC3-36-2-2-1-1-B-B X CML258/CML206	32
LPSC3-40-1-1-1-1- B-B X CML258/CML206	33
LAPOSTA SEQC3-H1-2-2-2-1-1-#-#-B-B X CML254/CML206	34
LPSC3-36-2-1-1-2-B-B X CML254/CML206	35
TS6C2-2-1-1-2-2-B-B X CML271/CML206	36
SPLC7F52-1-3-1-1-3-B-B X CML258/CML206	37
SPLC7F275-1-1-1-1-2-B-B X CML258/CML206	38
SPLC7F275-1-1-1-1-2-B-B X CML258/CML206	39
LAPOSTA SEQC3-H297-2-1-1-1-2-#-#-B-B X SPL254-1-2-3-2-2-B/CML206	40
LPSC3-36-1-1-2-1- B-B X SPL254-1-2-3-2-2-B/CML206	41
POOL PHYLLACORAcO#-4-3-#-1-1 CML254/CML206	42
P.22 DMR-s2-F1-#-s2-##-1-1-3-1-B X CML254/CML206	43
P.72 Reformed-s2-#-s2-##-1-1-1-3-B X CML258/CML206	44
P.72 Reformed-s2-#-s2-##-1-1-2-2-B X CML258/CML206	45
La posta Sequia (LPS) Synthetic /CML206	46
TASEQ-SR/CML206	47
CML202/CML206 X CML247/CML254	48
CML247/CML254 X CML202/CML206	49
CML202/CML206 X CML247/CML254	50
HB512 CHECK 1	51
H511 CHECK 2	52
HPB3253 CHECK 3	53
HBCG4141 CHECK 4	54
HB5222SR CHECK 5	55
LOCAL CHECK 6	56

rotten). All ears, including the rotten ones were kept for measuring field and grain weight. Ear aspect was scored on a scale from 1 (nice and uniform cobs, flint or semi flint) to 5 (ugly cob, too dent). Diseases were scored (1-5) where 1 was equal to none or very few symptoms, 3 equal to intermediate and 5 was equal to very susceptible. The weight of the ears per plot was taken directly after harvest and grain moisture was measured.

RESULTS AND DISCUSSION

The results reported in Table 2 were obtained under a fairly uniform environment so that the variations observed were due to the differences in the genotypes. Plant stand ranged from 6.8 % to 92 % with entry 11 having the lowest and entry 32 having the highest followed by entry 31. The differences observed were not significant and most of the entries were falling between 67 % and 90 %. High plant stand corresponded with high yield in most cases. Plant height indicated that plants were generally medium to tall ranging from 166 cm in entry 49 to 266 cm in entry 51

Table 2. Agronomic characteristics of drought and low-N tolerant hybrids at Moso Research Station, 2000

Entry	Yield (T/ha	Plant stand (%)	Anthesis date	Plt Ht (cm)	Ear Ht (cm)	Root Lodging	Shoot Lodging	Plt at harvest	Ears harvested	Ear rot	Ear aspect	MSV	E. Turci
8	8.40	84.0	67	238	117	0	2	30	35	0	1.5	2.5	2
31	7.79	89.7	67	244	119	0	1	31	33	0	2	2.5	2
21	7.78	87.5	66	201	96	0	0	31	36	1	2	2.5	1
34	7.68	77.2	67	241	114	0	1	27	39	1	2	2.5	3
16	7.48	73.8	68	228	113	0	0	28	40	1	2	2.5	1.5
35	7.24	82.9	68	226	107	0	1	30	38	0	1.5	2	3
37	7.20	76.1	68	222	109	0	1	27	35	0	2	3.5	2.5
9	7.19	77.2	70	219	100	0	2	27	31	0	1.5	2.5	2
3	7.06	73.8	68	264	141	0	0	23	33	3	2.5	2.5	2
32	6.90	92.0	67	231	92	0	1	32	32	1	2	2.5	2
22	6.86	67.0	66	219	104	0	1	23	29	1	2.5	3	2
14	6.84	67.0	64	234	101	0	0	24	35	1	2	2.5	1
4	6.67	70.4	69	238	120	0	1	23	29	2	2	2.5	1
49	6.55	78.4	68	166	98	0	0	28	31	1	2	2.5	2.5
44	6.46	77.3	68	186	86	0	1	27	31	1	2.5	2	2.5
26	6.43	70.4	69	196	79	0	1	23	29	1	2.5	2.5	3
42	6.43	87.5	69	208	87	0	0	31	32	0	2	3	3.5
18	6.34	72.7	69	213	89	0	0	26	35	1	2	2.5	2
12	6.37	85.2	69	236	118	0	1	28	31	0	2	2	2
47	6.37	87.5	69	201	78	0	1	30	33	0	2	3	2.5
10	6.33	67.0	70	219	112	0	1	23	39	1	2	3.5	1.5
38	6.26	84.1	70	210	80	0	2	30	34	1	2.5	3	3.5
5	6.25	64.7	67	230	123	0	1	21	28	1	2.5	2.5	2.5
6	6.19	60.2	68	231	110	0	0	20	26	0	2	2.5	3
20	6.15	59.1	66	296	100	0	0	20	25	1	2	2	1
30	6.09	55.1	69	214	80	0	0	24	40	0	2	2.5	2
40	6.94	77.0	67	221	98	0	1	29	29	0	2.5	3	2.5
1	6.82	72.7	68	234	127	0	1	25	35	2	2.5	3	1.5
15	5.78	73.8	69	226	98	0	1	26	32	2	2	3	2.5
48	5.78	81.8	67	220	106	0	2	28	34	1	2.5	3	2.5
28	5.75	81.8	70	210	94	0	0	29	31	0	2.5	3	2.5
13	5.70	61.3	70	235	116	0	0	21	35	0	2.5	2	1
43	5.61	82.9	69	216	97	0	2	29	26	1	2.5	3	4
7	5.63	59.1	64	244	125	0	0	19	22	2	2	2	1.5
19	5.61	55.7	70	229	104	0	0	17	29	0	2.5	2.5	1
46	5.48	76.1	67	209	106	0	0	27	31	3	3	3	2
41	4.46	72.7	69	225	104	0	2	24	24	2	2.5	2	2
29	5.41	60.2	69	205	94	0	1	20	34	1	2	2.5	1.5
39	5.31	80.6	69	229	99	0	0	28	27	0	2.5	3	1.5
17	5.10	73.8	68	223	103	0	1	19	30	2	3	2	1
25	5.02	75.0	68	194	92	0	2	25	19	0	2.5	3.5	3
23	4.56	38.6	68	224	100	0	1	13	23	0	2	2	1
50	4.52	60.2	69	210	103	0	0	20	24	1	2.5	2.5	2.5
36	4.41	59.1	69	195	76	0	1	21	23	2	3	2.5	2
45	4.39	67.0	67	208	95	0	1	18	23	1	2.5	3	2.5
33	4.07	53.4	70	195	77	0	1	18	18	1	2	2.5	1.5
53	3.93	65.9	62	209	99	0	0	21	22	4	3.5	3.5	1
2	3.64	28.4	70	219	103	0	0	9	13	2	2.5	2.5	2
56	3.60	55.7	65	225	112	0	4	17	22	4	3.5	2.5	2
24	3.60	29.5	67	189	91	0	0	11	16	1	2.5	2	1
27	3.57	55.7	70	215	78	0	1	20	24	1	3.5	2.5	2
52	3.42	70.4	63	230	117	0	1	18	21	3	4	4	1
51	3.11	67.0	65	266	143	0	4	12	24	4	3.5	4	2.5
55	2.60	33.0	70	232	120	0	7	11	13	0	3.5	3	1
54	1.91	65.1	63	195	96	0	10	13	19	6	4.5	3.5	2
11	0.81	6.8	68	207	99	0	1	3	6	2	3	2.5	1
Mean	5.59	67.7	67.8	218.5	102.4			22.7	28.0	1.0	2.33	2.7	2.0
LSD5%	3.63	ns	3.3	33	23			ns	ns	2.3	1.053	ns	1.7
CV%	32.9	29.9	2.5	7.44	11.4			33.5	31.6	11.9	22.4	29.4	44.3

(check, hybrid HB512). The differences observed were highly significant with a low coefficient of variation.

Ear height was, to a certain extent, related to the plant height in that tall plants had high placed ears. The same tall hybrid HB 512 had the highest ear placement of 143 cm, but the lowest ear placement of 76 cm was in entry 36. The differences observed were highly significant with a good coefficient of variation. Days to 50 % anthesis showed highly significant differences between genotypes, the earliest hybrid with 62 days was entry 53(PHB3253, one of the checks); the upper limit of the range was 70 days with the entries 9, 10, 38, 5, 28, 13, 33, 2, 27 and 55. These observations on 50% anthesis were reliable as the coefficient of variation was very low. MSV and *H. turcicum* were the only diseases that occurred at significant level. The differences observed were not significant for MSV and susceptible entries were 51 and 52. Turcicum was even less severe as compared to MSV but the differences between genotypes were significant. The most susceptible genotype was entry 43.The ear rot was negligible except in the entries 54, 51, 56 and 53 (all checks) . There was no root lodging and the stalk lodging was also negligible. The number of plants at harvest ranged from 2 (4.5%) for entry 11 to 32 (72.7%) for entry 32. The differences observed were not significant but it was clear that genotypes with less plants yielded less. Number of ears harvested was mainly there to indicate the presence or absence of single eared, double eared and barren plant. All the entries had more ears than plants at harvest except entries 39 and 25. Ear aspect was based on of look and appeal and entries differed significantly. The best ears were found in entries 8, 35, and 9. The worst looking ears were of entries 54, 52, 55, 27, 51, 56 and 53 (all checks except 27). Differences among entries for yield were significant. The lowest yielder was entry 11 and entry 8 was the highest followed by 31, 21, 34 and 16.

CONCLUSION

The overall results indicated that almost all the hybrids evaluated in this trial were superior to the local checks. Only entries 11, 24, 27 and 2 did not perform better than the checks. The five best hybrids based on the yield and other agronomic characters were entries: 8, 31, 21, 34, and 16. More evaluations will be continued and recommendations made accordingly

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PRELIMINARY RESULTS ON THE RESPONSE OF 'NITROGEN USE EFFICIENT' OPV AND HYBRID MAIZE TO N FERTILIZER ON SMALLHOLDER FIELDS IN ZIMBABWE

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ABSTRACT

Southern Africa Drought and Low Fertility (SADLF) project breeders have developed 'nitrogen use efficient' (NUE) maize genotypes, selected under both managed nitrogen stress and optimum nitrogen conditions. An experiment was conducted during the 2000-2001 season to test the response of these genotypes to several rates of mineral N applied on farmers' fields. The aim was to determine whether the new genotypes offer better returns to the small amounts of expensive N fertilizer that farmers now apply. Four NUE genotypes (two hybrids and two open pollinated varieties (OPVs)) and a commercially available check hybrid (SC501) were evaluated at 0, 15, 30, 60 and 90 kg ha^{-1} of applied N. The experiment was conducted in four districts in sub-humid and semi-arid zones of Zimbabwe. Maize grain yield response to N was larger at the more fertile sites with short cropping histories, but there was no response at some depleted communal area sites. There was preliminary evidence that the elite NUE maize hybrids can provide more grain with modest amounts of N fertilizer than can the commercially available hybrid SC501. CML395/CML312//CML440 had the highest grain yield and CML395/CML312//CML440 and CML395/CML444//CML440 had the highest biomass at the responsive sites. At the less responsive degraded sites, there was no difference between varieties for any measured trait. There were some indications that experimental genotypes had higher NUEs. On average, varieties selected for NUE produced 17 kg grain per kg of N applied, whilst the check entry produced 10 kg grain per kg N applied. More data are required from infertile communal area fields that are so widespread in Zimbabwe.

Keywords: Hybrid maize, N fertilizer, N use efficiency, on-farm experiments, open-pollinated maize, Zimbabwe.

INTRODUCTION

Maize is the most important staple food crop grown by the majority of smallholder farmers in Southern Africa including Zimbabwe, even in some agro-ecological regions that are marginally suitable for maize. Two of the major biophysical limitations to greater smallholder maize productivity in the region are low soil nutrient status and an unreliable rainfall pattern (e.g. Piha, 1993; Waddington, Edmeades, Chapman and Barreto, 1995; Waddington and Heisey, 1997). Nitrogen is the mineral element required in greatest quantity by maize, thus efficient N uptake and use by maize plants is of fundamental importance to maize production systems in Southern Africa. However, the performance of most commercial maize hybrids and varieties under low nitrogen smallholder conditions in Southern Africa is limited because they were developed under very high nitrogen levels in good soils found on research stations. The high soil fertility status and optimum agronomic management of most breeding nurseries are opposite to the conditions in which the varieties are finally grown on smallholder fields in the region. In Zimbabwe, these farmers often have very sandy soils, characterized by low organic matter content and nitrogen and phosphorus deficiency. Those conditions are worsened by the negative nutrient budgets on most smallholder farms, as farmers cannot afford sufficient amounts of fertilizer (Piha, 1993; Waddington and Heisey, 1997). Nitrogen use efficient varieties give higher returns to N fertilizer applied. Even if farmers cannot afford to apply the recommended amount of fertilizers, they receive higher yields and farm incomes. This may allow farmers to purchase more inputs in the following year, or diversify crop production with legumes or cash crops as an equal quantity of maize can be obtained on a smaller area. Thus nitrogen use efficient varieties may have an expanding niche in many of our farming systems.

Ma and Dwyer (1998) identified fertilizer N as the most energy-consuming component of maize grain production and recommended that as the economic and environmental costs of excessive N rise, there should be more emphasis on the selection of varieties with greater N use efficiency (NUE). They demonstrated that NUE at low soil N levels may not be comparable to crop responsiveness to high soil N levels. Lafitte and Edmeades (1994a) at CIMMYT, Mexico suggested that selection for yield and NUE is more appropriate under low soil N conditions. During the early 1990s, CIMMYT developed lowland tropical maize genotypes with improved grain yield under low N, while maintaining yield under high N (Lafitte and Edmeades, 1994a and b). Improvements in grain yield under low N were reported to be between 75 and 100 kg ha^{-1} per cycle of recurrent selection and somewhat higher at high rates of applied N (Lafitte and Edmeades, 1994a and b; Lafitte and Bänziger, 1997). Additionally, improvement in the drought tolerance of maize (through better anthesis-silking synchrony under water deficit) was found to be closely associated with improved N use (Bänziger, Edmeades and Lafitte, 1999).

Southern Africa Drought and Low Fertility (SADLF) Project breeders began a programme in 1997 at CIMMYT-Zimbabwe to incorporate nitrogen use efficiency into maize genotypes that are broadly adapted to Southern Africa. The genotypes that are broadly adapted to Southern Africa. The programme has produced a range of experimental NUE and

Table 1. Site information for the variety-by-mineral N application experiment, Zimbabwe, 2000-2001.

Site	Natural region	Latitude	Longitude	pH ($CaCl_2$)	Organic carbon (%)	Soil texture	Available N (ppm)
Dombosh	IIB	17°40'S	31°10'E	4.5	0.43	Loamy sand	24.1
Chinyika	IIB	18°20'S	32°25'E	4.3	0.42	Sandy loam	3.7
Chihota	IIB	18°15'S	31°15'E	4.5	0.23	Medium grain sand	13.0
Zimuto	IV	19°50'S	30°55'E	4.4	0.25	Medium grain sand	19.0

drought tolerant OPVs and hybrids that are now being widely tested and distributed in the region (e.g. Bänziger and De Meyer, 2000; Bänziger, Pixley, Vivek and Zambezi, 2000; Vivek, Bänziger and Pixley, 2001; Bänziger, 2001). Some of these genotypes are evaluated in this study for their responsiveness to applied mineral N fertilizer on smallholder farms and on station in Zimbabwe. The aim was to determine whether they offer better returns to the small amounts of expensive N fertilizer that farmers now apply.

MATERIALS AND METHODS

The experiment was carried out at four locations in Zimbabwe: Domboshava (17°35'S, 31°10'E, 1,500m above sea level), Zimuto (19°50'S, 30°55'E, 1,200m above sea level), Chihota (18°15'S, 31°15'E, 1,450m above sea level), and Chinyika (18°20'S, 32°25'E, 1,300m above sea level). Domboshava is a station site, Chihota and Zimuto contain smallholder communal farms whilst Chinyika is a smallholder resettlement area. Chihota, Chinyika and Domboshava are in Natural Region IIb with an annual average rainfall of about 850 mm falling in five months, whilst Zimuto is in the semiarid Natural Region IV with an average annual rainfall of about 650 mm. Soils at the sites ranged from medium grain sands to loamy sands. Table 1 shows site details.

In each location except at Domboshava there was a fully replicated trial at the main site (termed the 'mother trial') and near the mother trial there were three single replicate trials (termed the baby trials). The sites were then Domboshava (site 1), Chihota Mother site (site 2), Chihota baby 1, baby 2, baby 3 (sites 3, 4, 5), Zimuto Mother site (site 6), Zimuto baby 1, baby 2, baby 3 (sites 7, 8, 9) and Chinyika mother site (site 10) and Chinyika baby 1, baby 2, baby 3 (sites 11, 12 and 13).

The experiment was arranged in a randomized complete block design with split plots. Fertilizer rates were placed on the main plots and genotypes were allocated to the sub plots. The experimental treatments were replicated three times at each mother site. Maize was planted at 90cm between rows and at a 30cm within-row spacing, with two seeds per station. Thinning to one plant per station, to give a projected plant population density of 37,037 plants ha^{-1}, was carried out at three weeks after maize emergence. The gross plot size was four rows, 4.5 m long and 3.6m wide, whilst the harvest plot was the central two rows, 3.3 m long and 1.8 m wide. Five maize genotypes; two experimental CIMMYT open pollinated varieties (ZM421 and ZM521), two experimental CIMMYT hybrids (CML395/CML 312//CML440 and CML395/CML444// CML440), and a commercial three-way cross hybrid control (SC501), were used. The genotypes were fertilized at 0, 15, 30, 60 and 90 kg N ha^{-1}, using ammonium nitrate. The entire N in the 15 and 30 kg N ha^{-1} treatments was applied at planting, as was 30 kg N ha^{-1} of the other N rates. The remainder of the N fertilizer was applied when the crop was approximately waist height. A uniform basal application of 60 kg P_2O_5 ha^{-1} (as single super phosphate) and 30 kg K_20 ha^{-1} (as muriate of potash) was applied at planting at all sites. The sites were not limed. Thiodan (1% granular) was applied four weeks after germination to control maize stalk borer. Experiment fields were hoe-weeded twice at four and eight weeks after planting.

The agronomic use efficiency of applied mineral N was calculated as: [Maize grain yield (kg) at an N level - Maize grain yield (kg) at zero N applied] / N applied (kg ha^{-1}).

RESULTS

After conducting a normal three-factorial ANOVA, all interaction effects except for variety-by-N interactions were non-significant, indicating that varieties responded differently to N levels at different sites. Error variances, however, were not homogeneous in this set of trials. Site-by-N-by-variety interactions became non-significant once sites and N levels were weighted in the ANOVA with the inverse of the error variance, as was suggested by Cochrane and Cox (1957) for dealing with non-homogeneous error variances.

Grain yield response to fertilizer N averaged across genotypes at the individual sites is presented in Figure 1. As expected, given a range of site management and soil fertility histories, responses were good at some sites such as Domboshava station and Chinyika Resettlement Area (which has a short history of cropping, less than 15 years, and so is relatively fertile), while communal area sites in Chihota and Zimuto (with long histories of cropping, low conducted. This analysis revealed that the sites can be grouped into three groups. Group 1 included Domboshava mother site, Zimuto mother site, Zimuto baby site 3 and Chinyika mother site. Chihota mother site and Zimuto baby site 1 made the second group whilst, Chihota baby site 3 and Zimuto baby site 2 formed the third group. Chihota baby site 1, Chihota baby site 2 and Chinyika baby site 2 did not fit into any of the three groups nor did they form a group on their own. Generally, group 1 sites have less degraded soils compared to group 2 and group 3 sites.

Except for biomass at Chihota baby site 3 and Zimuto baby site 2, there were no significant variety-by-N interactions at any of the sites. Differences between varieties in group 1 sites were significant ($P < 0.05$) for grain yield and biomass, CML395/CML312//CML440 had the highest grain yield and CML395/CML312//CML440 and CML395/CML444//CML440 had the highest biomass (Table 2). The genotype response to N application at Domboshava station (Figure 2) illustrates those obtained at group 1 sites. Differences between varieties in group 2 were significant (at $P=0.10$) for grain yield and biomass. CML395/CML444//CML440 had the highest yield in this group followed by the check entry, SC501. The two hybrids bred for N-use efficiency also had the highest biomass at group 2 sites. Differences between varieties at group 3 sites

Figure 1. Grain yield response to N application in 11 experiments at Zimuto, Domboshava, Chihota and Chinyika, Zimbabwe in the 2000-2001 season. M=Mother Site, B=Baby Site.

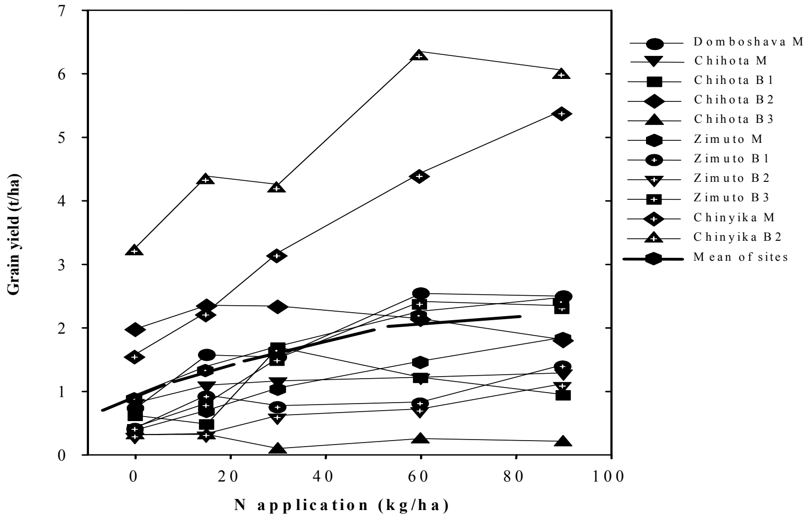


Table 2. Grain yield across N levels of five varieties evaluated in 11 experiments, Zimbabwe, 2000-2001. Varieties with the same letter are not significantly different at P< 0.05.

Site group 1. Domboshava mother site, Zimuto mother site, Zimuto baby site 3 and Chinyika mother site

Variety	Grain yield		Ears/ plant	Biomass	
ZM421	2.03	b	0.87	3.23	c
ZM521	2.01	b	0.87	3.10	c
CML395/CML312//CML440	2.38	a	0.84	4.32	a
CML395/CML444//CML440	2.10	b	0.76	4.15	b
SC501	2.05	b	0.88	3.06	c
P	0.0182		0.0789	<.0001	

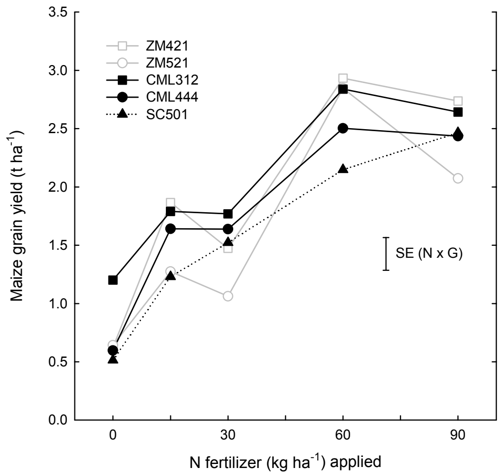
Site group 2: Chihota mother site and Zimuto baby site 1

Variety	Grain yield		Ears/ plant	Biomass	
ZM421	0.62	c	0.67	0.71	c
ZM521	0.75	bc	0.78	0.92	bc
CML395/CML312//CML440	1.07	abc	0.83	1.87	ab
CML395/CML444//CML440	1.68	a	0.81	2.33	a
SC501	1.30	ab	0.88	1.61	a
P	0.0945		0.2886	0.0597	

Site group 3: Chihota baby site 3 and Zimuto baby site 2

Variety	Grain yield	Ears/plant	Biomass
ZM421	0.27	0.54	1.18
ZM521	0.27	0.66	1.31
CML395/CML312//CML440	0.24	0.57	1.61
CML395/CML444//CML440	0.56	0.70	2.09
SC501	0.49	0.72	1.54
P	0.3326	0.5088	0.2365

Figure 2. Maize grain yield (t/ha) of experimental N use efficient maize genotypes across five N rates at Domboshava, Zimbabwe, in the 2000-2001 season.



were not significant for any trait. Thus, at those sites where variety effects could be established, hybrids bred for N-use efficiency were best performing at all N levels. This agrees with the selection history of these varieties as they were selected both under N stress and fertilized conditions. One of the two open-pollinated varieties, ZM421, was inferior to the check hybrid at group 2 sites (Chihota mother site and Zimuto baby 1 site), but there were no significant differences compared to SC501 at the other sites.

Because these experiments were conducted at a limited number of locations with large error variances, and in one cropping season, N use efficiency (NUE) results have to be taken with caution. There were some indications that experimental genotypes had higher NUEs (Table 3). Except for site group 2, the two OPVs and the two hybrids selected

Table 3. Grain yield (kg/ha) produced per kg N applied (N use efficiency) by various varieties in 11 experiments in Zimbabwe 2000-2001 season.

Variety	N application (kg/ha)				Mean NUE
	15	30	60	90	
Site group 1: Domboshava mother site, Zimuto mother site, Zimuto baby site 3 and Chinyika mother site					
ZM421	35	32	26	25	30
ZM521	50	36	42	24	38
CML395/CML312//CML440	34	32	31	27	31
CML395/CML444//CML440	44	45	29	23	35
SC501	20	27	33	26	26
Site group 2: Chihota mother site and Zimuto baby site 1					
ZM421	33	6	4	4	12
ZM521	55	3	5	10	18
CML395/CML312//CML440	-21	20	- 3	6	0
CML395/CML444//CML440	72	10	14	22	29
SC501	-7	18	15	- 1	6
Site group 3: Chihota baby site 3 and Zimuto baby site 2					
ZM421	-4	4	10	3	3
ZM521	0	3	- 3	5	1
CML395/CML312//CML440	- 8	-1	3	4	0
CML395/CML444//CML440	27		3	2	11
SC501	-11	-1	0	5	- 2

for improved NUE produced more grain per kg of N applied than the check variety, SC501. At site group 2, CML395/CML312//CML440 seemed inferior to the check entry while the other three experimental varieties had NUE values above the check entry. On average, varieties selected for NUE produced 17 kg grain per kg of N applied, the check entry produced 10 kg grain per kg N applied.

DISCUSSION AND CONCLUSION

These results have provided some initial evidence that the SADLF experimental maize varieties and hybrids tested here yield better when grown without added fertilizer N than do commercial hybrids like SC501 and may be more efficient at using N fertilizer at some sites. These effects tended to be at sites with better soil and shorter years in cropping such as Chinyika resettlement area. These conditions of little or no added N are those for which the materials were developed (Bänziger and De Meyer, 2000). They were also selected under optimum fertilization. The same cultivars were also evaluated at 58 (hybrids) and 35 (OPVs) Mother-Baby locations across Zimbabwe using recommended, farmer-representative and farmer-managed input conditions (De Meyer and Banziger, 2000). In those experiments, both NUE hybrids out-yielded SC501 and this advantage was particularly evident under lower input levels.

Farmers do like many of the characteristics of the new genotypes (De Meyer and Banziger, 2000; De Meyer et al, 2001, unpublished). It remains to be seen whether by adopting these new genotypes and getting some additional returns from current low investments, smallholder farmers may be convinced to make more investments in fertilizer and so make higher gains. A concern is that according to these results, in very degraded sites such as Chihota which represents many smallholder farming areas in Zimbabwe, the NUE varieties are not responding to N application, and thus may offer no benefit to many smallholder farmers in the country. These concerns need to be tested more widely through continued testing under such conditions.

Little is known about the physiological mechanisms for the apparent increased NUE at low applied N in these experimental genotypes, but some of the earlier work conducted in Mexico indicated that they partition more CHO to the grain sink for the same amount of N in the plant, rather than increasing the uptake of N from the soil (Lafitte and Edmeades, 1994b). They have a greater utilization efficiency for N within the plant rather than a better acquisition efficiency. Future physiological studies may help to reveal the characteristics of these experimental genotypes which help them respond differently to N application. ^{15}N isotopes can be used to better determine the fate of applied mineral N. This will in turn help breeders in their selections. There are limits to how far reliance just on improved internal use or partition efficiency (using less N in the plant to produce a kg of maize grain) can go. The reality in Zimbabwe is that the agronomic NUEs of smallholder maize crops remain often extremely low (e.g. Mushayi, Waddington and Chiduza, 1999). Thus there is great scope and need for increasing the uptake of N by smallholder maize crops through the manipulation of root systems (Eghball and Maranville, 1994), such as by increased maize root biomass deeper in the soil.

We have planted the experiment at six sites in the same parts of Zimbabwe this 2001-02 cropping season to further examine these variable but somewhat promising yield effects with the experimental OPVs and hybrids.

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SESSION IV:

Breeding and agronomic approaches to abiotic stress management - drought

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DEVELOPMENT OF EARLY AND EXTRA EARLY DROUGHT AND LOW NITROGEN-TOLERANT VARIETIES USING EXOTIC AND LOCAL GERMPLASM FOR THE DRY MID-ALTITUDE ECOLOGY.

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ABSTRACT

Maize is the most important staple food crop of Kenya. It is grown on 1,600,000 hectares in the country. It is the most important single agricultural commodity. It is estimated to contribute more than 20% of total agricultural production, 25% of agricultural employment, about 78% of total cereal consumption, 44% of total energy needs and 32% of the total protein in the country. In the Dry mid-altitude ecology comprising upper midland (UM4), 1,300-1,800m above sea level, lower midland (LM5 and LM6), 800-1,300masl; moisture stress, low soil fertility and lack of appropriate varieties are the major constraints to maize production. This agro-ecological zone, covers 12% of the national maize production area and produces 15% of the national maize basket. Farmers' yields average 1.2 t/ha but the yield potential is currently 3.0 t/ha, giving a yield gap of 1.8 t/ha. As a medium term strategy to reduce the yield gap, breeders need to provide new early drought- and low nitrogen-tolerant higher yield varieties. Using the local adapted varieties, and exotic drought- and low N-tolerant germplasm, new drought- and low nitrogen-tolerant varieties have been developed by back-crossing local adapted Katumani to drought- and low N-tolerant exotic germplasm. These varieties have been evaluated at several drought-prone locations within the Dry mid-altitude zone, using alpha lattice design under random drought, managed drought and optimal conditions. Data have been analysed by Alpha programme. Some of these new open pollinated varieties (OPVs) have been found to be of the same maturity as the local widely grown Katumani Composite B (KCB) but have significantly better yield than Katumani and are more drought- and low nitrogen-tolerant than Katumani Composite B. This paper presents the results of evaluation of these new varieties, some of which yield significantly higher than Katumani and have been put forward for the National Performance Trials (NPT) in the dry mid-altitude ecology.

INTRODUCTION

Maize (*Zea mays*) is the most important staple food crop in Kenya. In Kenya maize is grown over a wide range of agro-ecological zones from sea level to over 2,100 metres above sea level, with average rainfall varying from 250mm to 2,000mm per season. The total land area under maize production in Kenya is about 1.6 million hectares. Seventy to ninety percent of this production is from small-scale farms ranging in size from 0.2 hectares to 8 hectares. The annual production is estimated at 3.3 million metric tones giving a national average yield of 2 metric tons per hectare. These yields range from 8 metric tons per hectare in the high potential areas to less than one metric ton per hectare in the marginal areas. According to FAO statistics between 1972 and 1992, the area under maize production remained stagnant while production due to improved yield increased by 1.6 percent per year. Consumption by contrast increased at a the rate of 2.1 percent per year.

Kenya Agricultural Research Institute (KARI) Maize Improvement Programme has identified six maize growing agro-ecological zones with relatively homogeneous biotic and abiotic stresses, cropping system requirements and consumer preferences. The three key environmental determinants of these agro-ecological zones are elevation, rainfall and temperature.

Drought is widely considered the most important abiotic constraint to production in dry areas of tropical maize production (CIMMYT, 1999). Drought stress is evenly distributed across the world's major maize producing regions and is a particularly severe problem for slightly more than one-fifth of the tropical and sub-tropical maize planted in developing countries (Heisey and Edmeades, 1999).

Maize is produced under rain-fed conditions in all ecologies in Kenya. Edmeades (1992) estimated that annual losses in the early 1990s across tropical maize growing environments totaled about 19 million tons representing a 15% loss in production. Individual events of losses due to drought can, however, be extreme. For example, a devastating drought in Southern Africa in 1991-1992 reduced maize production by about 60% (Rosen and Scott, 1992) as reported in Heisey and Edmeades (1999).

Drought and low soil fertility have been identified as the major abiotic constraints to maize production in several maize growing ecological zones in Kenya and particularly so in the Dry mid-altitude ecological zone. Dry mid-altitude (800–1,500m above sea level) has bimodal rainfall of three months each, averaging 250–500mm per season. The maize production area in this zone is currently approximately 60,800 hectares with an average yield of 1.2 tons per hectare and potential yield of 3 tons per hectare, if improved varieties are planted.

Drought at any stage of crop development affects production but maximum damage is inflicted when it occurs around the flowering stage. Farmers in the Dry mid–altitude zone respond to drought at the seedling stage by replanting their crop but drought at flowering can be mitigated only by irrigation

In the dry mid–altitude and other zones of Kenya, maize yield is seriously reduced by drought in at least six out of ten years (Fisher *et al*., 1989: Shaw, 1983; Stewart and Faught, 1983). This has been confirmed by Njoroge *et al.* (1996).

Recent data indicate that the probability of obtaining drought tolerance is significantly greater when the source population from which the lines were extracted also has a high level of drought tolerance (Edmeades *et al*., 1997c). For example, the probability of obtaining a hybrid that yields 40% greater than the trial mean under severe drought stress was four times greater if the lines had been extracted from a population improved for drought tolerance rather than from the same base population that has been improved by conventional means (Edmeades, 1996).

Breeders may transfer drought tolerance to adapted but otherwise susceptible materials by backcrossing using either conventional methods or marker assisted selection (Edmeades *et al*., 1996). Progress in plant breeding depends on being able to identify alleles related to improved performance and either fix them in specific genotypes or cultivars so as to increase their frequency within a population so that the performance of the population *per se* is improved (Falconer, 1981). The choice of source population therefore plays a critical role in any breeding programme since it determines the frequency of desirable alleles at the onset of selection (Hallauer, 1991).

CIMMYT and KARI, through the Africa Maize Stress Project (AMS), have identified good sources of drought- and low nitrogen-tolerance which, were backcrossed to adapted cultivars. The populations so formed were evaluated for drought and significant improvement of drought tolerance was found among some of the crosses. They were found to be higher yielding than Katumani, a popular open pollinated variety widely grown in Eastern Africa which does not have drought tolerance but uses a drought escape mechanism.

Soils in the dry mid-altitude zone are known for their low soil fertility particularly low nitrogen and consequently this ranks as the second most important abiotic constraint to maize production in this area. Nitrogen (N) and Phosphorus (P) deficits are severe and widespread biophysical constraints to smallholder maize production and in turn to the long-term food security of the resource-poor farmers (Sanchez *et al*., 1997). For these farmers drought and low soil fertility are intertwined because the risk of crop failure due to drought influences their decision on whether to apply fertilizer. Even when fertilizers are applied, the quantities are often so low that they contribute little to long-term fertility management. It has been estimated that the average fertilizer application in sub-Saharan Africa is a mere 7 kg/ha. A relatively high grain to nutrient price ratio and high level of production risk are two of the underlying factors for low use of fertilizers in Africa (Heisey and Mwangi, 1996). The same case applies to the smallholder farmers in Kenya and particularly in dry mid-altitude areas where there is a high risk of drought.

The primary objectives of the breeder in dry mid-altitude areas are to develop extra early and early maturing, drought- and low nitrogen-tolerant varieties. The breeding strategies to combat these two abiotic constraints fall under breeding for drought escape and drought- and low N-tolerance. Drought escape is imparted through developing extra early and early maturing genotypes (40–50 and 50-60 days to flowering, respectively)

Drought tolerance is sought through use of identified drought tolerance sources in combination with local adapted germplasm. The germplasm so developed should be evaluated under controlled and random drought to make certain of the incorporation of drought tolerance.

Low nitrogen tolerance is sought through development and evaluation of the varieties under managed low–N and at the farmers' fields. KARI and CIMMYT breeders have developed early and extra early drought escaping and, drought- and low N-tolerant varieties and have evaluated them in drought-prone locations in dry mid-altitude ecology, and confirmed the existence of drought- and low N-tolerance in the new varieties.

MATERIALS AND METHODS

In 1998, two sets each of 120 entries, streak resistant (59 F1s, 59 parents and 2 checks) extra early and early exotic varieties were evaluated at Kiboko, Embu, and Machanga. Katumani was used as a common check and the second check was a local adapted variety for each location. Each variety was planted in a 2 row plot, 5m long and spaced 75cm by 25cm between rows and hills, respectively, and 2 seeds per hill were thinned to one plant per hill. DAP and CAN fertilizer was applied appropriately. The trial design was Alpha lattice, replicated thrice. Data was taken of stand count, days to pollen shed and silking, plant and ear height, plant and ear aspect, ears per plant, grain texture and grain yield.

Data were analysed using Apha programme. Based on the data, twenty three entries of similar maturity to Katumani but higher yield than Katumani were selected from the extra early set. From the early set, twenty eight entries of around 55 days to silking and close to maturity of Katumani but higher yield than Katumani were selected. From the two sets a total of 51 early and extra early entries were selected.

The 51 early and extra early entries were crossed to Katumani composite; a popular open pollinated variety widely grown in Eastern Africa. The 51 crosses were backcrossed to Katumani to reduce the maturity of the early set and to improve adaptation and initiate the conversion of Katumani to streak resistance.

In 1999 the 51 early and extra early selected backcrosses together with 4 commercial checks were evaluated at 7 locations, including 4 random drought and low nitrogen, one optimum, one managed drought and one managed low nitrogen. Each variety was planted in a 2 row plot, 5m long and spaced 75cm by 25cm between rows and hills, respectively, using 2 seed per hill then thinned to one plant per hill. DAP and CAN fertilizers were applied appropriately. The trial design was Alpha lattice, replicated three times. Data were taken of stand count, days to pollen shed and silking, plant and ear height, plant and ear aspect, ears per plant, grain texture, grain yield and diseases. Data was analysed using Apha programme.

A selection index was used to select 16 backcrosses as early as Katumani but higher yielding under both stressed and unstressed environments. In the year 2000, the selected varieties together with commercial checks were evaluated in 11 sites within the dry mid-altitude ecology under rain fed conditions and under fertilized (optimal) and unfertilized conditions (farmers conditions). The trial design, spacing and data taken remained the same as for the previous evaluations.

A selection index was used to select 5 streak resistant varieties as early as Katumani but higher yielding. These 5 streak resistant varieties have been nominated for the National Performance Trial (NPT) awaiting recommendation for release as new varieties for the dry mid-altitude ecology.

RESULTS

Table 1 and Figure 1 show the results of 1999 of the 16

Table 1. Mean grain yield in dry-mid altitude ecology under Optimum, Random drought and low N, Managed drought and low N conditions in 1999

Entry	Pedigree	Grain Yield Averages and % yield above checks						Anthisis date
		Optimum	% yield above Check mean Optimum	Random Drt/LN	% yield above Check mean Random Drt/LN	Managed Drt/LN	% yield above Check mean	
6	ECA-EE-6	4.2	35	0.9	300	2.9	71	54
8	ECA-EE-8	5.3	68	0.4	33	2.5	47	53
9	ECA-EE-9	3.7	15	0.4	33	2.4	41	53
13	ECA-EE-13	3.5	12	0.5	66	2.8	65	53
16	ECA-EE-16	5.2	68	0.4	33	3.0	76	53
18	ECA-EE-18	4.0	29	0.5	66	2.3	35	53
21	ECA-EE-21	4.8	55	0.5	66	2.6	53	53
29	ECA-EE-29	5.1	65	0.2	-33	2.5	47	53
31	ECA-EE-41	4.8	55	0.4	33	2.2	29	54
33	ECA-EE-33	3.7	19	0.3	0	1.3	-24	54
34	ECA-EE-34	5.2	68	0.2	-33	2.3	35	52
36	ECA-EE-36	4.5	45	0.3	0	2.1	23	53
38	ECA-EE-38	5.6	81	0.2	-33	2.4	41	55
45	ECA-EE-45	5.0	61	0.4	33	2.4	41	55
46	ECA-EE-46	4.1	32	0.3	0	2.3	35	54
49	ECA-EE-49	3.9	26	0.3	0	2.0	18	53
52	KCB(check)	1.8	-42	0.5	66	1.5	-12	54
53	DH1(check)	4.2	35	0.2	-33	2.0	18	56
54	DLC1(check)	2.0	-35	0.5	66	1.7	0	49
55	Local Check	4.4	42	0.4	33	1.5	-12	56
	Check Means	3.1	0	0.3	0	1.7	0	54
	Grand means	4.4	42	0.3	0	2.3	35	54
	LSD		1.7		0.35		1.4	
	CV		19		105		30	
	P		0		0.5		0.4	

Figure 1. Mean grain yield in dry mid-altitude ecology under Optimum, Random drought and low N, Managed drought and low N conditions in 1999

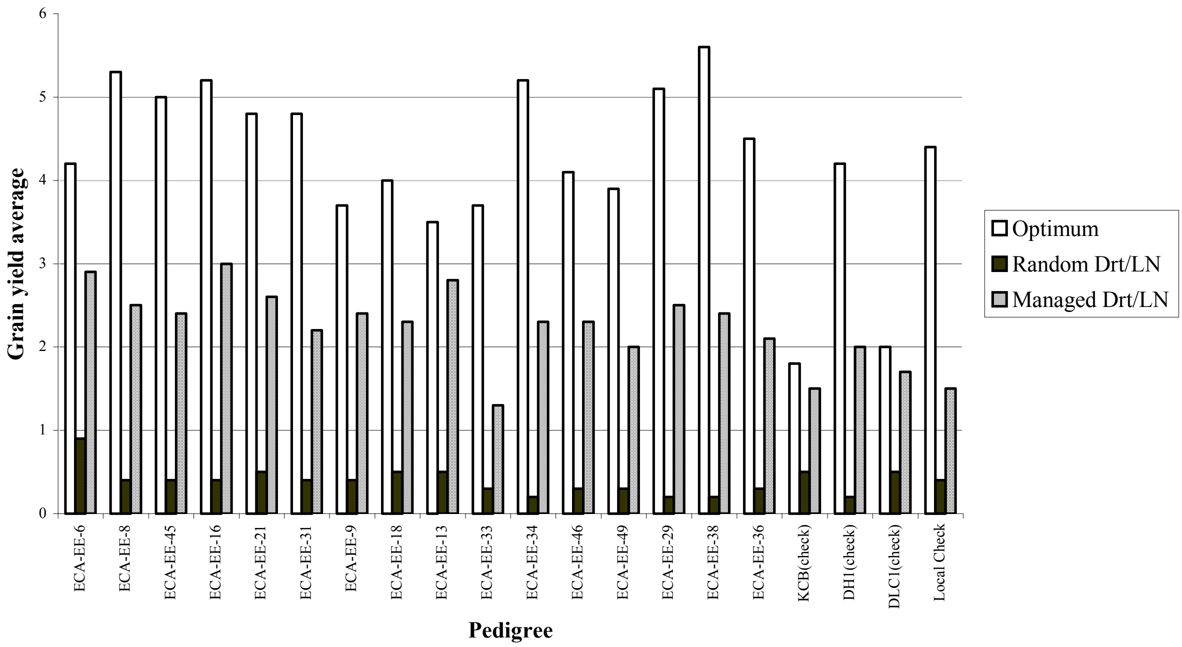
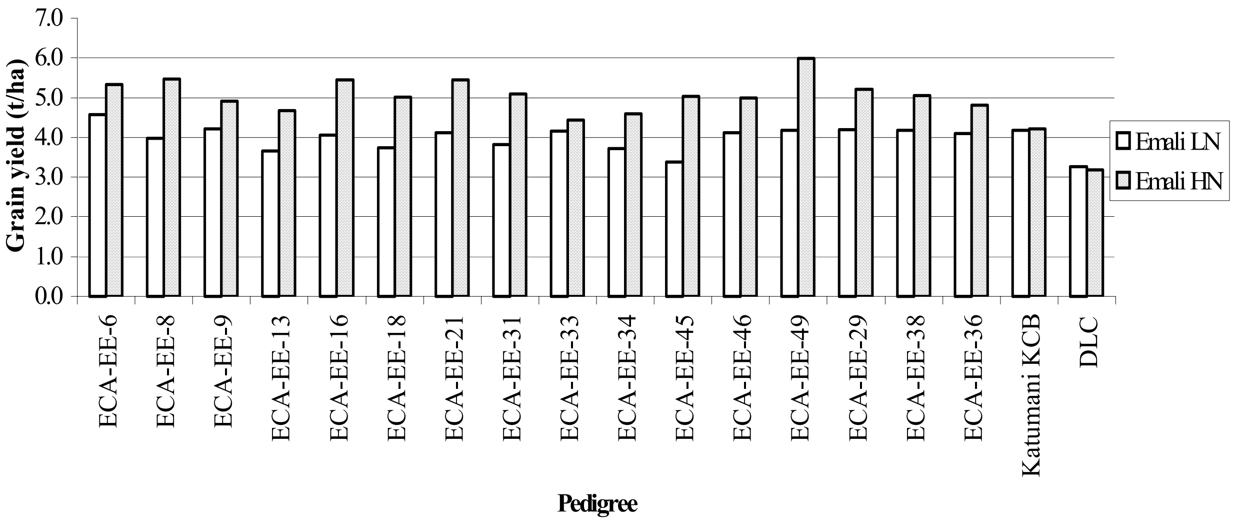


Table 2. Mean grain yield (t/ha) of 16 selected early and extra early varieties at 6 locations in dry altitude ecology under low nitrogen (LN) and fertilised (HN) conditions planted in 2000

Entry	Pedigree	Makindu	Emali		Kampi ya Mawe		Kiboko		Kitui		Katumani	
		LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN
1	ECA-EE-6	3.6	5.6	4.6	5.3	6.0	7.2	3.6	4.3	5.6	5.8	5.4
2	ECA-EE-8	3.9	4.8	4.0	5.5	5.4	4.0	4.3	4.8	5.6	6.6	5.3
3	ECA-EE-9	3.7	5.1	4.2	4.9	5.8	4.4	3.5	4.2	4.9	6.6	6.7
4	ECA-EE-13	3.9	4.6	3.7	4.7	7.0	6.1	3.5	3.8	5.5	5.5	5.9
5	ECA-EE-16	3.4	4.9	4.1	5.5	6.1	3.6	3.6	4.9	5.2	6.6	6.3
6	ECA-EE-18	3.6	5.7	3.7	5.0	5.8	6.0	3.8	4.8	5.1	6.6	6.3
7	ECA-EE-21	3.9	6.2	4.1	5.5	6.2	5.7	4.5	4.7	6.2	7.7	6.7
8	ECA-EE-31	4.2	5.2	3.8	5.1	6.3	6.0	4.1	4.1	5.4	6.6	6.9
9	ECA-EE-33	4.0	5.2	4.2	4.4	6.6	4.7	3.6	4.8	5.6	7.2	5.9
10	ECA-EE-34	3.9	5.2	3.7	4.6	5.8	6.1	3.6	4.7	5.4	6.6	6.4
11	ECA-EE-45	3.2	5.0	3.4	5.0	5.3	6.6	2.6	4.1	5.5	5.6	5.5
12	ECA-EE-46	3.5	4.7	4.1	5.0	6.3	6.3	2.9	4.3	5.7	6.7	6.3
13	ECA-EE-49	3.7	6.2	4.2	6.0	5.8	6.9	4.5	4.4	6.3	6.6	6.8
14	ECA-EE-29	3.3	6.1	4.2	5.2	6.7	4.9	3.7	4.7	5.9	6.2	6.6
15	ECA-EE-38	3.4	4.9	4.2	5.1	6.0	5.6	3.9	5.0	4.5	7.0	6.1
16	ECA-EE-36	4.0	5.4	4.1	4.8	6.2	6.5	4.1	4.4	5.9	6.0	6.1
17	Katumani KCB	2.6	4.2	4.2	4.2	5.2	5.6	3.7	4.2	4.4	6.2	6.1
18	DLC	2.3	3.9	3.3	3.2	6.1	3.8	2.5	3.1	4.0	4.4	4.3
	Mean	**3.58**	**5.16**	**3.98**	**4.94**	**6.04**	**5.55**	**3.68**	**4.40**	**5.37**	**6.36**	**6.08**
	LSD	**0.8**	**1.38**	**0.7**	**0.95**	**1.10**	**2.6**	**1.04**	**0.8**	**1.02**	**1.15**	**1.36**
	CV	**12.9**	**15.5**	**10.8**	**11.2**	**10.6**	**27.0**	**16.3**	**10.9**	**11.0**	**10.5**	**13.0**
	P	**0.017**	**0.147**	**0.238**	**0.004**	**0.226**	**0.179**	**0.019**	**0.035**	**0.035**	**0.012**	**0.216**
	Min	**2.3**	**3.9**	**3.3**	**3.2**	**5.2**	**3.6**	**2.5**	**3.1**	**4.0**	**4.4**	**4.3**
	Max	**4.2**	**6.2**	**4.6**	**6.0**	**7.0**	**7.2**	**4.5**	**5.0**	**6.3**	**7.7**	**6.9**

Figure 2. Mean grain yield (t/ha) in dry mid-altitude ecology under low N and fertilized condition in 2000 at Emali



varieties selected from the 51 entries crossed and backcrossed to Katumani (KCB) and planted under optimal conditions, random drought and low N (LN), managed drought (Drt) and low N (LN).

Under optimal conditions all the varieties yielded significantly higher than Katumani (KCB) and the mean of the checks. There were also significant differences in yield among the selected varieties.

The highest yielding variety was 68% more than the checks mean and the lowest was 12% above the checks mean. Katumani yielded 42% less than the checks mean. Under random drought and low nitrogen (LN), despite the fact that the season almost failed, there were some significant differences among the varieties and nine of them were higher yielding than the checks mean with the highest yielding 300% more than the check mean and 66% more than Katumani.

Under managed (controlled) drought and low N, 15 varieties were higher yielding than the checks mean, and KCB. The highest yielding variety was 76% above the check mean while the lowest was 24% less than the checks mean. In terms of date to anthesis, only 2 varieties were one day (55) later than Katumani (54) and the checks mean.

Table 2 and Figs 2-7 show the results of the selected 16 varieties in the year 2000 under rainfed conditions and planted under fertilized conditions and unfertilized conditions (farmers' practice) across 11 sites.

Under unfertilized conditions (LN) there were significant differences between the selected varieties at Makindu, Kiboko and Kitui, but no significant differences among varieties at Emali, Kampi ya Mawe (KYM) and Katumani. This may be because the soil was fertile enough.

Under fertilized conditions (HN) the 16 varieties differed significantly at Emali, Kiboko, and Kitui but not at Makindu and Kampi ya Mawe. At all the locations some of the selected varieties yielded significantly higher than the two checks, KCB and Dryland Composite (DLC). Presumably this was because some of the new varieties are better utilizers of nitrogen (low nitrogen tolerant) than the checks and are also more drought tolerant than the checks.

Figure 3. Mean grain yield in dry mid-altitude ecology under low N and fertilized conditions in 2000 at Kitui

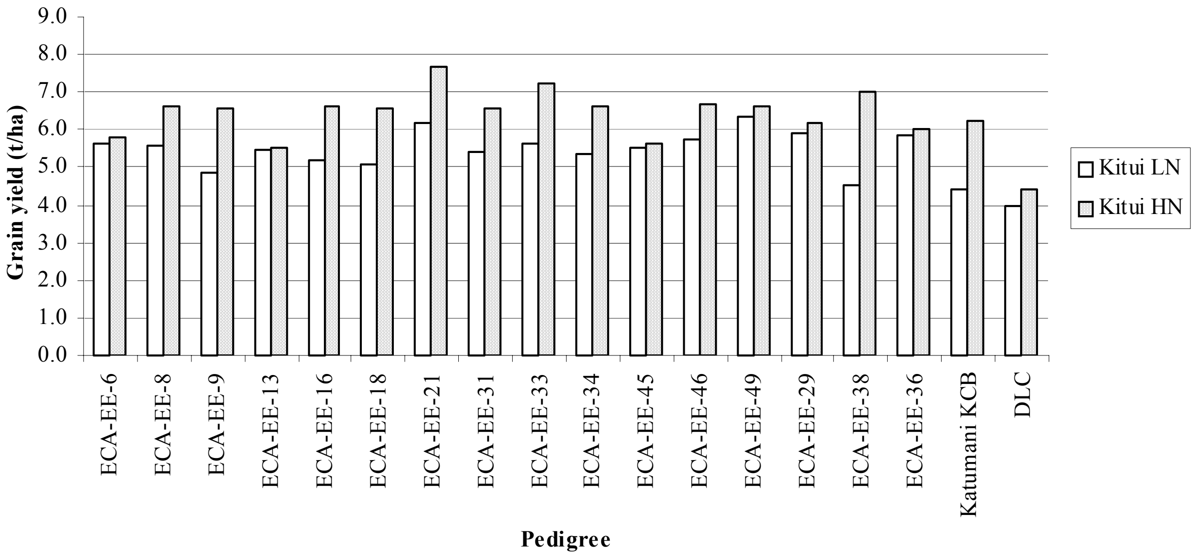


Figure 4. Mean grain yield in dry mid-altitude ecology under low N and fertilized conditions in 2000 at Makindu

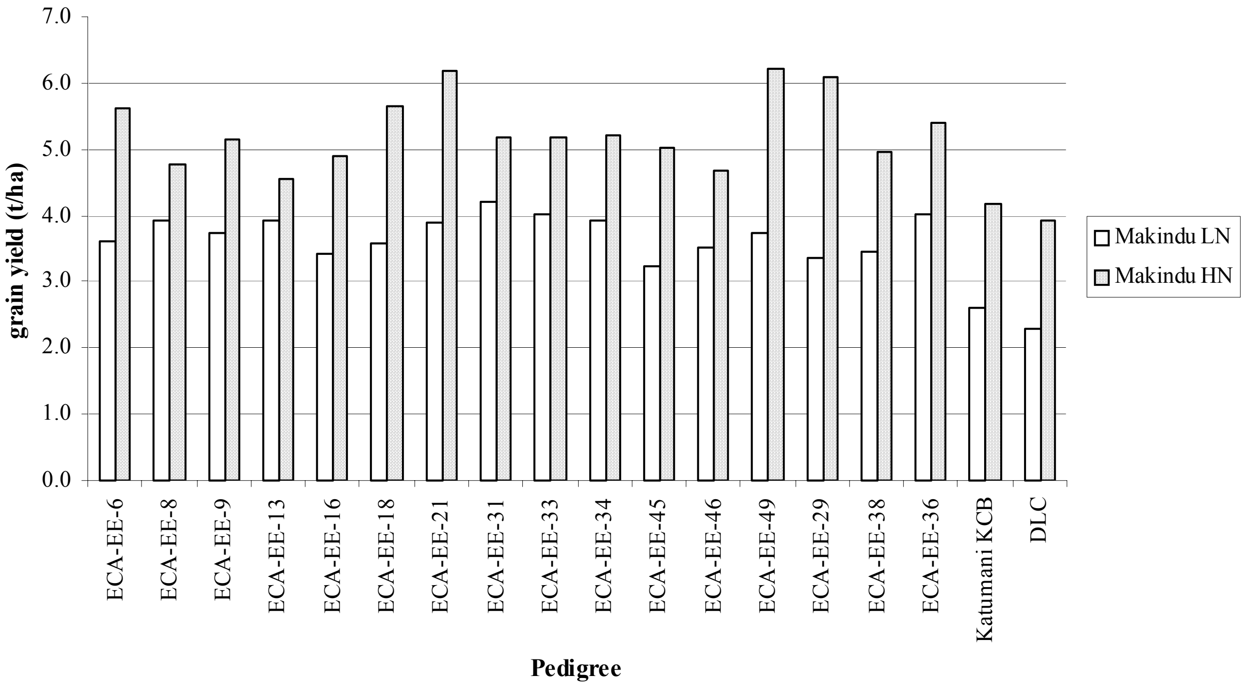


Figure 5. Mean grain yield in dry mid-altitude ecology under low N and fertilized conditions in 2000 at Kampi ya Mawe

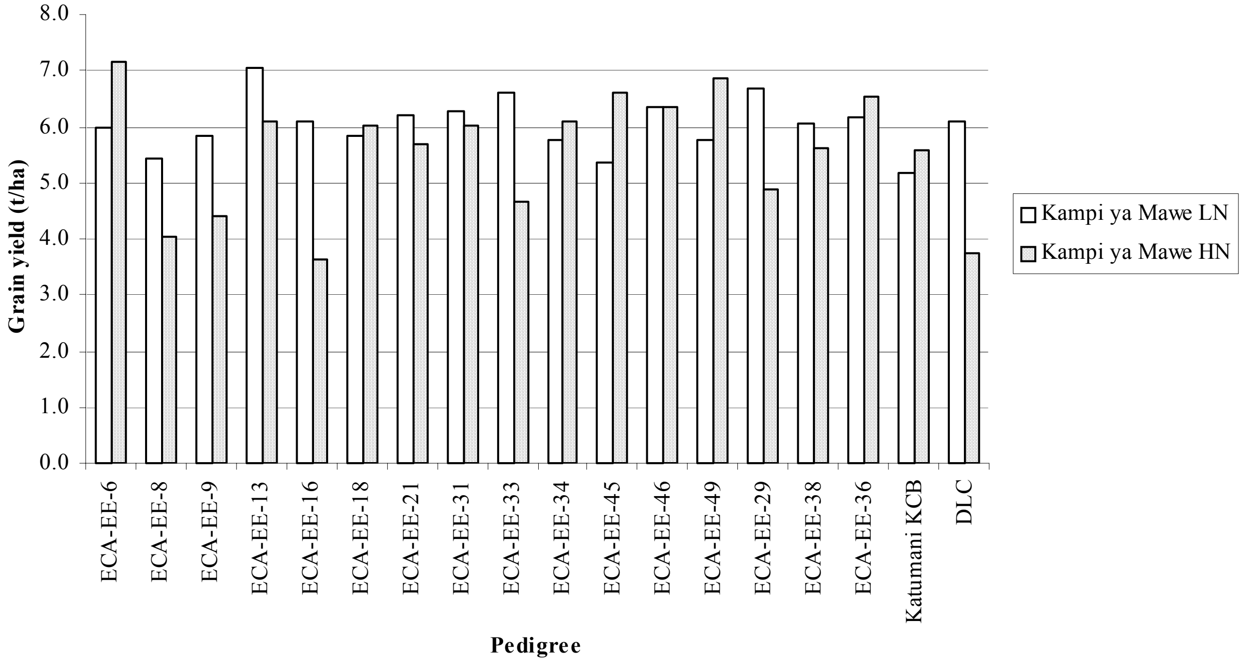


Figure 6. Mean grain yield in dry mid-altitude ecology under low N and fertilized conditions in 2000 at Kiboko

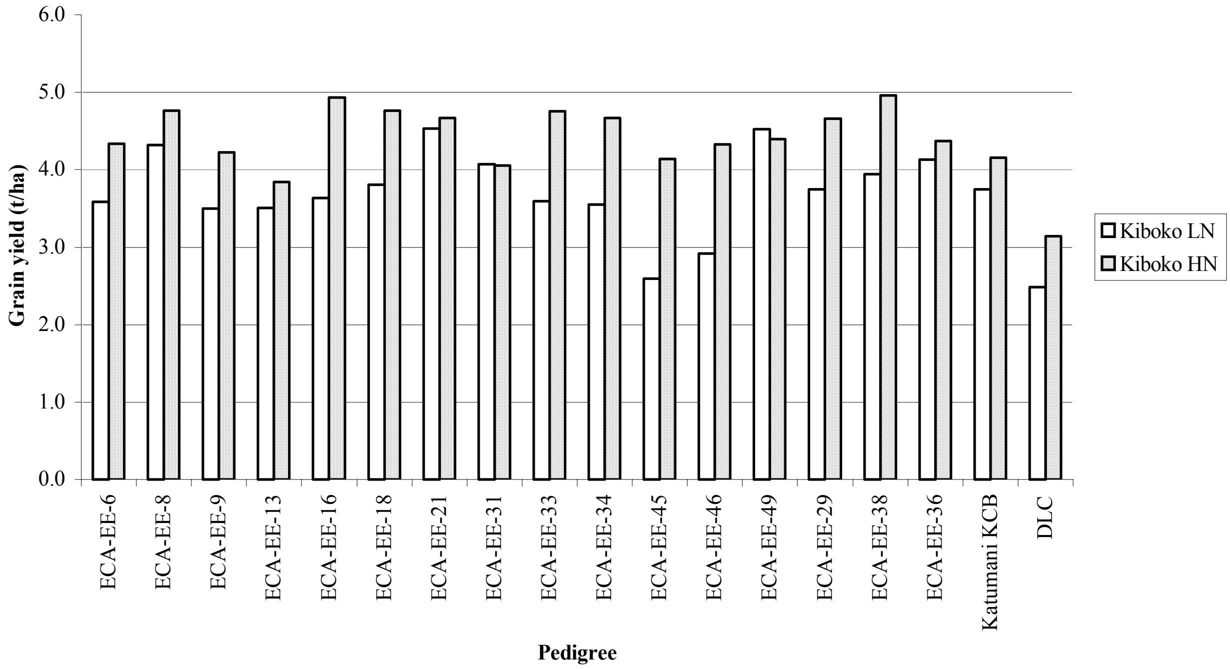
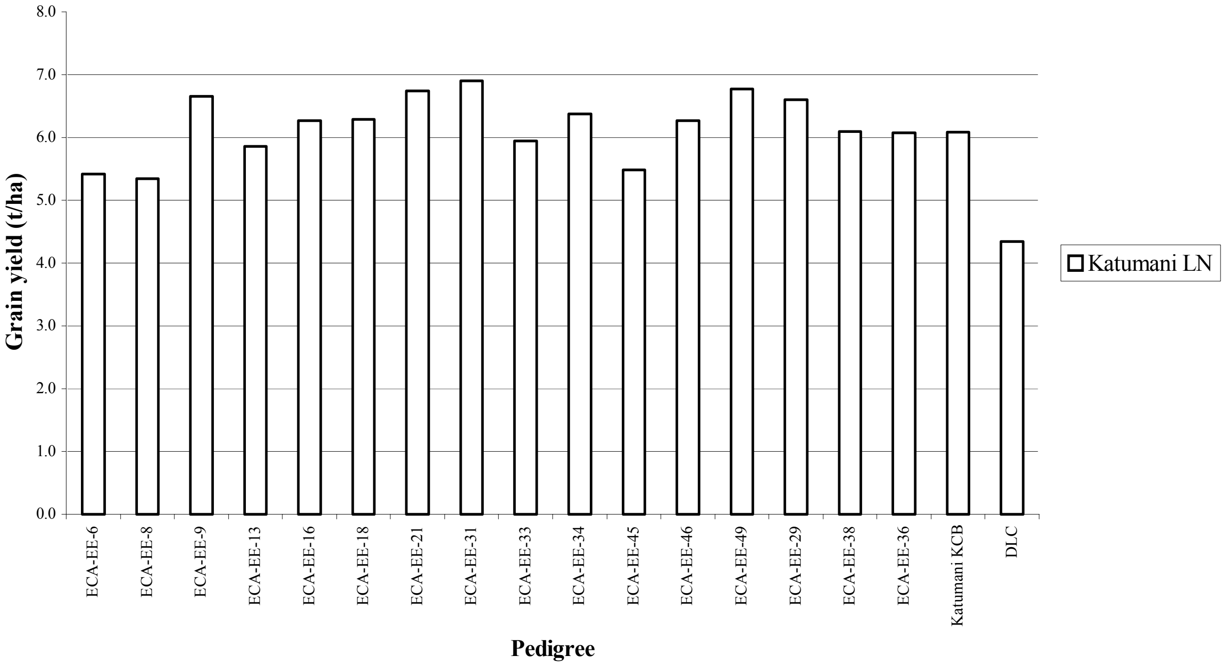


Figure 7. Mean grain yield in dry mid-altitude ecology under low nitrogen (LN) condition in 2000 at Katumani



CONCLUSIONS AND DISCUSSION

The probability of obtaining drought tolerance is significantly greater when the source germplasm has a high drought tolerance. This has been confirmed by backcrossing Katumani to several exotic sources of drought tolerance, whereby the new varieties have been found to have reasonable drought tolerance. Drought tolerance and low N tolerance can be transferred to adapted but otherwise susceptible materials by crossing using conventional methods. This has been confirmed by backcrossing a local adapted susceptible variety KCB to various identified exotic sources of drought- and low nitrogen-tolerance

Among the selected varieties there was significant improvement to drought- and low N- tolerance of the local germplasm in a short time. Five of these varieties have been nominated for National performance trials (NPT) and for eventual release in the dry mid-altitude ecology of Eastern Africa, and could be alternative varieties to replace Katumani, which has been found not to be drought- or low N-tolerant, under managed drought and low nitrogen and optimal conditions and random drought and low N conditions.

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CHARACTERIZING DROUGHT PATTERNS FOR APPROPRIATE DEVELOPMENT AND TRANSFER OF DROUGHT RESISTANT MAIZE CULTIVARS IN UGANDA

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ABSTRACT

Drought during past years has been frequent in most of the maize growing zones of Uganda. Farmers lack precise information on the frequency, severity and probability of occurrence of this phenomenon. This exacerbates its impact on maize yield. Daily climate data series obtained from the Department of Meteorology in Uganda were analyzed using INSTAT to generate this information. The length of the growing season is the difference between the dates of onset and cessation of the rains. Dry spells during the growing season were defined as >7 days (loam soil), > 5 days (sandy soil), > 10 days (clay soil) and are prevalent in the transitional areas. The relationship between evapotranspiration and rainfall was also used to delineate favourable growing periods. Generated climatic information was used to fit the growth cycles of different maize varieties defined by their Kc values. Farmers produce low on the production curve due to a mismatch between the two peaks of secure rains and crop water requirement stages as a result of seasonal variability. Farmers have to plant during the defined planting windows if the peak crop water requirement stages have to match with the peak secure rains for sustainable outputs.

Keywords: Drought, seasons, variability, yield.

INTRODUCTION

Maize is a crop widely grown under rain-fed conditions in various agro-ecological zones of Uganda. These agro-ecologies are characterized by marked climatic variations particularly rainfall distribution. Basalirwa (1994) reported thirteen agro-ecological zones based on rainfall distribution. Wortmann (1999) reported thirty-three agro-ecological zones based on rainfall distribution and other social economic factors. Seasonal rainfall variability is being expressed through uncertain start, cessation and resultant seasonal length. The impact of this variability is, however, more pronounced in the bimodal and transitional regions of Uganda than in the uni-modal rainfall pattern experienced in Northern Uganda.

Yield losses of up to 78% of the maize crop have been reported in Masindi during 1998 (Byabakama 1998). Elsewhere yields fluctuate with the season. This results from a mismatch between seasonal rainfall distribution and crop water requirements at key developmental stages. To optimize maize yields, crop water requirements at different growth stages must be tailored to the possibilities offered by the potential crop growing periods. Although selection for drought tolerance is always the desired goal for risk management, definition of the potential crop growing period offers more dynamic alternatives.

MATERIALS AND METHODS

Daily rainfall data for stations representing major maize growing regions were obtained from the Department of Meteorology archives for years with consistent data sets. The stations used were: Namulonge Research Institute in central, Masaka in southwest, Masindi in western, Ivukula in eastern, Sipi in the highland Kapchorwa. The data were checked for quality and appropriate processing was done to ease statistical applications. Definitions for the start and end of the rains are well postulated by many agro-meteorologists. The one adopted is that of Dennet et al. (1981), and this takes into account the influence of the occurrence of the Inter Tropical Convergence Zone (ITCZ) as the governing force in rainfall formation within the tropics; the dominant soil texture over a location; the principal rainfall amounts that must be received during a stated period and the dry spell that must not follow those rainfall amounts at the time of the expected overhead appearance of the sun. The criteria adopted therefore is that a place must receive 20mm of rainfall over two successive days and not be followed by a dry period of seven days at the time of the overhead appearance of the sun (March and September). The end of the season was described as being the first seven-day dry spell after May first and November first for the cessation of the first and second season, respectively. Other definitions of the start of the growing season involve the relationship between precipitation and evapotranspiration ratios. With the above conditions, the start (S), and end (E) columns were generated. The difference between the two columns gives the length of the growing season (L). For a crop variety growth cycle length, crop water requirement coefficients (kc) values which relate the actual crop transpiration to atmospheric reference evapotranspiration demand as calculated using the FAO method by Doorenbos and Pruitt (1984) were used. The kc value curve may be superimposed on the seasonal rainfall distribution graph to make the best fit between the available moisture during the growing season and the water requirement of the crop at different developmental stages. This can be of great assistance in deciding on the appropriate planting windows.

DISCUSSION

The rainy season does not begin uniformly over the regions. The intertropical convergence zone is of rising turbulence. Its passage above Uganda as it advances in a south to north direction during the first season brings rain. Rainfall often follows, rather than accompanies, the passage of the zone. The onset of the first season follows suit and advances in the same direction with a time lag of between

Table 1. The Julian Day Numbers of the start (S), End (E), and Length (L)

Year	S	E	L	S	E	L
1970	67	158	91	235	321	86
1971	72	168	96	240	351	111
1972	76	156	110	236	336	100
1973	74	180	106	214	333	119
1974	62	151	89	234	346	112
1975	79	158	79	223	326	103
1976	87	167	80	223	338	115
1978	63	145	82	234	332	98
1980	62	151	89	252	355	103
1981	65	142	77	223	315	92
1982	80	168	83	217	329	112
1983	73	164	91	224	335	111
1984	77	158	81	230	343	113
1985	82	147	65	239	341	104
1986	79	157	78	262	361	99
1988	67	145	78	228	319	91
1990	67	150	83	265	351	86
1991	78	151	80	243	333	95
1992	71	159	81	230	323	93
1993	71	167	96	248	313	65
1994	73	166	93	229	356	127
1995	71	172	101	246	327	81
1996	75	151	116	243	353	110
1997	84	139	53	274	386	112
Minimum	46	142	65	214	313	65
Maximum	87	180	110	265	361	119
Range	41	38	43	51	48	54
Mean	71	157	86	235	335	100
SD	9.2	9.5	10.5	13.8	13.5	12.9

Years skipped had insufficient data

Avg.	start 11 March SD 9 days	22nd Aug SD 14 days
End	5th June SD 10 days	20th Nov. SD 14 days
Avg.	length 86 days SD 11 days	100 days SD 13 days

200 to 300 km as reported in bulletin number five of the International Crops Research Institute for the Semi Arid Tropics (ICRISAT). The water bodies and relief features resulting in diverse agro-ecologies modify the passage of the ITCZ over Uganda. From the stations used in the study, the season starts earliest at Masaka, which is south of the equator during the last half of February. At Lira, which is north of the equator, the season starts during the first half of April and progresses into a single season up to the last half of November. Around the Lake Victoria crescent, the season starts during the first half of March. Masindi in the west and Soroti in the East lie in the transitional zone and here the first season starts during the last half of March but is highly variable as seen in Table 1. The second season in all areas is more reliable than the first except for Masaka. Variability in the start and end of the rains is quite high as evidenced by the standard deviations of greater than 2 weeks for most of the regions. This results in shorter crop growing periods for maize growing in the bimodal and transitional areas. Such fluctuations in the length of the growing period only permits full confidence of receiving rainfall in the peak periods between April-May and October–November (Fig 1) for the first and second seasons, respectively. It is vital to note that the average potential crop-growing period in the bimodal rainfall areas is short of the average 100 days. In this region therefore, variabilities in the start and end of the season greatly affect the duration of the favourable crop growing period. Seasonal length can vary from 72 to 120 days for Soroti while at Masaka the season can vary between 82 to 114 days. Maize varieties currently grown by farmers like Longe 1 are 120-day growth cycle. Strategic planting periods are needed to iron out yield losses caused by such fluctuations.

For Masindi and Mpigi, the difference in seasonal length between the first and second seasons is quite pronounced with the second season being considerably longer than the first. Chances of crop failure during the first season are high unless more drought tolerant varieties of maize are availed to improve crop output at household level in these areas. Considering labour constraints, it would be advisable for farmers in Masindi to grow more pulses during the first season and concentrate on maize growing during the second season when chances exist for longer cycle crops to succeed.

In contrast, considerably greater seasonal security is evident in the unimodal rainfall areas. For Gulu, the average start of the season is the 15th of April with the 30th of September being the mean end date (Fig 1). The mean variability in the start and end of rains is 15 days. The seasonal start therefore ranges between 1st April to 30th April and the end varies between 15th September and 15th October. The shortest expected season is when the season starts late 30th April and breaks early 15th September, giving a seasonal length of 135 days. Even this shorter rainy season can easily accommodate the growth cycle of 140-day maize cultivars. At Masaka, the shortest expected season would be when the season starts late 11th March and breaks early 27th of May giving a seasonal length of 77 days. In this situation, dry planting during the last half of February would utilize the pre-season rainfall for germination. The rains would get the crop at an advanced stage. The most critical moisture requirement stage of Longe 1 is between 41 days after sowing to 69 days after sowing. The crop would attain these between 28th March and 25th of April leaving still 30 days for part of grain filling. From this, it is possible for the farmers to still get some yield even during bad years. Kanemasu (1986) obtained similar results while defining growing seasons for Sorghum. Longer cycle varieties that have their peak water requirements between 73 and 101 days after sowing would totally fail in this environment.

Nevertheless, it should be possible to improve and stabilize maize yields in the bimodal and transitional zones through variety selection and manipulation of current planting dates. Fig 2 suggests that it is of considerable advantage to adjust the planting period in the first rainy season to February utilizing pre-season rainfall for germination. This early planting strategy ensures that the period of rainfall uncertainty will coincide with the least vulnerable stage. Conversely, the peak rainy period will match the maize growth stages with high Kc values (high moisture demand).

CONCLUSION

The Cereals Programme in Uganda must have a wide collection of maize germplasm from which varieties should be tailored specifically for particular regions. Demarcation of the maize growing areas into high, mid and low altitudes is not enough as numerous ecologies defined by climate and soils exist and to a greater extent influence the success of maize growing in Uganda. Various agronomic packages should also be tested to fit the selected technologies into environmental limitations imposed by uncertain seasons. Appropriate planting dates for each zone that match stable rainy periods with peak maize crop water requirement stages should be identified. In the bimodal areas with a short rainy period of 21/2 –3 months, early planting before the actual start of rains at the end of February can allow the maize crop to capture the full length of all incidental rainfall. Focus here should be placed on selecting those varieties and agronomic practices that can enable the maize crop to germinate and establish on low moisture soil profile before the actual rainy season sets in. Although this calls for expanded experimental field activities to test germplasm over the years and locations, new tools for research are now available that can assist in such wide adaptability studies namely GIS and modelling. The use of these tools should be promoted to save on time and money as they provide cost-effective mechanisms for hypothesis testing.

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STRATIFICATION OF MAIZE TEST-SITES IN BOTSWANA IN RELATION TO SELECTED SITES WITHIN THE SADC REGION BASED ON YIELD PERFORMANCE

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ABSTRACT

Stratification of maize test-sites in Botswana was done to identify key benchmark testing sites similar to testing sites in the SADC region.. Grain yield from 31 testing sites across 3 years were compared with four test-sites in Botswana. Sequential retrospective (Seqret) pattern analysis methodology was used to stratify the test-sites according to their similarity and dissimilarity based on genotype yield. Seqret pattern analysis methodology uses historical data, taking into account complicated imbalances of data caused by change over the years and loss of whole locations and genotypes in some years. Analysis of cumulative data from 1998/99-2000/2001 seasons captured the major patterns of similarities among test- sites by clustering 25 retained sites into 4 clusters with an overall R^2 = 0.61. The test-sites in Botswana clustered into one of the four clusters, which captured some of the major similarities. The results obtained from this data set will be useful in restricting few testing sites in the future.

Keywords: Genotype x Environment, maize, stratification, sequential retrospective pattern analysis.

INTRODUCTION

Maize (*Zea mays L.*) is one of the major cereals in Botswana under rain fed conditions. The production of maize has declined while the area cultivated has remained constant. The number of testing sites is important when it comes to the efficiency and potential gains from breeding experiments. Production can be improved if selection is effective and improved genotypes are released to target production areas. This makes appropriate testing sites crucial in determining efficiency of plant breeding and selection. Test-sites must be similar to the representative samples of production areas targeted by plant breeders in order to be effective in selection (Cooper *et al*., 1993a). Testing sites are usually not representative of production areas due to the way that research stations are chosen, based on politics, resources, convenience and in other cases it is difficult to find suitable testing sites. On the other hand, some genotypes fail to perform relatively similarly across environments and years. These difficulties are also caused by differences in yearly fluctuations of rainfall and temperatures. Some differences could be predictable and repeatable such as general climate and soil.

In order to overcome yearly fluctuations due to genotype by environment interactions (GxE), rainfall and temperature patterns, multi-environmental trials (METs) are conducted over years and locations to minimize the fluctuations. On the other hand Multi-environmental trials are imbalanced due to failure of some genotypes in some environments or breeders choose to replace poor performers with elite germplasm from the breeding programmes. Multi-locational testing will minimize the effect of GxE interactions, but it is obvious that genotypes differ significantly in the extent of their interactions (Russell and Eberhart, 1968). When hybrids are compared over a series of locations their relative rankings differ significantly, which makes it difficult to demonstrate the significant superiority of any hybrid. Only extensive testing can identify genotypes with the least interaction with the environment (Eberhart and Russell 1966). Peterson (1992) used one of the methods that minimize missing data by averaging of location proximity matrices across sites. Peterson and Pfeiffer (1989) used factor analysis on the average correlation matrix to stratify international winter wheat testing sites using 17 years of trial data. Correlations of cultivar yields among test sites were averaged across years to provide a weighted correlation matrix for factor analysis. Fifty-six international sites were grouped into 7 mega environments and 21 smaller adaptation zones within these regions based on yield performance.

The objective of this paper was to identify similar or representative maize testing sites in Botswana to regional maize testing sites in the SADC region based on regional maize trials.

MATERIALS AND METHODS

Early to intermediate maize maturing open-pollinated varieties (EPOP) trials were conducted between 1999 and 2001 in Southern and Eastern Africa. The study was based on yield data from 31 maize testing sites in Southern Africa and compared to testing sites in Botswana. The selection of testing sites in Botswana was based on proximity to major maize production areas. The test sites in Botswana were Sebele (with codes Sebe, Sebe1), Goodhope (Good), Pandamatenga (Pand) and Pelotshetlha (Pelo) and other sites from the SADC region are listed in Table 1.

The open pollinated varieties (OPVs) were elite pre-release and released maize germplasm ranging between 56 to 77 days to anthesis. CIMMYT, National Agricultural Research Programmes, and private seed companies in the SADC region supplied the OPVs. Trials in each country were conducted using an alpha (0,1) lattice design with three replicates with the number of entries ranging from 25 to 30. Data were collected on yield performance, and other important agronomic traits.

Statistical Analysis

Sequential retrospective pattern analysis was used for stratification of testing sites according to Mirzawan *et al*., (1994), DeLacy *et al,* (1994). The analysis was implemented

Table 1. Locations used in the stratification of maize testing sites

Code	Location	Country
Good	Goodhope	Botswana
Pand	Pandamatenga	Botswana
Pelo	Pelotshetlha	Botswana
Sebe	Sebele	Botswana
Seb1	Sebele1	Botswna
Leri	Leribe	Lesotho
Mase	Maseru	Lesotho
Mase	Maseru	Lesotho
Mac	Machache	Lesotho
Baka	Baka	Malawi
Chit	Chitala	Malawi
chitl	Chitala	Malawi
Ngab	Ngabu	Malawi
Muta	Mutarara	Mozambique
Sus	Sussundenga	Mozambique
Umb	Umbeluzi	Mozambique
Grey	Greytown	South Africa
Pot	Potchefstr.	South Africa
Potc	Potchefstr.	South Africa
Magoye	Magoye	Zambia
Mak	Mt.Makulu	Zambia
Msek	Msekera	Zambia
Msekera	Msekera	Zambia
Nan	Nanga	Zambia
Art	ART Farm	Zimbabwe
Art1	ART	Zimbabwe
Chir	Chiredzi	Zimbabwe
Hara	Harare	Zimbabwe
mako	Makoholi	Zimbabwe
Mazo	Mazowe	Zimbabwe
Cim	Cimmyt-Harare	Zimbabwe

using the Seqret package Version 1.1 (DeLacy *et al.,* 1998). The proximities of the sites on the first two principal coordinates analysis were used to reflect the relationship among environments. The analysis parameters employed in the clustering strategy were incremental sum of squares, weighted averages, standard error of the difference (SED) and standardized SED. The adequacy of the model was calculated from the R^2–statistic as explained by DeLacy *et al.*, (1996) which is a measure of the effectiveness of the model.

RESULTS AND DISCUSSION

The proximities of the environments on the first two vectors of the principal coordinate analysis (PCA) reflected the relationship between the locations in 1999, 2000 and 2001 (Fig. 1, 2, and 3).

The results from 1999 indicated that the first two PC's in 1999 accounted for more than 46% of the total variation.

Figure 1. Priority plot vectors one and two from principal coordinates of 31 locations in 1999 using standardized squared Euclidean distances.

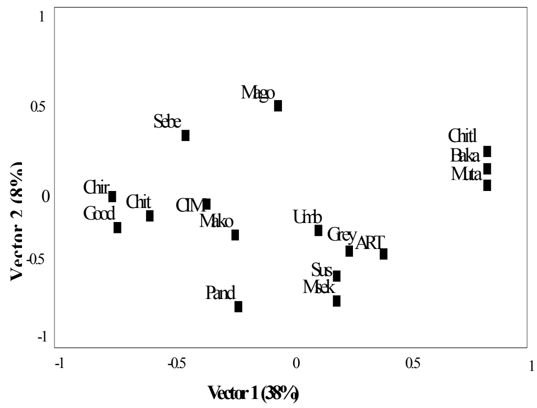


Figure 2. Proximity plot of vectors one and two from principal coordinate analysis of 31 locations for 2 years using standardized squared Euclidean distances.

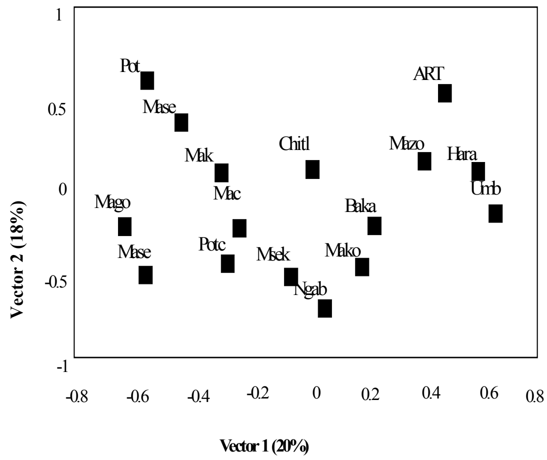
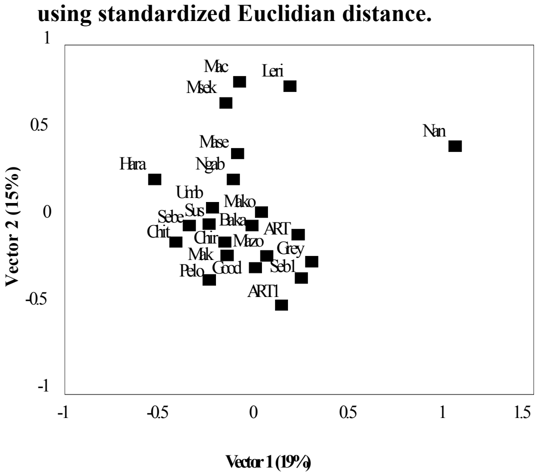


Figure 3. Proximity plot of vectors one and two from the principal coordinate analysis 31 locations in 3 years using standardized Euclidian distance.



Sebele, Goodhope, Chitala, Chiredzi, CIMMYT Harare and Makoholi fell into the same side of the vector due to the negative coefficient of the first vector (Fig. 1). Sebele and Pandamatenga did not cluster closely with Goodhope and other locations in the same group. Within the region, Goodhope clustered closely with more locations than Pandamatenga and Sebele. This clustering indicates the similarity of these locations. The maize yield results indicate that Goodhope ranked higher than Sebele and Pandamatenga (DAR Annual Report 1999). Pandamatenga is comparatively different from Goodhope and Sebele. Sebele and Goodhope are in the southern part of the country while Pandamatenga is on the northern part of the country characterised by vertisols. The differentiation of sites based on soil types has also been reported by Delancy et al. (1996). This indicates that Pandamatenga discriminated genotypes differently compared to Sebele and Goodhope in the same year. The sites that are in the same quadrant with Goodhope and Sebele discriminated genotypes similarly in 1999. Data from the African Maize Research Atlas (1999) classified Goodhope and Sebele in the subtropical mid-altitudes while Pandamatenga is in the Subtropical lowlands. The sites that are in the same Quadrant with Goodhope and Sebele could be used to discriminate genotypes similarly in a particular year.

In the cumulative analysis from 1999 to 2000, the first two PC's accounted for 38 % of the total variation (Fig. 2). The sites were more scattered and with no particular unique groupings as compared to 1999.

In the cumulative analysis for 3 years, the first two PC's accounted for 34 % of the total variation (Fig. 3). More sites clustered together compared to the previous years only few sites formed a distant group from other testing sites in the SADC region. Chitala and Chiredzi closely clustered with Goodhope as in 1999. Nanga was one of the sites, which did not cluster with any site. Sebele 1, which was a drought site in Botswana, grouped closely with Greytown and Art Farm 1, which were used as drought testing sites. Goodhope, Pelotshetlha and Makoholi also grouped together. The two sites are in the Southern part of Botswana and are 30 kilometres apart.

Dendrograms labelled Fig. 4 to Fig. 6 further explain the stratification of the testing sites, and the results are presented below by year.

For year 1999, 16 out of 31 sites were retained in the classification analysis while the other sites were eliminated in line with the method of analysis as adopted from DeLacy *et al,* (1998). It can be deciphered from Fig. 4 that the 16 retained sites were clustered into 5 sets comprising (Makoholi, CIMMYT-Harare), (Sebele, Chiredzi, Goodhope, Chitala), (Baka, Chitala, Mutarara), (Magoye, Umbeluzi, Msekera, Greytown, Art), and (Pandamatenga, Sussundenga). The model fit with eliminated sites had an overall $R^2 = 0.75$.

In the cumulative analysis from 1999 to 2000, 17 sites were retained and the rest were eliminated due to lack of comparisons (Fig 4). The retained sites where clustered into 4 sets The clusters were (Art, Harare, Umbeluzi, Mazowe), (Magoye, Makohole, Potchefstrom, Masere), (Baka, Chitala, Leribe, Machache, Potchefstrom1), and (Makole, Ngaba, Msekera, Maseru). The model fit with eliminated sites yielded an overall $R^2 = 0.67$.

The cumulative results for 3 years are summarised in Fig. 6 which shows 4 clusters into which the analysis grouped 23 retained sites with an overall $R^2 = 0.61$. The groups comprise (Nanga, Leribe, Machache, Msekera, Maseru), (Art-Farm, Sebele1, Mazowe, Greytown, Baka, Art-Farm1, Chitala, Pelotshetlha), (Umbeluzi, Harare, Sebele, Chitala), and (Sussundenga, Ngaba, Makoholi, Chiredzi, Goodhope, Makohole). The sites grouping ranged from a minimum of 4 sites to a maximum of 8 sites per cluster. The cumulative analysis for three years had the number per cluster compared with the previous years.

A summary of results across years shows the pairs (Sebele, Chitala), (Greytown, Art) and (Chiredzi, Goodhope) being clustered together in years 1999 and the cumulative analysis from 1999 to 2001, (Harare, Umbeluzi), (Leribe, Machache) and (Msekera, Maseru) in the cumulative analysis from 1999 to 2000 and 3 years cumulative data, respectively. This suggests some consistency in the clustering of the sites and an analysis of data collected for more than the 3 years may only confirm this. With particular reference to Botswana sites, Sebele and Goodhope were in same cluster in 1999 while Sebele1 and Pelotshetlha clustered together in the cumulative analysis for 3 years. These 3 sites are geographically in the southern part of the country, which may explain the observed clustering. Pandamatenga has a longer growing season from December to May while Sebele and Goodhope have shorter growing season characterised by cool nights starting in late march. This difference has an effect on relative development performance of genotypes. Each cumulative analysis fitting each year sequentially generated different number of groups and pattern and these clusters will be useful to breeders to adjust the selection pressure applied to breeding populations. Had the number per cluster compared with the previous years.

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CONCLUSION

The analysis of the data enabled one to recognize the major agro-ecological zones in Botswana by identifying test sites that have similarities and dissimilarities within the country and the region. The analysis has shown also shown that repeatability patterns can be identified among test sites from 3 years data. The similarities in sites gave us the opportunity to select and exchange germplasm within the cluster groups. This analysis provides a challenge and an opportunity to improve efficiency in selection strategy by knowing countries within the region that one can share germplasm with.

Figure 4. Classification of 31 sites for 1999.

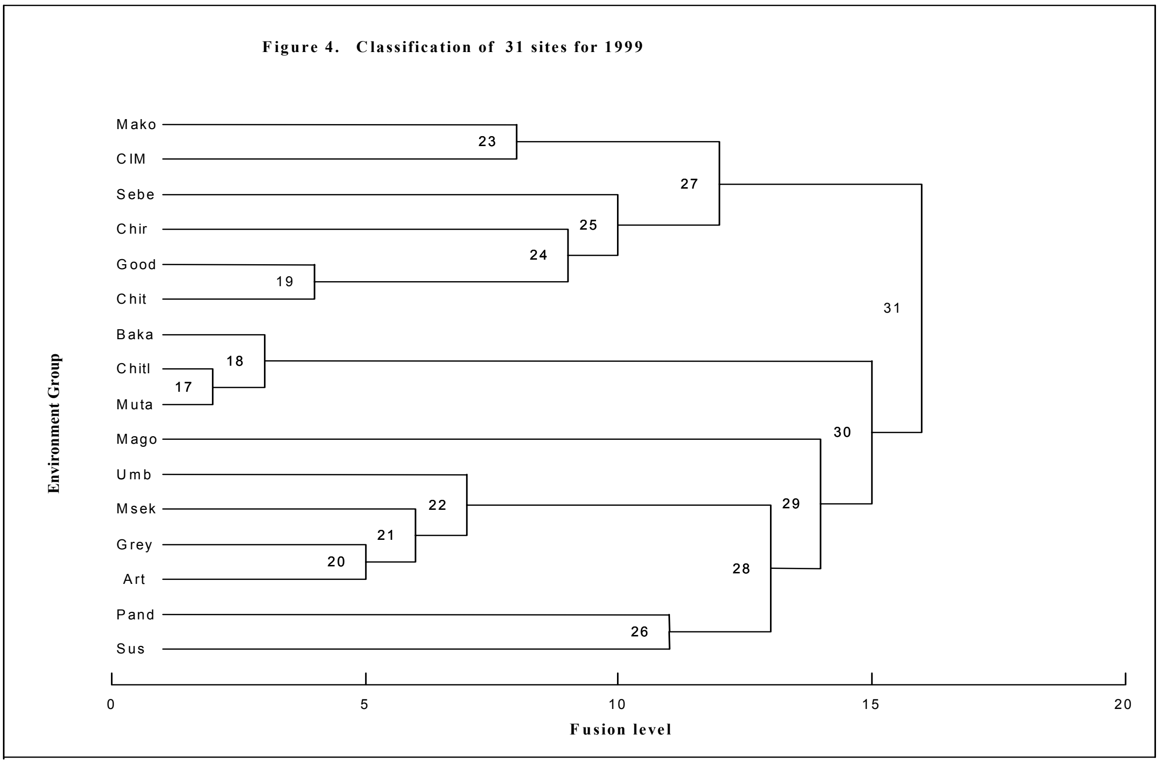


Figure 5. Classification of 31 sites for 2000.

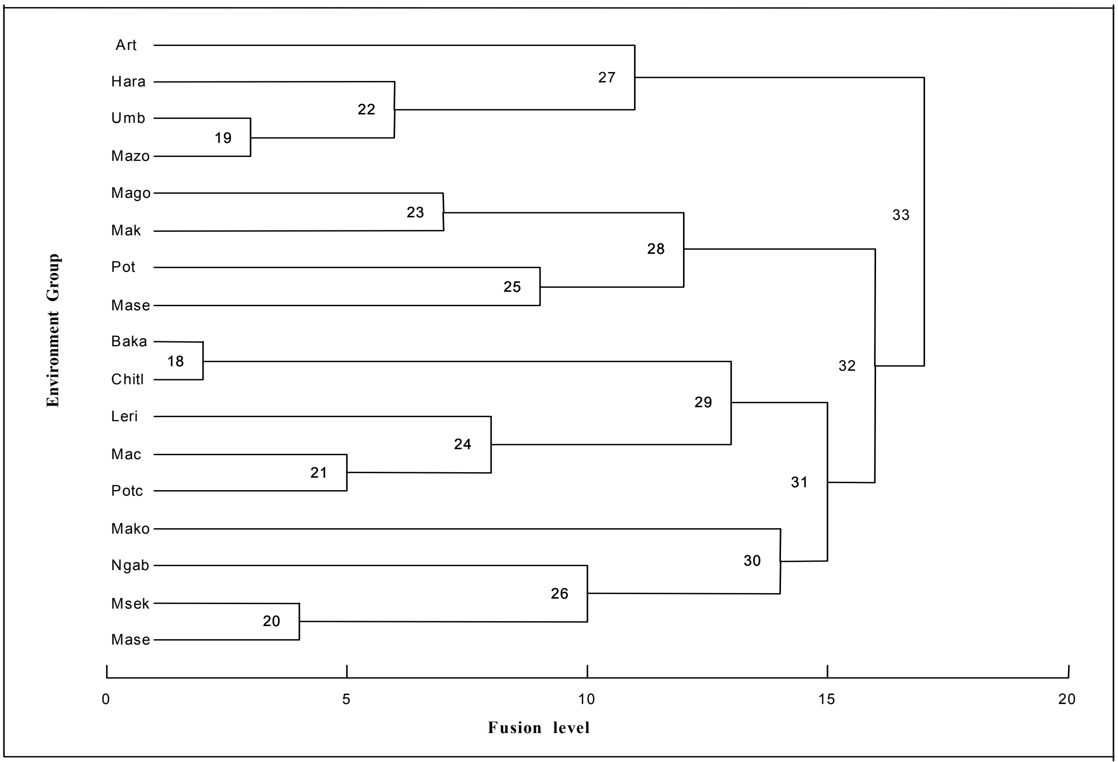
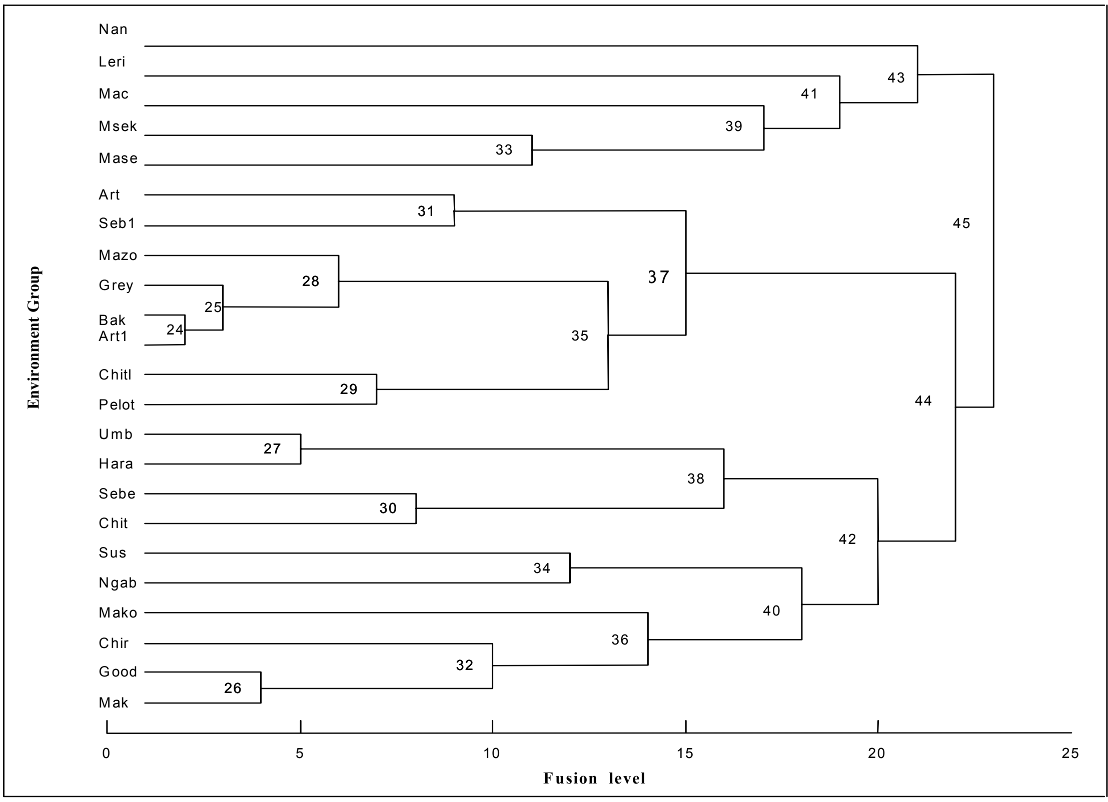


Figure 6. Classification of 31 sites for 2001.



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ON-FARM SEED PRIMING IN MAIZE: A PHYSIOLOGICAL EVALUATION

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ABSTRACT

Poor crop establishment can be a major constraint to crop establishment in the semi-arid tropics. Simply soaking seed in water overnight before sowing can increase the rate of germination and emergence. This procedure, called 'on-farm seed priming', has also been reported to increase the rate of crop development and increase yields. The overall objective of the work described here is to investigate the physiological basis for these benefits using a mixture of laboratory and field experiments. Germination experiments at constant temperatures in moist conditions showed that seed soaking for 17 h decreased the optimum and ceiling temperatures for germination rate. At temperatures above 30 ^{0}C, fewer seeds germinated following soaking. When maize was planted in tubes of moist sand in controlled environments, the effect of soaking on emergence also depended on temperature. With a day temperature of 30 ^{0}C, soaking advanced time to 50% emergence by 12 h, but only by 5 h at 35 ^{0}C. At 40 ^{0}C, soaking *delayed* time to 50% emergence by 20 h. When grown in favourable conditions in controlled environments or in the field, soaking had little effect on growth or development of maize. There appeared to be no differences in the subsequent growth of primed and un-primed plants that emerged on the same day. However, when soaked and un-soaked seed was planted into progressively drier pots of sand at 35^{0}C, soaking advanced time to 50% emergence by 70 h. Field experiments in Zimbabwe also showed that soaking gave a greater benefit to maize emergence at lower soil moisture contents. The benefits of priming appear to follow from the advantage that priming gives to the seed in relatively dry seedbeds.

Keywords: Controlled environment, field, maize, priming, soaking, temperature.

INTRODUCTION

In the semi-arid tropics, crops often fail to establish quickly and uniformly, leading to decreased yields because of low plant populations. Constraints to good establishment include poor seedbed preparation (Joshi, 1987), low quality seed, lack of soil moisture (Gurmu and Naylor, 1991), high temperature (Weaich *et al.* 1992) and crust formation (Townend *et al.*, 1996). Resource-poor farmers often lack the means to optimise seedbed conditions before sowing and they are particularly at risk from adverse weather after sowing. On the other hand, good establishment increases competitiveness against weeds, increases tolerance to dry spells, maximises yields and avoids the costly and time-consuming need for re-sowing.

Recent research (Harris, 1996) has shown that on-farm seed priming can lead to better establishment in tropical crops such as maize, sorghum, rice and chickpea. On-farm seed priming (referred to hereafter as priming) involves simply soaking the seed in water overnight, surface drying and sowing the same day. Participatory approaches have led to rapid acceptance of the technique in parts of India and Zimbabwe as the technique gives clear benefit for little risk (Harris *et al.*, 2001). As well as improved crop establishment, priming led to crops growing faster, flowering earlier and yielding higher (Harris *et al.*, 1999). However, the physiological processes leading to these benefits are not well understood. In particular, the benefits later in the growth of the crop are much greater than might be expected from emergence 1-3 days earlier. This research suggests that some of the benefits of on-farm seed priming can be gained in un-primed seed by seedbed preparation and sowing methods that give better seed-soil contact. This indicates that a large part of the benefit of on-farm seed priming results simply from fast hydration of the seed, giving the primed seedlings an advantage in deteriorating seedbeds. It appears that seedlings that germinated and grew rapidly were able to produce sufficiently deep root systems before the seedbed dried out, hardened or became too hot. However, these suggestions had not been tested experimentally.

In this paper, we report on work carried out to establish the physiological basis for the effects of priming. The aim was to study possible mechanisms in controlled environments and in field experiments, and relate these finding to farmers' experiences and perceptions.

MATERIALS AND METHODS

Controlled-environment studies

Priming procedure:
Maize seeds were covered with demineralised water and allowed to imbibe water, then drained and blotted with tissue paper. The same soaking procedure was used throughout: a single layer of seeds in a Petri dish was covered under 1 cm depth of water for 17 h at 20 ^{0}C.

Germination test:
Seeds were set to germinate on two sheets of moist filter paper in Petri dishes in an incubator at constant temperatures. The effects of temperature, priming, and orientation of the seed on

the germination of SC403 were tested. Eight replicates of ten seeds were used for each treatment combination. Germination rate was calculated from the reciprocal of time to 50% germination.

Emergence and growth in controlled environments: Experiments were carried out in one of the following growth conditions: 30/20 ^{0}C refers to a 30 ^{0}C day, 20 ^{0}C night with a daylength of 14 h, and a relative humidity (RH) of 60% by day and 70% by night; 35/28 ^{0}C refers to a 35 ^{0}C day, 28 ^{0}C night with a daylength of 14 h, and a RH of 55% by day and 60% by night; 40/28 ^{0}C refers to a 40 ^{0}C day, 28 ^{0}C night with a daylength of 14 h, and a RH of 50% by day and 60% by night.

In one series of three experiments, the effects of these three temperature regimes on emergence and growth of SC403 were tested in sand cores that were moist at the time of planting. For each experiment, cores of sand were set up in tubes (550 mm long, 160 mm diameter). Dry sand was poured into the tubes, which was then watered with an excess of full nutrient solution (Clark et al., 2000) and then allowed to drain. Later that day, un-primed seeds were planted into the cores of sand at 5 cm depth. At the same time, the seeds to be primed started their imbibition process. The following day, the primed seeds were planted, and a second un-primed control treatment planted. A total of 18 tubes were planted, arranged in three blocks in the controlled environment room. Two seeds of each treatment were planted per tube. Emergence was monitored over the following days. Each core was watered with 400 ml water 6 days after the U and P treatments were planted. Plants were harvested 3 days later and maximum rooting depth, pseudo stem height and leaf lengths were measured.

In a second design of experiment at 35/28 ^{0}C, the effect of allowing the sand cores to drain and dry out before planting was tested. The experiment was a 2 by 3 factorial, with the factors being priming (or not) and three planting occasions. A total of 36 cores of sand were set up, with each core being prepared as described above. The 36 tubes were arranged in 6 randomised blocks. The day after they were set up, 12 tubes were planted with primed and un-primed SC403 seed, 6 tubes for each seed treatment, at 5 cm depth. Three seeds were planted per core. Four days later, 12 of the remaining cores were planted in the same way. A further 4 days later, the remaining 12 cores were planted in the same way. For each drying treatment, the cores were watered with 400 ml nutrient solution 7 days after each core was planted. Plants were harvested 14 d after planting.

On-station study

The study was carried out at Save Valley Experiment Station in Chipinge district, Zimbabwe. The soil is generally deep, and is a medium-grained sand loam. The experiment had two factors: date of planting and seed treatment. A day before planting, the land was irrigated through overhead irrigation to field capacity. Primed and un-primed seeds of SC401 were planted over a period of eight consecutive days in a drying seedbed. Seeds were sown 4-5 cm deep, starting on 8 January 2000, at a spacing of 33,000 plants ha^{-1}. There were three plots for each priming by sowing date combination. The aim of the experiment was to compare the growth of seedlings that had emerged from primed or un-primed seed on the same day, but in this paper we will compare emergence at two planting dates (8 January and 12 January) and relate this to measurements of soil moisture made using a Theta Probe (Delta-T Devices).

On-farm studies

On-farm studies were conducted in Small Scale Commercial and Communal farming areas in Masvingo Province, Zimbabwe in 1999-2000 and 2000-2001 to allow farmers to assess the value of priming for themselves. In 1999-2000 farmers were asked to compare the growth of maize hybrid R201 grown from primed and un-primed seed. Farmers were supplied with sufficient seed to plant two plots of approximately 10 rows, each 20 m long. Primed and un-primed seed was planted side by side in paired plots. In the subsequent analysis of crop yield each site was considered as a replicate in the ANOVA. Farmers managed the trials using their usual management practices.

Discussions were held in each community during the season to assess farmers' perceptions of the strengths and weaknesses of priming. A questionnaire survey was also undertaken of 50 households prior to maize harvest to establish the seed soaking methods, if any, already used and views on the trials.

The trials were modified in 2000-2001 to include four maize cultivars, each planted on plots of 10 rows each 10 m in length. All farmers were provided with seed of SC513 (137 days to maturity), SC627 (144 days) and SC709 (151 days). The majority also planted SC501 (maturity 134 days), which had become the most commonly-planted cultivar in the area. In some areas this was replaced by DK8031. Once again trials were farmer-managed and assessed by farmers at a group meeting prior to harvest. Yields were recorded at 23 sites by project staff.

RESULTS AND DISCUSSION

Controlled environment studies: germination

The rate of germination increased with temperature for all treatments up to 30 ^{0}C (Fig. 1a). However, at higher temperatures big differences between treatments were seen. The rate of germination in un-primed seeds showed an optimum around 37 ^{0}C, but germination rate declined sharply with temperature above 30 ^{0}C when the seeds had been primed. This was especially evident when the seed orientation was embryo down (the same as in the un-primed seed). Indeed, at the optimum temperature for germination rate in un-primed seeds, the primed seeds with the embryo down failed to reach 50% germination. Similarly, the data on final percentage germination (Fig. 1b) showed that primed seeds were more sensitive to heat stress in this moist environment. The embryo of the maize seed appeared to be sensitive to excess water at high temperatures, which would account for the effect of seed orientation on germination.

Controlled environment studies: shoot emergence and early growth

Effect of temperature in moist planting conditions: At 30/20 ^{o}C, although primed seeds gave faster shoot emergence than un-primed seeds planted at the same time, a similar advantage was obtained by planting un-primed seeds 17 h earlier (Fig. 2). At 35/28 ^{0}C, priming gave a smaller advantage compared to un-primed seeds planted at the same time. Emergence of the early-planted un-primed seed was

Figure 1(a). Effect of priming on the temperature-dependence of germination in maize SC403, showing rate to 50% germination.

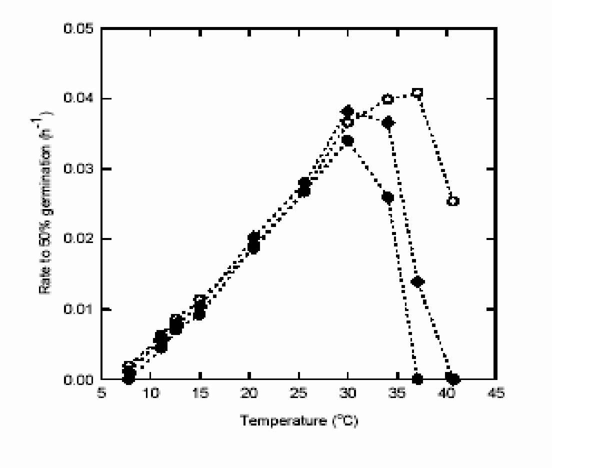


Figure 1(b) Effect of priming on the temperature-dependence of germination in maize SC403, showing rate to final percentage germination.

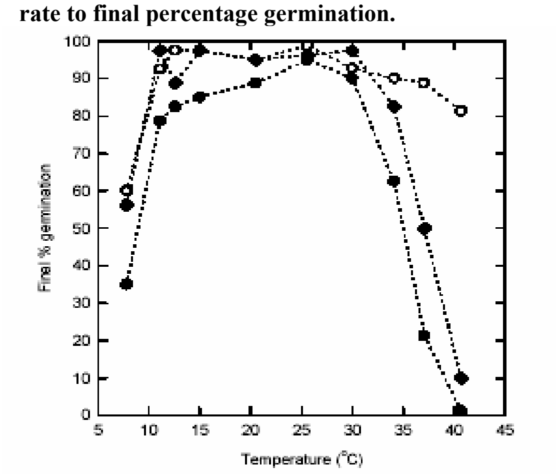


Figure 2. Effect of planting treatments on emergence of maize SC 403 at 30/20 □C.

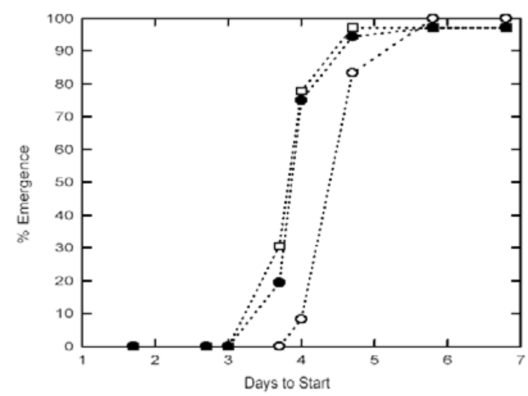


Figure 3. Effect of planting treatments on emergence of maize SC 403 at 35/28 □C.

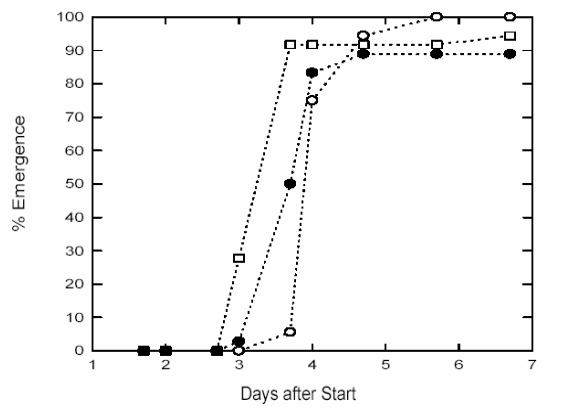


Figure 4. Effect of planting treatments on emergence of maize SC 403 at 40/28 □C.

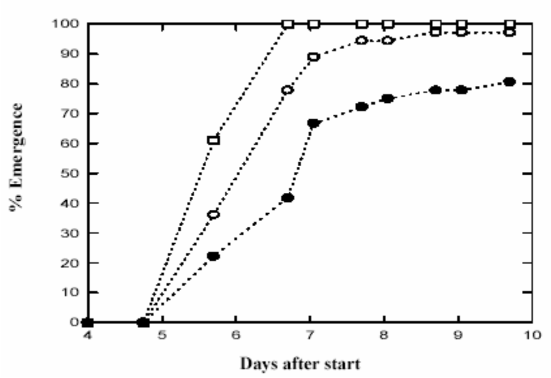


Figure 5. Effect of planting treatments on emergence of maize SC 403 at 35/28 □C in drying sand cores.

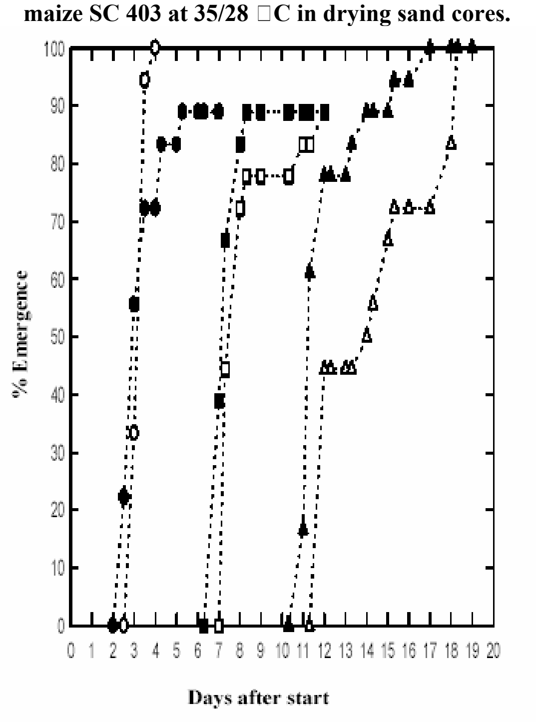


Table 1. Effect of planting treatments on growth in maize SC 403 at three temperature regimes.

	Planting Treatment			
	E	U	P	s.e.d. (d.f.)
30/20^{0}C				
Maximum root length (mm)	326	293	303	12.3 (85)
Pseudo-stem height (mm)	29	23	22	1.6 (85)
Length of longest leaf (mm)	129	117	111	4.0 (85)
35/28^{0}C				
Maximum root length (mm)	357	319	349	17.5 (79)
Pseudo-stem height (mm)	33	30	31	1.4 (79)
Length of longest leaf (mm)	144	127	128	5.9 (79)
40/28^{0}C				
Maximum root length (mm)	100	97	85	4.4 (69)
Pseudo-stem height (mm)	6	7	7	0.6 (69)
Length of longest leaf (mm)	46	42	36	2.4 (69)

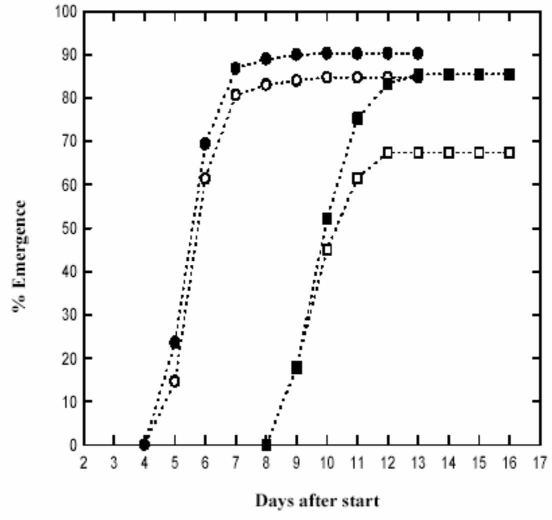
ahead of the primed seed. At 40/28 ^{0}C, the primed seeds gave slower emergence and lower final percentage emergence than both the un-primed treatments. This pattern is consistent with the observed effects of priming on the temperature-dependence of germination (Fig. 1). At harvest, the planting treatment led to some significant differences in maximum root length, pseudo-stem height and the length of the longest leaf, although the size of these differences was relatively small (Table 1). There was a general trend that the un-primed seed planted 17 h earlier gave the largest plants: priming gave no advantage over early-planting in these conditions.

Effect of priming in drying conditions at 35/28 ^{0}C.:
There was a large effect of drying treatment on the effect of priming (Fig. 5). At the first planting, priming gave a slight advance to 50% emergence, but slightly lower final emergence, as in Fig. 3. At the second planting, there was a slight advance to 50% emergence, but no indication of any adverse effect. At the third planting, there was a strong beneficial effect of priming. In effect, priming was buffering the seeds from the deteriorating conditions at planting. Emergence of the un-primed seedlings from the third planting resumed from a plateau at about 70% following the rewatering 7 days after planting (16 days after start).

On-station study

There was little effect of priming on time to 50% emergence when the seeds were planted the day after irrigation, or 4 days later (Fig. 6). However, final emergence from primed plants was greater, but especially so in the later planted treatment. The priming treatment has effectively buffered the crop from the drying seedbed so that the later planted primed seeds gave the same final emergence as the early planted un-primed seeds. The mean gravimetric soil moisture for the two days after each sowing occasion was 16.1% for the first planting, and 11.7% for the second. Therefore the benefits of priming on emergence have been demonstrated to be greater at low soil moisture in both controlled environment and field experiments. While planting the day after watering in controlled environments led to an adverse effect of priming on final emergence, this adverse effect was not seen in the field experiment (nor was it seen the following year, results not shown).

Figure 6. Effect of planting treatments on emergence of maize SC 401 at Save Valley Experiment Station in 1999/01 season.



Farmer-managed trials: effect of priming on maize yields

Across sites, priming led to a significant increase in maize grain yield in 1999-2000 (Table 2). On average, primed yields were 105 kg ha^{-1} higher than those from un-primed maize, a 14% increase. With the exception of three sites, priming had a positive effect on yield. Priming also significantly increased yields across farms in 2000-2001 by an average of 182 kg ha^{-1} (14%). However, there was no significant difference between the yields of different cultivars despite their somewhat different durations, suggesting that priming may be effective for all cultivars under farmer management.

Farmer-managed trials: farmers' perceptions

Formal survey:
A quantitative estimate of the importance of the main issues raised by farmers was obtained from the survey (Table 3). Results from the formal survey indicated that 38% of respondents normally prime maize seed. Those who did not indicated that they either lacked the knowledge, stated that "it is not our practice", or indicated that it was too time consuming. Both purchased and farm saved maize seed is soaked. Of those who reported priming, 16% soak all their seed, 21% about half, 26% about one quarter and 37% soak sufficient for gap filling only. Where priming is already undertaken most farmers soak the seed for more than 12 hours. The practice is most usually used for planting into residual moisture in *vlei* soils. These are seasonal wetlands where the crops are established ahead of the rains. Only 10% of farmers said they used primed seed on the sandy topland soils, which are planted following rain. Farmers use primed seed largely for gap filling after crop emergence rather than for planting whole fields. Priming is therefore used to improve crop emergence and ensure an adequate plant stand either when planting into residual moisture or "to catch up" when gap filling. The majority of the trials were planted on sandy to sandy loam soils (81%) and nearly all (95%) were sown after rain into moist soil.

Table 2. Effect of seed priming on yield of farmer-managed maize in Masvingo province.

	Yield (kg ha^{-1})	
	1999-2000 (18 farms)	**2000-2001 (21 farms)**
Primed	835	1523
Un-primed	730	1341
% increase	14.4%	13.6%
P	0.018	0.023
S.e.d.	40.3 (17 d.f.)	79.2 (142 d.f.)

Field Days and Focus Group Discussions:
Farmers' perceptions of the advantages and disadvantages of priming were explored in detail during the field days and at focus group discussions after farmers had gained more experience of priming seed. In particular, problems of handling and seed wastage are likely to be overcome with increased familiarity with the technique. Increased pest damage on primed seed is partly due to it being more attractive to seed eating birds. At the field days prior to the second season of trials the following farmer comments were recorded:

Emergence of primed seed is one to two days earlier than non-primed seed, even when soil moisture is low; use of priming allows planting to be undertaken in drying soils;
Less gap filling is needed when primed seed is used and this saves money;
Primed seed out-competes weeds;
Primed plants grow faster and mature earlier than non-primed counterparts;
Larger cobs can be harvested from primed plants;
Farmers thought that SC627, SC701 and DK8031 responded well to priming.

Handling of soaked seed, which is surplus to immediate requirements, was still perceived as a problem. This is partly associated with the current AIDS epidemic as farmers indicated that they are often called away to funerals at short notice. This is seen to be a problem if seed has been soaked overnight for planting the next day. Since hybrid seed is a major expense the farmers incur in producing maize, they are reluctant to risk losing costly seed.

It is interesting to note that primed crops were associated with increased competitiveness with weeds in both seasons. In the discussions, farmers indicated that in their view primed crops are more vigorous at the seedling stage and are growing faster than crops developing from dry seed. However, their observations from the 1999/2000 year indicate that priming did not decrease the interval between emergence and tasselling/silking (nor was this seen in on-station trials at Save Valley, Henderson and Makaholi). Two schools of thought emerged about how the use of priming could interact with the timing of weeding operations. On the one hand, some farmers believe that it is important to weed the best maize stands first. This would lead them to weed primed maize first as it has a better plant population and is vigorous. The other view is that because primed maize is thought to be more competitive with weeds, it can be left longer than un-primed stands before weeding is started. In both cases the earlier emergence and increased vigour of a primed stand are the key factors and are clearly seen as an advantage for tolerating weeds.

Table 3. Farmers' perception of advantages and disadvantages of priming maize. (% farmers mentioning each issue).

Advantages	Disadvantages
Earlier emergence (80%)	Seed difficult to handle (24%)
Better crop stand (24%)	Poor germination when soils are dry (10%)
Improved crop growth (22%)	Increased pest damage esp. birds (10%)
Less competition from weeds (14%)	Seed dressing is lost (10%)
Crop better able to withstand drought (6%)	Unused seed wasted (8%)
Earlier planting is possible (4%)	Seed rots easily (6%)
Fewer weeds in primed plot (4%)	Also mentioned: seed may not emerge
Increased crop yield (4%)	Additional labour needed

Labour costs associated with priming are in most cases minimal since a farmer needs only to soak the seed for planting the following day. However, some farmers observed that the seed is sticky so there is a small increase in the time taken to plant. As yields are marginally increased, there will be a corresponding increase in the labour needed for harvesting, transport of cobs and threshing. Economic analysis of the on-farm trials (Jasi *et al.,* 2000) indicates that there are generally net benefits from priming. Net benefits were higher for the well-resourced farmers than poorly- resourced farmers. This is due primarily to better-resourced farmers having better access to draught power and fertiliser which allows them to plant earlier, weed on time and to top dress the crop with nitrogen. However, although poorly resourced farmers generally achieve lower levels of production, any increase in yield gained without significant cost is likely to be of considerable benefit.

CONCLUSIONS

In laboratory experiments, primed maize seeds appear to be more vulnerable than un-primed seed to high temperatures in moist conditions. However, even at high temperatures, primed seed is less vulnerable to low soil moisture at planting. This beneficial effect was seen in both laboratory and field experiments, and agrees with farmers' perceptions of the effect of priming on emergence and crop stand.

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SOIL AND WATER MANAGEMENT OPTIONS FOR SEASONAL WETLANDS (*VLEIS*) IN SEMI-ARID AREAS OF MASVINGO PROVINCE, ZIMBABWE.

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ABSTRACT

***Vlei*s are low-lying, usually gently sloping, seasonally waterlogged areas. Two major problems facing farmers in this environment are weed control and water management. On-farm tillage trials tested in four locations were broad-beds, pre-plant ridges, post-plant ridges, drainage furrows and flat-planting. PVC pipes were installed to 1m depth and height of water table was recorded monthly. Maize and rice yields were recorded from each plot. Mean water level below the soil surface under broad-beds was 63 cm compared to 56 and 57 cm under post-plant ridges and furrows, respectively. The effect of the broad-beds on water levels was consistent across the season. Broad-beds gave significantly higher maize yields compared to the worst performing treatment, flat planting, where areas of inundation and waterlogging were recorded. However, rice yields were favourable under flat planting. Post-plant ridges and furrows produced no rice yield due to inappropriate timing of their construction. Economic analyses indicate that despite the increased labour and draft animal requirement, beds give better returns than other treatments. Flat planting, being the one most commonly used by farmers, is the second most productive treatment and for those without access to DAP, this is likely to be the one they continue to use.**

Keywords: Groundwater, herbicides, ridges, tillage, wetlands (*Vleis*), Zimbabwe

INTRODUCTION

Vleis are areas that are saturated by surface or ground water frequently and for long enough periods to support vegetation typically adapted to such conditions (Snyder, 1995). They are also referred to in Zimbabwe as *matoro* or *bani* (Shona), and elsewhere in south-central Africa comparable features are called *dambos* (Thomas and Goudie, 1985). *Vleis* have a long history of use which pre-dates European settlement. They are recognised as a valuable resource, which play an important role in smallholder household food security in Zimbabwe, especially during seasons of low rainfall when crop production on sandy topland soils is poor (Kundlande *et al.*, 1992). Many *vleis* are also a valuable source of water through shallow wells or springs, providing opportunity for irrigation and provision of water for people and livestock (Rattray *et al.*, 1953).

Of the 240,000 hectares of wetlands found in Zimbabwe's communal lands, some 80,000 hectares is estimated as cultivable. Current legislation in Zimbabwe is aimed at conserving these wetland areas by restricting their use, especially through cultivation (Water Act 1998; Natural Resources Act, 1992; and 1952 Stream Bank Protection Regulation). However, in reality the legislation is not enforced and cultivation is widespread. Much of the erosion occurring in *vleis* has been attributed to inappropriate agrarian reforms and growing population pressures in communal areas (Bullock, 1995; McFarlene, 1995), although some believe that the effects can mainly be linked to large-scale commercial utilisation. A safe limit on the extent of *vlei* cultivation is considered to be 10% of the catchment area or 30% of the *vlei,* whichever is the smaller (Bullock, 1995). Where cultivation occurs, which in the smallholder sector is predominantly maize/rice intercrops, two of the major problems facing farmers are soil/water management and control of weeds. In seasons with excessive rainfall *vlei* maize crops are often abandoned (Mutambikwa *et al*., 2000). Rice pits (matimba) and ridge-furrow planting were two widely practised, but subsequently abandoned, methods used to control water and facilitate cropping (Whitlow, 1989). Remains of ridge and furrow systems can be seen in many *vleis* throughout Zimbabwe, providing evidence of past cultivation (Mharapara, 1994).

In communal areas close to Harare, *vlei* use is predominantly in the form of small-scale commercial vegetable gardens (Adams *et al.*, 1997). This is in contrast to the drier southern parts of Zimbabwe, particularly in communal lands north of Masvingo, where *vleis* are incorporated within large fields, laid out as arable blocks on valley slopes and bottom-lands (Ellis-Jones and Mudhara, 1995). These studies show that large areas of potentially cultivable *vleis* are currently under-utilised in the communal areas. Yet, if effectively managed they could make a major contribution to improving food security, alleviating poverty and helping to stabilise rural households' incomes. Little work has been carried out to understand and alleviate the production problems faced by farmers to ensure that the *vleis* are used in a sustainable manner. Currently there is inadequate information on how *vleis* can be effectively managed at the household level and there is a need for scientific understanding to develop and support new guidelines on *vlei* utilisation. Appropriate tillage techniques that will allow excess water to be drained during wet periods, retain water in dry periods, retain soil and allow effective weed management are needed.

From focus group discussions held in Masvingo Province (Mutambikwa *et al*., 2000), it is apparent that farmers recognise two main types of *vlei*s based on their

Table 1. Tillage treatments assessed in on-farm trials on wet and dry *vleis* in Masvingo Province

T1	**Beds**	Two rows of maize planted on raised beds and rice planted in furrows between the beds.
T2	**Pre-plant ridges**	Maize planted on ridges constructed at planting and rice planted in the furrow.
T3	**Post-plant ridges**	Maize and rice planted on the flat and ridges made after the crops have established.
T4	**Furrows**	Maize established on the flat, with furrows made after the rains start, rice planted in the furrow.
T5	**Flat** Farmer practice	Maize planted on the flat with rice planted either in the same row or broadcast between the maize rows.

hydrology and soil type, *dhorobvukwa* (dry *vlei*s) and *dhoro* (wet *vlei*s). Dry *vlei*s are composed of light textured soils located on the valley sides that receive water as runoff from upland areas. Although the surface may appear dry during the dry season, they are often planted on residual moisture in October just prior to the first rains, with yields usually assured regardless of the rainfall received during the coming months. The wet *vlei*s comprise heavier textured soils found on the lower end of the granite catena close to the valley bottoms (Mutambikwa *et al*; 2000). The soils are typically black in colour and sticky to the touch and are waterlogged for much of the rainy season. They are normally planted in August/September prior to the onset of the first rains so that the crop becomes established before waterlogging occurs. However, in particularly wet seasons the crop may be abandoned as waterlogging prevents access for weed control and stunts maize growth.

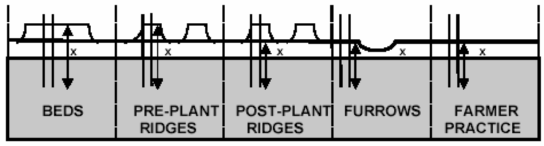
Ongoing research in Masvingo Province is aimed at addressing the problem of soil and water management, by identifying a range of water and weed management options from which farmers can select those most suited to their resources. Work on the development of weed management options for *vlei* crops is reported in Muzenda *et al.* (2002). This paper concentrates on the physical manipulation of the soil surface in order to control groundwater levels in the *vleis*. This study has two objectives:

- The comparison of the effects of a number of different tillage treatments on ground water levels through the season
- The assessment of the effects of these treatments on maize and rice yields.

MATERIALS AND METHODS

On-farm trials were established in four areas of Masvingo Province, encompassing both wet and dry *vleis*: Mashagashe small-scale commercial farming area; Gutu/Chatsworth re-settlement area; Zimuto communal area; and Chikwanda/Mukaro communal area. In each area, four farmers hosted tillage trials on their *vleis*. Two offered wet *vlei*s, two offered dry *vlei*s, giving a total of eight wet and eight dry *vlei*s. The five treatments tested at each site were agreed following a project initiation workshop and farmer focus group discussions (Mutambikwa *et al*., 2000) (Table 1). All plots were graded at a 1:100 slope to ensure that water could be safely discharged into contour drains at a

Figure 1. Cross-section of the five tillage treatments with observation pipes.



1:250 slope.

Plots varied in size from site to site depending on the area available on each farm, but the crop rows were always a minimum of 30m in length. The maize and rice were planted on residual moisture in September 2000 before the onset of the rains. Maize variety SC513, tolerant to grey leaf spot, was planted at all sites. The rice used in the trials was a local variety (*Muchecheni*). Maize was planted at a spacing of 0.9m (between row) x 0.3m (within row), while the rice was planted at a rate of 60 kg ha^{-1}. Compound D fertiliser (8%N, 14%P, 7%K) was applied to all plots at a rate of 150 kg ha^{-1} while a top-dressing of ammonium nitrate, 34%N, (AN) was applied at 100 kg ha^{-1} approximately 2 months after planting. Each plot was split in half, one half where the weeds were treated with herbicide and the other where they were controlled by hand hoeing only. On the herbicide sub-plots, bentazone (1,440 g a.i. ha^{-1}) was applied 3 weeks after crop emergence (WAE) using a knapsack sprayer producing a spray volume of 300 litres ha^{-1}.

Groundwater levels were monitored using a number of observation pipes, which were inserted, into auger holes to approximately 1m depth (or to the limiting layer, eg. rock or gravel, if this was encountered first). Two pipes were placed on the upper part of the *vlei* (one on the herbicide treated plot, one on the hand hoed plot) and two were placed at the bottom end, closest to the waterway, thereby ensuring that the range in water levels across the treatments was encompassed. The groundwater levels were measured at approximately 2-3 weeks intervals. Figure 1 shows a simplified cross-section of the five treatments and the position of the monitoring pipes assuming a constant water level. It is important to note that the depth being measured at each time interval is from the soil surface to the water table (depths x on Figure 1). However, with the post-plant ridges, since the first few measurements were made on the flat before the ridges were formed, this was continued throughout the season even after the ridges were constructed to avoid misrepresenting true changes in the groundwater levels.

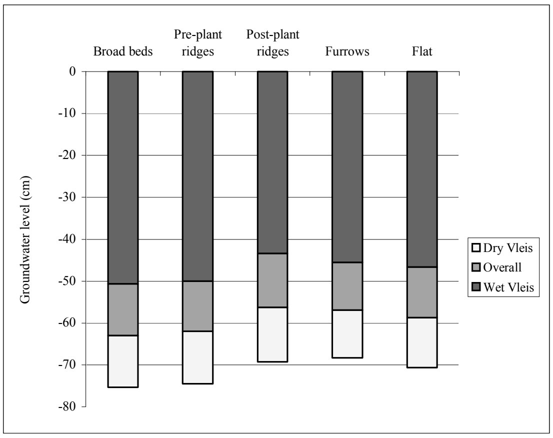
Maize and rice yields were measured by sampling sub-plots. The results were standardised to 12.5% moisture content and expressed on a kg per hectare basis. They were then statistically analysed using individual farms as replicates in ANOVA in Genstat.

RESULTS AND DISCUSSION

Groundwater levels

Seasonal groundwater levels for each tillage type are presented in Figure 2. Each bar is based on seven individual readings. They indicate that the mean groundwater levels under the beds and pre-plant ridges were furthest from the soil surface at 63 and 62 cm respectively, while with post-plant ridges the water table was on average only 56 cm from the soil surface. Groundwater levels under furrows were also relatively close to the soil surface with a mean of 57 cm.

Figure 2. Mean depth to groundwater level across the five tillage treatments for the 2000/2001 season.



This pattern was largely observed on both *vlei* types, although on the dry *vlei* the furrows showed the highest water table. However, the means mask the variations within the season, therefore Table 2 shows the highest and lowest values observed for each treatment averaged across the four areas. They indicate that the effectiveness of the beds in controlling the water level was most evident during the wetter periods, with the water table lying an average of 21.7 cm below the surface, compared to 13.8 cm with the flat planting. If the assumption is made that the water table is at a constant level across the treatments, then the difference between the beds and the flat planting (equal to 7.9 cm) is effectively the height of the bed. During drier periods, the order of the treatments changed, with the water table typically lying between 90 and 100 cm below the soil surface. The results indicate that in the *vlei* environment, creating either broad-beds or ridges at planting can effectively lower the water table. Such an effect may be particularly important in either very wet vleis or during excessive rainfall conditions, where waterlogging and the creation of anaerobic conditions within the topsoil can severely affect maize rooting systems and crop development.

Figure 3 illustrates the temporal variation in groundwater levels averaged across the four areas. The mean rainfall received over the season was 642 mm, with individual figures of 725, 669, 596 and 576 mm for Mushagashe, Zimuto, Mukaro (Chikwanda) and Chatsworth, respectively. The groundwater levels are closely related to the pattern of rainfall received, with the lowest levels associated with the depressed rainfall between 110-120 days after planting (DAP) and a significant increase in water levels on all plots as a result of the rainfall received between 140 days and 180 DAP. On the wet *vleis*, the beds had the lowest water table on five of the seven measurements, an effect which was more pronounced during the latter half (>170 days after planting) of the season. At the fifth recording time, the water table was closest to the soil surface with the flat planting treatment, although there was little difference between that treatment and the post-plant ridges. The highest water levels on the dry *vleis* were also recorded under the flat planting treatment with a more pronounced difference compared to the other four treatments, although this was restricted to the measurements taken during the wetter part of the season. Furrows showed the highest water table during the first 125 DAP, but proved more effective in reducing groundwater levels during the wetter periods.

Table 2. Highest and lowest groundwater levels (cm) recorded during 2000/2001 season across both *vlei* types for each tillage treatment and their ranges

Treatment	Highest	Lowest	Range
Beds	-21.7	-98.2	76.5
Pre-plant ridges	-18.5	-100.0	81.5
Post-plant ridges	-14.9	-90.7	75.8
Furrows	-17.1	-88.5	71.4
Flat	-13.8	-96.4	82.6

Figure 3. Temporal variation in groundwater levels on wet and dry vleis averaged across the sites for the five tillage treatments.

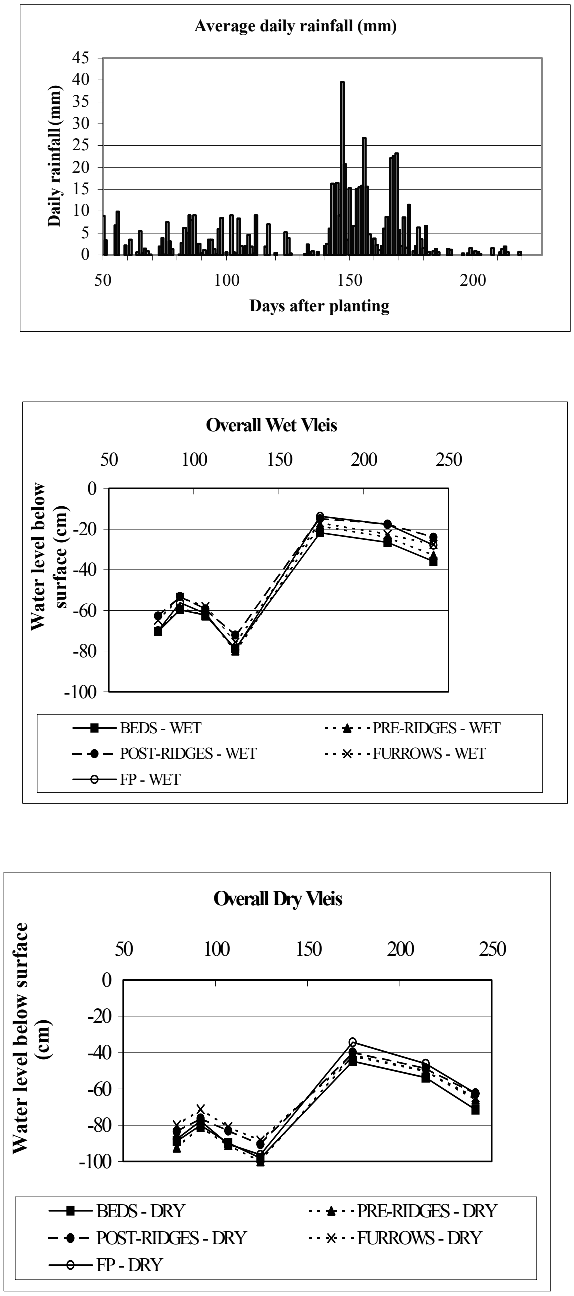


Table 3. Main sources of variation in maize and rice yields (kg ha^{-1}) in on-farm tillage trials on *vleis* in Masvingo Province.

Source of variation	Maize yield	Rice yield
Area		
Mushagashe	3988	407
Gutu/Chatsworth	1687	240
Zimuto	3052	279
Chikwanda	2367	491
SED	414	155
Significance	**	NS
df	6	6
Vlei type		
Wet vlei	2919	324
Dry vlei	2628	385
SED	156	58
Significance	NS	NS
df	2	2
Tillage		
Beds	3441	578
Pre-plant ridges	2417	522
Post-plant ridges	2725	0
Furrows	3077	0
Flat	2206	671
SED	192	98
Significance	***	***
df	32	32
Weeding		
Herbicide	2691	329
Hand hoe	2856	380
SED	99	18
Significance	NS	**
df	40	40
Position		
Upper vlei	2924	359
Lower vlei	2622	350
SED	134	28
Significance	*	NS
df	80	40

SED Standard error of differences
NS not significant
* P<0.05, ** P<0.01, *** P<0.001

Maize and rice yields

Table 2 summarises the main sources of variation in maize and rice yields identified by ANOVA, showing the overall yields for each area, *vlei* type, tillage treatment, weeding method (herbicide or hand hoeing) and position in the *vlei*. Significant treatment effects were observed with both maize and rice yields. In terms of area, significant differences were found between the four sites, with the small-scale commercial area of Mushagashe almost giving 4,000 kg ha^{-1}, in contrast to only 1,687 kg ha^{-1} at Gutu/Chatsworth. Maize yield under the beds system averaged just less than 3,500 kg ha^{-1}, while drainage furrows showed the second highest yield of 3,077 kg ha^{-1}. The lowest yields were observed on the farmer practice treatment at 2,206 kg ha^{-1}. This pattern was observed regardless of herbicide usage. Interestingly, the yields from the herbicide treated half-plots were on average lower than those not treated with herbicide, although this effect was not statistically significant. Bentazone, the herbicide used in the trials, provided good suppression of *Cyperus esculentus* at all sites but did not control some other abundant species including *Leersia hexdandra, Setaria pumilla* and *Richardia scabra*. These were removed by hoe weeding, possibly accounting for the higher yields with this method of weed control. The position in the vlei also significantly affected the maize yields, with higher yields measured on the upper part of the vlei. The lower part of the *vlei* will always be the area that suffers most from inundation, particularly where water is not effectively draining out of the *vlei* into the waterway. As the results suggest, this can adversely affect final maize yield.

Area, vlei type and position did not significantly affect rice yields. However, tillage treatments showed interesting differences. Contrasting with the maize yields, the highest rice yields were obtained on the farmer practice flat planting system, reaching an average of 671 kg ha^{-1}. Beds gave the second highest yields almost 100 kg ha^{-1} lower than flat planting. Zero yields on the post-plant ridges and furrows were due to a combination of reasons. In respect of the post-plant ridges, the timing of the construction of the ridges was such that the disturbed soil from the plough when thrown up next to the maize plants smothered the young rice alongside, preventing it from growing any further and thus giving no yield. However, the construction of the ridges could not have been left till later because this would have resulted in severe maize damage by cattle. This problem could possibly be overcome by using the plough without the mouldboard to create the ridges, where less soil would be disturbed in construction. Alternatively, the amount of soil disturbed could be minimised by reducing the plough depth to ensure that the rice plants are not completely covered by ridge formation. The zero yields on the furrows can be attributed to late planting, since the rice could not be sown until after the furrows had been constructed. Since the beds were not constructed until late November, it was not possible to sow rice.

Economic analysis

Key variables in determining highest productivity are crop yields (Figure 4), market prices, and the cost of labour for tillage and weeding operations and applying herbicide against savings in labour for each system. Average yields from each of the treatments and average farm-gate prices have been used to determine the value of the crops produced (Figure 5). Additional herbicide and labour costs for weeding and tillage and other operations for each cropping system using either market or opportunity cost for household supplied inputs have been determined and a partial budget analysis used to determine the most profitable treatment for 2000/2001 season, based on 2001 prices (Table 4). Differences in net benefit between treatments have been compared showing an increase or decrease over those most commonly used by farmers (Table 4 and Figure 6a and 6b).

Sensitivity analysis on these variables indicates that the prices of labour and herbicide are key. When the price of labour is low, traditional farmer practice on the flat and the broad-bed system without herbicide are the most productive. As labour price increases, due to unavailability or opportunity elsewhere, flat systems with herbicide become more productive. At a labour price of \$1.60 per day, bed systems without herbicides are the most productive but at \$3.20 per day flat planting with herbicide is most productive, even at high costs of herbicide. Labour availability remains a key concern and many farmers continue to lose their entire crop due to weeds. This is not reflected in trial results, but

Figure 4(a). Average yields (kg per ha) for each treatment.

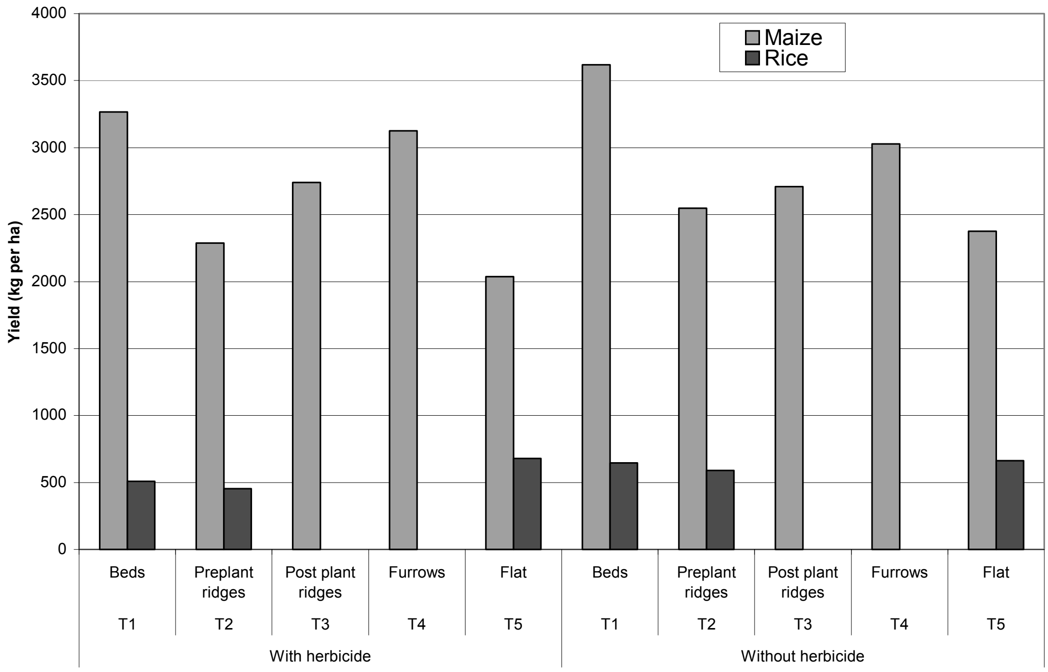
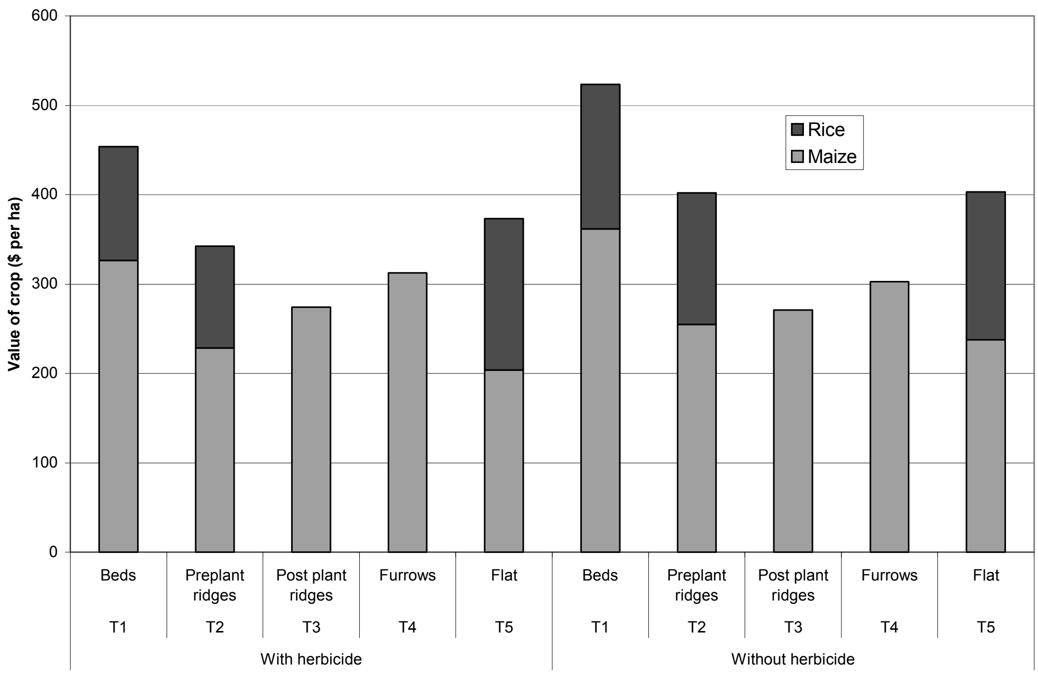


Figure 4(b). Gross benefits from each treatment.



makes the use of herbicides particularly attractive.

CONCLUSIONS

After one seasons work, the best options are beds and flat systems, the choice being largely dependant on the availability of labour and draught animals. If these are available the bed system is appropriate. The beds are able to control the water level to minimise any adverse effects due to waterlogging, whilst still allowing a rice crop between the beds to be harvested. However, without the resources required for making the beds, the flat system remains the best option. Worst options are post-plant ridges and furrows, although the drawbacks to these treatments, especially in terms of rice production, were operational (i.e. rice smothered at ridge construction or furrows made too late in season). The largest drawbacks remain the increase in labour and DAP required for making the beds and creating a tilth for for planting. These do however occur outside the main labour peak for weeding and farmers may be willing to test

Figure 5(a). Comparison with farmer treatment (T5 flat without herbicide) at a labour price of $1.60 per day.

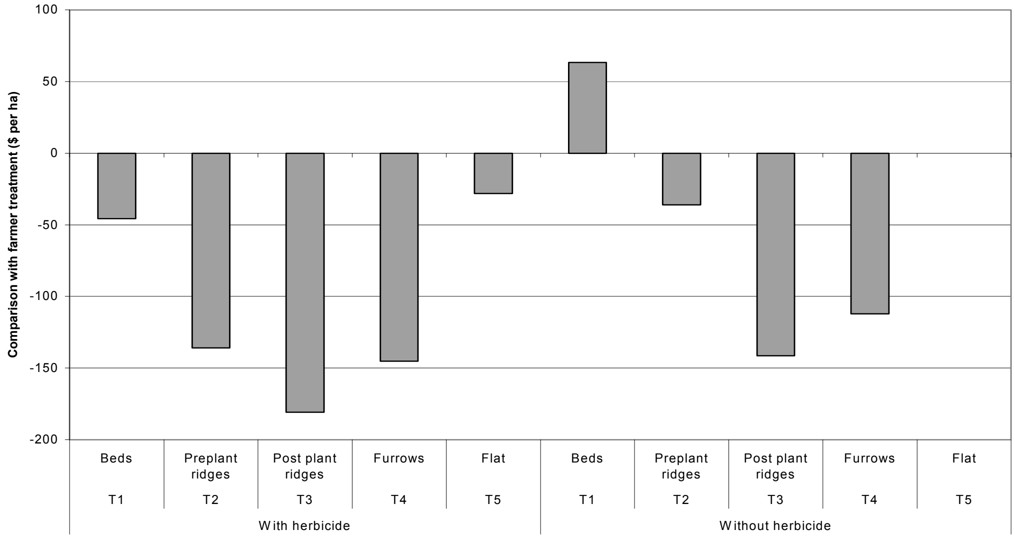


Figure 5(b). Comparison with farmer treatment (T5 flat without herbicide) at a labour price of $3.20 per day.

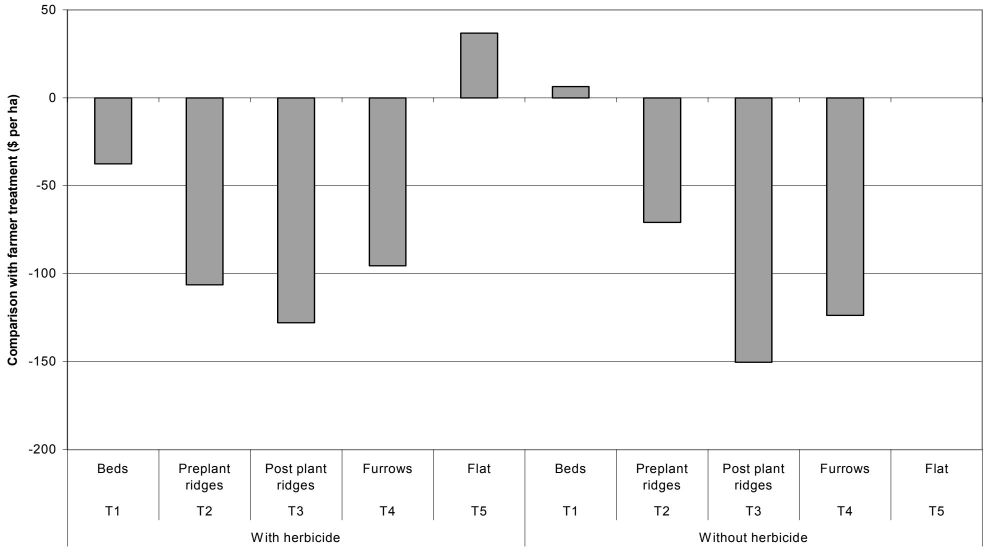


Table 4. Partial budget analysis

Treatment		Value of crop			Additional costs			Value less costs	Differences with farmer method
		Maize	Rice	Total	Herbicide	Labour	Total		
With herbicide									
T1	Beds	327	127	454	104	151	255	199	-46
T2	Pre plant ridges	229	114	342	104	130	234	108	-136
T3	Post plant ridges	274	0	274	104	106	210	64	-181
T4	Furrow	313	0	313	104	109	214	99	-145
T5	Flat	204	170	373	63	94	157	216	-28
Without herbicide									
T1	Beds	362	162	523	0	216	216	308	63
T2	Pre plant ridges	255	148	402	0	194	194	208	-36
T3	Post plant ridges	271	0	271	0	168	168	103	-141
T4	Furrow	303	0	303	0	171	171	132	-112
T5	Flat	238	166	403	0	159	159	244	0

[1] Farmer method

Key assumptions

Maize price: $ 100 per tonne, Rice price: $ 250 per tonne, Labour price: Z$ 1.60 per day

Herbicide costs: Include cost of herbicide and knapsack sprayer (spread over 5 years, 5 ha each year). Herbicide costs have increased 500% in the last year due to shortages of forex.

US $ 1=Z$ 150

the bed systems. Those with insufficient DAP are likely to want to continue with flat planting systems. For these households it may be more appropriate to plant sole crop rice on regularly inundated portions of wet *vleis*, where maize is commonly affected by waterlogging as discussed by Muzenda *et al.,* 2002.

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DROUGHT MANAGEMENT OPTIONS IN MAIZE PRODUCTION IN NORTHERN TANZANIA

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ABSTRACT

The northern zone of Tanzania is one of the major maize producing areas of the country. Population increase is pushing maize production into marginal areas with little and unreliable rainfall. Irrigation, which could support maize production under these conditions, is underdeveloped and expensive to operate by the poor communities. Options available to improve maize production to feed the rising population include the use of in-situ holding of rainwater using landforms like ridges, tied ridges and planting pits. Three moisture conservation methods were evaluated in on-farm and on-station verification trials and demonstrations in northern Tanzania from 1998 to 2001. Medium- and short-term maize varieties were used in the trials in a split plot and split-split plot designs for the on-farm and on-station trials, respectively. Seed placement on the ridges was also evaluated in the on-station trial for verification purposes. Both on-station and on-farm trials proved that tied ridges were good and economical means of soil and water conservation. Yield increase for Kito (short maturing variety) was from 0.8 t/ha on flat planting to 2.3t/ha under tied ridges and for medium maturing variety Tuxpeno 0.3t/ha to 0.7t/ha respectively in a season with less than 500mm rainfall. Under normal rainfall conditions of about 800mm rainfall no added advantage was realized with tied ridges, ridges and pit planting when compared to flat planting. Crest and side seed placements in the ridge system did not differ significantly ($p \leq .05$). The adoption process of this technology is insignificant compared to the benefits and enthusiasm among the community members. Some technology transfer pathways had to be formulated for adoption purposes and these are still underway.

Keywords: Drought, maize production, moisture conservation

INTRODUCTION

Agriculture is the key economic sector accounting for half of Tanzania's GNP, 80% of recorded export earnings and 90% of rural employment. Such an important sector in the economy of a country requires a favourable environment to express its full potential. However, most agricultural activities depend on natural rainfall, which is reliable in only 22% of the land (Hatibu *et al*, 1995). The low and unreliable rainfall is a key factor in causing yield losses to crops, maize being among them. In Tanzania, average maize yield loss due to drought is estimated at 50% but can be as high as 100% in dry years (Nkonya *et al* 1990). On the other hand, favourable environments for agriculture can be created through irrigation, if available, but this is underdeveloped or non-existent in most areas of Tanzania.

In the absence of irrigation, proper management of rainwater to ensure effective utilization by the plant is essential in marginal rainfall areas. Ridging, tie ridging, ripping, sub-soiling, mulching and potholing or pit planting are some of the methods that have been used to conserve moisture in such situations. These have shown positive responses in terms of yield increase in maize and other crops. The moisture conservation methods contribute to increased infiltration rate, reduction of run-off and increased rooting volume especially in shallow soils (Vogel *et al*, 1994).

Moisture conservation techniques have been studied in other areas of Tanzania since 1942 and yield benefits in the tie ridge system were reported (Prentice, 1942). Other studies (Dagg and MaCartney, 1968) of tied ridges under different soil types showed significant increased maize yield only on *vertisols* but not on *alfisols* or *andisols.* Similar results were obtained (Mansoor and Ndakidemi, 2000) in Dodoma, Tanzania where maize yields were increased under tied ridges compared to flat planting ($p=0.01$) by 43 to 99%, more so from black soils than red and sandy soils. In Ethiopia, tied ridges were compared to flat planting in two soil types and tied ridges were superior to flat planting in terms of grain yield (Belay *et al*., 1999). Other studies (Selvaraju, *et al*, 1999) in India compared tied ridges and conventional flat planting in sorghum production and tied ridges increased yields and soil water storage compared to flat planting. In- depth studies of soil moisture conservation have not been done in drought-prone areas of northern Tanzania. This paper describes the evaluation of the effectiveness of soil moisture conservation technologies including tie ridging, open ridging and potholing in increasing maize yields and yield stability in small-scale farming systems of northern Tanzania.

MATERIALS AND METHODS

Two moisture conservation trials were carried out in the northern zone of Tanzania seeking the most effective method in terms of yield increase and economical effectiveness. The trials were carried out over four seasons starting from 1997/98 to 2000/2001 seasons.

Locations and their characteristics

The on-farm trial was conducted in two districts of Arusha and Kilimanjaro regions during the (1997/98 and 1998/99) seasons. The first two seasons were used to verify moisture conservation methods and maize varieties appropriate for moisture stressed areas and the following seasons (1999/2000 and 2000/2001) were used to demonstrate appropriate technology (tie ridging), with further verification.

Table 1. Characteristics of the testing sites

Site	Soil type	Annual Rainfall (mm)	Soil and land characteristics
A. On-farm			
Maroroni in Arumeru district - 1997/1998 (5 farms) - 1998/1999 (11 farms) - 1999/2000 (15 farms) - 2000/2001 (10 farms)	Lithic Regosols (FAO)	300 - 500	• Soils are stony with shallow depth • Hard pan present • Gentle slope (2-5%)
Kikatiti in Arumeru district - 1999/2000 (6 farmers) - 2000/2001(5 farmers)	Eutric Regosols (FAO)	300 - 600	• Soils are stony with shallow depth • Hardpan • Gentle slope (2-5%)
Rundugai in Hai district - 1997/1998 (4 farmers) - 1998/1999 (5 farmers) - 2000/2001 (8 farmers)	Luvic Chernozem (FAO)	300 - 600	• Gentle slope 2% • Deep • No hard pan
B. On-station			
Selian Agricultural Research Institute	Eutic Haplustoll (USDA classification)		• Surface texture is Clay Loam • Deep and Good drainage • Very gentle slope (2%)

Figure 1. Monthly Rainfall (mm) for 1998 and 1999 at on-farm sites during the growing period.

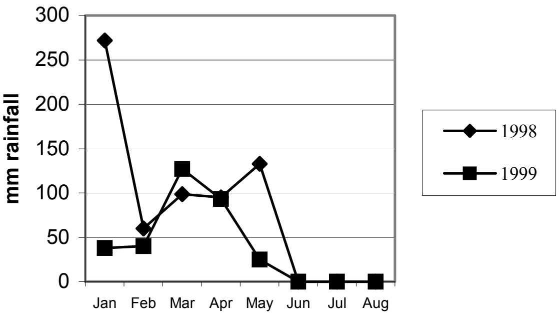
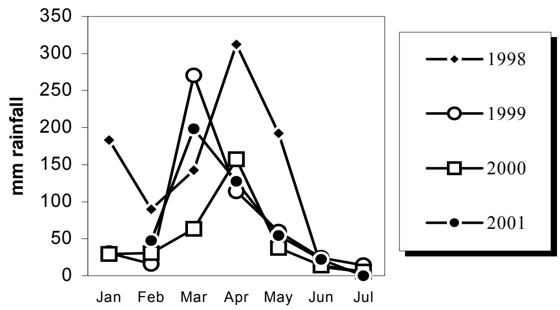


Figure 2. Monthly Rainfall (mm) for 1998-2001 during the growing season at S.A.R.I.



The on-station trial was initiated at Selian Agricultural Research Institute in 1999 after realizing that in using tied ridges, there were seed placement options namely crest, side and bottom which were suggested by different farmers. This was essentially a verification trial on seed placement on the ridges but different maize varieties were also compared and potholing and flat planting were included to fine-tune the on-farm trial. The characteristics of the on-farm sites do no differ much but the on-station site is quite different as indicated in Table 1and rainfall patterns in Figs 1 and 2.

Experimental design and management

A split plot experimental design was used for the verification trial and strip plot for the demonstrations in on-farm trials. Land formations (tied ridges, open ridges, potholes and flat planting) were made before the onset of the rains and assigned to main plots and varieties were assigned to subplots. Each plot constituted six rows of 5m length spaced at 0.75m apart. The spacing within the rows was 0.6m two plants per hill giving a plant population of 44,444 plants per hectare

Four maize varieties, Katumani, Tuxpeno, TMV-1 and CG4141 were compared. The first three varieties are open pollinated while the last one is a hybrid, which is the most common variety grown in the study area. Maize was planted at the on-set of rainfall in mid-March at a spacing of .75m x .60m two seeds per hill for the first two years. During the third and fourth years, a regional trial was started in Kenya, Ethiopia and Tanzania demonstrating tie ridging in comparison with farmers' practice. In Tanzania only one maize variety was used which was the farmers' commercial variety. In the demonstrations, a strip plot design was used where one plot was about 200m^2 (20 ridges spaced at 0.9m apart 20m long). The plots were purposely made large for ease of collecting economic data. Nitrogen fertilizer was applied to all plots at the recommended rate of 60kg/ha N in the form of Urea.

A split-split plot design was used where main plots were moisture conservation methods, sub-plots were seed placements and varieties were sub-sub plots. The same moisture conservation methods used on-farm was used on-station (flat, pot-holed, open ridged and tied ridged). Within the ridges, three seed placements were used namely crest, side, bottom of ridge. Five maize varieties were used for this trial: Katumani, Kito, CG4141, TMV-1 and Tuxpeno (CG4141 and C 5051 hybrids of medium maturity). Variety Tuxpeno was used during the first year only and was replaced by C5051 due to poor performance. The plot sizes were varied due to the extra treatments of seed placements within the ridges. The main plot for the tied and open ridges

Figure 3. Effect of soil moisture conservation methods on maize grain yield on-farm.

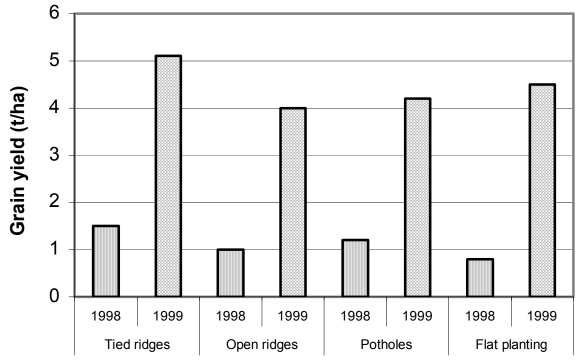
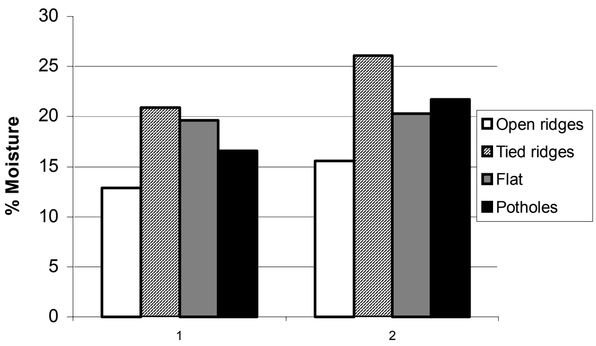


Figure 4. Moisture retained in the soil up to physiological maturity during 1999/2000 & 2000/2001



was 24 rows x 0.9m/row x 10m x 3 sub-plots = 648m^2. Main plots for flat planting and pot holes was 21.6m^2 and sub-plots were 24 rows x 0.9m/row x 10m= 216m^2.

Ridges were tied at 2m intervals using hand hoes, which is what farmers are using, and planting was done in 1st April, 16th March and 7th March for 1999, 2000 and 2001, respectively, for the on-station trial. Soil moisture data were collected prior to land formation i.e. pot holing and ridging and after harvest to a depth of 1m in 15cm intervals and just before harvesting. All other crop husbandry practices were performed (thinning, weeding, fertilizer application (100kg/ha Nitrogen as Urea and 60 k/ha P_2O_5 as Triple super phosphate) and insect control).

Data collection

Data were collected on plant stand, plant height, biomass, grain yield and rainfall during the growing season. Economic data were collected as follows:

1. Information on land preparation was gathered through talking to several farmers since all farmers in this area use ox-ploughs.
2. Changes in labour implied by the different treatments were estimated through direct observation in the field (e.g. time taken to make 18 ridges 20m long).

Statistical data were analyzed using Analysis of Variance (ANOVA) with the MSTAT package and treatment means were separated using Least Significant Difference (LSD). Economic analysis using partial budgetting and gender analysis using Gender Analysis Matrix (GAM).

Figure 5. Effect of soil moisture conservation methods on maize grain yield on-station.

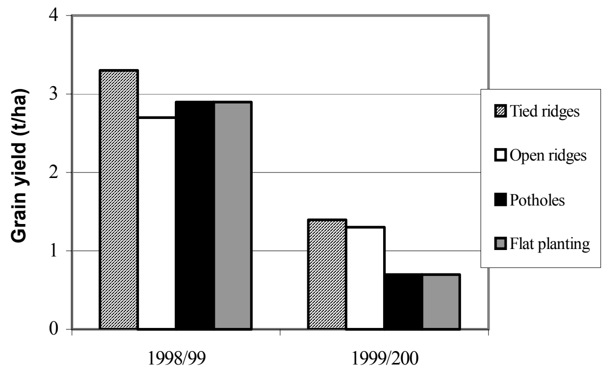


Table 2. Maize yield under tied ridges and flat planting at six sites

Sites	Tied ridges	Flat planted
	(t grain ha^{-1})	
1	5.30	3.03
2	5.25	4.52
3	5.25	4.43
4	6.01	2.65
5	5.65	4.48
6	3.75	3.01
Mean	5.2	3.7
LSD	1.44	
CV (%)	17.3	

RESULTS AND DISCUSSION

Effects of soil moisture conservation methods

Yield responses to soil moisture conservation were apparent both in the on-farm and on-station trials (Figs 5 and 6). Both on-station and on-farm trials showed significant maize yield increases under tie ridging though at different levels in different seasons and sites. Maize yields are presented in Figure 3 where maize var. CG4141 was used and a yield increase of 47% over flat planting was observed. These yield increases translate to seven bags extra per hectare with CG4141. Open ridges had the lowest yield during the first year and least water retention during the second season in the on-station trial.

Figure 4 presents percent moisture retained in the different moisture conservation methods on- station and it is consistent with the maize yield increase. Tie ridging retained more moisture than the other methods; likewise, maize yield increase was more pronounced under tie ridging compared to the other methods. Demonstrations of tied ridges and flat planting under wider environments shows that tie ridging can increase maize yield by almost 100% in some sites (Table 2).

The increase in grain yield implies that more moisture was retained under tie ridging than the other land formations,

Figure 6. Effect of soil moisture conservation on maize grain yield on farmers' fields.

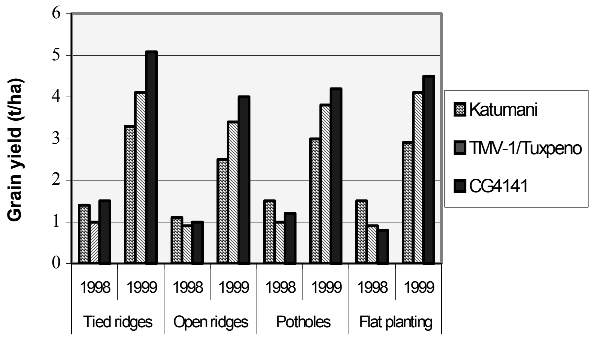
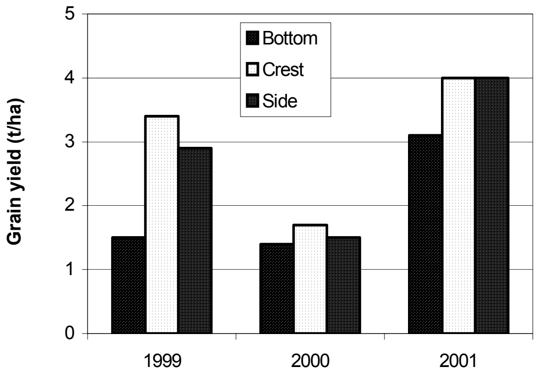


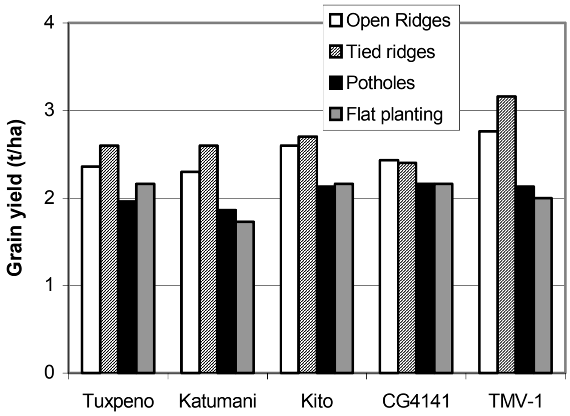
Figure 7. Maize grain yields as affected by seed placement across seasons.



since fertilizer was applied uniformly. The rainfall pattern during the 1999/2000 season on-station was poor and inadequate for proper crop growth (Fig 1 and 2). This season amplified the advantage of tied ridges compared to the previous season, which had adequate rainfall for the on-station trial (Fig 5). During the following season of 2000/2001 that had about 800mm rainfall the differences in yield were not significant. The added yield increase under tie ridging in a dry season implies that more moisture was retained in tie ridging than the other systems. The response to moisture conservation was related to amount of rainfall received. Similar findings have been reported in Katumani, Kenya where tie ridging resulted in the production of a maize crop in low rainfall years when flat-planted crops gave no yield (Njihia, 1979). Other similar findings were reported in Zambesi valley, Swaziland, Botswana and U.S.A. (Honisch, 1973; Warwick, 1979,1980; DLFRS, 1984 and Stewart *et al.*, 1985)

The 1999/2000 on-station results suggest that under drier conditions both tied ridges and open ridges can be beneficial in terms of maize yield. The reason for increased grain yields under the two methods is probably increased rooting volume as well as increased infiltration due to the ridges. In other countries there are conflicting reports on tie ridging. McCartney *et al.,* (1971) reported that tied ridging in Tanzania gave higher maize yields not only in low but in high rainfall years as well, while the opposite was reported to be true by Lawes 1963; Dagg and McCartney, 1968). Under such conditions, tied ridging enhanced waterlogging.

Figure 8. Effect of moisture conservation methods on varieties across years.



Effects of seed placement

Seed placements had significant difference only in the 1998/99 season ($p<0.05$). Bottom seed placement had the least yield and crest the highest (Fig. 7). There was adequate rainfall during this season on-station (Fig. 2). Therefore the low yield in the bottom seed placement could be attributed to waterlogging in tie ridging and probably removal of nutrients in the open ridges. The 1998/1999 and 2000/2001 seasons were quite similar in rainfall pattern and distribution. However, the latter received lower total rainfall, that could not have caused waterlogging. There was therefore no significant yield difference between seed placements in the consecutive seasons.

Effects of moisture conservation on maize varieties

Significant differences were observed between conservation measures and varieties during the second season, which represents true dry conditions (Table 3). There were also significant differences between moisture conservation measures and varieties across the seasons (Figs 6 and 8 and Table 3). The performance of varieties across moisture conservation methods shows that, TMV-1 had the highest yield followed closely by Kito. This is an indication that the two varieties are more stable in varying moisture regimes. These yield increases translate to seven bags extra per hectare with CG 4141 and one bag per hectare for TMV-1. Open ridges had the lowest yield during the first year and least water retention during the second season in the on-station trial.

Seasonal variation of rainfall was reflected differently by the different varieties. Yields were quite different from year to year each variety showing its reaction to the different moisture regimes. The short-term varieties (Katumani and Kito) gave significantly higher yields across moisture conservation methods during the drought year (1999/2000). The same varieties gave significantly higher yields under tie ridging and open ridges compared to the rest of the varieties (Table 3).

Table 3. Yields of maize varieties under different moisture conservation methods in different seasons

	Open ridges			Tied ridges			Potholes			Flat planting		
	1999	2000	2001	1999	2000	2001	1999	2000	2001	1999	2000	2001
Tuxpeno	2.6	1.1	3.4	3.7	0.8	3.5	2.9	0.3	2.8	3.1	0.6	2.7
Katumani	2.0	2.0	2.9	2.8	2.3	2.9	2.3	1.1	3.1	1.9	0.9	2.2
Kito	2.6	1.7	3.7	3.3	1.8	3.0	3.1	0.8	2.6	3.1	0.8	2.5
CG4141	2.9	0.7	3.7	3.3	0.8	3.5	2.9	0.5	2.8	3.3	0.4	3.1
TMV-1	2.5	1.0	4.8	3.5	1.2	4.8	3.4	0.4	2.5	2.9	0.6	2.6
Mean	2.5	1.3	3.8	3.3	1.4	3.5	2.9	0.6	2.8	2.9	0.7	2.6
LSD α= 0.05	0.33											
CV (%)	17.5											

Economic evaluation of Soil moisture conservation methods

Partial budgetting for grain yield across seasons show that potholes and tied ridges give marginal rate of return that is higher than the minimum acceptable level (Table 4). Open ridges had less net benefits and more marginal cost compared to the next treatment thus it was not further considered. Although the marginal rate of return for potholing is more than that of tie ridging, the latter provide more marginal benefits. The choice between the two will depend on resource endowment of the farmers. This analysis suggests that it would be beneficial for maize farmers to practice potholing and tie ridging rather than flat planting in drought prone areas.

Farmer's views on soil moisture conservation methods

Evaluation of farmer's views on moisture conservation showed that farmers of all categories appreciate tie ridging more than the other methods (Table 5). However, even after exposing tie ridging for four seasons, its adoption is still minimal. One reason for the low adoption of the system is the labour involved in the technology. The high labour demand was a common bottleneck to the adoption of tie ridging in Ethiopia, Kenya and Tanzania. The cost of making tied ridges is estimated at 33% higher than conventional land preparation using hand hoes in Tanzania.

In order to make tie ridging more efficient, a tie ridger using drought power has been identified and demonstrated in northern Tanzania. Farmers' views on using the implement show that the technology can be adopted by all gender categories since it has an added advantage over the common practice.

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CONCLUSIONS AND RECOMMENDATIONS

Technical and socio-economic information gathered in this and other studies show that tied ridges give positive responses in terms of yield due to moisture conservation. Positive responses are likely to be obtained under drier rather than wetter conditions. The soil type also can influence the effectiveness of the tied ridge. Positive effects are expected from loamy, sandy loams and clay loam soils. Some flexible recommendation are thus summarized:

1. In areas with average rainfall of about 800mm or more, tied ridges may not be beneficial so conventional planting may be practised.
2. In areas with more than 1,000mm rainfall, tied rigdes are not necessary as they may cause waterlogging.
3. In drier areas with about 500mm rainfall, tie ridging is recommended to farmers who have easy access to capital resources. Potholing is recommended to farmers with scarce resources.
4. In areas with clay or sandy soils tie ridging is not recommended due to high water percolation and water logging respectively.
5. Crest and side seed placement within the ridges is recommended since water logging will be eliminated.

Table 4. Partial budget for moisture conservation in maize across three years on-station.

(a) Net benefit analysis

	Treatments			
	1	2	3	4
Average maize yields kg/ha	2260	2560	2130	2160
Adjusted maize yield (-10%)	2034	2304	1917	1944
Gross field benefit (Tsh/ha)	203,400	230,400	191,700	194,400
Labour cost for land formations Tsh/ha)	21,000	27,000	19,000	18,000
Labour cost for weeding (Tsh/ha}	20,000	20,000	15,000	12,500
Total costs that vary (Tsh/ha)	41,000	47,000	34,000	30,500
Net benefits (Tsh/ha)	162,400	183,400	157,700	163,900

C1 = Open ridges; C2 = Tied ridges; C3 = Potholes; C4 = Flat planting

(b) Marginal analysis

Treatment	TCV (Tsh/ha)	MC (Tsh/ha)	NB (Tsh/ha)	MNB (Tsh/ha)	MRR (%)
4	30,500	-	136,900	-	-
3	34,000	3,500	157,700	20,800	594
1	41,000	7,000	162,400	4,700 **D**	
2	47,000	6,000	183,400	21,000	350

D = Dominated treatment
TCV = Total costs that vary MC = Marginal costs NB = Net Benefits
MNB = Marginal net benefits MRR = Marginal Rate of return
Notes: Maize farm gate price = 100Tsh/kg Labour for making tied ridges = 15 man days/ha Open ridges = 12 man days/ha Potholes = 11 man days/ha Flat planting = 10 man days/ha
Labour for weeding: 12,500 Tsh /ha in flat planted plots 20,000 Tsh/ha in ridged plots 15,000 Tsh in potholed plots. Acceptable marginal rate of return = 100%

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Table 5. Gender Analysis Matrix (GAM) for tied ridges technology in moisture conservation in maize Production (Arumeru and Hai Districts)

Categories	Labour	Time	Resources	Culture
Men	Reduced work load (+)	-Less time used on land preparation (+) -Time saved for undertaking other productive activities (+)	- High initial costs i.e. money required for hire/purchase of, tie ridger, operators (-) (instead of other family expenditures)	No cultural change (+/-) - Cultural conservation i.e. better off people will be settled and be able to hold traditional meetings (+)
	- Little change on responsibility work plan for the season (+/-)	- Interference with other activities' work plan for the season due earlier land preparation than usual (+) - but acceptable)	More yield expected leading to food sufficiency hence better health.	
	- Training for the skill required (+/-)	- Time will be available for attending other family matters (+)	-Increased income on selling of the surplus – which will bring about: -Better housing (+) -Affording school fees and medical services. (+) -Better clothing. (+) Expansion of agricultural production after being able to afford the purchase of ox-tie-ridger, oxen and possibly water pump (+) - Easier household management +	
Women	- Reduced work load and increased efficiency (+)	-Saves time (+)- -Time available for other Income generating activities like making and selling of *maandaz*i (Doughnuts), bread, embroidery and others (+)	-High initial cost -More cash income on selling the surplus thus will be able to afford school fees, medical service, and better housing (+) - Better living standard will bring love, peace and harmony in the home (men will settle at home (+)	- No change (+/-)
Household	- Reduced work – load (+)	- Saves time (+)	- High initial costs if the tie ridger, oxen, and the operators are to be hired/Purchased (-)	- No change (+/-)
	-Little change on work plan for the season, but can be accommodated (+/-) -motivation to work harder with great hopes (+) - More work load for operators (+)	-Time available for other house hold activities -Time available for the family to be together, hence peace and harmony in the home (+) - Time available to attend communal activities like weddings, funerals whenever required (+)	-Land intensification leading to food sufficiency and more cash income from the surplus and be able to manage Medical services (+) Better housing (+) School for the children (+) Better clothing (+) Therefore love, peace and harmony in the house hold	
Community	-Reduced work load (+) -More work load for the operators (-) -Training for the skill required for efficient operation -Will create employment for youths -Training for the skill needed for efficient operation +/- -Training for the skill needed for efficient operation +/- - Will create employment for the wondering strong youth (+)	-Saves time + -"HOPE" will lead to more time devoted agricultural production rather than staying idle, drinking beer and mass movement of youths to urban areas (+) -Children will get time to attend school (better education) + - Time available for recreation (-) and people to be together to exchange ideas and experience – the better way	-High initial costs (-) -Moisture conserved will bring more yield hence -Food security and increased incomes -More people involved in agricultural production (+) -Soil conservation leading to environmental conservation -Positive movement to – wards development (+)	- Cultural Conservation – strong and settled people will be able to hold cultural meetings and activities whenever called for (+)

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TROPICAL MAIZE SYNTHETICS IMPROVEMENT FOR MOISTURE-STRESS TOLERANCE FOR SMALL-SCALE FARMERS

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ABSTRACT

Improved maize cultivars that tolerate water stress conditions to produce high yields would be highly desirable for areas practicing low input agriculture. Recurrent selection schemes for improving stress tolerance characteristics have been successfully demonstrated. Thus, our objective was to evaluate 144 S2 progenies from each of two synthetic maize populations, Syndent and Synflint, from an improvement breeding programme for drought tolerance, to obtain synthetics with high yield potential and good agronomic performance under the water stress conditions of the semi-arid regions of Brazil. The 288 S2 progenies from the two synthetics were evaluated using a 14 x 14 lattice design with two replications in two conditions with water stress (WS) and no water stress (NS) at Janaúba, MG, Brazil, in 2000. The combined analysis of variance showed highly significant ($P<0.01$) effects for environments and progenies and the interaction between them for Synflint, but a significant effect ($P<0.05$) for the interaction for Syndent. The estimates found for the broad sense heritability for ear yield of Synflint, were of 0.382 and 0.752 for WS and NS, respectively; and for the Syndent the estimates were of 0.607 and 0.635 for WS and NS, respectively. The genetic variance estimates were greater in NS than in WS environments. The error variance estimates were great for the WS x NS interaction for the two synthetics. The predicted responses to selection pointed out better gains for yield when selection is done in NS than in WS environments.

INTRODUCTION

In tropical regions drought, low natural soil fertility, biotic stress like leafborer, among other effects are major constraints to maize production. The northeastern region comprises 18.28% of the total area of Brazil, contributes with 5.32% of the national maize production, and has the highest incidence of drought or lack and irregularity of rainfall distribution (Santos et al., 1997). Most of the maize produced in this region comes from small farms and drought has been the main constraint responsible for severe yield losses. Maize is the most important food crop in the region and the need to increase its production cannot be overemphasized. As pointed out by Ceballos and Pandey (1991 a, b) in marginal areas maize is generally cultivated as a staple food, using low agronomic inputs, limited financial support and low use of resources.

Therefore, small-scale farmers in the tropical areas are often the people hardest hit by drought and other adverse natural conditions. Water stress tolerant germplasm is expected to be very useful to small-scale farms who grow maize in areas frequently affected by drought. Drought stress occurs with different intensity at any plant development stage from germination to physiological maturity and flowering is the most critical stage in maize for drought stress (Hall *et al*., 1982, Bolaños and Edmeades, 1993).

A selection program for non-biotic stress tolerance should put emphasis on the importance of evaluation in stress and non-stress environments. The pre-flowering stress treatment allowed for manifestation of the genetic variability for ears per plant, kernel weight, etc. Therefore severe water stress treatments will reduce genetic variation for grain yield (Bolaños and Edmeades, 1997).

There is strong agreement that selection for yield under drought stress is less efficient than under non-stress conditions, mainly because of reduction in heritability of yield under stress (Rosielle and Hambling, 1981; Blum, 1988; Johnson and Geadelmann, 1989). Selection would be better under both stress and non-stress environments.

The type of progenies evaluated affect the rate of improvement and the ability to discriminate among genotypes for stress tolerance. Thus, selfed progenies, as shown by many research results on yield improvement, are preferred over non-inbred progenies, because heritability increases with levels of inbreeding (Bolaños and Edmeades, 1997; Lamkey and Hallauer, 1987).

The objectives of this study were to present the genetic parameters estimates for ear yield used in selection in inbred progeny trials under water stress and non-stress conditions as part of a recurrent selection programme for drought tolerance in two heterotic tropical maize synthetics.

MATERIALS AND METHODS

The Syndent was synthesized by the recombination of 13 elite dent type inbred lines of Tuxpeño germplasm (CIMMYT) and the Synflint through the recombination of 15 flint type inbred lines from Caribbean and Cateto germplasm (CIMMYT), in 1995. Selection began in 1996 and then underwent 3 cycles of full sib recurrent selection scheme in the rainfed seasons at Sete Lagoas, MG, Brazil. Each cycle of full-sib selection required one year to complete. In 1998, 200 S1s were obtained from each synthetic and the S1 families were prescreened under mild drought at Sete Lagoas. They were also selected for desirable plant characteristics where the selected ones were advanced to S2 by self pollination.

The superior 144 S2 progenies of each synthetic were grown for yield evaluation at the experimental station of Janaúba, located in North region of MG State, altitude 516 masl, latitude 15º 47´S and longitude 43º 18´W, where stress could be managed by irrigation during the hot rain-free season under two water regimes (environments). Each of the two 144 progeny sets were evaluated using a lattice design 12 x 12 with a tester (experimental double-cross hybrid) and 2

Table 1. Combined analysis mean square results for ear yield (kg/plot), for the two synthetics, evaluated at two water conditions, at Janaúba, MG, in 1999.

		Synflint	Syndent
SV	DF	MS	
Environment (E)	1	328.8177**	191.7071**
Progeny (P)	143	0.7079**	0.9494**
E x P	143	0.3157**	0.2851*
Mean Error	266	0.1933	0.3017
CV%		20.08	21.68
Mean (kg/plot)		2.19	2.53

*,** significant at P<0.01.and P<0.05 levels, respectively.

replications, in single-row plots of 5 m long and spaced 0.90 x 0.20 m between row and plant within the rows, respectively. The water regimes were classified into two types, a well-watered (NS) and a moderated stress (WS) where irrigation was suspended two weeks prior to anthesis and was reinitiated two weeks after flowering to ensure that kernels set under this stress would be filled. The main limits of soil depth and soil moisture depletions under both treatments are illustrated in Figure 1.

Data were collected for ear yield (kg/plot). Statistical analyses of variance followed procedures described by Falconer (1989). Each experiment was analyzed separately as a lattice design, and broad-sense heritability of ear yield and predicted responses of yield to selection were calculated as:

Broad-sense heritability, $h^2 = 6^2_g / (6^2_g + 6^2_e / r)$

Where: 6^2_g = Genetic variance, 6^2_e = Error variance and r = No. of replications (Hallauer and Miranda Filho,1981).

Predicted response to selection in percentage was:

$R\% = (h \times 6_g)/M_{yield} \times 100$, assuming a standardized selection differential of 1.0.

Analysis for genotype distribution was performed based on a water stress index based on yield under drought condition to identify the most tolerant progenies to the moisture stress imposed in the experiments. The environment index or water stress index (WSI) was calculated by the equation:

$$\mathbf{WSI} = (\mathbf{Y}_{WATER} - \mathbf{Y}_{DROUGHT}) / (\mathbf{Y}_{M\ WATER} - \mathbf{Y}_{M\ DROUGHT})$$

RESULTS AND DISCUSSION

For the trait ear yield, results of the combined analysis of variance showed highly significant differences (P<0.01) among the progenies for both synthetics, and the environment x progeny interactions showed statistically highly significant (P<0.01) and significant (P<0.05) for the Synflint and the Syndent, respectively (Table 1).

Ear yield means (Table 2) were higher for both synthetics at the non water stress condition (NS), and the Syndent yielded relatively more (66.64%) than Synflint (63.00%) related to the tester. The Syndent performed better than the Synflint material at this stress condition (WS), where the Syndent and the Synflint yielded 52.23% and 38.26% of the tester, respectively.

The efficiency of selection under water and non water stress conditions for increasing ear yields under water stress is determined by the broad-sense heritabilities (h^2) of ear

Table 2. Broad-sense heritability (h^2) genetic variance (6^2_g), error variance (6^2_e) and predicted response to selection (R), for ear yield (kg/plot), for two moisture stress environments, at Janauba, MG, in 1999.

Experiments	h^2	6^2_g	6^2_e	R% (kg/plot)	Yield Mean
Synflint (WS)	0,382	0,054	0,196	0,144(10,05)	1,433
Synflint (WS)	0,752	0,289	0,171	0,466(15,82)	2,945
Syndent(WS)	0,607	0,157	0,270	0,309(15,79)	1,956
Syndent(WS)	0,635	0,235	0,204	0,386(12,41)	3,110
Tester (NS)					4,675
Tester (NS)					3,744

WS= With water stress NS= No water stress Tester = Experimental double cross hybrid.

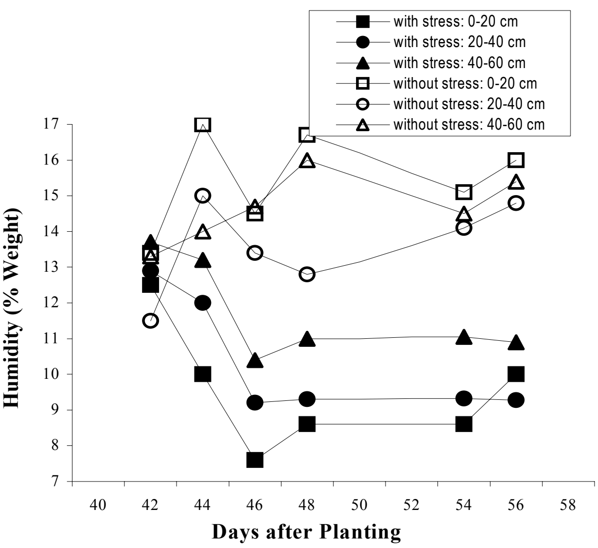
yield under water stress and non-stress conditions (Falconer, 1989).

Broad-sense heritability estimates calculated for ear yield under no water stress exceeded those under water stress, and were 0.382 with stress and 0.752 without stress for Synflint, but of similar trends for Syndent with 0.607 with stress and 0.635 without stress (Table 2). Betran *et al.* (1997) and Bolaños and Edmeades (1997) found similar results (h^2>0.50) testing inbred lines of different endogamy levels, derived from CIMMYT germplasm under selection for drought resistance.

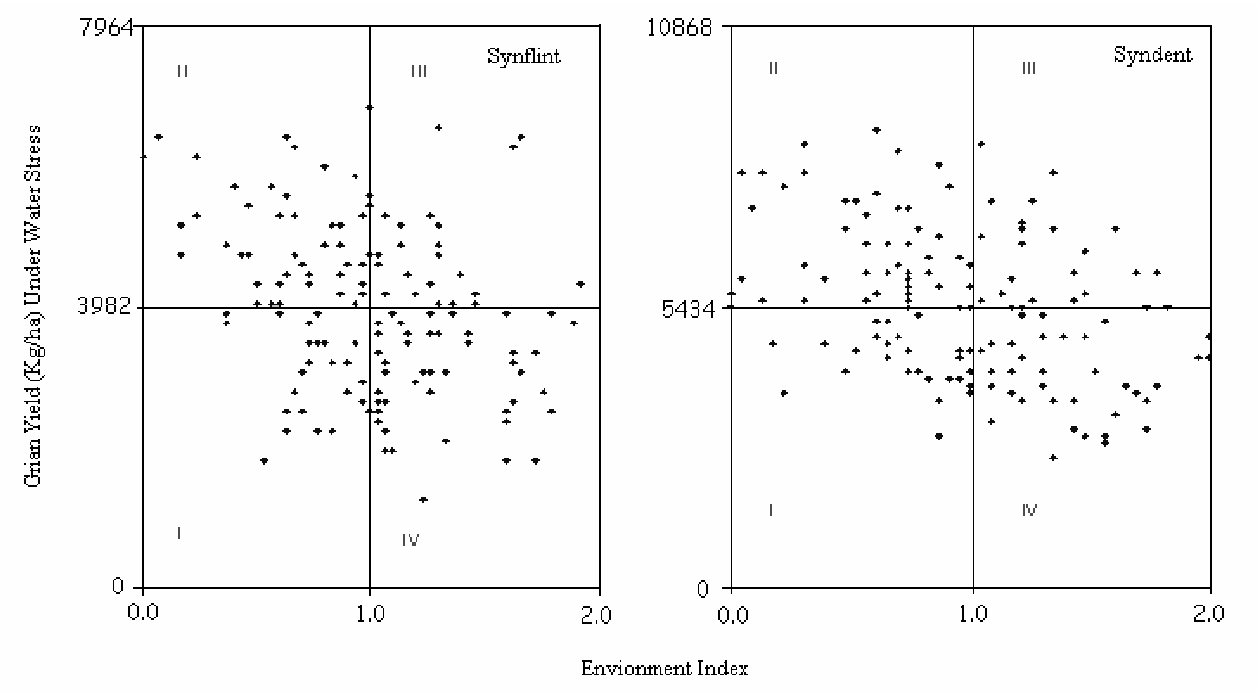
Therefore, gains in selection can only be possible when the genetic variation for tolerance to water stress, through whatever mechanism, can be observed (Bolaños and Edmeades, 1997). Thus, better genetic gains can be obtained with the Synflint material.

Error variance was a little higher under stress than without stress for both synthetics. Predicted response of ear yield to selection estimates presented a trend of higher values (kg/plot) under non-stress treatment. Larger predicted selection gains (0.466 kg/plot) was found for Synflint and lower gain (0.386 kg/plot) for Syndent, both at the non-stress condition.

Figure 1. Soil water content profiles under two irrigation treatments, with and without water, at pre-flowering, using a line source sprinkler system, Janaúba 2000.



Figures 1 & 2. Ear Yield as function of *environment index* or *Water Stress Index – WSI*, for 144 S2 progenis trials each across two replications from 2 tropical synthetics under two water regimes at Janaúba, Brazil, 1999.



To identify superior endogamy progenies for the moisture stress imposed in the experiments, an analysis for genotype distributions was performed based on a water stress index (WEI) and yield under drought condition (Figures 1 and 2). According to the yield under water stress (ordinate) and the environment index (EI - abscissa) we can place the progenies in four groups. Group 1, characterized by low EI and yield, was composed of 31 progenies (22%) and 24 progenies (17%) for Syndent and Synflint, respectively, and were classified as low yielding and non-responsive to drought.

Group 2, characterized by low EI and high yield, was composed of 48 progenies (33%) and 47 progenies (32.5%) for Syndent and Synflint, respectively, and were classified as high yielding and non-responsive to drought.

Group 3, characterized by high EI and yield, was composed of 22 progenies (15%) and 26 progenies (18%) for Syndent and Synflint, respectively, and were classified as high yielding and responsive to drought

Group 4, characterized by high EI and low yield, was composed of 43 progenies (30%) and 47 progenies (32.5%) for Syndent and Synflint, respectively, and were classified as low yielding and responsive to drought

Genotypes of group 3 interact in a positive direction with our objective. We then select the progenies in group 3 for recombination for continuing our breeding selection second phase.

Rosielle and Hambling (1981) pointed out that usually selection is made under non-moisture stress conditions, with water supplementation, where heritability and genotypic variance for yield and, therefore, potential selection gains for non-stress conditions are high.

The results found in this study showed the need to modify this scheme of selection with these two synthetics for yield improvement in this specific drought environment. Selection gains under low water can be considerably enhanced if secondary traits other then yield are used when evaluating progenies in drought stress selection experiments. Selection under water stress conditions using topcross progenies and other traits related with drought besides yield should be a better strategy. These two synthetics could be released for farmers whose yields are reduced drastically by drought occurring near flowering and during the grain filling period.

CONCLUSIONS

- The Syndent material appears to be most drought tolerant as seen by the relatively low percentage of yield losses due to water stress.
- Syndent progenies showed to be superior to Synflint progenies under drought stress.
- Broad sense heritabilities estimates for Syndent presented values of lower trend between the two environments then the Synflint material.
- Based on literature results there is a need to use secondary traits in addition to yield *per se* for selection, mainly reduction in ASI, in order to make faster progress in these two synthetics.
- These two synthetics can be used in hybrid programmes since studies have shown that stress-tolerant hybrids are developed with a greater frequency from stress tolerant source populations than from their conventionally selected counterparts.
- Substantial variability exists in these two synthetics for drought tolerance and toward the expression of traits related to tolerance, indicating that there is an opportunity for improving their tolerance via selection.

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USE OF TIED RIDGING AND SOIL FERTILIZATION TO IMPROVE MAIZE YIELD IN RIFT VALLEY, KENYA.

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ABSTRACT

An experiment was carried out at Chemogoch in Koibatek district with the aim of developing management techniques that improve soil fertility and conserve soil moisture at low cost and thus improve crop yield. Two combinations of water harvesting techniques and organic and inorganic fertilizer were utilized. Maize (*Zea mays* L.) variety Katumani Mpya was used as the test crop. The 1997 results did not show any significant difference (p=0.05) between treatments, though the combination of tied ridging and 4 tons ha^{-1} farm yard manure (W1T2) gave the highest grain yield (3.5 tons ha^{-1}). In the second year the highest grain yield (5.3 tons ha^{-1}) was obtained in the combination of the conventional water harvesting technique and CAN at 150 kg ha^{-1} (W2T3). The results indicate that the use of 4 tons ha^{-1} farm yard manure in combination with tied ridging was beneficial in terms of giving reasonable crop yield and net benefit (KSh 21,502.10 ha^{-1}) at lower cost than of using expensive inorganic fertilizer and larger quantities of farm yard manure. Generally, a combination of tied ridging and use of farm yard manure could improve crop yield as much as using inorganic fertilizer especially when rainfall is not enough to sustain a crop under the conventional water harvesting system.

Keywords: Drought prone areas, farm yard manure, maize, soil fertilization, tied ridging, water harvesting

INTRODUCTION

The major constraints to food production in drought prone areas of Rift Valley are low soil moisture and low soil fertility. Average annual rainfall is low in most areas (650 mm) and total annual evapotranspiration is high (1,360 mm). The evapotranspiration exceeds rainfall in every month of the year, and can be as low as 19 mm in May and as high as 109 mm in February, necessitating water harvesting or irrigation of crops throughout the year (Mwangi, 1983). Different water harvesting techniques i.e. level basin, tied ridges and conventional have been studied for their water retention, availability and suitability to crops. Results from the tied ridge water harvesting technique have given high yields for various crops (Kipserem, 1996). The ASAL areas have traditionally been considered best suited to extensive grazing by livestock but not any more as more people have moved into these areas and introduced crop farming and sedentary lifestyle. Most of these people will necessarily produce food and earn income from a mixed crop-livestock farming system (MOALD and Winrock International, 1985). In areas where arable farming can be practised, soil fertility could be improved through mineral fertilizer application or addition of manure and crop residues to the soil (Range Resource Management Plan, 1991). The ASAL areas are endowed with a large number of livestock which provide large amounts of Farm Yard Manure (FYM). However, this FYM is not utilized by farmers to improve soil fertility in their farms. Despite the adversity of the marginal areas, farming is practiced despite the frequent crop failure.

To improve crop production in marginal areas, appropriate management techniques that improve soil fertility and moisture conservation at low cost to the farmer are desirable. In this study, the combination of two management aspects namely; tied ridging and organic and inorganic fertilizer were utilized to address the problem of low soil moisture and low soil fertility in order to improve maize yield in ASAL areas. The main objective was therefore to determine the best combination of farm yard manure and fertilizer application rates and water harvesting techniques for increased food production.

MATERIALS AND METHODS

The experiment was carried out at Chemogoch site in Koibatek district. The area has a unimodal rainfall mainly received from April to October and averages 825 mm per annum. It is at an altitude of 1,500 m above sea level. The soils are well drained, brown to dark brown, loam to sandy clay loam (vitric andosols) (Jaetzold and Schmidt, 1983). Rainfall data were recorded for the two seasons i.e. May-Sept 1997 and 1998 (Table 1). The farm yard manure applied to the plots had 1.54 % nitrogen, 0.32 % phosphorus, 1.71 % potassium and 30 % moisture content.

The experimental design was a randomized complete block design with 12 treatment combinations each replicated 3 times. Maize variety Katumani Mpya was used as test crop. The treatments were: W1 - Tied ridging water harvesting, W2 - Conventional water harvesting, T1 - 0 tons ha^{-1} FYM (0 kg FYM/plot), T2 - 4 tons ha^{-1} FYM (5.62 kg FYM/plot), T3 - Calcium ammonium nitrate (CAN) alone at 150 kg ha^{-1} , T4 - 12 tons ha^{-1} FYM (17.63 kg FYM /plot) , T5 - Combination of 2 tons ha^{-1} FYM (2.81 kg FYM /plot) and 65 kg ha^{-1} of

Table 1. Rainfall May-September, 1997 and 1998 Chemogoch field site.

Month	Total Amount of Rainfall (mm)	
	1997	1998
May	56.0	264.0
June	55.5	66.0
July	88.5	245.5
August	90.0	83.0
September	7.0	91.0
TOTAL	297.0	749.5

Table 2. Effects of water harvesting techniques and different organic and inorganic fertilizer rates on yield components of Katumani Mpya maize variety 1997.

Treatment	Yield (Tons/ha)	Ear length after de-husking (cm)	1,000-seed weight (kg)	Ear height (cm)
W1T1	3.427	14.13	0.3733	50.03
W1T2	3.520	13.43	0.3633	57.20
W1T3	3.150	13.93	0.3600	51.10
W1T4	2.500	11.23	0.3767	58.33
W1T5	1.850	10.10	0.3067	66.67
W1T6	2.963	12.67	0.3567	43.87
W2T1	2.687	13.27	0.3600	55.33
W2T2	2.687	9.967	0.3167	57.80
W2T3	3.427	13.87	0.4067	64.43
W2T4	2.313	12.07	0.3600	56.67
W2T5	2.317	12.80	0.3400	57.23
W2T6	3.427	11.50	0.3167	53.33
MEAN	2.856	12.414	0.353	56.00
CV %	43.040	13.61	10.35	15.62
LSD	NS	NS	NS	NS

NS = Not significant p=0.05.

20:20:0 inorganic fertilizer and T6 - Compound fertilizer (20:20:0) at 130 kg ha^{-1}.

In 1997 T3 had 8 tons ha^{-1} of FYM and T5 had 16 tons ha^{-1} of FYM. In the second year these treatments were replaced by CAN and a combination of compound fertilizer and FYM respectively. This was in order to increase treatments containing both inorganic and organic sources of nitrogen and nitrogen alone and thus provide more comparisons. The treatment combinations were: W1T1, W1T2, W1T3, W1T4, W1T5, W1T6, W2T1, W2T2, W2T3, W2T4, W2T5 and W2T6.

The plot size was 4 rows by 2.70 m. All plots were planted with 4 rows of maize spaced at 90 x 30 cm. For all treatments except T3, FYM was applied on ploughed and demarcated plots before tied ridges were made. For treatment T3, CAN was applied as a topdressing while for the other treatments, compound fertilizer was applied at planting. Weeding was done by hand and stalk borer was controlled using dipterex (Trichlorphon 2.5 %).

Measurements included ear length after de-husking, 1,000-seed weight and grain yield. The data were subjected to analysis of variance using a computer software programme (MSTAT) and separation of means using Duncan Multiple Range Test (DMRT) (Freed *et al*., 1988). Also partial budget economic analysis was performed on grain yield per treatment combination (except treatment T3 and T5 combinations which were different in both years) per hectare (CIMMYT, 1998).

RESULTS AND DISCUSSION

The results on grain yields, ear height and length, and net benefit are shown in Tables 2, 3 and 4. The yield results shown in Table 2 for the 1997 crop season did not show any significant difference between the twelve treatment combinations. However, the highest yield of 3.5 tons ha^{-1} was obtained in the combination of tied ridging and 4 tons ha^{-1} of FYM (W1T2). The lowest yield of 1.8 tons ha^{-1} was recorded in the combination of tied ridging and 16 tons /ha farm yard manure (W1T5). Yield decrease at high rate of farm yard manure under conditions of limited rainfall has been reported in maize (Ikombo, 1984). In the second season however, results showed that the combination of conventional water harvesting technique and CAN at 150 kg ha^{-1} (W2T3) gave the highest

Table 3. Effects of water harvesting techniques and different organic and inorganic fertilizer rates on yield components of Katumani Mpya maize variety 1998.

Treatment	Yield (Tons/ha)	Ear length after de-husking (cm)	1,000-seed weight (kg)	Ear height (cm)
W1T1	2.417	9.733	0.373	54.47
W1T2	3.815	11.93	0.420	62.90
W1T3	4.333	14.10	0.413	48.50
W1T4	5.009	17.73	0.413	47.43
W1T5	3.273	14.73	0.413	58.27
W1T6	4.241	13.47	0.423	59.70
W2T1	4.116	8.40	0.420	53.90
W2T2	2.829	10.87	0.393	51.80
W2T3	5.319	17.80	0.413	58.53
W2T4	3.787	14.57	0.420	60.97
W2T5	4.167	13.50	0.42	56.53
W2T6	3.088	12.20	0.407	62.87
MEAN	3.866	13.253	0.411	56.32
C. V %	20.04	6.95	7.78	17.20
LSD	1.312	1.560	NS	NS

NS = Not Significant p=0.05.

Table 4. The total variable cost, net benefit and marginal rate of return (MRR) from partial budget analysis for yields of the different treatments.

Treatment	Total variable cost (KSh/ha)	Net benefit (KSh /ha)		Marginal rate of return (%)
W2T1	700	20,726.3	FP	
W2T2	1,100	16,275.4	*	
W1T1	1,200	17,208.6	*	
W2t4	1,500	17,725.0	*	
W1T2	1,600	21,502.1		86.2%
W1T4	2,000	21,656.5		38.6%
W2T6	3,600	16,919.1	*	
W1T6	4,100	18,592.6	*	

FP = Farmers practice, * Treatments dominated by farmers practice.
Yield adjustment = 10%
Minimum rate of return = 80%.

yield of 5.3 tons ha^{-1} while the second highest yield (5.0 tons ha^{-1}) was obtained from a combination of tied ridging and 12 tons ha^{-1} of FYM (W1T4), though the two treatments were not significantly different (p=0.05). The lowest yield was obtained in the treatment combination of tied ridging with no application of FYM nor inorganic fertilizer (W1T1). In comparison, conventional water harvesting technique (W2T1) had significantly higher yields. This could have resulted from incidence of waterlogging in the tied ridged plots caused by above average rainfall (749.5 mm), which was recorded in the 1998 season (Table 1).

The combination of conventional water harvesting and CAN (W2T3) is significantly different with treatments W1T2, W2T4, W1T5, W2T6, W2T2 and W1T1 but not significantly different from treatments W1T4, W1T3, W1T6, W2T5 and W2T1. Although not significant, the low yield obtained from combination of tied ridging and CAN compared to combination of conventional technique and CAN could have resulted from waterlogging and/or leaching of nutrients from the ridged plots. Generally, mean grain yield increased significantly in the 1998 crop season compared to 1997 from 2.86 to 3.87 tons ha^{-1}. This could be attributed to appreciably higher rainfall received over the crop growing period (May to September) in 1998.

The results of the ear length after de-husking (Table 2) for 1997 did not show any significant difference among treatments, though the combination of conventional water harvesting and 4 tons ha^{-1} of FYM (W2T2) gave the lowest ear length after de-husking. However, for 1998 results (Table 3) the combination of conventional water harvesting technique and CAN alone (W2T3) and the combination of tied ridging technique with 12 tons ha^{-1} of FYM (W1T4) were not significantly different and had the highest and second highest ear lengths (17.80 and 17.73 cm) respectively. These two treatments are significantly different from the other treatments. Treatments W1T1 and W2T1 had the least average ear lengths compared with the other treatments indicating that lack of nutrients in form of FYM or inorganic fertilizer could have contributed to poor growth of the ear length.

The ear height and 1,000-seed weight per treatment did not show significant differences among treatments over the two crop seasons. Days to 50% flowering was attained 41 days after emergence in 1997 and 42 days in 1998 while 50% silking was achieved 52 and 57 days after emergence respectively. There was no significant difference among treatments in the two seasons.

The results of partial budget and marginal rates of return analysis (Table 4) showed that the treatment combination of tied ridging and 12 tons ha^{-1} FYM (W1T4) gave the highest net benefit (KSh 21,656.50 ha^{-1}) followed by the combination of tied ridging and 4 tons ha^{-1} of FYM (W1T2) with KSh 21,502.10 ha^{-1}.

CONCLUSION

In summary, the results of this study suggest that 4 tons ha^{-1} FYM in combination with tied ridging water harvesting technique could reasonably give high yield and acceptable minimum rate of return. Combination of tied ridging technique and soil fertilization by use of organic fertilizer could improve crop yield as much as using inorganic fertilizer especially when rainfall is not enough to sustain a crop under conventional water harvesting system.

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EFFECTS OF SOWING DATE AND CULTIVAR ON THE YIELD AND YIELD COMPONENTS OF MAIZE IN NORTHERN SUDAN

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ABSTRACT

An experiment was conducted for two seasons (1999-2001) at Hudeiba Research Station, Northern Sudan, to study the effect of sowing date and cultivar on yield and yield components of maize (*Zea mays* L.). Three open-pollinated cultivars, namely Hudeiba-1, Hudeiba-2 and Mojtamaa-45 were sown at three sowing dates: October 1, November 1 and December 1. The design was a split-plot replicated three times with sowing date as main plots and cultivar as sub-plots. The results showed that sowing date had a significant effect on yield and yield components of the crop. October sowing (4,097 kg /ha) outyielded November and December sowings by 36.5 and 53.0%, respectively. The cultivars grown varied significantly in their yield potential. Hudeiba-1 and Hudeiba–2 gave similar yields but exceeded Mojtamaa-45 by 24.7 and 25.5%, respectively. Grain yield of the crop was positively correlated with cob yield, 1000-seed weight and number of cobs/m^2 (0.807*, 0.732*** and 0.468***), respectively. The study indicates that substantial grain yield of maize can be obtained during the winter season in Northern Sudan in contrast to other findings in other parts of the country. Therefore, it was concluded that maize could be an alternative winter cash crop for farmers in Northern Sudan**

Keywords: Cultivar, grain yield, maize *(Zea mays* L.), sowing date, yield components

INTRODUCTION

Maize (*Zea mays* L.) started to gain more importance as a food and forage crop in Sudan since the last decade. The high potential of the crop in Northern Sudan led the State Government to introduce the crop into the existing farming system to become an important cash crop. The crop is grown with irrigation during late summer and early winter. In fact, research in maize at this part of the country has been started since the early sixicties at Hudeiba Research Station. The work at that time focused more on breeding aspects rather than crop management. Furthermore, research has not continued at all times and some of the results regarding cultural practices were not conclusive. For example, Imam (1965) found that the optimum planting time for maize under Hudeiba Research Station conditions would be from the last week of September to the end of October. High grain yield (2,952 kg/ha) was obtained during this period. While Ibrahim (1995) at Hudeiba Research Station obtained high grain yield (2,843 kg/ha) from November sowing compared to December sowing which gave only 30%. On the other hand, Elkarouri (1980) reported that, the period from November to February is the best time for maximum dry matter production in the Khartoum area. He also reported that the mean daily temperature is the major environmental factor that influences the crop development and yield. It had been reported that maize grain yield was reduced when sowing was delayed to the end of October (McCormick, 1971). Tanaka and Hara (1974) in India reported that, variation in maize grain yield is due to the reduction in 1000-seed weight when sowing was delayed to the end of October. Furthermore, Cirilo and Andarade (1996) in U.S.A reported that, delaying sowing to mid-December reduced the individual kernel weight". While Quayyum and Raquibullah (1987) in Bangladesh obtained highest grain yield (4.35 t/ha) from November 15 sowing due to higher number of grains/cob and reported that the cultivar Lamaquina 7827 produced significantly higher grain yield (4.24t/ha) compared to other cultivars used in the study. In Sudan, very little work was done on the effect of sowing date and cultivar on the performance of maize as a winter crop. Therefore, the present study was carried out to study the effect of sowing date and the cultivar on the yield and yield components of maize as a winter crop.

MATERIALS AND METHODS

The experiment was conducted during (1999-2001) seasons at Hudeiba Research Station in Northern Sudan. Some climatic data for the area are given in Table 1. Three open-pollinated cultivars, namely, Hudeiba-1, Hudeiba-2

Table 1. Some meteorological data at Hudeiba Research Station during (1999-2001) seasons

Month	Mean daily temperature (^{O}C)		Mean daily R.H. (%)		Sunshine (h/day)	
	(1999/2000)	(2000/2001)	(1999/2000)	(2000/2001)	(1999/2000)	(2000/2001)
October	30.9	31.1	41.5	33.0	9.7	n.a
November	26.8	26.1	37.8	36.9	10.0	n.a
December	24.9	22.7	49.0	47.7	10.3	n.a
January	21.3	20.7	45.5	49.9	n.a	10.3
February	22.4	37.8	39.1	34.6	n.a	9.6
March	25.7	27.0	28.0	24.5	n.a	10.9

Source: Hudeiba Meteorological Station, Ed-damer, Sudan
R.H. = Relative humidity n.a: not available

Table 2. Effect of sowing date and cultivar on grain yield and yield components maize grown at Hudeiba Research Station during two seasons.

Treatments	Grain yield (kg/ha)	No. cobs/m^2	Cob yield (g)	1,000-seed wt. (g)
a) Sowing date				
October 1	4097 a	6.0 a	70.0 a	218.0 a
November 1	2600 b	5.0 b	52.0 b	201.0 b
December 1	1922 c	4.0 c	49.0 b	195.0 b
LSD	670.7	0.49	5.9	18.6
b) Cultivar				
Hudeiba –1	3153 a	5.0 a	59.0 a	211.0 a
Hudeiba-2	3118 a	5.0 a	59.0 a	212.0 a
Mojtamaa-45	2348 b	5.0 a	53.0 a	191.0 b
LSD	321	0.6	9.6	15.0
Mean	2540	5.0	57.0	205.0
C.V %	18.5	15.1	16.7	3.14

Means followed by the same letter(s) within a column are not statistically different at the p= 0.05 level according to the LSD test.

Table 3. Interaction effect of sowing date x cultivar on grain yield (kg/ha) of maize grown at Hudeiba Research Station during two seasons.

	Cultivar			
	Hudeiba-1	Hudeiba-2	Mojtamaa-45	Mean
Sowing date				
October1	4492 a	4571 a	3230 b	4097
November1	2925 b	3052 b	1819 c	2600
December1	1936 c	1834 c	1995 c	1922
Mean	3118	3153	2348	2540

LSD = (0.05) = 670

Means within each sowing date followed by the same letter(s) are not statistically different at the 0.05 level according to the LSD test.

(released by the Agricultural Research Corporation of Sudan in 1998) and Mojtamaa-45 (introduced from Egypt) were sown at three sowing dates: October 1, November 1 and December 1 during the two seasons. The design was a split-plot replicated three times, with sowing date as the main plots and the cultivar as the sub-plots. Plant spacing was 60 cm between ridges and 30 cm between plant holes. Three to four seeds were sown and after 2 weeks thinned to one plant/hole to give about 55,555 plants/ ha. Plot size was 6 m x 3.6 m out of which 5 m x 2.4 m was used to assess the final harvest. Ten cobs, selected at random, were used to determine yield per cob and 1,000-seed weight. The plots received 1P (43.0 kg P_2O_5 /ha) as Triple Super Phosphate (TSP) at seeding time and 2N (86.0 kg N/ha) in form of urea before the second irrigation. The experiment was irrigated every 10 to 12 days and hand-weeded as necessary. Data regarding the grain yield and its components were statistically analyzed by the combined analysis procedure to test differences among and within the different factors. The least significant difference (LSD) was used to separate the means of the main and interaction effects.

RESULTS

Grain yield (kg/ha)

The effects of sowing date and cultivar on the yield and yield components are shown in Table 2. Sowing date had a significant effect on grain yield. October 1 sowing significantly out yielded November 1 and December 1 sowings by 36.5 and 53.0%, respectively. The cultivars grown varied significantly in their yield potential. Hudeiba–1 and Hudeiba–2 gave similar yields, but exceeded Mojtamaa-45 by 24.7 and 25.5%, respectively. The interaction effect of sowing date and cultivar on grain yield was not significant (Table 3), however, the season by sowing date and cultivar interactions on grain yield were significant (Table 4).

Yield components

All measured yield components were significantly reduced by delaying sowing from October 1 to December 1 (Table 2). The number of cobs/m^2, cob yield and 1,000-seed weight of the crop were reduced by 33.3, 30.0 and 10.5%, respectively. Cultivar had a significant effect on the 1,000-seed weight. Hudeiba-1 and Hudeiba-2 were not significantly different, but they gave heavier seed weights than Mojtamaa-45, respectively, which was reflected in their higher grain yields, compared to Mojtamaa-45. Grain yield of the crop was positively correlated with cob yield, 1,000-seed weight and number of cobs/m^2 (0.807***, 0.732*** and 0.498***), respectively (Table 5). The 1000-seed weight was positively correlated with cob yield and compensated for the low correlation coefficient between number of cobs/m^2 and grain yield.

Plant and ear heights (cm)

Sowing date significantly affected both plant and ear heights. October and December sowings were similar in plant height, but they gave taller plants than November sowing (Fig.1a). On the other hand, cultivar significantly

Figure 1. Effect of sowing date and cultivar on ear and plant heights (cm) of maize grown at Hudeiba Research Station during two seasons.

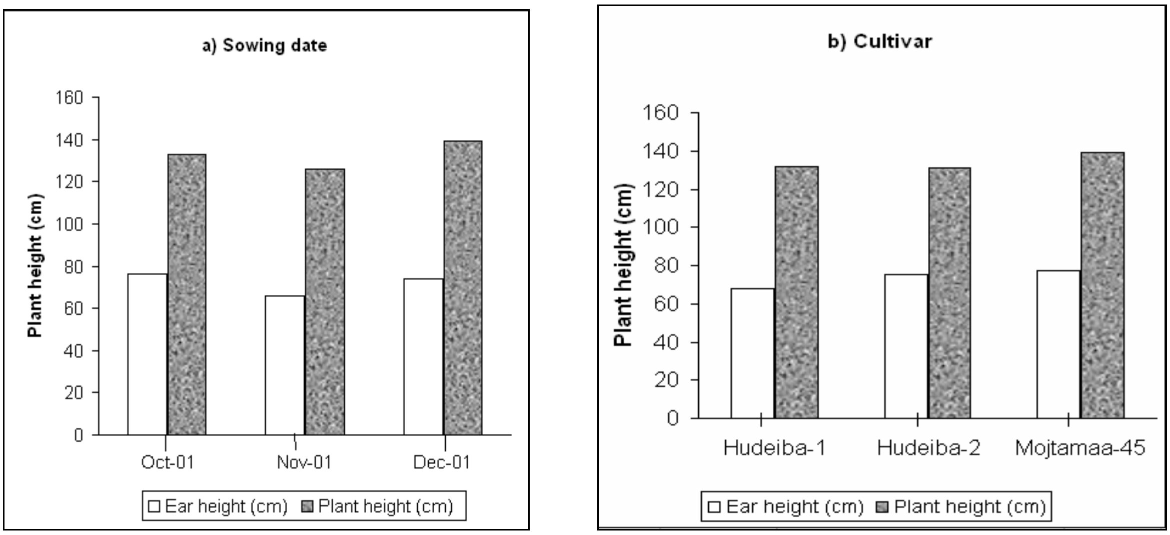

Table 4. Interaction effects of season x sowing date and season x cultivar on grain yield (kg/ha) of maize grown at Hudeiba Research Station during two seasons

	Season	
	(1999/2000)	(2000/2001)
a) Sowing date		
October1	3627 b	4568 a
November1	3865 b	1334 d
December 1	2419 c	1425 d
	LSD =454.3	
b) Cultivar		
Hudeiba –1	3908 a	2328 b
Hudeiba-2	3594 a	2711 b
Mojtamaa-45	2409b	2287 b
	LSD=406.6	
Mean	3304	2442

Means of the same season for sowing date or cultivar followed by the same letter (s) are not significantly different at the 0.05 level according to LSD test

affected the ear height and not the plant height (Fig. 1b). Hudeiba-1 gave slightly lower ear position (68 cm) compared to both Hudeiba-2 and Mojtamaa-45. The cultivar Mojtamaa-45 was the tallest (139 cm) compared to the other two cultivars.

DISCUSSION AND CONCLUSIONS

Determination of the optimum sowing date for maize is very crucial for better crop yields. The study revealed that both sowing date and cultivar had significant effects on grain yield and yield components of maize. Similar results have been obtained in Bangladesh where seeding dates and varieties/lines significantly influenced number of grains/cob, 1,000-grain weight and grain and stover yields (Quayyum and Raquibullah, 1987). The results obtained from the present experiment agree well with the finding of Imam, (1965) who reported that the optimum time for planting

Table 5. Correlation coefficients between and among grain yield and yield components of maize.

	No. of cobs/m^2	Cob yield	1000-seed wt
Grain yield	0.498***	0.807***	0.732***
No. of cobs/m^2	-	0.269*	0.272*
Cob yield	-	-	0.773***
1000-seed wt	-	-	-

* = $P \leq 0.05$, *** = $P \leq 0.000$

maize under Northern Sudan conditions was from the last week of September to the end of October and high yield of maize (2,952 kg/ha) can be obtained during this period. However, (Ibrahim, 1995; Quayyum and Raquibullah, 1987) in northern Sudan and in Bangladesh, respectively, obtained high grain yields (2,843 and 4,350 kg/ha) from November 15 sowing. The high grain yield obtained from October sowing is in agreement with the findings of (McCormick, 1971) who reported that maize grain yield was reduced when sowing was delayed to the end of October. Delaying sowing from October to December reduced the 1,000-seed weight and, therefore, low grain yield was obtained from this planting. It had been reported that variation in maize grain yield due to reduction in 1,000-seed weight was mainly due to the decrease in translocation of photosynthates to the ripening grain (Tanaka and Hara, 1974).

On the other hand, the cultivars varied significantly in their grain yield. Such results are in accordance with the finding of (Quayyum and Raquibullah, 1987) who reported that both seeding dates and varieties significantly influenced grain yield, 1,000-grain weight and number of grains/cob." The season x sowing date interaction was significant (Table 4), indicating that the first season was more favourable in terms of average main daily temperature (25.3 ^{O}C) than the second season (27.5 ^{O}C) (Table1). Similar results were reported by (Elkarouri, 1980) in Sudan, that the average mean daily temperature during the highest producing period for maize (October to January) was about 24.6 ^{O}C which is within the temperature range of 21-26 ^{O}C in the corn belt of the United States. The cultivars Hudeiba-1 and Hudeiba-2 were released for planting in Northern Sudan according to their seed color and, therefore, their similarities in grain yield and other characters are expected. Both Hudeiba-1 and Mojtamaa-45 can be used when planting is delayed up to December. A similar result was obtained by (Ibrahim, 1995) at Hudeiba Research Station, that Mojtamaa-45 was good for late sowing. The study showed that sowing date had a significant effect on plant height. November planting gave the shortest plants. Remison and Dele (1978), in Nigeria, reported that lodging in maize was associated with ear and plant heights and length of basal internodes. Moreover, plant and ear heights in maize were affected by plant density and maturity periods (Pucaric, 1976). In conclusion, the study revealed that a substantial maize grain yield can be obtained during winter season and, therefore, maize can be another cash crop for farmers in Northern Sudan. This is of more value when unfavorable winter seasons markedly affect the yield of the cash leguminous crops such as faba bean, chickpea and lentils. Further studies need to be conducted to compare the yield of maize as a late summer crop with that grown during the winter season.

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IMPROVED MAIZE PRODUCTION IN CENTRAL KENYA WITH ADOPTION OF SOIL AND WATER CONSERVATION MEASURES

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ABSTRACT

Maize is an important agricultural commodity in central Kenya and grown by about 70 percent of the farmers. Soil erosion has caused losses in maize grain yield of up to 83 percent and has greatly contributed to food deficit, famine and rising levels of poverty in central Kenya. To boost food security, farmers need to control soil erosion in order to maintain the physical, chemical and biological soil conditions favorable to crop production. A study was carried out in Kiambu District, central Kenya in 1999 and 2000 to determine maize grain yields from sloping land with terraces, hedgerows, grass strips and a control without conservation measures. Results show that maize grain yields improved substantially in terraced land and marginally on land with grass strips. The hedgerows had a negative effect on maize grain yield. Soil and nutrient losses were highest from the control plot. This paper also discusses the long-term implications of these soil and water conservation measures on general food production, land degradation and farm incomes in central Kenya where there is an acute land pressure and increasing dependence on agriculture for livelihood.

Keywords: Grass strips, hedgerows, improved maize production, soil conservation, terraces

INTRODUCTION

The annual maize production in Kenya is about 2.7 million tonnes and is slightly lower than the domestic consumption needs (KARI, 1999). The high and medium potential zones in Kenya account for more than 70% of the county's maize production and have the highest potential for productivity growth of almost 5 t/ha if farmers overcome production constraints like poor soil fertility, soil erosion and moisture stress (Hassan *et al*., 1998; KARI, 1999; Smaling *et al.,* 1993). About one million more tons of maize grain could be added to the current domestic production if farmers improved their soil fertility and land management practices (Mwangi *et al*., 1998).

Despite efforts to control soil erosion, it continues to hamper crop production and is rated to be the highest contributor to poor food production in central Kenya. Successful soil conservation practices however have to incorporate aspects of fodder production due to the importance of dairy production among small-scale farmers in central Kenya (Pereira, 1979). This study compared the production of sloping lands under different land management practices.

MATERIALS AND METHODS

On-farm trials were conducted in the main coffee zone on sites with a 22 percent ground slope in Kiambu District in Kenya at Waruhiu Farmers Training Centre and Gathiga in Githunguri and Kikuyu Divisions, respectively, between 1999 and 2001. The experimental design was a randomised complete block with four treatments each replicated three times for four seasons. The treatments were *fanya juu* terrace, Napier grass strip, *Calliandra calothyrsus* hedgerow along contours at 5.2m spacing as recommended (Tefera, 1983; Thomas and Biamah, 1987) and control plot without any conservation measures. Maize crop (H513) was grown in all the treatment plots and agronomic recommendations were observed in all the treatments during the crop season. Data on fodder and maize grain yield were collected during the seasons. Runoff was measured from the treatments to estimate soil and nutrient losses. The data was analyzed by regression analysis using GENSTAT statistical package.

RESULTS AND DISCUSSION

Maize yields

The maize crop grew to maturity at the two experimental sites in 1999/2000 and 2000/2001 short rain seasons. The total rainfall for these seasons, in general, was lower and was poorly distributed than for a normal season for the main coffee zone in both sites and yields were lower than expected for the region. There were also variations in rainfall amounts and distribution at Waruhiu and Gathiga sites and this was reflected in the maize grain yield for the sites (Tables 1 and 2). There was crop failure due to drought in 2000 and 2001 long rain seasons. The maize grain yields in 1999/2000 and 2000/2001 short rains season show the treatments are significantly different from each other with *fanya juu* terraces and Napier grass strips, respectively, being the worst for the two seasons. The yields for 2000/2001 short rains season are significantly different from those for 1999/2000 short rains season. On average however, the yields were higher from plots with soil and water conservation measures than the control by 23.1% for the *fanya juu* terraces, by 12.1% for Napier grass strips and by 19.9% for *Calliandra calothyrsus* hedgerows. These results show that soil and water conservation measures improved crop growth conditions during the season and are similar to findings of Ariaga and Lowery (1999) and Young (1989). The trial needs to be conducted for a longer duration to allow more time for *Calliandra calothyrsus* seedlings to establish and form hedgerows and for more data to be obtained in order to make firm conclusions.

Table 1. Maize yield during the 1999/2000 short rains

Treatment	Mean grain yield (t ha^{-1})	
	Gathiga	Waruhiu
Control	1.22	0.72
Calliandra calothyrsus hedgerow	1.36	0.80
Napier grass strip	1.37	0.85
Fanya juu terrace	1.25	0.79

Table 2. Maize yield during the 2000/2001 short rains

Treatment	Mean grain yield (t ha^{-1})	
	Gathiga	Waruhiu
Control	3.4	2.1
Calliandra calothyrsus hedgerow	4.2	2.8
Napier grass strip	3.7	2.3
Fanya juu terrace	4.5	3.1

Fodder yields

The fodder biomass yields from the *fanya juu* terraces and Napier grass strips treatments were significantly lower in 2000/2001 than in 1999/2000 short rains seasons in both sites. There was no fodder harvested from the *Calliandra calothyrsus* hedgerows in both sites because the trees did not establish during the trial period.

CONCLUSION

The trial needs a longer duration to obtain more data in order to make firm conclusions and recommendations. However, results for the two seasons indicate that soil and water conservation measures tested contributed to an increase in maize grain yield. There was an additional benefit of fodder production with *fanya juu* terraces and Napier grass strips treatments. Adoption of these conservation measures by farmers can complement maize production with livestock farming to not only increase farm incomes but also make manure and improve soil fertility to sustain crop production.

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STABILITY OF DROUGHT TOLERANT MAIZE GENOTYPES IN THE DROUGHT STRESSED AREAS OF ETHIOPIA

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ABSTRACT

Drought stressed areas devoted to maize (Zea mays L.) production occupy 40% of the maize growing area but contribute only about 20% to the total maize production in Ethiopia. Unavailability of suitable maize varieties is responsible for such a yield gap. Taking this problem into account the Melkasa Maize Programme introduced and evaluated 400 experimental maize populations at Melkasa Research Center maize quarantine field. Then, 19 promising maize genotypes were selected and evaluated at six locations for three years to determine their performance and stability. The combined analysis of variance showed highly significant ($p < 0.01$) genotype, environment, genotype x environment, and genotype x year effects on grain yield. Genotype DTP-1 C6 with regression coefficient close to 1.0 and small deviations from regression, was fairly stable across environments and had mean yield above the grand mean. Genotypes Banswara 9331 and La Posta Seq. C5 were more productive where growing conditions were better. Hence, it is suggested that genotype DTP-1 C6 has potential for future use in the drought-prone areas of the country.

INTRODUCTION

Maize is used as a human food, feed for livestock and industrial purposes (Dowswell *et al*., 1996). Millions of people depend on maize for their daily food in sub-Saharan Africa (Byerlee and Heisey, 1996). In Ethiopia, maize is the staple food and one of the main sources of calories in the major maize producing regions. It is cultivated on about 1.2 million hectares accounting for 19.3 percent of the nearly 6 million hectares of land allocated to all cereals. It stands first in total national production and yield ha^{-1} (CSA, 1998/1999).

In the drought stressed areas of Ethiopia, which cover about half (46%) of the total arable land (Reddy and Kidane, 1993), maize is one of the most important food crops and is grown by almost all farmers. Although maize is widely grown in these areas, suitable varieties are very few. Drought stressed areas devoted to maize production occupy 38-42% of the maize growing area but contribute only about 17% to the total maize production (Mandefro *et al*, 1995). Unavailability of suitable maize varieties is responsible for a such yield gap. Taking this problem into account the Melkasa Maize Programme introduced 400 experimental maize populations (from CIMMYT) and evaluated them at the Melkasa quarantine site. Then 19 promising maize genotypes were selected and evaluated at six locations for three years to determine their performance and stability.

Knowledge of G x E interaction and stability of genotypes across environments is essential to any breeding work. It helps in identifying genotypes that are widely or specifically adapted to unique environments.

Previous breeding work by the Melkasa Maize Programme has only evaluated maize germplasm on the basis of mean performance across the testing sites. As a result, there was little information on the interaction effects of genotype by environment and/or by year. Hence, this work is intended to fill this gap and generate some information for future-breeding work in the drought-stressed areas.

MATERIALS AND METHODS

The Melkasa Maize Programme introduced 400 maize genotypes and screened at Melkasa Research Center maize quarantine field in 1997 and selected 19 genotypes based on the overall performance. Description of the genotypes is given in Table 1. The 19 selected maize genotypes and one standard check were evaluated for three years (1998-2000) using a randomized complete block design with three replications, at six locations (Melkasa, Ziway, Mieso, Kobo, Dhera and Mega) in the drought stressed areas of Ethiopia (Table 2). The trials were carried out under rain-fed conditions during the main season (June to September). The gross plot size was 18 m^2 (4 rows each 6 meters long)

Table 1. Description of 20 maize genotypes tested at six locations for three years in the drought stressed areas of Ethiopia

No.	Pedigree	Grain color	Maturity
1.	Banswara 9331	Yellow	Medium
2.	Laposta Seq C5 F1	White	Medium
3.	Dholi 9331	Yellow	Medium
4.	TS6 C3 F2	White	Medium
5.	DTP1 W C 6	White	Medium
6.	Porto Viejo 9330	White	Medium
7.	Across 9331	Yellow	Medium
8.	DTP1 Y C6 early sel F2	Yellow	Medium
9.	DTP1 W C6 early sel F2	White	Medium
10.	Melkasa 92 DTP1 W C6 F2	White	Medium
11.	Var / Temp Hiland Pop	White	Medium
12.	TEWD-SR Dr syn/NAW 5867/P32	White	Medium
13.	Across 8730	White	Medium
14.	Chain Cross - I W	White	Medium
15.	Early - mid-2/PL 16-SR	White	Medium
16.	EV7992/pool 16-SR	White	Medium
17.	DMRESR-W/early Sel	White	Medium
18.	ZS 225/pool16-SR	White	Medium
19.	92SEW-2XA-8047	White	Medium
20.	A-511 (check)	White	Medium

Table 2. Description of the testing locations.

Location	Annual Rainfall, (mm)	Altitude (masl)	Latitude	Longitude	Soil type
Dhera	520	1680	8º 20' N	39º 23' E	Sandy-clay
Kobo	570	1470	12º 9' N	39º 38' E	Clay
Melkasa	710	1550	8º 24' N	39º 21' E	Sandy-clay-loam
Mieso	560	1470	9º12' N	40º 52' E	Clay-loam
Zwai	640	1637	8º N	38º 35' E	Silt
Mega	510	1630	4º 2' N	38º 25' E	Sandy

and the harvestable plot was 7.5 m^2, (2 rows of 5 meters long) using 75 cm and 25 cm spacing between rows and plants, respectively.

The fertilizer rate and other cultural practices were as per recommendation for the respective locations. Plots were harvested and shelled manually. The shelled grain yield (q/ha) was calculated after adjusting the moisture content to 12.5 percent.

Analysis of variance for each location was made for grain yield using the standard procedure as cited in Gomez and Gomez (1984). Bartlett's test to assess homogeneity of variances was also performed prior to combined analysis. Genotype x location interaction were quantified using the most common procedure, i.e., pooled analysis of variance, which partitions the total variance into its component parts (genotype, environment, genotype x environment, genotype by year and G x E x Y interaction and the error). The statistical significance of these components was determined using the F-test.

The stability of grain yield for each genotype was calculated by regressing the mean yields of individual genotypes on environmental index and by calculating the deviations of the regression coefficients from unity as suggested by Eberhart and Russell (1966). The model is:

$$Y_{ij} = \mu_i + \beta_i I_j + \sigma_{ij}$$

Where:

Y_{ij} = mean of i^{th} genotype at j^{th} environment, (i = 1, ... G; j = 1,... L), μ_i = mean of the i^{th} genotype over all environments, β_i = regression coefficient measuring response of the i^{th} genotype to change of environments, I_j = environmental index (mean of all genotypes at location j^{th} minus grand mean), σ_{ij} = deviation from regression, $\beta_i = \sum(Y_{ij}\ Ij)/\sum I_j^2$ $S^2d_i = \sum\sigma^2{}_{ij}/L - 2 - S^2_e/r$, and S^2_e = estimate of pooled error mean square

The regression coefficients (bi) were tested for significant differences from unity using t-tests, while the significance of the deviations from regression (S^2d) were tested by the F-test based on pooled error estimates. Coefficients of determination (r^2) were also calculated and genotypes with high r^2 values were considered as having more predictable performance than those with low r^2 values (Pinthus, 1973; Langer *et al.*, 1979).

RESULTS AND DISCUSSION

The combined analysis of variance for grain yield showed significant differences among genotypes, locations, years and their interactions for all sets. The linear component of G x E was significant indicating that differences existed among the regression coefficients. The non-linear component was also found to be significant implying that there were differences among stability parameters. Significant differences for grain yield were observed among genotypes at all locations with the exception of Ziway.

Interaction of genotypes with environments (G x E) and genotypes with years (G x Y) were both highly significant (Table 3). Highly significant (P<0.01) yield differences between genotypes and environments, and highly significant interaction of genotypes with environments and years, indicate the need to 1) develop cultivars that are adapted to specific environmental conditions, and 2) identify cultivars that are exceptional in their stability across environments. Both approaches necessitate the evaluation of genotypes under multiple and diverse environments within the drought stressed maize growing areas of the country.

The overall mean grain yield of the genotypes ranged from 28.6 q/ha (A511) and 60.4 q/ha (DTP1 W C6 Es) as shown in Table 4.

Among the genotypes evaluated, DTP-1 W C-6 E sel F_2 showed b_i value close to 1.0 and small deviation from regression (Sd^2i) and hence was fairly stable in performance across environments and had grain yield above the grand mean (Table 4). Banswara 9331, La Posta Seq C5, TEWF-SR DR TOL syn. were more productive where growing conditions were relatively favorable ($b_i > 1$).

The reliability of a cultivar's performance across environments is an important consideration in plant breeding. Some cultivars are adapted to a broad range of environmental conditions, while others are more limited in their potential distribution. There are cultivars that perform similarly regardless of the productivity level of the environment, and others whose performance is directly related to the productivity potential of the environment (Fehr, 1991). This clearly indicates the importance of stability analysis.

According to Ghaderi *et al* (1980) standard analysis of variance procedure is useful for estimating the magnitude of genotype x environment interaction but it fails to provide

Table 3. Combined analysis of variance for grain yield (q/ha) of 20 maize genotypes evaluated at 6 sites in the drought stressed areas of Ethiopia, during 1998-2000.

Source	DF	MS
Environment, E	5	8704.05**
Reps/E	12	156.8
Genotype, G	19	179.99**
G x E	95	72.89**
Year,Y	2	891.2**
E x Y	10	7982.2**
G x Y	38	4762.0**
E x G x Y	190	897.4**
Pooled error	**684**	**21.7**

*, ** Significant at 0.05 and 0.01 level of probability; CV=12.36%

Table 4. Mean grain yield (q/ha) and estimates of stability parameters for 20 maize genotypes evaluated at six sites in the drought stressed areas of Ethiopia, 1998 –2000

Pedigree	Grain yield	b_i	Sd^2i	r^2
Banswara 9331	41.94	1.23*	5.58*	69
Laposta Seq C5 F1	41.77	1.43*	30.50*	90
Dholi 9331	33.61	1.27*	-7.60*	91
TS6 c3 f2	38.39	1.2	-5.80*	64
DTP1 W C 6	40.35	1.26*	-10.35*	88
Porto Viejo 9330	40.58	1.33*	-12.14*	75
Across 9331	38.88	1.36*	-10.23*	83
DTP1 Y C6	47.81	0.89	13.01*	78
DTP1 W C6	60.40	0.98	1.24	70
Melkasa 92 DTP1	47.11	1.50*	6.21*	77
Var / Temp Hiland Pop	41.49	1.01	-11.98*	64
TEWD-SR Dr	41.53	1.21	-10.35*	71
Across 8730	35.21	0.93	-5.57*	78
Chain Cross - I	51.02	1.14	8.36*	64
Early - mid-2/PL	49.01	1.03	6.84*	65
EV7992/pool16-SR	39.43	1.63*	-7.71*	61
DMRESR-w	36.61	1.04	-6.92*	64
ZS 225/pool16-SR	45.84	1.33*	4.73*	76
92SEW-2XA-8047	35.14	1.05	-11.86*	71
A-511check	28.60	1.08	-7.67*	82

* significant at 0.05%

the environment, and others whose performance is directly related to the productivity potential of the environment (Fehr, 1991). This clearly indicates the importance of stability analysis.

According to Ghaderi *et al* (1980) standard analysis of variance procedure is useful for estimating the magnitude of genotype x environment interaction but it fails to provide information on the contribution of individual genotype to genotype x environment interaction. To alleviate the problem, a number of statistical procedures have been developed. Detailed discussions on stability analysis could be found in Hill (1975), Westcott (1986), Zobel *et al*. (1988), Crossa (1990), Kang (1993), Romagosa and Fox (1993) and Duarte and Zimmermann (1995).

Romagosa and Fox (1993) used regression analysis to calculate stability of genotypes. According to Finlay and Wilknson (1963) individual variety yields are plotted against the mean of all the variety yields. Regression coefficients approximating to 1.0 indicate average stability. When this is associated with high mean yield, varieties have general adaptability; when associated with low mean yield, varieties are poorly adapted to all the environments. They also stated that regression values increasing above 1.0 describe varieties with increasing sensitivity to environmental change (below average stability), and greater specificity of adaptability to high yielding environments. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change (above average stability) and therefore, increasing specificity of adaptability to low-yielding environments.

In the Eberhart and Russell (1966) stability model, the regression of each variety is an experiment on an environmental index and a function of the squared deviations from this regression would provide estimates of the desired stability parameters. Thus the model partitions the genotype x environment interaction of each variety into two parts: (1) the variation due to the response of the variety to varying environmental indexes (sum of squares due to regression); and (2) the unexplainable deviations from the regression on the environmental index. Thus the adaptable variety in this model is the one with high mean yield, b = 1.0 and $S^2d = 0$ and those significantly deviating from unity are either adapted to high yielding environments if $b_i > 1$ or low yielding environments if $b_i < 1$. Several authors regarded mean square for deviations from regression as the most appropriate criteria of stability while b_i is an indication of the type of response of a cultivar to varying environments rather than a measure of stability (Gupta *et al*., 1974; Chaudhary *et al*., 1994).

Graphing b_i and mean grain yield for each genotype can be useful in selecting cultivars with large grain yield and either stable (b_i=0), responsive (b_i>1) or non-responsive (b_i<1) to favourable environments. Genotypes with large mean grain yield and b_i <1 may be desirable for low-yielding environments, and genotypes with large mean grain yield and b_i near one are desirable if recommending one genotype for all environments.

Squared deviations from linear regression (Sd^2_i) were significantly different from zero for most of the genotypes, indicating wide fluctuations of genotypes to changes in environments. The significant G x E interaction was also accounted for by non-linear component (data not shown). Therefore, usefulness or desirability for these genotypes was evaluated by considering deviation from regression (stability) and average grain yield. Eberhart and Russell (1966) also suggested Sd^2 as a true measure of stability. Hence, DTP-1 C6 early Sel F2 has potential for future use in Sub Moist (SM2) agroecological zone because the genotype had grain yield above the average was fairly stable and had non-significant deviation from regression line.

The coefficient of determination (r^2) for grain yield ranged from 61 to 91 %. The highest value of r^2 was recorded for the top yielding genotypes. Coefficient of determination (r^2) is also used to estimate predictable performance of genotypes (Pinthus, 1973). Since then scientists (Langer *et al*., 1979) have used it. A coefficient of determination was also used to estimate predictable performance of sorghum genotypes (Abebe *et al*., 1984 a and b)

The simple correlation coefficient between mean yields and regression coefficients (b_i) was positive (r=0.51) (not shown) indicating that the high yielding genotypes were the most responsive to favourable environments. This result is in agreement with those of Eberhart and Russell (1966), and Anderson *et al*. (1989).

Therefore, we conclude that genotype DTP-1 C6 that performed above average across the environments can be used directly or in synthesizing open pollinated varieties for drought stressed environments in which they have been tested. Significant effects of environments on grain yield were noted implying that the need to evaluate genotypes at sites representative of the region where the germplasm is targeted. The study has confirmed the importance of stability parameters in identifying superior genotypes of maize for drought stressed areas of Ethiopia.

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SELECTING AND BREEDING MAIZE CULTIVARS FOR DROUGHT TOLERANCE IN MALAWI

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ABSTRACT

Maize is one of the main cereal crops in Malawi and plays an important role in farmers' lives and on-farm income. However, yield is low with drought and low soil fertility among the principal factors influencing maize production. The development of drought tolerant cultivars represents an important method for reducing the effect of drought stress on maize production. Since 1997, Malawi has worked hard to develop maize varieties with drought tolerance during the flowering period with funding from the CIMMYT SADLF project. Four open pollinated populations were improved for tolerance to drought at Chitala using S_1 recurrent selection scheme. S_1 lines were selected under normal and artificial drought conditions and were recombined, forming improved populations. The four populations, together with several OPVs and hybrids were evaluated from 1998/99 season to compare yield potential and other agronomic characteristics under artificial and non-stress conditions in summer and winter. Several varieties were selected together with the improved populations for drought tolerance and ZM 621, ZM 521 and ZM 421 were released in 2001. From the population improvement programme, Matindiri C_1 had 10-16% genetic yield advantage over the original population. These cultivars have shown good performance and production stability in low rainfall areas, showing the potential for improving the performance of maize under conditions of water stress through plant breeding. These varieties were also put under multilocation testing using the Mother and Baby concept as well as running 600 demonstrations. In future, our drought programme will get increased attention with objectives of (1) adapting high yielding germplasm to stress conditions (2) to develop inbred lines tolerant to drought and low fertility (3) identify hybrids/OPVs with broad adaptation to the highly variable growing conditions in Malawi.

INTRODUCTION

Maize is the main staple food in Malawi and is a major source of carbohydrates. The rising demand for food has also turned it into a cash crop. Maize is planted on 70% of arable land with an average yield of 1.3 metric tons per year (Smale, 1999 and CIMMYT, 1999). However, yield is low with drought and soil fertility among the principal factors influencing maize production in Malawi.

Drought, through insufficient rainfall and poor distribution during growth, is one of the most important abiotic stresses affecting maize production in Malawi and is the most important source of variation in yield over time. The development of varieties with high and stable grain yields under drought in Malawi would, therefore, be an important priority as the use of drought-tolerant cultivars may be the only affordable option for small-scale farmers. Furthermore, it has been shown that germplasm developed for drought tolerance is likely to be as stable across environments as conventionally developed germplasm (Byrne *et al*, 1995).

In 1997, we began a special programme working to develop maize varieties with drought tolerance during flowering with funding from the SADLF project from CIMMYT Zimbabwe. Two approaches were made: (1) screening several germplasm sources from the regional trials under stressed artificial drought conditions (2) S_1 recurrent selection for drought tolerance in four populations. Our objective was to identify economically desirable maize cultivars which will be able to establish, develop and maintain themselves through drought periods by efficient and economic use of moisture.

MATERIALS AND METHODS

S_1 recurrent selection for drought tolerance

The S1 progenies were formed in 1997 summer in four populations, Matindiri (408 lines), Sundwe (229), Chitibu (140) and CCD (159 lines). These were prescreened in summer in unreplicated observation nurseries for yield potential and agronomic traits. One hundred and thirty-nine, 99, 82 and 54 lines were selected from Matindiri, Sundwe, Chitibu and CCD, respectively. Simultaneously, 936 S_1 were advanced to S_2. The selected lines were screened under drought stress in winter 1999 at Chitala and the tolerant lines were selected based on an index in which anthesis-silking interval (ASI) and ears per plant were the major criteria. The best 30-40 lines from each population were recombined to form drought populations and these populations were screened under normal and drought stress in the 2000/2001 season at Chitala. At the S_4 stage, the lines were crossed to two testers, A (CZH 999030/CML 312) and tester B (CZH 99029/CML 395) in order to group them into their respective heterotic groups. The progenies are being evaluated in 2001/2002 summer cropping season and will be tested under drought stress in 2002 winter at Chitala.

Screening local and regional varieties

From 1999 up to 2001, local and regional varieties were screened under drought stress at Chitala. The regional trials from CIMMYT are EPOP, ILOP, EIHYB and ILHYB. The experimental design ranged from randomized complete block to alpha-lattices, with three replications. The plot sizes were 5.0m x 0.9 m. The spacing between plants within a row was 30 cm, giving plant population of 37,000 plants per

Table 1. Maize OPV Trial under normal testing at three sites 2000.

	Grain Yield (tons/ha) and agronomic traits										
Var	**Bak**	**Chita**	**Nga**	**mea**	**Rank**	**PH**	**EH**	**DP**	**DS**	**Asi**	**gi**
Sun0	5.8	4.6	2.3	4.2	5	203	111	58	59	1	3
Sun1	5.4	4.7	1.9	4.0	6	167	107	58	59	1	3.2
mt 0	6.0	5.3	2.3	4.6	3	147	86	56	58	2	2.2
mt 1	6.0	5.1	2.7	4.6	1	175	97	57	58	1	2
ccd 0	3.3	4.0	1.5	2.9	8	160	90	56	59	3	3.2
ccd 1	4.1	4.8	1.6	3.5	7	187	99	56	58	2	3
chi 0	6.3	5.2	1.8	4.4	4	205	104	59	61	2	3
chi 1	6.9	5.6	1.3	4.6	2	204	104	59	61	2	3
Mean	5.5	4.9	1.89	4.1		181	100	57	59	1.8	2.8
Cv %	12.5	6.9	25.7	13.2		11	3.6	2.3	2.2		14.7
Lsd	1.0	0.51	0.73	0.76		29.4	5.3	2.0	2.0		0.7
P	***	***	**			*	***	*	ns		***

PH = plant height in cm
EH = ear height in cm
DP – days to 50% pollen seed
ES – days to 50% silking
ASI – athesis – silking interval
Gi = grain index (1 = 100% flint; 5 = 100% dent)

Table 2. Maize OPV trial at Chitala under drought stress Winter 2001.

	Grain Yield (tons/ha) and agronomic traits									
Var	**Yield**	**Rank**	**DP**	**DS**	**ASI**	**PH**	**EH**	**EPP**	**Senes**	**GI**
Su c0	2533	9	74	74	2	176	88	0.81	5.6	2
Cu c1	2669	7	76	76	1	171	87	0.87	4.6	2.3
ma c1	2563	8	76	76	1	165	78	0.83	5	2
ma c0	2996	2	76	76	1	165	77	1.15	4.6	1.6
ch c0	2963	3	79	79	1	179	98	0.85	4	2
ch c1	2708	6	80	80	1	176	88	0.83	4.3	2
ccd0	2871	4	70	70	1	136	63	0.96	5	3.6
ccd1	2373	10	76	76	2	167	76	0.89	4.6	1.6
sylow	2202	11	79	79	1	184	90	0.91	3.3	1.6
symid	2142	13	80	80	1	176	84	1.06	3	2.6
opvla	3064	1	76	76	1	188	87	1.0	5	3
opvm	2184	12	76	76	3	176	83	0.97	4	2.3
kaful	2788	5	79	79	2	189	96	0.75	4.3	2.6
mean	2620		77	77	1.2	173	84	0.92	4.4	2.2
CV %	23.7		2.4	2.4		5.1	7.8	17.5	31.8	23.6
Lsd	1048		3.1	3.1		14.9	11.2	0.027	2.3	0.91
P	ns		***	***		***	***	ns	ns	**
Min	2142		70	71		136	63	0.82	3	1.6
Max	3064		80	81		189	98	1.15	5.6	3.6

EPP = number of ears per plant
Senes = senescence scores (1-10 score)
Mat = Matindiri
Su = Sundwe
Chi =Chitibu
ccd = Chitedze composite D

Screening local and regional varieties

From 1999 up to 2001, local and regional varieties were screened under drought stress at Chitala. The regional trials from CIMMYT are EPOP, ILOP, EIHYB and ILHYB. The experimental design ranged from randomized complete block to alpha-lattices, with three replications. The plot sizes were 5.0m x 0.9 m. The spacing between plants within a row was 30 cm, giving plant population of 37,000 plants per hectare. The traits that were recorded were grain yield, number of ears per plant, senescence (1-10 scale), anthesis-silking interval and other agronomic traits. Fertilizer was applied at the rate of 120 kg/ha N and 60 P_2O_5. Data were adjusted at 12.5% moisture content before analysis and data were analyzed using alpha lattice.

RESULTS AND DISCUSSION

S1 recurrent selection.

The results are shown in Tables 1 and 2 for grain yield and other agronomic traits for the normal and drought screening trials, respectively. Under normal testing, there were significant yield differences between varieties at all sites. The highest yielding variety was Matindiri C_1 with 4,629kg/ha, followedby Chitibu C_1 with 4,568 kg/ha and Matindiri C_o with 4,560kg/ha. There was 10.3%, 10.2% and 11.9% genetic yield improvement for Chitibu, Matindiri and CCD, respectively. There was a negative genetic improvement for Sundwe.

For the drought screening trial, there were no significant differences between varieties for grain yield, ears per plant, leaf blight and rust. There was a negative genetic improvement for Chitibu and CCD whilst there was 16.8% and 5.37% genetic improvement for Matindiri and Sundwe respectively. It can be construed from the data that only Matindiri population performed well under both screening regimes.

Screening local and regional varieties under drought

For the three seasons of screening, several varieties were identified with drought tolerance and these were Early-mid/Katumani, ZM421, ZM 521, Z97SYNGLS, LAT A/LAT B, ZM 621, SC 407, SC 403, G16/CML 202, CX 8026, CX 8001, P501/502, EV98ZM605, CZH 99018, CZH 99006, PHB 30R93, CZH 99037, SC 627, CZH 99036, CX 8001, CZH 99042, ZS 255, CZH00023 and CZH 99044. From this work, we released three drought tolerant open pollinated varieties in 2001 in Malawi and these are ZM 621 (Giring'ande), ZM 521 (Mpesi) and ZM 421 (Kalawe). 527 demonstrations have been conducted in 2001/2002 throughout the country with the help of extension agents and NGO'S. Small-scale seed production has been initiated.

CONCLUSIONS

From the three years work on breeding and selecting for drought tolerant varieties, we have identified and released three varieties and some varieties are in the pipeline. In our approach, we test cultivars under both favorable and unfavorable conditions. We also emphasize testing using both controlled field screening and multilocation testing where we test under both stress and non-stressed conditions. We focus our selection work on flowering period when maize is most vulnerable to stress. We use secondary traits such as anthesis- silking interval, ears per plant that are highly heritable indicators (Banziger and Latiffe, 1997). We are using these traits along with yield to select for drought tolerance.

The Future

In future, our drought breeding programme will get increased attention with the objective: (1) to select locally adapted germplasm containing genetic variability for high yields, short ASI and morphological and physiological traits associated with drought tolerance. (2) to characterize lines developed in Malawi or introduced from abroad for drought tolerance, combining ability and yield potential, with the aim of developing new hybrids and composites from these sources (3) identify hybrids/OPVs with broad adaptation to the highly variable growing conditions in Malawi.

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DEVELOPMENT AND EVALUATION OF TILLAGE IMPLEMENTS FOR MAIZE PRODUCTION IN THE DRYLAND AREAS OF ETHIOPIA.

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ABSTRACT

Ethiopian farmers have been using an inefficient traditional ard plough known as the *Maresha* for all kinds of cultivation. This has resulted in lower productivity of maize. Farmers in Ethiopia did not accept implements introduced from other countries because they were too heavy and complicated compared to the *Maresha.* Therefore, new types of implements were developed based on the design features of the *Maresha*. The implements were tested both on-station and on-farm. They were found to have superior field performance while being simple and cheap. Farmers reported 20-100% increments in maize grain yield due to the use of the improved implements. Two factories have commercialised the improved implements.

Keywords: conservation tillage, implements, maize, *maresha*, participatory, planter, plough, ripper, weeder/

INTRODUCTION

Ethiopian farmers have been using an ox drawn ard plough known as the *Maresha* for thousands of years. Most of the components of the plough are wooden except two pieces: the ploughshare and a tying unit. It is cheap and simple but inefficient compared to mouldboard ploughs and other types of implements. Its depth of operation is low, its weeding efficiency is low and it causes run-off leading to soil erosion and loss of soil water (Muluneh Sime, 1986). Ploughing with *Maresha* results in low soil moisture and since soil moisture is a limiting factor under dry land farming, crop productivity is very low with the traditional cultivation systems. The inefficiency of the *Maresha* in accomplishing the tillage task forces farmers to plough the land several times. Such a repeated tillage causes structural damage and loss of organic carbon from the soil. Moreover, the need for repeated tillage forces farmers to keep a large number of cattle for the purpose of breeding oxen for traction. Overstocking of cattle in turn causes land degradation. The high amount of time spent on tillage also delays planting and hence farmers in dryland areas cannot use the full growing period of the already short growing season. As a result, crop productivity is reduced and sometimes farmers face total crop failure when the rain stops earlier than the average, leading to famine.

In the past, several researchers and organisations made repeated attempts to replace the *Maresha* by the mouldboard plough. Michael Goe (1987) has summarised the efforts made in Ethiopia to introduce improved small farm implements. The following paragraphs are taken from his review work.

Italians for the first time introduced the animal drawn mouldboard plough to Ethiopia in 1939. However, farmers rejected the plough for its heavy weight, high draft power requirement and complicated adjustment and attachment systems. The Italians concluded that the Ethiopian farmers were conservative and do not want to take up new technologies. This has been probably one of the major causes for failures to improve farm implements in Ethiopia. Farmers' ideas were not taken seriously. Their traditional plough, the *Maresha*, was not studied well. Its simplicity, lightness and low cost nature were not considered. Several attempts made after the Second World War followed similar trends. FAO conducted several trials on small farm implements in the 1950s. The Jimma and Alemaya Agricultural Colleges also conducted trials on implements between 1955 and 1965. The Chilalo Agricultural Development Unit (CADU) started research on farm implements in 1968 and had some success stories but could not go any further.

In 1976 the Institute of Agricultural Research (IAR) began testing and modification of farm implements. However, the methods followed were more or less similar to the previous ones and hence development of acceptable implements proved to be difficult. In 1985 the Agricultural Implements Research and Improvement Centre (AIRIC) was established to co-ordinate research nationally. A national survey was conducted to identify implements; related production constraints and research priorities were set up (Pathak, 1986). Extensive testing and modification of implements were made. However, farmers did not accept the implements developed.

Recently, the approach was somewhat changed and thus the indigenous implement, the *Maresha*, was studied well and many of its design features were incorporated into the newly developed implements after isolating the weak points. Field trials were conducted both on-station and on-farm to study the effect of the new implements on time requirement and grain yield of Maize. This paper presents the results of such activities as the development and evaluation of the newly developed implements.

MATERIALS AND METHODS

Development

The development of the implements was based the following design criteria and principles:

1. The design should be as simple as possible. It should have the minimum possible deviation from the farmer's traditional implements. In other words, modifications should be made only where necessary.
2. The design has to perform better than the traditional

Figure 1. The Modified Plough.

Figure 2. The Ripper / Subsoiler

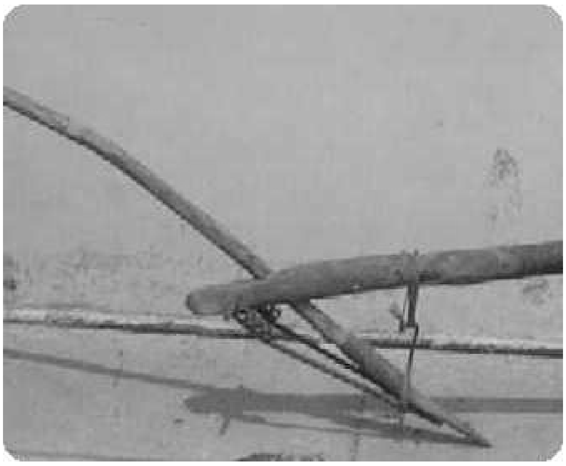


Figure 3. The Winged Plough / Weeder

Figure 4. The Row Planter

implement in terms

3. The design has to perform better than the traditional implement in terms of time and labour requirement, draft words, modifications should be made only where necessary.
4. The design has to perform better than the traditional implement in terms of time and labour requirement, draft power requirement and improvement in crop productivity.
5. The implement should be light and simple (easy to operate, manufacture, repair and carry from place to place).
6. The implement should be economical.

The main design features and mechanisms of the traditional implement, the *Maresha,* were studied and the undesirable features were isolated. Mechanisms and design parts from other implements used in other countries were identified and incorporated into the new designs. The mouldboard plough used in other countries was modified such that the handle and the beam were replaced by the respective components of the *Maresha* (Fig. 1*)*. The Ripper/Subsoiler (Fig. 2) was developed by replacing the wooden boards of the*Maresha* known as *Deger* by a pair of rods that are designed to improve penetration. The Winged Plough was developed by integrating the standard sweep plough design with the tip of the *Maresha* (Fig. 3). The row planter was an exception because a new type of metering mechanism was invented. The ground wheels used to drive the metering mechanism of previously developed planters were avoided because they failed to rotate effectively in the rather rough and cloddy fields of the small-scale farmers. Such mechanisms have been effective for tractor drawn row planters as the field is level and clods are made fine using disc harrows. Moreover, the size of the wheels was bigger thus capable of overcoming obstacles. On the other hand, animal drawn row planters had to be equipped with smaller wheels and have less overall weight to make them suitable for small-scale farmers. The reduced weight negatively affected the effectiveness of metering fertiliser as small particles of fertiliser get stuck between rotating and stationary parts and require so much torque which can only be achieved with heavy overall machine weight. Therefore, a new type of metering mechanism whereby the operator oscillates a wooden lever attached to the metering unit

Figure 5. The Tie Ridger

corresponding to his or her foot steps was developed and the unit was mounted on the traditional *Maresha* (Fig. 4). The tie ridger was also developed by modifying the shape of a standard ridger and by making it part of the *Maresha*. The ridger was modified in such a way that it does not carry so much soil as in order to ease regular raising and lowering of the implement during operation (Fig. 5).

Evaluation

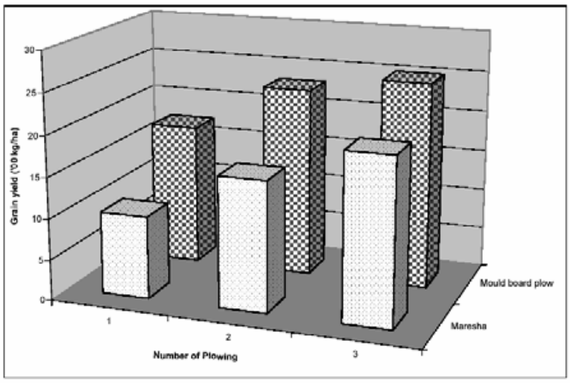
Once the implements were designed and fabricated they were tested following standard test procedures (Melesse Temesgen, 1995) and modified several times over a period of six years until they performed satisfactorily. The implements were then evaluated in comparison with the traditional implement both on-station and on-farm. Farmers were involved in the testing and evaluation of the implements. Further refinements were also made on the implements based on feedback collected from farmers. Agronomic trials were conducted on the newly developed implements both on-station and on-farm. Major data collected include time and labour requirement, draft power requirement, crop establishment, growth and yield. Plot size under controlled testing was 5m x 20m while farmers used plot sizes ranging from 2,500 m^2 to 1 hectare. Maize varieties used were Katumani, local varieties and A511.

Several meetings were held with farmers to discuss the performance of the different implements. Farmers were encouraged to list the weaknesses and strengths of each implement. They also presented their findings of experiments with the implements during the meetings, discussed the findings and made their own conclusions and recommendations. Techniques of using the implements studied by farmers include tillage frequency and sequencing/combination of the new implements and comparisons between open furrow planting and closed furrow planting.

RESULTS

The effects of use of the modified plough and tillage frequency on grain yield of maize are shown in Table 1 while the results of participatory testing and evaluation of each of the newly developed implements by farmers are listed below.

Figure 6. Effect of Tillage Frequency and Plough Type on Grain Yield of Maize. (Melkassa 1999-2001)



1. Modified plough

The attachment of the mouldboard plough to the traditional Maresha made it simple and easy to assemble as well as to operate. Farmers had rejected previously introduced animal drawn mouldboard plough because they were complicated and heavy. But the new modification reduced the weight of the mouldboard plough from about 26 kg to 15 kg (*Maresha* weighs 14 kg). Even in some cases the original steel mouldboard plough weighed up to 35 kg. So, farmers appreciated and adopted the new plough.

The results of on-station tests made on the modified plough in comparison with the *Maresha* showed a clear advantage of the new plough over the *Maresha* (Table 1). Both plough type and tillage frequency showed a statistically significant ($P<0.01$) effect on grain yield of maize. The increase in yield due to the use of the mouldboard plough was the highest (75%) when ploughing only once followed by 43% when ploughing twice and the least increment (25%) was obtained when ploughing three times.

Farmers also compared the new plough with that of the traditional plough, *Maresha*. They reported 20 to 100% increase in yield of maize because of use of the new plough, the highest advantages having been obtained in seasons of severe moisture stress (Melesse Temesgen, 2000). Most of the farmers who tested the new plough reported the following advantages:

It cuts deeper and hence more water can be retained, roots can grow deeper in search of moisture and nutrients. It inverts the soil and hence weeds are better controlled, trash and crop residues are incorporated into the soil thereby improving soil fertility. More weed seeds are brought to the surface and can be destroyed during the next ploughing thereby producing a relatively weed-free field after planting. It reduces surface area thus minimising loss of moisture through evaporation. It leaves a dead furrow that can be laid along the contour to check run-off thus conserving soil and water. Statistical analysis revealed highly significant differences ($P<0.01$) due to plough type as well as frequency of tillage.

It undergoes complete ploughing in one pass thereby reducing frequency of tillage by 50% and hence farmers can get free time to do other activities. In addition, the draught oxen can get rest and use the extra time available for grazing which will help them maintain their body weight and remain powerful during planting time when in particular draft power

Table 1. Effect of Tillage Frequency and Type of Plough on Grain Yield of Maize (Melkassa, 1999-2001)

Plough type and tillage frequency	Grain Yield (kg/ha)
Maresha x 1	1008
Modified Plough x 1	1735
Maresha x 2	1594
Modified Plough x 2	2321
Maresha x 3	2029
Modified Plough x 3	2517

power shortage is critical. The plough needs the use of proper techniques to achieve this.

Cross ploughing is not required and, therefore, farmers can plough their fields only along the contour to avoid run-off. Usually when farmers use *Maresha* they are forced to orient the line of ploughing along or nearly along the slope in one of any two consecutive operations resulting in run-off and loss of soil and water. When ploughing along terraces the farmer can follow only one direction parallel to the terraces if he is using the modified plough. However, with *Maresha* cross ploughing takes more time because the width of terraced fields are so small that it will take a long time to go back and forth along them. On the other hand, ploughing along one direction alone i.e., along the contour is very inefficient with Maresha owing to the design feature of the implement.

The modified plough cuts thick-stemmed weeds that cannot be cut by *Maresha.* Owing to the nature of *Maresha* such weeds are missed during ploughing and farmers have to pull them by hand, which takes time and is usually non-hygienic.

Width adjustment is possible without reducing the depth and the weight acting on the soil. When ploughing with *Maresha* farmers have to lift the implement in order to reduce its draft force. With the modified plough this can be done by reducing the width of furrow slice cut. Thus depth of operation is maintained and draft force is reduced for weaker animals and/or hard soils.

Furrow slices are cut from one side and thrown to the ploughed area (furrow). This reduced the draft force because the soil being moved faced little resistance. But when ploughing with *Maresha* the soil pushed to the left and right slides by *Deger* faced resistance from the undisturbed soil. Therefore, the draft force required by the modified plough for a given area of cross section was smaller than that of the *Maresha*.

The Akaki Spare Parts and Hand Tools Factory has already started manufacturing the plough for sale. They have sold more than 2,000 pieces over the last three years. The factory sells the plough for 217 Birr (about 25 dollars) excluding the wooden parts of the *Maresha* that are owned by farmers. The price is less than one fourth of the price of a previously manufactured plough by the same factory.

2. Ripper/Subsoler.

The Ripper/Subsoiler is made by replacing the wooden boards of the Maresha, known locally as *Deger* by a pair of rods that are tied with the tip of *Maresha* (Fig. 2). Farmers appreciated the depth of this implement. On-station tests showed that the ripper can penetrate up to 10 cm deeper than *Maresha* (26.7 versus 16 cm). Farmers realised that because of the replacement of the *Deger* by rods the new implement penetrated deeper. The implement can be used for conservation tillage.

A private company has started making the implement and supplies the remaining parts free of charge for those who purchase either the Tie Ridger or the Winged Plough.

3. The Winged plough

Farmers tested the original plough and commented that it was too heavy and complicated. It was, therefore, modified in such a way that its weight was reduced from 11 kg to 3 kg (Fig. 3). This does not include the weight of the components of the *Maresha* that will be attached to the new implement. The new implement was tested in comparison with the traditional plough. Farmers reported the following advantages of the winged plough.

The draft power requirement is low and hence it can be pulled by very weak oxen or by a pair of donkeys. (On station tests have shown that the draft force requirement of the winged plough is only 60% of that of the *Maresha*). One farmer, upon observing the low draft power requirement of the implement decided to use a pair of donkeys instead of oxen. He modified the traditional yoke in such a way that it suits donkeys.

It does not invert the soil during secondary tillage thus preventing evaporation of soil moisture.

A private company has started manufacturing the implement selling at a price of 86 Birr (about 10 dollars) excluding the wooden parts of the *Maresha*.

4. The Row planter

The new planter (Fig. 4) that was developed by avoiding ground wheels worked effectively in the rough and cloddy fields of the small-scale farmers unlike previously introduced planters.

Farmers adopted the practice of row planting because of the presence of the row planter. The farmers in Wulinchity and Bofa area had not adopted manual row planting due to its drudgery despite popularization activities carried out by the extension department of the Ministry of Agriculture. Farmers then conducted trials on the operation techniques of the row planter. For instance, the decision was left for them as to whether the planter should be used with open or closed furrow planting system. Closed furrow planting refers to covering the seeds on the return pass with the implement (planter mounted on *Maresha*) while open furrow planting system employs a seed covering device attached behind the planter that covers seeds and fertilizer with a small amount of soil. The operator makes each pass 75 cm apart and performs planting in every pass. Farmers found out that if they do not expect any rain in the next seven days after planting, closed furrow planting would be advantageous. In contrast, if it rains in the first few days after planting crust formation was found to hinder seedling emergence with closed furrow planting. Many farmers have been able to demonstrate this phenomenon using replicated trials in which they compared closed and open furrow planting. Farmers were also able to practise tie ridging on the open furrow planted fields.

Farmers tested the row planter in their fields and came up with the following results. The row planter saves time and labour. When operated with open furrow planting system one person can finish a given area of land in 3 hours while 3 persons will take 9 hours to do the same manually. When closed furrow system is used the time required will be doubled. With open furrow planting system, the row planter facilitated moisture conservation through tie ridging. In crust forming soils the use of open furrow system with the row planter improved crop emergence.

With open furrow system, weeding was more efficient and helped in earthing up the crop. Some farmers have demonstrated this phenomenon by planting the same crop with the two systems side by side. Heavy run-off that occurred 30 days after planting washed all the crop planted using conventional techniques while those planted using the row planter and weeded by the cultivator survived because of the strong support the crop got from earthing up. The planter was also found useful for intercropping.

5. Inter-row weeder

The animal drawn inter-row weeder is the same as the winged plow (Fig. 3) but with a reduced width of cut and slightly higher rake angle to improve penetration. A single ox or a pair of donkeys can pull it.

According to field tests conducted by farmers the weeder reduced the time and labour required for manual weeding 30 Man-days/ha to 2 man-days/ha.

A private company is making the weeder for sale at a rate of 68 Birr (about 8 dollars) excluding the wooden parts of the *Maresha*.

6. The tie-ridger

The tie ridger (Fig. 5) is meant for reducing run-off by creating a series of basins in the field. Farmers did not accept a prototype developed earlier as it was mounted behind the *Maresha*, which had to be lifted independently and the draft requirement was higher than *Maresha*. The tie ridger was, therefore, modified such that it is mounted on the *Maresha*. Its draft power requirement was thus reduced to 77.8% of that of the *Maresha*. On-farm tests revealed that the use of the Tie Ridger increased grain yield of maize by 22.3% compared to the farmers' practice of flat planting although this is a one season result. However, the most important point here is that farmers are now provided with an implement to make tied ridges and it is the performance of the implement that is more important as the practice of tie ridging has been found to be advantageous by previous investigators.

The Tie Ridger was operated by one hand only. Farmers tested the implement for the last three years. They found it easy to operate. The cost has been reduced to only 85 Birr (about 10 Dollars) excluding the wooden parts of the *Maresha*. The implement is being manufactured by a private company for sale.

DISCUSSION AND CONCLUSION

The use of the new implements increased grain yield of maize generally because of moisture conservation, better weed control and timely operations.

As it can be seen in Table 1, the increase in grain yield with tillage frequency was higher for *Maresha* than for the modified plough. The difference between ploughing three times and two times with the modified plough made little difference.

Hence, tillage frequency can be reduced with the new plough that will enable farmers to plant early thus utilising larger proportion of the growing period.

Adoption of the implements by farmers was the result of the design principles employed while developing the implements. The use of indigenous knowledge that means the use of the design features of traditional implement and the feedback collected from farmers in developing the new implements has contributed to the simplicity, lightness and low cost nature of the new implements. Quicker adoption of the implements by farmers that has not been achieved earlier despite attempts made by several organisations for more than 60 years has led to commercialisation.

Manufacturers have been encouraged by the demand the farmers have shown for the new implements. The new implements reduced drudgery of farm operations, labour and time required for maize production because of their superior design features which also made them reliable under the farmer's field conditions.

It is now possible to introduce the new implements to other Eastern and Southern African countries. In these countries, farmers use less animal traction because of lack of appropriate implements. The existing implements are too heavy, complicated and expensive for small-scale maize growers. Moreover, lack of reliability of some of the implements such as the row planter has discouraged many farmers from using them. So, it would be a good idea to test the *Maresha*-based improved implements in these areas with a view to tackling the above problems.

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ON-FARM EVALUATION OF SOIL MOISTURE CONSERVATION TECHNIQUES USING IMPROVED GERMPLASM

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ABSTRACT

The dry land areas of Ethiopia account for more than 66.6% of the total land mass. In the dry land areas, the major constraint to agricultural production is moisture stress. The main causes of moisture stress are low and erratic rainfall, run-off losses due to poor water retention and infiltration and steep slopes. Tie- ridging has been found to be very effective in reducing runoff and soil erosion and in making more water available to the crop. However, the adoption rate by farmers has been low because it is tedious and time consuming to make them by hand. Recently, an animal drawn tie ridger has been developed to alleviate the problem of labour and time requirement. An on-farm experiment was thus carried out in order to verify the effectiveness of the tie ridger in combination with improved varieties. Two types of improved maize varieties: Katumani and Awassa-511 were tested in combination with tie ridging and fertilizer application. According to the results of the trials there were average yield increments of 22% and 28% due to the use of the tie ridger and improved varieties, respectively.

Keywords: Dry land areas, implements, improved variety, maize, moisture stress, tie ridger.

INTRODUCTION

The Ethiopian Economy is mainly agrarian. It employs 85% of the population and contributes 45% of the gross domestic product and 90% of the national export earnings. The population of the country is increasing at an alarming rate of 3.3% annually and is expected to reach 117.2 million by the year 2030. Food deficit in the whole country, in general, and in the dry land areas in particular, is increasing mainly due to drought.

The dry land areas of Ethiopia account for more than 66.6% of the total land mass ranging from arid with <45 days of LGP to sub moist and moist zone with LGP of 60-120 days. In the dry land areas, the major constraint to agricultural production is moisture stress. The main causes of moisture stress are low and erratic rainfall, run-off losses due to poor water retention and infiltration and steep slopes, high evapo-transpiration losses caused by high temperatures, strong wind and weeds. Low soil fertility and shallow soils due to soil erosion that are caused by the use of improper tillage implements stand next to soil moisture stress. Moreover, weed competition, poor seedling emergence, compaction and crust formation are important constraints in dry land areas.

Although drought is the major reason causing famine in Ethiopia, low level of agricultural productivity due to poor management of the available resources is a very important factor that has rendered the country sensitive to even tolerable shortages of rainfall. Efforts made to develop improved crop varieties alone have not been successful and it has recently been recommended that improving the management aspect would be a better option for the dry land areas (Georgis, *et.al*, 2000). Improved management focuses not only on improving crop yields but also in maintaining and improving the soil productivity for a sustainable agriculture. The major problem contributing to the low agricultural productivity in the dry land areas is moisture stress. The areas receive less than adequate rainfall for

Table 1. Effect of Soil and Water Conservation Methods (Tied Ridges) on Grain Yield of Sorghum, Mung Bean, and Maize in the Semi-Arid Areas of Ethiopia (Kobbo and Melkassa)

Soil conservation method	Average grain yield (t ha^{-1})		
	Kobbo	Melkassa	Mean
Sorghum			
Flat planting (farmers' practice)	1.6	0.80	1.20
Tied Ridges planting in furrow	2.9	3.0	2.95
Mung bean			
Flat planting (farmers' practice)	0.4	-	0.4
Tied Ridges planting in furrow	0.7	-	0.7
Maize			
Flat planting (farmers' practice)	1.2	-	1.2
Tied Ridges planting in furrow	2.7	-	2.7

Ridge height = 35 cm, Ridge spacing = 80 cm for mung bean, 75 cm for sorghum and maize, ridges tied at 6 m interval.

Table 2. Mean grain yield (t ha^{-1}) of five improved maize varieties grown in the semi-arid eastern Ethiopia under unfertilized conditions

Varieties	Grain yield (t ha^{-1})		
	Without tied ridges	With tied ridge	Increase (%)
Alemaya composite	2.8	4.8	70.9
KCC	2.6	4.3	67.5
EaH-75	2.6	3.6	38.6
Ca 5	2.3	2.9	26.4
Bukri	2.0	2.9	47.6
Mean	2.5	3.7	51.2

profitable agriculture throughout the year. Maize is an important food crop. A number of improved maize varieties have been developed for moisture stress. Also, other technological packages have been developed among which the most effective agronomic practice developed for these areas is tie ridging. Tied ridges are a series of basins created in the field in order to retain rainwater by retarding run off.

Several research activities were carried out to address the pressing water stress problem at Kobbo and Sirinka research centers in North Wello and other dry land areas of the country. Tie-ridging, an *in situ* rainwater harvesting technique, has been found to be very efficient in reducing runoff, soil erosion and resulted in effective soil and water conservation (Georgis, 1999). The yield of crops (sorghum, maize, wheat and mung bean) grown using tied ridges also increased substantially ranging from 50 to > 100% compared with the traditional practice of planting on flat seedbed at Kobbo. Similar grain yield and total biomass increase was also observed at other dry land areas of Ethiopia including Nazret, Meiso, Mekelle and Bablie. The increase in grain yield of some of the important dry land crops in semi-arid areas obtained with tied ridges is given in Table 1.

Field trials were also conducted in the semi-arid areas of eastern Ethiopia to determine the effect of moisture conservation on the yield of maize and sorghum with and without fertilizer application. The results of these experiments show a substantial yield increment from the water conservation practices (Tables 1 and 2). On the average, yield increment of more than 50% was attributed to the water conservation practices under unfertilized conditions. Under fertilized conditions the overall yield increment was not relatively high (27%). However, in terms of absolute yield, the combination of moisture conservation and use of fertilizer gave the highest attainable yield. The results indicate that fertilizer application combined with moisture conservation gives better yield than either fertilizer or moisture conservation alone.

Similar grain yield increment in both sorghum and maize was also obtained with N and P application in conjunction with tied ridges on farmers field in a sandy loam soil in Central Rift Valley around Melkassa area. The results indicated that the highest yield of maize was obtained with the application of 40 kg N and 46 kg P_2O_5. The net benefit analysis also indicated that a farmer willing to spend 214 birr ha^{-1} on fertilizer application will obtain a net benefit of 2,244 birr ha^{-1} (Georgis, 1999).

Several N and P fertilizer response trials were conducted in the past to solve the low soil fertility problem. Application of 100 kg ha^{-1} P basal and 50 kg ha^{-1} urea as top dressing was found to increase maize and sorghum yield by about 1 t ha^{-1} for every 214 birr ha^{-1} spent on fertilizer application under sandy loam soils in the Central Rift Valley areas.

Field results also indicated that both tied ridges or fertilizer application can be economically profitable in increasing yields (by about 50-100%) of several field crops. But, when both are combined the interactive effect was found to be increasing yield by more than the sum of the yields when the two techniques are used alone. However, with insufficient soil water, fertilizer may not be profitable.

The results of these experiments clearly indicate that the use of tied ridges is very effective in conserving the limited amount of rainwater available in the dry land areas. The results also indicated that the high risk associated with fertilizer application under dry land farming conditions particularly under the conditions of resource poor farmers could be minimized or avoided if use of chemical fertilizer is combined with appropriate soil water conservation practices. This could facilitate the use of chemical fertilizer application in the dry areas and increase and stabilize food and feed production and lead to food security and enhancing the natural resource base. The advantages of tied ridges is well appreciated by farmers, although, the adoption rate is very slow, because it is tedious and very time consuming to make them by hand. Based on the recommendation made by the agronomists on the need for the development of a tie ridger the Agricultural Mechanization Research Program of the Ethiopian Agricultural Research Organization developed an animal drawn tie ridger. According to field test results, the tie ridger operated 4 times faster than manual tying. However, farmers complained about the heaviness and the inconvenience of the tie ridger. Therefore, a new type of tie ridger (Fig. 1) that was found to be easy to operate (only one hand is used as opposed to the original that required two hands) was developed. The new tie ridger also required lower draft force than the traditional plough.

The African Maize Stress Project (AMS) has embarked on the development of maize varieties that would be tolerant to low nitrogen, drought and pests. This proposed project seeks to test some of the new varieties on farmers' fields, as a partnership in developing a management package that would ensure achievement of the potential of the new varieties.

In the main season of 2000 the tie ridger was tested in combination with improved and local maize varieties. The objective of this trial was to verify the effectiveness of tied ridges in combination with improved varieties and fertilizer application in moisture stress areas.

MATERIALS AND METHODS

Two types of improved maize varieties: Katumani and Awassa-511 were tested in combination with tie ridging using an animal drawn tie ridger (Fig. 1) and fertilizer application. Thus, there were eight treatments (Table 4).

The trials were conducted at three locations (two in Zeway and one in Welenchity). At each location four farmers hosted the trial. The soil type in Zeway were sandy while those in Welenchity were sandy loam with relatively dark color. The areas are characterized by low rainfall and moisture stress. The major crop is maize. The plot sizes were 20 m by 6 m each at Zeway and 20 m x 10 m at Welenchity. Training was given to farmers on the use of the implement. Each farmer made tied ridges on their respective fields.

Figure 1. The Ridger

Table 3. Mean grain yield (t ha^{-1}) of five improved maize varieties grown in the semi-arid Eastern Ethiopia under fertilized conditions

Varieties	Grain yield (t ha^{-1})		
	Without tied ridges	With tied ridge	Increment (%)
Alemaya composite	5.4	7.1	33
KCC	4.7	6.6	39
EaH-75	4.8	6.0	25
Ca 5	3.8	4.7	23
Bukri	3.7	4.0	9
Mean	4.5	5.7	27

Table 4. Effect of tie ridging, use of improved seeds and fertilizer On Yield of Maize (Q/ha)

Trt.No.	Location		
	Ada Jela	Welen Ansura	Aluto chity
1*	55.33	17.55	18.85
2	45.48	13.47	16.49
3	42.91	14.14	13.78
4	34.40	11.35	11.02
5	43.41	13.54	16.35
6	37.11	10.38	12.60
7	37.80	11.60	11.59
8	27.47	8.47	10.37

*Treatments:
1. Tied + Improved Seed + Fertilized
2. Tied + Improved Seed + Unfertilized
3. Tied + Local Seed + Fertilized
4. Tied + Local Seed + unfertilized
5. Untied + Improved Seed + Fertilized
6. Untied + Improved Seed + Unfertilized
7. Untied + Local Seed + Fertilized
8. Untied + Local Seed + Unfertilized

Data were collected on days from planting to emergence, days to anthesis, days to physiological maturity, bio-mass and grain yield. Thousand seed weight was also recorded.

RESULTS

The results on grain yield are presented in Table 4. There were significant yield increments (average 22%) due to the use of the tie ridger ($p<0.1$) at the three sites. The yield increments (average 28%) due to the use of improved maize varieties were also significant ($p<0.01$) at the three sites.

Farmers' assessment

All the farmers who hosted the trial reported that the tied ridges are effective in retaining rainwater. The reduction in soil erosion due to the use of the tie ridger has also been appreciated by 60% of the farmers. All the farmers said that the tie ridger was within the pulling capacity of local oxen. The extension agents appreciated the improvements made on the previously developed tie ridger which had been found to be inconvenient to operate and more difficult to pull than the traditional implement, the *Maresha*. The new tie ridger was easier to operate and required less draft power than the traditional implement. Farmers have now been using the implement for three years.

DISCUSSION

Above average rainfall was received in Welenchity which somehow reduced the advantage of the tie ridger. In Zeway, delayed planting lowered maize grain yields in the second site, Jela Aluto, compared to Odu Ansura. However, we were able to see the advantages of tied ridges. There was no significant interaction among the three factors.

The advantages of tie ridging have been verified by a number of on-farm trials executed earlier (Georgis, Kidane1999). The major setback to the adoption of the technology was lack of an appropriate implement for making tied ridges. Now, the implement has been developed and verified on farmers' fields. The next step should be popularization of the implement among small-scale dry land farmers both in Ethiopia and other East African countries.

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SESSION V:

Integrated approaches for overcoming soil fertility constraints

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LEGUME FALLOWS FOR MAIZE-BASED CROPPING SYSTEMS IN EAST AFRICA: SCREENING LEGUMES FOR ADAPTABILITY, BIOMASS AND NITROGEN PRODUCTION.

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ABSTRACT

Soil fertility is one of the major maize production constraints in Eastern Africa and nitrogen is considered the most limiting nutrient. Use of nitrogen–fixing legumes as fallow is one of the ways used to improve nitrogen availability in the soil. In a regional trial, involving Ethiopia, Tanzania and Uganda, thirteen legume species were screened for efficiency in nitrogen supply to the soil and their adaptability to the farming system in terms of nodulation, seed production, resistance to pests and diseases. The legumes screened were; soybean (*Glycine max*) crotalaria (*Crotalaria ochroleuca*) , lablab (*Dolichos lablab*), mucuna (*Mucuna pruriens* var. *utilis)*, lana vetch, (*Vicia villosa*), purple vetch (V.. *dasycarpa*) Calopo (*Calopogonium mucunoides*) canavalia (*Canavalia ensiformis*), tephrosia (*Tephrosia vogelli*), sesbania (*Sesbania sesban* var *sesban*) cowpeas (*Vigna unguiculata)*, *Pueraria phaseoloides* , *Sesbania sesban* and Pigeon peas (*Cajanus cajana*). The performance of the legumes was influenced by the location but in general *Mucuna pruriens* var.*utilis,* and *Canavalia ensiformis* had wide adaptability , were resistant to diseases and produced high biomass though *C. ensiformis* had a low potential for nitrogen production. Tephrosia, pueraria and pigeon peas were promising although they required two seasons. Farmers appreciated the use of legumes for improved fallows but preferred species with more than one use.

Keywords: Canavalia, East Africa, legume fallow, maize, Mucuna, screening, soil fertility

INTRODUCTION

Low soil fertility is one of the most limiting factors affecting maize production in East Africa. The most limiting nutrient is nitrogen followed by phosphorus. The levels of nitrogen can be improved through the use of inorganic fertilizers, compost and farmyard manure or through the use of improved fallows. The use of inorganic fertilizers in East Africa is very minimal as most of the maize producers are smallholder farmers who are in most cases resource constrained and do not have cash or credit to purchase them. The problem of affordability is further exacerbated by the removal of subsidies on fertilizers. Fertilizers are in most of the cases not available at the right time especially in the rural areas where the road network is not well developed.

The use of farmyard manure is restricted to the farmers who can access the manure. In many areas, smallholder farmers do not have cattle and where they do, in most cases, the manure is of low quality as the animals feed on low-quality feed stuff. It is also bulky to the extent that it is most likely to be used only in the gardens close to the kraal. Making of compost heaps is quite laborious and requires a lot of water and skill such that most farmers will not be able to make good quality manure. In many highly populated areas, there also may be a shortage of materials for making compost. It is also bulky and heavy and farmers might not be able to move it long distances. Both farmyard manure and compost, therefore, are likely to be used on high value crops such as vegetables close to the homesteads.

The use of nitrogen-fixing legumes whether used in rotation or relay planted is a possible solution to the nitrogen problem for the small farmer who is resource constrained. The farmer does not have to move the legumes neither does he have to purchase anything if he uses his own saved seed. Legumes vary in their rate of growth, susceptibility to diseases and pests, adaptability to a given region and their ability to fix nitrogen (Peoples *et al*, 1995). The efficiency of nitrogen fixation is, however, very dependent on the soil and

Table 1. Characteristics of the legumes in the screening trial – Namulonge 1998.

Legume species	Nodu-lation	Ground cover	Diseases & pests	Seeding capacity	General adaptation	Total score
			Score (0-5)*			
Lana vetch	-	-	0	-	-	0
Canavalia	1	4	5	5	5	20
Soybean-Nyala	3	3	2	2	2	12
Soybean-SCs	3	2	3	2	2	12
Mucuna white	3	5	5	5	5	23
Mucuna black	4	5	5	5	5	24
Sesbania	1	3	3	4	3	14
Dolichos-Renga	3	4	3	0	5	15
Dolichos lablab	3	5	2	0	5	15
Tephrosia	1	4	3	4	5	17
Calopo	1	4	4	4	3	16
Purple vetch	-	-	0	-	-	0
Crotalaria	4	3	3	3	3	16

* 0–5 = lowest–highest score

Table 2. Biomass yield of the legume relay-planted with maize

Treatments	*Mucuna*	*Canavalia*
	(tons/ha)	
Sole planted 2 weeks after maize germination	4.89	6.72
Relay planted in maize at 6th leaf stage	0.54	1.02
Relay planted in maize 2 weeks after maize tasseling	0.09	0.31
Mean	1.84	2.68
$LSD_{0.05}$	1.56	
CV	32.40	

The efficiency of nitrogen fixation is, however, very dependent on the soil and plant management (Peoples *et al*, 1995; Muza and Mapfumo, 1998). Environmental stresses are also important for their growth, nodulation and the activity of the nodules. Albrecht and co-workers (Albrecht *et al*, 1984) found that moisture stress had a profound effect on nitrogen fixation of soybeans because nodule initiation, growth and activity were more sensitive to water stress than the general root and shoot metabolism. There is need for the improvement of legumes to maximize growth and minimize stress if nitrogen yield is to be enhanced (Peoples and Herridge, 1990). Though it is known that legumes fix nitrogen, there is need to determine whether the fixed nitrogen benefits the crop in the system and how much of the nitrogen is available at the right time (Peoples and Craswell, 1992).

There has been some research done on the use of legumes for soil nitrogen improvement in Kenya (Ojiem *et al*, 1998) and Uganda (Fischler, 1996) but their use by farmers has been limited. This could be associated with the limited number of species tested, which might not have included the efficient ones with good adaptation to the local conditions. This study was initiated as a regional trial for Ethiopia, Tanzania and Uganda with the objective of identifying legumes that could be used to increase the nitrogen available in maize-based cropping systems of Eastern Africa. Among the important characteristics of a suitable legume for maize-based systems is its biological nitrogen fixation efficiency and, consequently, the amount of legume biomass produced. The legume should be able to produce seed for eventual propagation by farmers on-farm.

MATERIALS AND METHODS

Nine legume species were evaluated in regional network trials in three countries: Ethiopia, Tanzania and Uganda in 1998. The species were soybean (*Glycine max*), crotalaria (*Crotalaria ochroleuca*), lablab (*Dolichos lablab*), velvet bean or mucuna (*Mucuna pruriens* var. *utilis*), lana vetch (*Vicia villosa*), purple vetch (*V. dasycarpa*), Calopo (*Calopogonium mucunoides*), and jackbean or canavalia (*Canavalia ensiformis*). In Uganda, tephrosia (*Tephrosia vogelli*) and sesbania (*Sesbania sesban*) were also included in the study. In Tanzania, cowpeas (*Vigna unguiculata)*, green grams and common beans (*Phaseolus vulgaris*) were included and, in Ethiopia, *Pueraria phaseoloides*, *Sesbania sesban* and Pigeon peas (*Cajanus cajan*) were included in the study.

In Uganda, the trial was planted at Namulonge Agricultural Research Institute. The institute is located at 0^0 32' N latitude and 32^0 37' E longitude at an altitude of 1,150 masl. Annual rainfall of 1,000mm is distributed in two rainy seasons. It has a tropical wet and mild dry climate with slightly humid conditions (average 65%). In 1998, the legumes were planted as sole "crops" and, in 1999, mucuna and canavalia were planted either as sole crops or relay planted with maize at 2 weeks after maize emergence and 2 weeks after the tasseling of maize. Mucuna, canavalia and crotalaria also relay planted with maize in 2000. Two species, mucuna and canavalia, were taken to farmers in two major maize growing districts to be planted and inform research about what they felt about the legumes and if it were possible to use them in their production systems.

In Ethiopia, the trial was planted at Jimma Agricultural Research Center located at 7^0 46' N latitude and 36^0 E longitude at an altitude of 1,753 masl. Rainfall averages 1,581 mm per year with mean temperatures of 29.8^0C (max.) and 8.1^0C (min.)**.** The trial in Ethiopia was planted in July in 1998 and earlier in subsequent years. The July planting was late for Jimma. All legumes were screened in 1998 in a single replicate while crotalaria, mucuna, lab lab, canavalia and soybeans were further evaluated in 1999.

In Tanzania, the trial was planted at two locations: Selian Agricultural Research Institute (SARI) near Arusha for the mid-altitude ecology, and Mlingano Agricultural Research Institute in Tanga as a tropical lowland site. At SARI, legumes were planted as sole crops in 1998 and, in

Table 3 Performance of the legumes screened at Tanga , Tanzania– 1998A

Species	Adaptation				Ground cover	Biomass Yield	Seed Yield
	Pests	Disease	Low altitude	Moisture stress			
	(Scores 1-5)*				(1-5)	(tons/ha)	
Mucuna Black	5	5	+	5	5	11.34	5.81
Mucuna white	5	5	+	5	5	12.04	6.2
Soybean SCs –1	5	5	+	3	2	.60	.0.20
Soybean -Nyala	5	5	+	3	2	.45	0.20
Purple Vetch	4	4	-	1	1	-	-
Lance vetch	4	4	-	1	1	-	-
Canavalia	3	4	+	5	3	7.72	4.94
Calopo	5	5	+	5	5	4.17	0.87
Dolichos lablab	3	3	+	3	5	16.6	2.40
Crotalaria ochroleuca	3	3	+	2	3	2.0	0.14
Green gram	2	3	+	3	3	2.04	0.34.
Cow peas	2	3	+	4	5	1.2	0.42
Beans(Selian wonder	2	2	-	1	2	0.1	0.024

* see Table 1.

Table 4. Attributes of legumes planted at Selian, Tanzania- 1998

Species	Establish-ment	Nodul-ation	Insect damage	Diseases	Ground cover	Biomass prodn.	Seed prodn.
						(tons/ha)	
Vicia dasycarpa	good	fair	none	drying of leaves	good	3.0	-
Calopo	good	poor	none	none	poor	-	-
Mucuna (black)	good		none	none	total	5.0	3.0
Vicia villosa	-	fair	none	drying of leaves	good	5.0	-
Canavalia	fair	good	none	none	poor	17.0	-
Lablab	v. good	v. good	Severe	none	v. good	10.2	0.3
Mucuna (white)	v. good	fair	none	none	total	4.5	2.1
Soybean (SG 2)	fair	fair	(rabbits)	none	poor	-	-
Soybean (Nyala)	fair	fair	severe	none	poor	-	-
Cowpeas	v. good	v. good	severe	leaf blight	v. poor	4.5	0.27
Crotalaria	poor	good	severe	leaf mottling		-	-

Table 5a. Agronomic characteristics of legumes grown for short fallow in a maize-based cropping system - Jima 1998

Legume species	% Active nodulation	Days to flower	% ground cover	Biomass (t/ha)	Seed Yield (t/ha)
*Glycine max (*Nyala*)*	85	65	100	3.7	2.27
Crotalaria Ochroleuca	90	96	100	10.6	2.04
Dolichos lablab	10	101	100	3.67	3.57
Mucuna pruriens	0	122	100	13.42	2.83
Vicia dysecarpa	0	116	100	-	-
Vicia vilossa	0	96	70	0.64	-
Calopogonium mucunoides	0	127	100	3.5	-
Canavalia ensiformis	0	96	100	16.85	2.58
Sesbania sesban	95	NF	60	12.30	-
Cajanus cajan	10	NF	100	17.10	-
*Glycine max (*SCs-1*)*	80	67	100	4.60	2.72
Pueraria phaseoloides	85	NF	100	2.05	-

Table 5b. Agronomic characteristics of selected legumes for use in soil fertility improvement in maize system at Jima in 1999.

Legume species	Nodul-ation	Establish-ment (%)	Ground cover (%)	Biomass (t/ha)	N content (%)	Seed Yield (t/ha)
Crotalaria	100	100	Full	15.0	2.61	2.40
Lablab	0	90	Partial	5.6	2.34	0.80
Mucuna	100	100	Full	20.7	2.74	3.00
Canavalia	100	100	Full	18.2	3.36	2.10
Soybean (SCs-1)	100	100	Full	4.7	2.49	2.50

1999, lablab, mucuna and canavalia were planted at 8 sites with 25 farmers for wide exposure and adoption.

Phosphorus was applied at planting at the rate of 45 kg P_2O_5 /ha at Namulonge and 30 kg P_2O_5/ ha in Tanzania.

In the Arusha region, Tanzania, three legumes (mucuna, canavalia and lablab) were intercropped with maize on 25 farms and men and women farmers were asked views about the use of legumes in relation to labour, time consumption and resource allocation. These data were analyzed using Gender Analysis Matrix (GAM).

Data collected at all sites included reaction to diseases and insects, percent ground cover, nodulation, biomass production, general adaptability and aspects of seed yield. Whenever possible actual counts or weights were recorded but in some cases actual measures were not taken and only relative scores were used to indicate differences. In the case of nitrogen fixation, active nodules were estimated and in the case of Ethiopia percent nitrogen in the biomass was estimated. Where discrete data was collected, it was analyzed using the ANOVA routine of MSTATC application.

RESULTS AND DISCUSSION

Attributes of the legumes screened at Namulonge are indicated by the respective scores in Table 1.

The most promising species was Mucuna which gave good ground cover (up to 95%), was not attacked by diseases and insects, and had good well-developed nodules. It also produced a lot of seed. Both black-seeded and white seeded mucuna were well-adapted to the mid-altitude conditions with no obvious differences in performance. The only negative attribute of mucuna was its climbing habit whereby it would not likely to combine well with other crops should the farmer want to intercrop. Dolichos lablab and Dolichos Renga had very good establishment and very good ground cover. However, they were very susceptible to pests at the time of flowering to the extent that no seed was set.

Among the erect species, canavalia produced good ground cover, a lot of seeds and was very resistant to pests and diseases. It being an erect bush makes it more compatible with intercropping. However, it took a long time to cover the ground compared to mucuna. Sesbania had good germination and establishment but gave poor ground cover such that there were a lot of weeds in the plot. It was also

Table 5c. Agronomic characteristics of legumes planted in association with maize in 2000

Legume/Maize System*	Reaction		Nodules		Stand		Ground cover	Biomass yield
	Disease	Insect	Count	(% active)	Count	(% est.)	(%)	(t/ha)
Mucuna S.I	-	Mild	AB#	100	40	100	50	2.4
Mucuna R.I	-	Mild	NH	-	-	-	-	-
Canavalia S.I	-	Mild	0	0	40	100	40	0.84
Canavalia R.I	-	Mild	NH	-	-	-	-	-
Crotalaria S.I	-	Mild	28	100	200	100	30	0.47
Crotalaria R.I	-	Mild	NH	-	-	-	-	-
Mucuna Sole	-	Mild	AB	100	91	100	100	7.46
Canavalia Sole	-	Mild	0	0	51	98	100	3.38
Crotalaria Sole	-	Mild	76	100	400	81	100	7.99

* S.I. (Simultaneous inter crop), RI (Relay inter crop)
# AB (Abundant), NH (Not harvested).

susceptible to pests at the time of flowering. Crotalaria had very poor early growth and thus allowed a lot of weeds such that it required two weeding operations where others needed one or none. It also had a lot of leaf eating insect pests. Its positive attributes were the fact that it nodulated well and early in the season. Tephrosia had good establishment but slow growth. It has a woody stem that could be used as fuel wood or used as staking material in relevant situations. Its main disadvantage is that it requires two seasons to grow and few farmers are likely to keep land under fallow for that long especially in areas where land shortage is a problem.

The introduced soybean varieties were not adapted to the local conditions. They put on very little biomass and flowered early and yet the adapted varieties are full season crops. Calopo had very slow growth at the beginning of the season and could not flower in the same season. When left for another season, it was able to cover the ground and produce a lot of seed. As a perennial it would be suitable for pastures and perhaps as a cover in perennial crops but would not be suitable as a short fallow for annual cropping systems. The two vetches were very susceptible to bacterial wilt to the extent that they died within two weeks after germination.

The biomass production of mucuna and canavalia were affected when relay planted in the maize crop (Table 2) where the growing maize offered strong competition for light. When they were planted without maize, they produced high biomass. In this study, Canavalia produced higher biomass than mucuna. It had a good spread and one could manipulate the population to get higher yield. It is also likely to be easy to manage should the farmer decide to cut the plants and leave them on the surface before planting the subsequent season. Canavalia might possibly combine with maize when planted at the same time with the maize as it would not compete with maize for light.

After considering the different attributes, mucuna and canavalia were selected to be used in the rotation trials. Mucuna represented the climbers and canavalia represented the bush types. Farmers were impressed with the performance of maize when planted following either mucuna or canavalia. They were also impressed with the yield of the two legumes and wished that they had other uses and could be directly converted into monetary value. They indicated preference to grain legumes that could also improve soil fertility.

The results obtained in Tanzania at the Mlingano site were similar to those obtained at Namulonge with only slight differences (Table 3). The two mucunas, lablab, calopo and canavalia were considered to be suitable for soil fertility improvement at Tanga. Mucuna and canavalia had high seed yield; that is, they had large seeds but at the same time they were also high yielding. They had good adaptability to the tropical lowland conditions, were highly resistant to diseases, pests and moisture stress and produced high biomass. The two vetch species were poorly adapted to coastal conditions, as they were to the mid-altitude conditions at Namulonge. Disease was the major cause of poor adaptation.

At Selian ARI, Arusha, drought conditions at flowering time affected seed yield for most of the species. The observed attributes of the species are indicated in Table 4. Most of the species had good establishment except for canavalia, crotalaria and soybeans which had poor germination. Lablab, mucuna and canavalia had good biomass production but only the mucuna varieties produced reasonable seed yield under the prevailing dry conditions in the area during the 1998 season. The cowpeas had good biomass and good ground cover but the yield was poor due to the insect damage at flowering and during pod growth. Cowpeas, canavalia, crotalaria and lablab nodulated well but the remainder of the species had poor nodulation. Rabbits ate the soybeans. The vetches established well and had good ground cover at Selian compared to Namulonge where they died within two weeks. This was related to the presence of bacterial wilt at Namulonge, which might not have existed at Selian.

In the initial screening in 1998 in Ethiopia (Table 5a, 5b and 5c), there was neither insect nor disease incidence on any of the species except for a mild insect attack on crotalaria (Table 5a). Five species (mucuna, canavalia, crotalaria, sesbania and pigeon pea) produced in excess of 10 t ha^{-1} of biomass (Table 5a). Only six of the twelve species evaluated produced seed, among them pigeon pea, which did not flower until the following season and sesbania, which also had a long growing, season. In 1999 five legumes from among the original twelve were evaluated (Table 5b). Only mild insect damage was found on crotalaria and mucuna and none on soybeans. Mucuna, canavalia and crotalaria again produced >10 t ha^{-1} biomass. Canavalia had the highest nitrogen percentage (3.36%) compared with the other legumes in the study. When these three legumes were planted in association with maize in 2000 (Table 5c) there was still only a mild attack on all the species and no diseases. Simultaneous planting of the legumes with the maize had little effect on the growth of legumes but relay planting the legumes in maize affected all aspects of growth of the legumes including biomass production. However, even biomass in the sole legume plots was greatly reduced in the 2000 season suggesting that other factors were also responsible for the

Table 6 Gender analysis matrix for legume manures in maize-based cropping system.

Gender category	Labour	Time	Resource	Culture
Women	1. Dereased due to weed suppression(+) 2. Decreased due to time saved from fertilizer application(+) 3. Increased due to extra time for planting legumes	1. More time for other activities for time saved from weeding (+) 2. No change as intercropping is already practiced(+/-)	Money saved fron inorganic fertilizers for other needs (+) Increased food availability due to increased maize yield (+) Decreased food variety since common beans will not be planted (_-)	No cultural change (+/-)
Men	No change because fertilizer application and weeding are done by women (+/-)	No change (+)	Increased income through increased maize yields (+)	No change (+)
Household	No change (+/-)	No change (+/-)	Increased food Increased income Sustainable land use (+)	No change (+/-)
Community	No change (+/-)	No change (+/-)	Improved food security (+) Food and cash increase (+) Sustainable land use (+)	No change (+/-)

reduction in production in the relay treatments. The high number of active nodules for crotalaria and soybeans was also observed by Ojiem and coworkers (Ojiem et al, 1998) in a study where canavalia had very few active nodules.

In Tanzania where farmer response was on gender basis, The results obtained were in favor of using the legumes for soil fertility improvement as indicated in Table 6. The fact that there were more plusses than minuses suggest that farmers were likely to accept the use of the short fallow legumes in there cropping system

CONCLUSION

In general, at most of the sites three legumes performed better than the others. These were mucuna, canavalia and lablab which had good attributes for use in improved fallows, such as high biomass yield and high seed yield, were not attacked by diseases and pests, and had good nodulation without inoculation suggesting that they were promiscuous in relation to the *Rhizobia* they used. Other species such as pigeon pea, tephrosia and sesbania required more than one season to produce high biomass and possibly nitrogen. This might not be acceptable to farmers who have smallholdings. Many of the species had good ground cover, which suggests that they could control weeds. This would be an important contribution since weeds are a major production constraint.

The number of the legumes screened was limited. As indicated in the results obtained, the performance of the legumes were related to the environment and it is possible that some efficient legumes could have been bypassed. Further screening should attempt to select for efficiency of nitrogen fixation among the local legumes as the efficiency might depend on the soil pH and related soil fertility factors (Brockwell *et al*, 1995). Farmers who were contacted indicated that they wanted the legumes that would have additional uses other than just soil fertility improvement. Crotalaria was found to be used as a potherb in Uganda whereby the shoot and some leaves were plucked. This could be a good drive to adopt the use of this species if more families were sensitized on how to use it. Green pods and young seeds of canavalia can be cooked for human consumption (National Academy of Science, 1979) and the dry seeds can be used after careful preparation.

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LEGUME FALLOWS FOR MAIZE-BASED SYSTEMS IN EASTERN AFRICA: CONTRIBUTION OF LEGUMES TO ENHANCED MAIZE PRODUCTIVITY AND REDUCED NITROGEN REQUIREMENTS.

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ABSTRACT

In the humid and sub-humid East African highlands, soil fertility situations are more serious due to continuous cropping with little or no external inputs and removal of crop residues. As a result, sustainability of soil productivity has been under threat due to continuous soil fertility depletion. The problem can be alleviated by inclusion of legumes in crop rotations and retention of crop residues. To properly popularize the merits of legumes for soil fertility improvement in maize systems, a network of research trials on potential legumes had been conducted in Ethiopia, Tanzania and Uganda. Research activities of the network during 1998-2001 included screening of potential legume species, and evaluation legume/maize crop management systems undertaken on-station and on-farm. Based legume species screening trials, *Mucuna*, *Canavalia*, *Crotolaria* and *Dolicos lablab* were used in maize/legume systems studies. Minimum dry biomass to be incorporated for better productivity of maize was determined to be 5 t ha^{-1}. A significant increase in maize yield was obtained where legumes were preceded as sole crops in rotations; increases were less consistent in simultaneous and relay intercropping systems. The yield advantages of maize/legume systems over the continuous maize without N fertilizer were from 0 to 135%. At Jimma and Tanga, higher productivity was obtained from maize following sole legumes. The fertilizer value of total legume N was estimated to exceed 50 and 69 kg N ha^{-1} that can replace the current need for mineral N fertilizer at Tanga and Jimma, respectively. In Hai District, Tanzania, economic and gender analysis found good possibilities to adopt these legumes in intercropping systems, particularly in the case of lablab for which there is a commercial market available for its grain.

INTRODUCTION

In sub-Saharan Africa, rapid human population growth has forced intensified land cultivation for crop production to fill the need for daily subsistence food requirements. As a result, traditional fallow systems that used to restore soil fertility have been abandoned (Ofori, 1995). As a particular case, in the humid and sub-humid East African highlands, soil fertility depletion is very serious due to high population density (> 64 person per km^2), continuous cropping with little or no external inputs, removal of crop residues and over-grazing between cropping seasons (Hudgens 1996; Smaling 1997). Hence, in the fragmented fields of smallholder farmers, sustainability of soil productivity has been under threat due to continuous soil fertility depletion. Moreover, although increased per capita grain production can be attained through addition of external inputs, mainly inorganic fertilizers, the high cost of fertilizers and other agro-chemicals together with transportation make their use on staple foods uneconomical for most smallholder farmers (Sanchez *et al.,* 1977; Benson *et al.,* 1997). Throughout East Africa, however, nitrogen (N) and phosphorus (P) are the most deficient nutrients in crop production (Zake, 1995; Woomer *et al.*1995) and mining of these soil nutrients through crops harvest and via different modes of losses is estimated to exceed 40 kg N and 15-kg P_2O_5 per hectare per year in the region (Zake, 1995).

Although P cannot be naturally replaced, legumes in symbiosis with *Rhizobium* bacteria can fix N and replenish its deficiency in soils. The value of legumes in crop rotation has long been recognized for their potential to supply a large amount of N to succeeding maize crops. For example, estimates of the fertilizer N-value of alfalfa to following maize were reported as high as 180 kg N ha^{-1} (Baldock *et al.,* 1980). Different winter legumes used as cover crops were also reported to reduce N-fertilizer requirements of the following maize, sorghum and cotton crops by 50 to 90 kg N ha^{-1} (Hargrove *et al*., 1987).

Another important mechanism of improved nutrient recycling is through the use of applied organic inputs and retention of crop residues (Sanchez *et al.,* 1989). Some researchers contend that the proportion of residual N that is mineralized after incorporation and made available to succeeding crops has not yet been well quantified. However, most agree that the critical C/N ratio of a crop residue for net mineralization to occur is less than 20-30 while a ratio greater than 30 favors net immobilization. Thus, the critical N factor or concentration in the residue has to be greater than 20 g/kg (Alexander, 1977; Iritani *et al.,* 1959).

Field experiments suggested that yield responses to incorporated residues are equivalent to those obtained by application of inorganic fertilizer N at a rate equal to two-thirds of the N yield of incorporated crop residue (Hesterman *et al.,* 1986). Likewise, the incorporated residues of alfalfa and red clover were reported to contribute 65 to 71% of their total N content to succeeding maize, an equivalent of 90 to

Table 1. Grain yield of maize as influenced by mineral N fertilizer and the below-ground N fixed by legumes

Fertilizer-N rate	Preceding legumes in rotation			Continuous maize	Nitrogen mean
	sesbania	Crotolaria	soybean		
kg N ha^{-1}	- - - - - - tons of maize grain per hectare - - - - - -				
0	7.03	7.10	6.71	4.69	6.38 d
46	9.18	7.60	9.17	6.33	8.07 c
69	10.78	9.07	9.67	6.62	9.04 b
92	10.88	9.92	10.02	8.60	9.85 a
System-mean	9.46 a	8.42 b	8.89 ab	6.56 c	

Figures followed by the same letter are not significantly different at $p<0.05$

to 125 kg N ha^{-1} from inorganic fertilizer (Bruulsema *et al.,* 1987). Incorporation of cowpea grown for 60 days as green manure two weeks before sowing of maize substituted 75 kg ha^{-1} of fertilizer-N requirements for grain maize production (Meelu, 1989). Although the benefits of legumes in maize cropping systems are recognized and promoted in many parts of the world, their use in East Africa is still low (Giller *et al.,* 1997). Possible reasons include unavailability of seeds of potential legume species, diminishing land holding by small-scale farmers, lack of knowledge on popularization and perhaps high labour requirement in management of forage legumes. To properly popularize the merits of legumes for soil fertility improvement in maize system, a research network coordinated by CIMMYT East Africa had drafted a research proposal on the uses of potential herbaceous legumes.

The objectives of the research network were to screen better N-fixing and high biomass producing legumes that could be used as short fallow or green manure for substitution of inorganic N-fertilizer in maize production systems of the region.

MATERIALS AND METHODS

In 1998, potential herbaceous legumes were screened at four locations in Eastern Africa for adaptation, biomass production, and biological nitrogen fixation capacity. The screening locations were Tanga and Arumeru/Hai districts in Tanzania, Namulonge in Uganda and Jimma in Ethiopia. The results of these screening trials are reported in a companion paper (Kikafunda et al., these proceedings).

Since 1999, on-station and on-farm trials have been conducted at these locations to evaluate the N contribution of legumes to maize crops in rotation or intercropped. At Jimma, sole crops of crotalaria, soybean, sesbania and maize were grown in 1999 in large plots of 125 m^2 with three replications. In 2000, these plots were partitioned into four N levels (0, 46, 69 and 92 kg ha^{-1}) and sown with maize. The design was a randomized complete block with three replications with a plot size of 30 m^2.

In another experiment at Jimma during 1999 and 2000, three rates (0, 5 and 10 t ha^{-}1 total dry biomass) of a legume residue were compared to equivalent rates of FYM and two rates of fertilizer N (0 and 69 kg ha^{-1}) from urea. The sesbania residue was selected to represent the other legumes.

During 1999-2000, intercropping experiments were established at Jimma, Hai and Tanga. Legumes were planted alone or intercropped (simultaneous and relay planting) with maize at all locations. Mucuna and canavalia were sown at all sites while lablab was included at Hai and crotalaria was included at Jimma. Control treatments were sole maize with and without the recommended N-rate for each location. Basal applications of 30 and 20 kg P ha^{-1} were applied to all plots at Tanga and Jimma, respectively. In Tanga in 2000, the trials (simultaneous intercropping) were carried out on fourteen farmers' fields while, in Arumeru/Hai districts, the trials (relay intercropping) were executed on 25 farmers' field. A randomized complete block design was used where farmer fields were replicates. Plot sizes were 64 m^2 and 100 m^2 at Tanga and Hai, respectively. Sole maize was sown in all plots in the 2001 season to observe the effects of legumes sown the previous season. The experiment at Jimma was conducted on-station commencing in 2000. The effects of legumes in sole and intercropping systems were evaluated on sole maize sown in all treatments in the 2001 season. At Jimma, a randomized complete block design with three replications and a plot size of 30 m^2 was used. Maize succeeding legume plots did not receive N-fertilizer.

All trials were researcher managed and followed recommended crop management practices for different locations. Legume residues were incorporated during the onset of the dry season at each location. At Tanga, an open pollinated variety maize (TMV-1) was sown at 75 cm x 50 cm (two maize plants per hill) spacing. At Hai, hybrid maize (C5051) was planted at 90 cm x 25 cm (1 plant per hill). At Jimma, hybrid maize (BH-660) was used in the legume/maize cropping rotation conducted on-station in 1999

Table 2. Grain yield of maize as influenced by mineral N fertilizer and N from legume residues applied and incorporated into soil

Fertilizer-N rate	Legumes residues applied			Continuous maize	Nitrogen mean
	sesbania	crotalaria	soybean		
kg N ha^{-1}	- - - - - - tons of maize grain per hectare - - - - - -				
0	9.19	8.41	8.40	6.12	8.00 b
46	9.96	11.91	11.15	7.52	10.13 a
69	11.06	11.30	11.21	8.07	10.41 a
92	9.86	11.29	11.45	10.42	10.76 a
System-mean	10.02 a	10.98 a	10.80 a	8.03 b	

Figures followed by the same letter are not significantly different at $p<0.05$

Table 3. Grain yield of maize as influenced by mineral N fertilizer and the total N derived from legumes grown *in situ*.

Fertilizer-N rate	Preceding legumes in rotation			Continuous maize	Nitrogen mean
	sesbania	Crotolaria	soybean		
kg N ha^{-1}	- - - - - - tons of maize grain per hectare - - - - - -				
0	8.18	8.48	7.08	5.00	7.19 b
46	9.23	8.88	7.43	6.54	8.02 ab
69	8.31	8.81	8.16	7.86	8.29 a
92	8.64	10.12	9.10	8.67	8.63 a
System-mean	8.59 ab	9.07 a	7.94 bc	7.02 c	

Figures followed by the same letter are not significantly different at $p<0.05$

and 2000. While an open pollinated maize variety (Kuleni) was used in the sole and intercropping maize/legume systems that started in 2000. In both cases the maize was sown at 80 cm x 50 cm (two maize plants per hill). Legumes were planted between the maize rows at all sites.

Data collected included legume biomass and maize stover and grain yield. Plant tissue and soil samples were collected and analyzed for total N and available P. Regression analysis was performed on continuous maize that received different N rates (Table 4) and N fertilizer value of the legumes (defined as the amount organic N derived from legume residues required to achieve the same yield in continuous crop by applying inorganic N fertilizer) was estimated from the linear/quadratic curves (Vigil *et al*., 1991; Fox *et al.,* 1988).

RESULTS AND DISCUSSION

Fertilizer value of below-ground N fixed by legumes in maize rotations:

Legume biomass was chopped down and collected from the field to further observe the effects of below-ground fixed N on maize yield in legume/maize sequences. Grain yield was significantly increased due to the N-fixed by legumes (Table 1).

The average soil N contributed by fixation from all legumes (namely soybean, crotalaria and sesbania) was equal to the grain yield obtained by applying approximately 69 kg N ha^{-1} in plots of continuous maize (estimated from the linear response curve of continuous maize to N fertilizer rates; Table 4). The yield increase due to N fixed by legumes was about 50% over that of continuous maize without N-application.

The response of maize in continuous cropping to N fertilizer was linear and did not reach a maximum in the range applied (0 to 92 kg N ha^{-1}). Further supplementing N on preceding legume plots with fertilizer N, raised maize grain yield from 6.71 to 10.88 t ha^{-1} (Table 1). Supplementing N derived from fixation in the preceding legume plots with 69 kg N ha^{-1} from urea produced maximum yield of the hybrid maize, BH-660, under the conditions of the experiment.

Fertilizer value of the residue-N from legumes in maize rotations:

Legume residues were chopped from other fields and transferred to plots previously cropped with continuous maize, and incorporated in order to observe the effect of legume residue-N on the following maize grain yield. Maize grain yield was significantly increased due to incorporation of all legume residues (Table 2). The fertilizer N value of residue-N (as estimated from the linear response curve of continuous maize to N fertilizer rates; Table 4) was found to be 71-78 kg N ha^{-1} applied as inorganic-N on continuous maize. Application of additional inorganic N-fertilizer with residues further increased maize yields from an average of 8.67 up to 11.91 t ha^{-1} (Table 2), reaching maximum yield of the hybrid maize, BH-660, at approximately 46kg N ha^{-1}.

Three rates of sesbania residues (0, 5 and 10 t ha^{-1}) were transferred from farm boundaries to a field previously cropped with maize and incorporated. The plots were sown with sole maize without fertilzer and compared to maize without residues at two rates of N-fertilizer in order to determine the minimum dry biomass of legume green manure in a maize/legume rotation system required to produce significant grain yield increase in maize. Maize with the highest rate of sesbania residues yielded significantly more grain than maize with 69 kg N ha^{-1} of N-fertilizer ($P<0.01$) (Table 5). The highest rate of residue application did not produce significantly more maize grain than the 5 t ha^{-1} of sesbania residues rate. Thus, it can be concluded that 5 t ha^{-1} at most of sesbania residues can substitute for the recommended N-requirement of maize of 69 kg N ha^{-1} from fertilizer at this site. However, it is also clear that 69 kg N ha^{-1} was not optimal since maize follwing residues was significantly greater than fertilized maize.

Fertilizer N value of legume residue-N and below-ground fixed N in legume/maize rotations:

To evaluate the combined N-fertilizer value of residue-N and the below-ground N fixed by legumes grown in rotations with maize, residues were incorporated on fields

Table 4. Regression equations of continuous maize grain yield on N-rate and estimated fertilizer value of legume-derived N.

Systems compared	Equation	Coeff. r	N value of preceding legume		
			Ses-bania	Crotal-aria	Soy-bean
				kg N ha^{-1}	
Below-ground fixed N	$Y = 12.02N + 35.52$	0.968*	72	72	69
Legume residue N	$Y = 13.43N + 46.72$	0.969*	78	71	71
Total legume N	$Y = 12.33N + 39.37$	0.991**	71	73	60

*, ** significant at $p<0.05$ and $p<0.01$, respectively.

Table 5. Minimum total dry biomass of a sesbania residues required to produce maize grain yield equal to that by the recommended rate of N fertilizer.

N source	Maize grain yield			% increase
	1999	2000	Mean	
Fertilizer: 0 kg N ha^{-1}	4.59	4.10	4.34 d	-
Fertilizer: 69 kg N ha^{-1}	5.52	4.45	5.04 cd	16
esbania residues: 5 t ha^{-1}	6.41	6.28	6.34 ab	46
Sesbania residues: 10 t ha^{-1}	7.19	6.96	7.08 a	63
Mean	6.06	5.91		

Figures followed by the same letter are not significantly different at $p<0.01$

and the below-ground N fixed by legumes grown in rotations with maize, residues were incorporated on fields where they were grown which were then sown with maize. The cropping history of the experiment field was continuous cereals so that soil fertility was very depleted. Despite the depleted situation of soil fertility, the yield performance of the following maize was significantly increased by the incorporation of the preceding legume residues (Table 3). Maize grain yield was progressively increased due to residue-N and fertilizer-N from 7.08-10.11 t ha^{-1} (depending on the residue type) and 5.01-8.67 t ha^{-1}, respectively. The N-fertilizer values of the fixed-N plus residue-N were from 60 to 73 kg N ha^{-1} (as estimated from the to linear response curve of continuous maize to N fertilizer rates; Table 4). This finding agrees with a previous report on sequences of sesbania and pigeon pea with maize at Jimma (Tesfa *et al.,* 2000). The study also confirmed that maximum yields of the hybrid maize, BH-660, were not attained with N-fertilizer alone nor with ploughed down residues alone, indicating the need to supplement legume residues with N fertilizer on similar fields when following them with maize.

Maize response to legumes in legume/maize intercropping and rotation systems:

In Jimma (Ethiopia), potential legumes for soil fertility improvement were planted on-station in the 2000 season in either (simultaneous or relay) intercropping or sole systems (Table 6). Intercropping systems significantly reduced the biomass yield of the intercropped legumes. In contrast, maize grain and stover yield during the same period was neither affected negatively nor positively by intercropping. In following year (2001), sole maize was cropped without N-fertilizer on all legume plots of the preceding year. Maize grain yield was significantly increased where sole legumes preceded it in rotation. The highest grain yield of 4.56 t ha^{-1} was recorded from plots where sole crotalaria preceded it; yields of maize following canavalia, fallow and mucuna in rotation were lower at 3.88, 3.58 and 2.92 t ha^{-1}, respectively (Table 6). Maize continuously cropped with N-fertilizer produced similar yields to maize in plots rotated with mucuna and canavalia the previous year. The productivity of sole maize without N-fertilizer application was not significantly improved when preceded by legume/maize intercrops. A possible reason for not obtaining a maize grain yield response from intercropped maize/legumes may be that insufficient legume biomass was produced for incorporation when grown as an intercrop. Earlier results have determined that legume (dry) biomass must be greater than 5 t ha^{-1} on Nitosols of Jimma and similar areas to be effective in improving maize yields. Nonetheless, these results reconfirmed that legumes preceding maize provide more than 69 kg N ha^{-1} in N-fertilizer requirements to the succeeding maize crop.

Similar trials to those carried out on station at Jimma were conducted on-farm at Tanga, Tanzania, using mucuna and canavalia in either intercropping or rotation systems with

Table 6. Grain yield of maize as influenced by preceding legume/maize intercropping and sole cropping systems on-station at Jimma, Ethiopia, during 2000-2001 seasons.

Cropping systems	2000 season			2001 season	
	Legume Biomass	Maize yield		Sole maize yield	% increase
		stover	grain		
	- - - - - - - (tons per hectare) - - - - - - -				
Sole maize + 0 kg N ha^{-1}	-	14.61	5.22	1.95 ef	
Sole maize + 69 kg N ha^{-1}	-	14.03	4.86	3.15 bc	62
Maize + Mucuna simultaneous interc.	2.4	15.34	5.96	1.60 f	-18
Maize + Mucuna Relay intercropping	-	15.40	5.62	2.36 de	21
Maize + canavalia simultaneous inter.	0.84	15.91	6.52	2.25 cde	15
Maize + canavalia Relay intercroping	-	15.46	5.34	1.88 ef	-4
Maize + crotalaria simultaneous inter.	0.47	13.13	4.89	2.15 ef	10
Maize + crotalaria Relay intercroping	-	15.40	6.02	1.96 ef	0
Sole mucuna rotated to maize	7.46	-	-	2.92 cd	50
Sole canavalia rotated to maize	3.38	-	-	3.85 ab	97
Sole crotalaria rotated to maize	7.99	-	-	4.56 a	134
Fallow rotated to maize	-	-	-	3.58 b	84

Figures followed by the same letter are not significantly different at $p<0.05$

Table 7. Maize grain yield as influenced by preceding legume/maize intercropping and sole cropping systems on-farm at Tanga, Tanzania, during 2000-2001 seasons.

Cropping systems	Preceding crops (2000)			Succeeding sole maize (2001)		
	Legume Biomass	Maize yield stover	Maize yield grain	Grain yield	% increase	NIC (US$)
		- - - - - - - (tons per hectare) - - - - - - -				
Sole Maize +0 kg N ha^{-1}	-	11.0	2.22	1.48 c	-	190
Sole Maize +50 kg N ha^{-1}	-	12.4	2.49	2.78 ab	88	216
Mucuna sole crop	8.20	-	-	3.22 a	118	177
Mucuna intercrop	7.42	12.3	2.32	2.40 b	62	247
Canavalia sole crop	7.83	-	-	3.25 a	120	179
Canavalia intercrop	4.62	12.1	2.49	2.31 b	56	253

Figures followed by the same letter are not significantly different at p<0.05 and NIC: net income

Table 8. Mean grain yield, tha^{-1}, of maize influenced by preceding legume/maize relay intercropping in different on-farm trials of Hai district in season 2000-2001.

Cropping systems	2000 season	2001 season	
	Intercropped maize grain yield	Sole cropped maize grain yield	Yield increase
	- - - (tons grain per hectare) - - -		(%)
Sole maize	0.8	2.2 b	-
Maize/Canavalia relay intercropped	1.1	4.3 a	95
Maize/Mucuna relay intercropped	1.1	4.1 a	86
Maize/D. lablab relay intercropped	-	4.6 a	109

Figures followed by the same letter are not significantly different at p<0.01

with maize commencing in the cropping season of 2000. In 2000, maize yields were uniformly low at about 2.4 t ha^{-1} but were not affected by the legume intercrops (Table 7). Legume biomass production ranged from 4.6 to 8.2 t ha^{-1} and was somewhat reduced when intercropped.

In following year (2001), sole maize was cropped without N-fertilizer on all legume plots to evaluate the effect of the preceding intercropped or sole-cropped legume. The preceding legumes had a significant effect on maize grain and stover yield during the succeeding season (Table 7). Mucuna and canavalia sole crop rotation treatments had the greatest effect on the subsequent maize crop, on average improving maize grain yield over the control by approximately 120%. The effects of the two legumes in intercropping systems were also significant but only about half as effective on maize yield improvement as they were when rotated, increasing grain yields by an average of about 59% over the control. Mineral fertilizer N (50 kg N ha^{-1}) increased maize grain yield by only 88%, more than the intercropped legumes but less than the preceding rotated legumes. The observed maize yield improvements effected by the preceding intercropped or sole cropped legumes can be attributed to soil fertility improvement from the sufficient plant biomass produced (4.6-8.2 t ha^{-1}; Table 7) in both systems. Although the effects of intercropping were significantly different from the effects of rotating legumes on maize yields, neither were significantly different from the application of 50 kg N ha-1 as fertilizer. Thus, the amount of N contributed by the legumes to the following maize was at least 50 kg N ha^{-1}. This finding agrees with a previous report on the N value of legume green manures in Tanzania (Brom *et al.,* 1988).

A net benefit analysis was performed for maize production in all systems (Table 7). It showed that legumes in intercropping system had a higher net benefit than sole legumes in maize rotation systems or even using mineral nitrogen fertilizer. However, in rotation systems where the maize crop was forgone in the first season and the only benefit the farmer can get is improved soil fertility. A higher net benefit could be obtained from use of the legumes in rotation system if alternative uses of the legumes seeds/green biomass for human or animals could be identified. Most of the farmers in Tanga are not very familiar with the two legumes as to their alternative uses other than soil fertility improvement. However, many farmers have chosen canavalia as the best for rotations as well as for intercropping because of its compatibility with maize. Mucuna is suitable only in sole crop rotations systems because of its trailing habit on the maize stand which causes severe lodging and difficulties in the harvest operation.

In Arumeru and Hai Districts of Northern Tanzania, the prevailing drought of season 2000 limited the establishment of legumes in most on farm trials; only on eight farms were all legumes well-established. In the 2001 season, sole maize was planted on these farms and the average results are shown in Table 8. Maize yields were significantly increased where legumes were relay intercropped into maize the preceding season. The yield increase over continuous maize was almost 100%. Although a recommended fertilizer treatment was not used in these trials, the fertilizer value of the relay intercropped legume N was apparently high and can replace mineral N fertilizer currently required for continuous maize production in Hai/Arumeru districts (Giller *et al.,* 1997). Although all legumes had similar residual effects on maize yield, lablab was slightly better; it is also favoured by the farmers since the grain has commercial value in this region. Here, these legumes were demonstrated to the communities. The gender analysis performed indicated the possibility to adopt these legumes since their effects were more positive as compared to the present practice.

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EFFECT OF RELAYING GREEN MANURE LEGUMES ON YIELDS OF INTERCROPPED MAIZE IN SMALLHOLDER FARMS OF TRANS NZOIA DISTRICT, KENYA.

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ABSTRACT

A number of smallholder farmers in Trans Nzoia District are experiencing low maize yields as a result of continuous cultivation without addition of adequate external nutrients. Integrating the use of green manure legumes into the smallholder farming systems may form an important strategy for soil improvement and hence yield. An on-farm trial was designed in 1997 to introduce legume intercrops and green manures in a maize-based cropping system. A randomised complete block design was used and each farmer served as a replicate. Maize hybrid H614 was intercropped with either common bean (*Phaseolus spp.)*, soybean (*Glycine max*) groundnuts (*Arachis hypogea),* and cowpea *(Vigna unguiculata)*. After harvesting the food legumes these four plots were relayed with green manure legumes, Sunhemp *(Crotolaria brevidens),* Velvet bean *(Mucuna spp.)* or Dolichos *(Lablab purpureus)*. The green manure legumes remained in the field after maize was harvested and were incorporated 2-3 weeks before planting the following season. Maize yields harvested from the plots were compared with yields from control plots. The soils under experimentation were strongly to moderately acidic (pH 5.0 - pH 6.9) with marginal amounts of exchangeable bases. Green manure dry matter (DM) varied for both years. In 1997 *Dolichos* spp. gave the highest yield of 2.5 t ha^{-1} while *Mucuna spp.* gave the lowest yields (0.38 t ha^{-1}). *Crotolaria spp* gave the highest DM yield (2.80 t ha^{-1}) in 1998, followed by Velvet bean (1.20 t ha^{-1}) and Dolichos (0.40 t ha^{-1}) in that order. There were no significant maize yield differences ($p<0.05$) after one or two years of green manure incorporations and fertilized maize. After one year maize following *Mucuna spp.* gave yield of 9.3 t ha^{-1} while after two years it was *Dolichos spp* that gave the highest yield of 8.5 t ha^{-1}, followed by *Crotolaria spp* and *Mucuna spp.* which yielded 6.3 t ha^{-1} each. After three years of incorporations maize yields following *Dolichos spp* continued to give the highest yield of 8.1t ha^{-1}. Throughout the four years growing period no fertilized maize gave the lowest significant yields ($P<0.05$). The utilization workshops for soybean and groundnuts were well attended. Initially farmers insisted on growing legumes as intercrops due to land pressure, but after three years exposure, they requested seeds for planting pure stands. Farmers may accept rotating legumes with maize in future to increase and diversify their food supply and at the same time improve their soils.

Keywords*:* Food legumes, green manure legumes, intercropping, relaying, soil fertility.

INTRODUCTION

Farmers throughout Kenya are experiencing lower maize yields due to a number of reasons. Continuous cropping of maize, removal of field crop residues for feeding livestock, overgrazing and burning of stover *in situ* to ease ploughing have resulted in the deterioration of both the physical and chemical soil properties (Smaling *et al*., 1992; Hudgens, 1996, Onyango *et al*., 1999). At the same time, high inputs and transport costs for agrochemicals make the use of inorganic fertilizers on staple food crops uneconomical for most smallholder farmers (KARI, 1995; Heisey and Mwangi, 1996; Bashir *et al*., 1997). A study by Odhiambo (1994) revealed that the rising cost of inputs has resulted in many smallholder farmers reducing or abandoning the use of chemical fertilizer altogether. This has significant implications for maize production levels in the country as 73% of Kenya's farmers use hybrid varieties that have been bred to respond to substantial amounts of Nitrogen (N). In Trans-Nzoia District (the main maize growing zone in Kenya) virtually 100% of the farmers grow the long maturing hybrid varieties (Hassan *et al*., 1998) developed in the 1960s at Kitale.

The ability of some leguminous plants to fix atmospheric nitrogen is well documented. Many researchers have advocated the integration of legumes into smallholder cereal-based cropping systems (Fujita *et al*., 1992; Palm *et al*., 1997; Peoples *et al*., 1995). According to Clement *et a*l., (1998) green manures (GM) can be used as alternatives to mineral fertilizers particularly for subsistence farmers whose resource base is small. Information on the influence of the chemical composition of GM on N dynamics on maize production in this region is scanty. In addition to adding biologically fixed N to the system and thus improving it, green manure legumes can provide rapid ground cover to reduce soil erosion, suppress weeds and produce abundant organic matter for improving soil physical and chemical properties. Some legumes (e.g *Mucuna spp*) which have a deep rooting system may also help alleviate compaction in intensively cultivated soils (Taylor, 1994). Deep rooting may also enable certain legumes to withstand prolonged dry periods. This is very important for rainfed agricultural systems as ours where farmers may be reluctant to displace valuable food or cash crops for a soil improving crop during the main rainy season Kirungu, (1997). All these positive attitudes mentioned should make green manures an attractive option for introduction to resource-poor farmers.

According to Gachene *et al*. (1997) some of the legumes recommended for use as green manure include *Crotolaria ochraleuca, Lablab purpureus* and *Mucuna pruriens*. These species were screened under optimum conditions including *Rhizobium* inoculation and P-fertilizer application when grown in pure stands. Green manure legumes should therefore be introduced to farm conditions with caution because the soils are usually characterised by severe nutrient depletion that would lead to their reduced performance and N-fixation Gachene *et al*., 1997; Gachene and Haru, (1998).

Due to an increase in population pressure in Trans Nzoia a large percentage of farmers intercrop maize with common beans. Although much work on quality and quantity of N that can be fixed by green manure legumes has been done, farmers' awareness of other legume varieties and their uses is very limited (Peoples *et al*., 1995). Recognising the current importance of the common beans in the Kenyan smallholder cropping systems, the focus would be on relaying the green manure legume into a maize/food legume intercrop following the food legume harvest. Intercropping maize with other food legumes other than common beans would hopefully expose farmers to more beneficial ones in terms of improving their diets and soil fertility. Growing of common beans production may not result in improved N status as they have low inherent capacity to fix N and a high N harvest index (Giller and Cadisch, 1995; Giller *et al* 1997). Soybean, on the other hand, has a higher Biological Nitrogen Fixation (BNF) capacity but with high N harvest index which often may also lead to a net negative balance of soil N. In order to satisfy the farmers' wish of improving soils and at the same time produce sufficient food for consumption, various types of green manure legumes were introduced to maize food legume intercrops with the following objectives:

1. Identification of suitable food legume for use in intercropping.
2. Investigation of farmer perceptions on relaying green manures on maize food legume intercrops.
3. Monitoring changes in the soil pH, nitrogen (N), potassium (K), phosphorus (P) and % organic carbon (C), and
4. Demonstrate the use of food legumes through utilization workshops.

MATERIALS AND METHODS

Smallholder farmers were selected from 3 locations of Cherengani Division of Trans Nzoia District. Suwerwa and Kapkarwa Locations were in the lower highlands (LH) zone and Kipsaina location was in the upper midland (UM) zone (Jaetzold and Schmidt, 1983).

Through a series of workshops, farmers were exposed to strategies for improving soil fertility and simplified explanation on research concepts for on-farm experimentation. After demarcating the trial areas, composite soil samples from the top (0 - 15 cm depth) and bottom (15 - 30 cm depth) were sampled and analysed for pH, N, P, K, Mg, Ca and % organic carbon in order to establish the initial nutrient status. The analytical procedures used for determining pH, organic carbon and all elements are as described by Page (1982). A randomised complete block design was used and each farmer served as a replicate. Maize hybrid, H614D was planted (3 seeds/hill) at a spacing of 75 cm between rows and 60 cm between hills and thinned to 2 plants/hill 3 to 4 week after emergence. It was intercropped with either common bean (*Phaseolus spp.)*, soybean (*Glycine max*), groundnuts (*Arachis hypogea)* or cowpea *(Vigna unguiculata)*. After harvesting the food beans, these four plots were relayed with green manure legumes, sunhemp *(Crotolaria brevidens),* velvet bean *(Mucuna spp.)* or dolichos *(Lablab purpureus)*. The green manure legumes remained in the field after maize was harvested and were incorporated 2 to 3 weeks before planting the following season. Important characteristics of these legumes including establishment, nodulation, tolerance to diseases and pests were recorded. Maize yields harvested from the plots were compared with yields from non-fertilized and fertilized plots. Initial land preparation was by tractor and subsequent ones by hand to avoid mix up of soils between plots. The plots occupied an area of 36 m^2 and observations were made on maize from 9m^2 area for the final harvests, which were set to standard of 12.5 % moisture. Maize stalk borers were controlled by using Dipterex at 4 to 5 kg ha^{-1}. Non-treatment variables (time of planting, weeding and pest control) were managed at near as optimal as possible. Farmers' opinions and evaluations were sought at individual farm level, workshops and field days using a checklist prepared by the research team. An analysis of variance (ANOVA) was conducted using the general linear models (GLM) procedures of the SAS program (SAS Institute, 1995) to determine the effects of the treatments on maize yields.

RESULTS AND DISCUSSION

a) Soil analysis

Analytical results are presented in Table 1. The soil reaction (pH) ranged from moderately acidic to neutral (5.0 to 6.9). The soils from the different farms had marginal amounts of exchangeable bases (K, Ca, Mg and Mn). These soils were generally deficient in extractable (available) phosphorus. Similarly, organic carbon (organic matter) was

Table 1. Initial soil nutrient status at the beginning of the experiment in 1997

Soil Depth	pH (H_2O)	Exchangeable cations					Available P	Organic C
		Na	K	Ca	Mg	Mn		
(cm)		- - - - - (cmol/kg) - - - - -					(ppm)	(%)
0 – 15								
Mean*	5.7	0.12	0.70	5.08	2.75	0.90	13.79	2.16
Range	5.0-6.8	0.07-0.24	0.13-1.75	0.08-15.4	0.30-5.00	0.16-1.14	3.5-41.5	1.1-3.6
15 – 30								
Mean*	5.6	0.12	0.40	3.1	2.57	0.74	9.53	1.46
Range	5.0-6.9	0.05-0.24	0.06-0.76	0.04-10.3	0.80-4.60	0.04-1.30	4.0-58.0	0.50-2.70

- Means are derived from 24 farmers

Table 2. Green Manure Dry Matter Yield in two seasons

Green Manure Legume	Years 1997/8[a]	1998/9[b]
	($t\ ha^{-1}$)	
Velvet bean	0.38	1.20
Sunhemp	1.90	2.80
Dolichos	2.50	0.40
Mean	1.59	1.40
C.V.	28.90	26.84

[a] means are derived from 10 farmers
[b] means are derived from 7 farmers

especially low in the sub soil, which gave an indication of N deficiency.

b) Legume characteristics

The food legumes intercropped with maize generally gave low yields. The cowpea gave no grain yield at harvest during the three years. Groundnuts, common bean and soybean did not perform well as the yields averaged 90 Kg ha^{-1} 225 kg ha^{-1} and 241 kg ha^{-1} respectively. The low grain legume yields may probably be due to the shading of maize. All these legumes, however, established well and all of them fixed N as indicated by the pink colour of nodules when cut into two. There were no severe pest problems but diseases were observed on cowpea, soybean, common beans, groundnuts and dolichos.

The green manure legumes including sunhemp, velvet bean and dolichos were relayed into the maize crop after harvesting the various food legumes. They yielded low and varying amounts of dry matter (DM) in both years as in Table. 2.

c) Maize yields

Maize yields following two and three green manure incorporations are as given in Tables 3 and 4. The initial number of farmers participating in this trial decreased from ten in 1997 to six by the year 2000. There were no significant maize yield differences ($p<0.05$) after one or two years green manure incorporations and fertilized maize. After one year maize following *Mucuna spp*. gave yield of 9.3 t ha^{-1} while after two years it was *Dolichos spp* that gave the highest yield of 8.5 t ha^{-1}, followed by *Crotolaria spp* and *Mucuna spp.* which yielded 6.3 t ha^{-1} each (Table 3). After three years of incorporations maize yields following *Dolichos spp* continued to give the highest yield of 8.1t ha^{-1}. This yield was not significantly different from fertilized maize (7.3 t ha^{-1}) but significantly different ($P<0.05$) from maize after *Mucuna spp.* 6.2 t ha^{-1} and maize after *Crotolaria spp* 6.1 t ha^{-1} (Table 4). Throughout the four years growing period non-fertilized maize never gave the lowest significant yields ($P<0.05$).

These results realised in the last 3 years have added to the basket of options on maize production for smallholder maize growers who normally have insufficient funds to purchase recommended inputs for optimum yields.

d) Farmers' observations and comments

In order to evaluate these treatments, farmers' opinions were sought during field days, farmer workshops and during inter-group visits. Some of the factors they considered included labour requirements during land preparation when establishing and incorporating green manure legumes. Low grain and dry matter yields from the various food and green manure legumes were of concern to them. The food bean yields were low as a result of multiple reasons, including diseases, pests and shading from maize. The green manure legumes were mainly affected by being grazed on by sheep and cattle. After harvesting maize, animals are normally left to graze freely in the fields and this affected the DM produced for incorporation. During farmer workshops, farmers were instructed to construct live fences or barbed

Table 3. Maize yield after intercropping and green manures incorporation twice

Treatments: Green manure	Intercrop	Maize grain yield* ($t\ ha^{-1}$) 1997	1998	1999	Treatment mean**
Crotolaria	Beans	6.8	6.5	6.0	6.4
	Cowpeas	6.9	6.9	6.5	6.8
	Groundnuts	6.6	5.1	5.8	5.8
	Soyabean	6.2	6.3	6.2	6.2
Crotolaria mean		6.6	6.2	6.1	6.3 (± 0.9) a
Dolichos	Beans	7.0	10.6	7.7	8.4
	Cowpeas	7.3	11.2	7.1	8.6
	Groundnuts	7.5	11.5	8.0	9.0
	Soyabean	8.4	11.1	4.9	8.2
Dolichos mean		7.6	13.1	6.9	8.5 (± 1.4) a
Mucuna	Beans	5.2	7.4	5.0	5.9
	Cowpeas	6.3	8.1	6.0	6.8
	Groundnuts	6.7	7.8	5.5	6.7
	Soyabean	5.8	6.9	5.2	6.0
Mucuna mean		6.0	7.6	5.4	6.3 (± 0.8) a
60 P_2O_5+ 60 N ha^{-1}		-	8.2	6.6	7.4 (± 0.6) a
No fertilizer		6.4	6.0	3.9	5.4 (±0.5) b
C.V %					22.0

* means are derived from 7 farmers.
** mean yields along columns (for green manure legumes and the controls) followed by same letter are not significantly different.

Table 4. Maize yield* after intercropping and green manure incorporation three times

Treatments		Maize grain yield (t ha^{-1})				Treatment
Green	Food beans	1997	1998	1999	2000	Means**
Crotolaria	Beans	6.8	6.5	6.0	5.6	6.2
	Cowpeas	6.9	6.9	6.5	6.5	6.5
	Groundnut	6.6	5.1	5.8	5.7	5.7
	Soyabean	6.2	6.3	6.2	5.8	6.1
Crotolaria		6.6	6.2	6.1	5.6	6.1 (± 0.8) b
Dolichos	Beans	7.0	10.6	7.7	6.4	7.9
	Cowpeas	7.3	11.2	7.1	5.2	7.7
	Groundnut	7.5	11.5	8.0	7.4	8.6
	Soyabean	8.4	11.1	4.9	7.4	8.0
Dolichos		7.6	11.1	6.9	6.5	8.1 (± 1.4) a
Mucuna	Beans	5.1	8.9	5.2	3.3	5.6
	Cowpeas	7.0	9.8	6.6	3.4	6.9
	Groundnut	7.0	9.5	6.5	4.5	6.9
	Soyabean	5.6	7.8	5.6	3.7	5.7
Mucuna mean		6.2	9.0	6.0	3.7	6.2 (± 1.0) b
$60P_2O_5$+60 N		_	8.1	6.5	7.3	7.3 (± 0.4) a
No fertilizer		6.5	6.7	4.1	4.4	5.4 (±0.5) c
C.V %						19.6

* means are derived from 6 farmers.

** mean yields along columns (for green manure legumes and the controls) followed by same letter are not significantly different.

wire for maximum DM production from these green manure crops.

Farmers were exposed to the use of soybean, groundnuts, cowpea and sunhemp. Their appreciation toward these legumes increased to such an extent that some of the participating farmers requested for a few seeds to plant in small areas as sole crops. They even suggested planting larger portions of their land with these legumes as sole crops if assured of market availability. From the researcher point of view, this offered an opportunity to introduce to farmers in this region the concept of crop rotation with these legumes, as another strategy for improving soil fertility. The perception of this concept had improved as compared to when the experiment began. The major constraint to the use of these technologies is the small land holdings.

CONCLUSION

There is great potential in using green manure legumes to sustain maize yields for resource-poor farmers. The stakeholders unanimously agreed that the technology can be viable if some issues were considered. These include fencing off farm areas where green manures are planted to deter wondering animals from grazing on established green manure crops; early planting of the maize crop to ensure early relaying of the green manure for maximum use of mineralized nutrients by the subsequent maize crop. Farmers will diversify their farming systems using these legumes when assured of stable markets for sale of surplus.

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EFFECT OF ENRICHING FARMYARD MANURE WITH MINERAL FERTILIZER ON GRAIN YIELD OF MAIZE AT BAKO, WESTERN ETHIOPIA.

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ABSTRACT

To find out the effect of enriched farm yard manure (FYM) on grain yield of maize, an experiment was conducted on farmers' fields around Bako during 2000 and 2001 cropping seasons. The experiment was laid out in a randomized complete block design (RCBD) with two replications. Enrichment of conventional FYM was done separately with 25 % and 50 % each of recommended nitrogen (N) and phosphorus (P) fertilizers and their combinations from urea and diammonium phosphate sources. Enrichment of conventional FYM improved the quality of FYM. Total N and P was increased from 1.8% and 0.35 ppm in conventional FYM to 2.43 % and 1.05 ppm in enriched FYM, respectively. The growth and yield of maize were increased significantly with the application of enriched FYM. Enriched FYM increased grain yield by 40% compared to conventional FYM. However, the residual effect of enriched FYM was very marginal. Application of 25% NP enriched FYM gave the highest marginal rate of return of 296%. This remained robust when maize price decreased by 20% and fertilizer cost increased by 10%. It was concluded that application of enriched FYM is superior to conventional FYM and on par with recommended mineral fertilizers on maize grain yield. By following enrichment technology 75% of mineral fertilizers can be saved for maize production in Bako area.

Keywords: Enriched farmyard manure, maize, yield.

INTRODUCTION

The single biggest obstacle to inorganic fertilizer use in Ethiopia is its cost. High cost does not favour the use of fertilizers if the yield response and grain price is not high enough to make its use profitable. Continuous use of inorganic fertilizer alone causes the soil condition to deteriorate and lowers the productivity of the soil. Moreover, there is a possibility of essential micronutrients of the soil being depleted, thereby resulting in serious deficiency of these nutrients and reduction in total crop production.

The importance of farmyard manure (FYM) and other organic manures is being realized again because of high costs of commercial fertilizers. FYM not only supplies a variety of macro- and micronutrients to the soil, but also improves the physico-chemical and biological properties of the soil, which helps to maintain the soil productivity and soil health. Use of FYM alone cannot satisfy the crop requirements. This is mainly due to low nutrient analysis and the slow decomposition rate of the manure. Thus, proper ratio between FYM and chemical fertilizer sources should be worked out to derive the best possible advantages of the inputs.

Conventional FYM commonly contains about 75 per cent water and very low concentration of nutrients. As a result large quantities are needed to supply an appreciable part of the nutrient requirement of the plant (Cooke, 1982). Hence, the bulky organic manure requires improvement in quality with reference to its nutrient content through enrichment. Shailendranath and Rao (1979) reported pre-treatment of FYM with urea and phosphate fertilizer had significantly increased grain and straw yield of finger millet. Nayak (1993) reported that application of one ton of enriched FYM/ha was on par with six tons of conventional FYM/ha in increasing finger millet yield. Thus, the present investigation deals with the efforts made to improve the quality of FYM by enriching with N and P fertilizers with the objective to compare enriched and conventional FYM on grain yield of maize.

MATERIALS AND METHODS

The experiments were conducted on farmers' fields around Bako during 2000 and 2001 cropping seasons. The altitude of Bako area is 1,650-1,750 masl with mean annual rainfall of 1,200 mm and in unimodal distribution between April to October. The climate is warm humid with mean minimum, maximum and mean temperatures of 13°C, 27°C and 20°C, respectively.

Process of enrichment: the required quantity of conventional FYM was enriched separately with 25% and 50% each of the recommended N and P fertilizers and their combinations. The materials were thoroughly mixed and heaped. They were incubated for three months at 80 percent moisture. The heaps were covered with polyethylene sheet.

The experiment was laid out in a randomized complete block design (RCBD) with two replications. Twenty five percent and 50% each of recommended N and P enriched

Table 1. Nutrient composition of enriched and conventional FYM used in the study.

	Total N (%)	Total P (ppm)
25 % N Enriched FYM	2.24	0.39
50 % N Enriched FYM	2.43	0.36
25 % P Enriched FYM*	2.31	0.80
50 % P Enriched FYM**	2.34	1.05
25 % NP Enriched FYM	2.34	0.92
50 % NP Enriched FYM	2.38	1.02
Conventional FYM	1.80	0.35

* With 7.5% N and ** with 15% N from DAP

Table 2. Effect of enriched, conventional and mineral fertilizers on maize grain yield (t/ha) at Bako 2000.

Treatments	Locations						Mean
	Bako	Shoboka	Tulu	Tibe	Oda Haro	Ilala	
25 % N Enriched FYM	6.07	5.35	5.27	5.59	6.55	5.37	5.70
50 % N Enriched FYM	6.46	6.51	6.17	6.15	6.70	6.09	6.35
25 % P Enriched FYM*	7.25	6.09	6.58	6.95	7.32	6.75	6.82
50 % P Enriched FYM**	8.05	7.51	6.66	7.62	7.32	7.56	7.45
25 % NP Enriched FYM	8.50	7.96	8.03	7.37	7.81	7.28	7.83
50 % NP Enriched FYM	8.89	8.93	8.57	8.13	8.78	8.29	8.59
Recommended NP	8.60	8.22	8.92	8.00	9.04	8.21	8.49
Conventional FYM	5.35	5.11	4.78	4.86	5.51	5.41	5.17
C.V. (%)	13.65	14.95	15.56	11.15	10.38	11.52	13.00
LSD (0.05)	2.39	2.46	2.5	1.80	1.81	1.87	0.76

*With 7.5 % N and **with 15 % N, DAP source

Table 3. Residual effects of enriched and conventional FYM on maize grain yield (t/ha) at Bako 2001.

Treatments	Locations				
	Bako	Shoboka	Tulu Sangota	Oda Haro	Mean
25 % N Enriched FYM	4.46	3.37	3.25	3.30	3.60
50 % N Enriched FYM	4.80	3.30	3.17	3.51	3.69
25 % P Enriched FYM*	5.86	3.22	2.95	3.25	3.82
50 % P Enriched FYM**	5.81	3.63	3.22	3.06	3.93
25 % NP Enriched FYM	5.24	3.56	3.18	2.95	3.73
50 % NP Enriched FYM	5.72	3.87	2.75	3.13	3.87
Recommended NP+	8.72	6.30	7.18	6.51	7.18
Conventional FYM	4.23	3.60	3.98	3.49	3.83
C.V. (%)	10.93	15.8	16.34	10.57	13.36
LSD (0.05)	1.45	1.28	1.43	0.91	0.58

+ Applied every year, * with 7.5 % N and **with 15 % N, DAP source

Table 4. Partial budget, dominance and marginal analysis for enriched FYM on maize grain yield around Bako.

Items	Conven -tional FYM	25% P enriched FYM	25% NP enriched FYM	50% NP enriched FYM	25% N enriched FYM	50% N enriched FYM	50% P enriched FYM	Recomm-ended NP
Average Yield (t/ha)	5.17	6.82	7.83	8.60	5.70	6.35	7.44	8.50
Adjusted yield (t/ha)	4.65	6.14	7.05	7.74	5.13	5.72	6.70	7.65
Gross benefit (Birr/ha)	1395	1842	2115	2322	1539	1716	2010	2295
Total costs that vary								
Cost of N	0	33	102	204	102	204	66	408
Cost of P	0	72	72	144	0	0	144	288
Labor cost	42	98	98	98	98	98	98	21.0
Total costs	42	203	272	446	200	302	308	717
Net benefit (Birr/ha)	1353	1639	1843	1876	1339^D	1414^D	1702^D	1578^D
MRR (%)		177.6		295.7		19.0		

^D = Dominated treatment

Table 5. Sensitivity analysis for stable recommendation of enriched FYM for maize production around Bako.

Items	Conven -tional FYM	25% P enriched FYM	25% NP enriched FYM	50% NP enriched FYM	25% N enriched FYM	50% N enriched FYM	50% P enriched FYM	Recomm-ended NP
Average Yield (t/ha)	5.17	6.82	7.83	8.60	5.70	6.35	7.44	8.50
Adjusted yield (t/ha)	4.65	6.14	7.05	7.74	5.13	5.72	6.70	7.65
Gross benefit (Birr/ha)	1116	1474	1692	1858	1231	1373	1608	1836
Total costs that vary								
Cost of N	0	37	112	224	112	224	74	448
Cost of P	0	79	79	158	0	0	158	316
Labor cost	42	98	98	98	98	98	98	21
Total costs	42	214	289	480	210	322	330	785
Net benefit (Birr/ha)	1074	1260	1403	1378^D	1021^D	1051^D	1278^D	1051^D
MRR (%)		108.1		190.7				

^D = Dominated treatment

FYM and their combinations applied at 8 t/ha were compared with the recommended conventional FYM (16 t/ha) and inorganic fertilizer (92-69 kg N-P_2O_5/ha) application. Both enriched and conventional FYM were applied to the plots in rows before planting maize. In the treatment with recommended inorganic fertilizers, N application was split with half applied at sowing and the remaining half at 35 days after sowing immediately after the first weeding. The entire dose of P was applied at sowing.

To observe the residual effects of the manure, plots were maintained intact for two seasons at all locations. Plots were formed of six rows of maize 10 m long planted 80 cm apart with within row spacing of 50 cm and two plants per hill. Data on grain yield and yield components were taken on the central four rows. Full season hybrid maize BH 660 was used. Land preparation, planting and weed management was set at representative farmers' levels. Planting was done in early to mid-May and farmers' weeding practice, hoeing, inter-row oxen cultivation, hand pulling and slashing were performed on average at 25, 35, 55 and 90 days after planting, respectively.

A composite soil sample was collected from 0-30 cm depth immediately before planting to determine the pH and nutrient status of the soils. Soil pH was analyzed by 1:2.5 in H_2O, total N content was determined by Kjeldahl method; available P was analyzed using Olsen method. The soils are slightly acidic (pH 5.6), medium in total N (0.11 %) and medium in available P (12 ppm). FYM samples (enriched and conventional) were analyzed for NP contents (Table 1).

To consolidate statistical analysis of agronomic data, economic analysis was done for enriched and conventional FYM, which were significant. For economic evaluation, partial budget, marginal and sensitivity analysis were used. To estimate economic parameters, maize was valued at an average open market price of 30 Birr/100 kg, N and P were at official price of 4.43 and 4.17 Birr per kg of N and P_2O_5, respectively. Twelve work-days/ha for manure transportation and application and wage rate of 3.5 Birr/work-day were used. Sixteen work-days were used for frequent watering of the enriched manure during the incubation period. FYM was not valued at any cost because FYM has no price in Ethiopia.

RESULTS AND DISCUSSION

Enrichment of conventional FYM with N and P fertilizer improved the quality of FYM. Total N and P increased from 1.8 % and 0.35 ppm in conventional FYM to 2.43 % and 1.05 ppm in enriched FYM, respectively (Table 1). Thus, by enrichment technology the quality of conventional FYM can be improved and the amount required for application can be reduced to reduce transportation and application costs.

At all sites, enriching FYM with N and P significantly increased maize yields compared to FYM alone, especially at higher rates of enrichment (Table 2). Combined analysis over locations showed that maize grain yield was significantly increased at all levels of enrichment except 25% N (Table 2). The interaction between treatment and location was non-significant, indicating that treatments performed similarly across the locations, i.e., the locations are from similar domain.

Application of 50% NP enriched FYM increased grain yield by 40% as compared to conventional FYM. The increase in yield may be attributed to the nature and quality of enriched FYM which supplies nutrients in readily available form to maize plants which in turn react with native soil nutrients in a way that enhance their availability to crops. Application of 25% and 50% NP enriched FYM was on par with application of recommended mineral fertilizers. This indicates that using enriched FYM can save 50% to 75% mineral fertilizers. Enrichment had no significant residual effect over conventional FYM which on average yielded about 50% that of the recommended NP fertilizer applied every year (Table 3).

Economic analysis showed that the highest net benefit of 1,876 Birr was obtained from 50% NP enriched FYM application. However, application of 25% NP enriched FYM gave the highest marginal rate of return of 296% (Table 4). Statistically, application of 25% NP enriched FYM is not significantly different from the application of recommended mineral fertilizers. Hence, application of 25% NP enriched FYM is agronomically optimum and economically feasible. Sensitivity analysis also indicated that application of 25% NP enriched FYM remained robust when maize price decreased by 20% and fertilizer cost increases 10% (Table 5). However, with the concurrent changes in maize price and fertilizers cost, the profitability of this rate becomes marginal.

It is concluded that application of enriched FYM is superior to conventional FYM and on par with recommended mineral fertilizers on maize grain yield. Hence, enriched FYM can substitute for mineral fertilizers for maize production in Bako and similar areas. By following enrichment technology the use of mineral fertilizers can be reduced by 75%.

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LONGER-TERM CONTRIBUTION OF GROUNDNUT ROTATION AND CATTLE MANURE TO THE SUSTAINABILITY OF MAIZE-LEGUME SMALLHOLDER SYSTEMS IN SUB-HUMID ZIMBABWE

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ABSTRACT

Experiments were conducted on farm and on station in northern Zimbabwe for up to nine years to assess how the application of cattle manure and rotation with groundnut (two of the most common smallholder soil fertility practices with maize) affect the short term productivity and longer term sustainability of maize-legume cropping systems. Indications of declines in maize grain yields were detected with nine years of continuous maize cropping at both the sandy soil Domboshava station and on-farm. Averaged over six on-farm sites, maize grain yields from 1994-1995 to 2000-2001 were estimated from linear regressions to have declined at a rate of 0.066 t ha^{-1} per year without fertilizer and are now below 0.5 t ha^{-1}. While two cycles of a 3-year rotation of groundnut with unfertilized maize raised maize grain yields by 2.15 t ha^{-1} and 1.48 t ha^{-1} at Domboshava, the effects on smallholder farms were much smaller. Existing smallholder practices (few inputs and moderate management) with groundnut produced relatively poor groundnut crops (averaging less than 0.10 t ha^{-1} groundnut grain) that raised maize grain yields by just 0.21 t ha^{-1} and 0.38 t ha^{-1} (48% and 44%) in two cycles of the rotation. Cattle manure, applied according to farmer practice (at large rates of 12-26 t ha^{-1} to a given field once every three years) appears to be a major contributor to sustained yield in this system, raising aggregate maize yields over three years without fertilizer by 102% in the first cycle and 285% (from 1.28 t ha^{-1} to 4.93 t ha^{-1}) in the second cycle of manure application. It raised maize yield in the season immediately after application and in the following two years. Manure + NPK fertilizer effects were generally less than additive, meaning that it was more productive to apply the inputs separately to different fields than to combine them. From this study it is clear that both farmer soil fertility practices are important for the sustainability of smallholder maize systems in sub-humid Zimbabwe, although as currently employed by farmers, cattle manure appears more important than the groundnut + maize rotation.

Keywords: cattle manure, groundnut rotation, longer-term experiments, maize, on-farm research, sustainability, Zimbabwe.

INTRODUCTION

During the 1990s, increased evidence of widespread soil fertility decline and stagnant food production in the smallholder arable systems of eastern and southern Africa led to a well-documented major expansion of research on soil fertility processes, the development and dissemination of integrated soil fertility technologies and advocacy for nutrient replenishment strategies (Waddington *et al.,* 1998). An emphasis on the related socio-economic dimensions has led some to question the assumptions and utility of this biophysical approach (e.g. Scoones and Toulmin, 1998; Budelman and Defoer, 2000; Scoones, 2001). They point out that smallholder farmers employ complex soil fertility management strategies in space and time, and their existing systems appear fairly resilient, rather than in a downward spiral. Biophysical soil fertility management initiatives need to be incorporated into farming systems, combined with livelihood strategies and supported by appropriate policies if they are to be effective. To maintain the productivity of smallholder farms in Zimbabwe, many (e.g. Kumwenda *et al.,* 1996, 1997; Snapp *et al.,* 1998; Giller *et al.,* 1998; Murwira and Palm, 1999) contend that farmers will need to more routinely implement integrated soil fertility management strategies that combine a range of on farm soil fertility resources with external ones, all of which are in short supply.

However, little information exists about the nature of longer term (over six to ten years, and onward) trends in soil fertility and crop productivity for current soil fertility practices in smallholder cropping systems of Zimbabwe and elsewhere in southern Africa, to better inform this debate (e.g. Kumwenda *et al.* 1996; Giller *et al.,* 1998; Harrington and Grace 1998). Such measurements need to be conducted on smallholder farms with the inputs and management that farmers use. This type of research is perceived to be difficult, expensive to implement and slow to generate results, and so is still rarely done. In an assessment of longer-term arable experiments in Africa, Greenland (1994) and Swift *et al.* (1994) found many experiments that address organic and inorganic soil fertility inputs and crop rotations. However, all were researcher-managed on research stations and reflected very poorly the circumstances facing the African farmer (Swift *et al.,* 1994; Scoones, 2001).

This paper reports one attempt to generate longer term on-farm data. It gives yield productivity trends over 8-10 years from a series of ongoing longer-term experiments (Waddington and Karigwindi, 2001) conducted on smallholder farms (and under simulated smallholder management on a research station) in subhumid zones of northern Zimbabwe. The experiments assess how rotation with groundnut and the application of cattle manure, two of the most common smallholder soil fertility practices employed with maize in northern Zimbabwe, affect short-term productivity and medium term sustainability of this system. When cropped to sole maize, the soils in these smallholder systems in Zimbabwe can supply only about 30 kg N ha^{-1} per cropping season because of critically low levels of soil organic matter (Mapfumo and Mtambanengwe, 1999). Further N mineralization is dependent on annual organic inputs produced in crop residues (e.g. groundnut and maize) and retained on the field or cycled through animals (as cattle manure). Non-systematic groundnut + maize rotations are widely practised by smallholders in northern Zimbabwe (Metelerkamp, 1987; Snapp *et al.,* 1998). Large increases in maize yields are common following groundnut on research stations in Zimbabwe (e.g. Mukurumbira, 1985; Waddington *et al.* 1998) but can be absent or very low on smallholder farms where farmers grow groundnut with few inputs (Waddington and Karigwindi, 2001). Cattle manure is the major organic fertilizer for smallholder farmers in these mixed crop + livestock systems and can often provide large yield benefits (Mugwira and Murwira, 1997). Traditionally farmers produce an aerobically composted low quality (0.8-2% N) manure, broadcast it at high rates (10-25 t ha^{-1}) and plough it (in a 3-4 year rotation) into fields that will be planted with maize (Mugwira and Murwira, 1997).

MATERIALS AND METHODS

Since 1992-93, CIMMYT has conducted maize + groundnut rotation experiments with smallholder farmers in Chiduku Communal Area and Chinyika Resettlement Area, and at the AGRITEX Training Centre station, Domboshava. These areas are located in the subhumid unimodal rainfall zone (800-900 mm in 5 months, 1,300-1,500 masl) of east central Zimbabwe. The experiments are fully described in Waddington *et al.* (1998) and Waddington and Karigwindi (2001).

Six experimental sites were chosen with farmers to be representative of the principal topland or mid-slope maize fields that they cultivate. The soils at the sites are predominantly ustalfs (loamy sands, sandy loams and sandy clay loams) derived from granite. They have low pH (pH 4.2 - 4.7, in 0.01M $CaCl_2$), a carbon content of between 0.4 and 0.8%, low cation exchange capacity (CEC) and low amounts of several cations. A major distinction between the Domboshava station and the on-farm sites was soil P (42 µg g^{-1} P (Bray) on station, 0.4-8.9 µg g^{-1} P on-farm). The sites had been cropped for various lengths of time, estimated to be between 12 years (sites in Chinyika) and over 70 years (in Chiduku) when the experiment began. Maize had been grown on each field in the year preceding the start of the experiment.

The experiment was arranged in a randomized complete block design with two replicates at each site. Experimental treatments were:

- T1. *Continuous maize (year-after-year).* Fertilizer was applied diffusely on the soil surface 4-10 cm from each maize plant, according to common farmer practice. NPK compound “D” (275 kg ha^{-1}) was applied 14 days after crop emergence and 70 kg N ha^{-1} topdress ammonium nitrate fertilizer when the crop was approximately 60 cm tall. This provides 92 kg N, 17 kg P and 16 kg K ha^{-1} per year.
- T2. *Continuous maize (year-after-year).* No fertilizer applied.
- T3. *Maize-Maize-Groundnut-Maize-Maize-Groundnut rotation (one crop per year).* Fertilizer on maize as in T1, no fertilizer on groundnut.
- T4. *Maize-Maize-Groundnut-Maize-Maize-Groundnut rotation (one crop per year).* No fertilizer applied.
- T5. *Continuous groundnut (year-after-year).* No fertilizer applied.

Fertilizer rates used in these treatments represented farmer practice when the experiment began and were obtained from detailed agronomic monitoring and surveys with farmers in Mangwende Communal Area (Waddington et al., 1991).

The plot size was 10.8 x 10.5 m (113.4 m^2) for both maize and groundnut. Seed of R215 or SC501 hybrid maize was planted to give a plant population density of 44,440 plants ha^{-1}. Groundnut (usually the small and bushy ‘Spanish’ type, widely used by smallholders) was planted to give a density of approximately 160,000 plants ha^{-1}.

Satellite plots (each 113.4 m^2) were established next to the main experiment at each site in 1994 to measure the effect of a factorial combination of cattle manure and fertilizer on the grain yield of maize under farmer management. We asked the host farmers to select their cattle manure and apply it to the plots according to their normal rates and practice. These high rates of manure (between 12.4 and 26.4 t ha^{-1}) were broadcast to the soil surface once each three years and incorporated into the soil using an ox-drawn plough early in October before rains began. N contents of the manure were between 1.25 and 2.52 % N. The cattle manure was applied in 1994, 1997 and 2000.

Management, both on-station and on-farm, was representative of farmers’ practices in the area and was jointly undertaken by the farmers and researchers. The land was prepared using an ox-drawn mouldboard plough. Groundnut was grown without P fertilizer or gypsum. Weeds were removed at two stages of crop growth using hand-hoes, and cattle and goats were allowed to graze the maize stover and groundnut haulms during the dry season, as happens on farm.

Each year, the maize and groundnut grain yields were harvested from whole plot areas of 113.4 m^2. Maize grain yields were measured at 12.5% moisture content and groundnut grain as sun-dried mass per hectare. Maize grain yields were used in single-site analyses of variance for each year. The results are presented as year-to-year trends in grain yields.

RESULTS

Continuous maize

There was some evidence of a decline in maize grain yields with continuous maize cropping at both the Domboshava station and on farm (Fig. 1). 1993-94 was dropped from the trend analysis using linear regression because the experiment was planted at only the higher yielding farm sites that year and very favourable weather combined to produce high yields. At Domboshava, the decline over the period 1992-1993 to 2000-2001 (estimated from linear regressions) was 0.42 t ha^{-1} per year with fertilizer and 0.21 t ha^{-1} per year without fertilizer (Fig. 1).

On-farm, the maize grain yields without fertilizer were generally below 0.8 t ha^{-1} (Fig. 1). Averaged over six on-farm sites, maize grain yields from 1994-1995 to 2000-2001 were estimated from linear regressions to have declined at a rate of 0.066 t ha^{-1} per year without fertilizer and are now below 0.5 t ha^{-1} (Fig. 1). With fertilizer, the on-farm yields were highly variable and no yield decline was apparent, but maize grain yield responses to the inorganic N fertilizer (calculated for 92 kg N ha^{-1} applied compared with zero N applied) were low (between 5 and 15 kg grain kg N^{-1}) in six of the nine years.

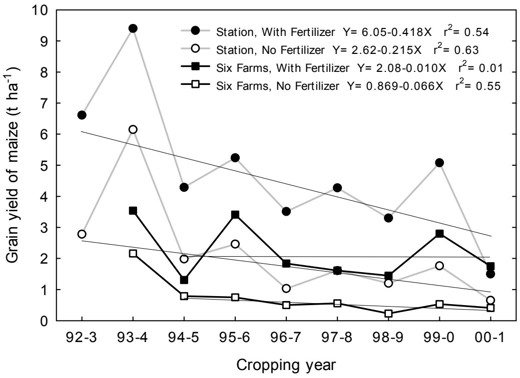

Figure 1. Trends for maize grain yield, with and without inorganic fertilizer (92 kg N, 17 kg P, 16 kg K ha^{-1}) applied each year for nine years, averaged over six smallholder farm fields and on a research station in northern Zimbabwe, 1992-2001. Narrow lines are linear regressions, disregarding 1993-94 data.

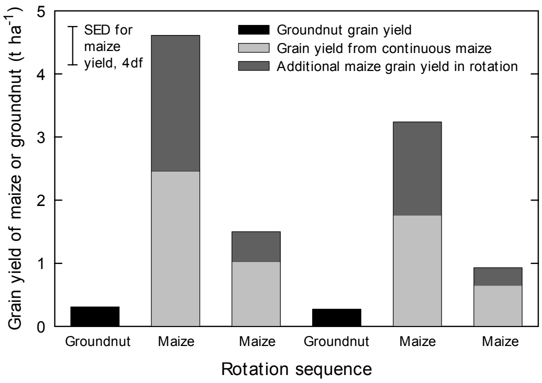

Figure 2. Grain yield of groundnut and maize (t ha^{-1}) in two cycles of a groundnut-maize-maize-groundnut rotation without fertilizer at Domboshava station, Harare, Zimbabwe, 1994-2001.

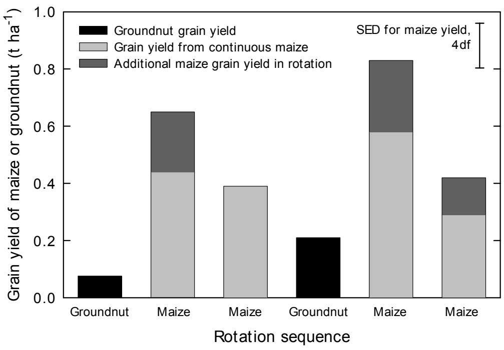

Figure 3. Grain yield of groundnut and maize (t ha^{-1}) in two cycles of a groundnut-maize-maize-groundnut rotation without fertilizer, averaged over five smallholder farms in Chinyika and Chiduku, northeast Zimbabwe, 1995-2001.

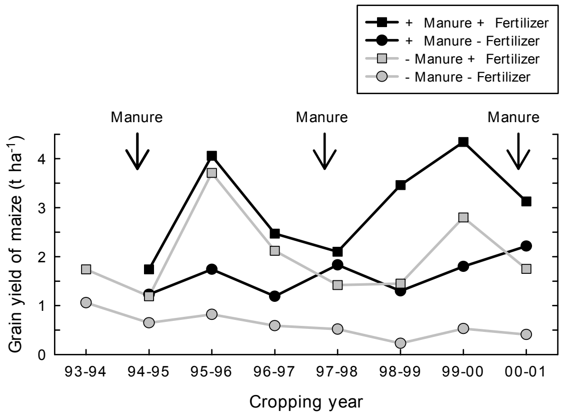

Figure 4. Maize grain yields from cattle manure (12 to 26 t ha^{-1}) and fertilizer (92 kg N, 17 kg P and 16 kg K ha^{-1}) combinations for seven years averaged over five farmers' fields in northeastern Zimbabwe, 1993-2001.

Groundnut rotation

Grain yield was measured for two complete cycles of unfertilized maize following groundnut in the rotation at Domboshava station (Fig. 2) and on five farms (Fig. 3).

At Domboshava, the rotated groundnut crops produced between 0.26 to 0.369 t ha^{-1} of shelled grain and 0.60 to 1.45 t ha^{-1} of aboveground haulms. In the first rotation cycle (1994-1997), the rotation with groundnut almost doubled the grain yield of the following maize crop (1995-1996) from 2.46 t ha^{-1} to 4.61 t ha^{-1}, an increase of 2.15 t ha^{-1} (87%) (Fig. 2). Effects of the groundnut on maize persisted in the second year of maize following groundnut (1996-1997) where maize grain yield increased by 0.47 t ha^{-1} (46%) (Fig. 2). In the second cycle (1998-2001), maize grain yields were again increased with the groundnut rotation (by 1.48 t ha^{-1} or 84% in the first year after groundnut, and 0.28 t ha^{-1} or 43% in the second (Fig. 2).

The productivity of both crops was far less on farm (Figs 1 and 3). There the first cycle of groundnut in rotation produced only between 0.025 and 0.11 t ha^{-1} of shelled grain and between 0.063 and 0.58 t ha^{-1} of aboveground haulms. The first cycle of rotation raised maize grain yields in the first year after groundnut at all five sites by an average of 48%. However, this was only 0.21 t ha^{-1} of maize grain (Fig. 3) and overall maize yields were only around 0.7 t ha^{-1}. The rotation did not improve the yield of maize in the second year. In the second cycle of the rotation, a somewhat better crop of groundnut was achieved, producing an average of 0.21 t ha^{-1} of shelled grain and 0.38 t ha^{-1} of aboveground haulms. This raised maize grain yields in both years after groundnut, by an aggregate 0.38 t ha^{-1} or 44% (0.25 t ha^{-1} in year 1 and 0.13 t ha^{-1} in year 2 (Fig. 3).

Cattle manure

Maize grain yields for seven cropping years from four combinations of cattle manure and fertilizer over two manuring cycles at five on-farm sites are in Fig. 4.

Large increases in grain yield were measured during both manuring cycles. We calculate that cattle manure alone without fertilizer raised the aggregate maize yield over the first three years (1994-1997) from 2.06 t ha^{-1} to 4.16 t ha^{-1} (an 102% increase), with a much greater 285% increase in the following cycle (1997-2000) (Fig. 4, Table 1). Cattle manure combined with fertilizer gave the highest yields (between 2 and 4.3 t ha^{-1}); a five-fold increase over unfertilized maize (Fig. 4, Table 1). Cattle manure raised maize yield in the cropping season when the manure was applied and in the second and sometimes third year and beyond (Fig. 4).

The cattle manure + NPK fertilizer effects were generally less than additive. Applying the two inputs

Table 1. Aggregate maize grain yields for cattle manure and fertilizer combinations over two 3-year manuring cycles at five on-farm sites in northeastern Zimbabwe.

Treatment	Aggregate maize grain yields	
	1994/5-96/7	1997/8-99/00
	($t\ ha^{-1}$)	
+ Manure + Fertilizer	8.27	9.90
+ Manure - Fertilizer	4.16	4.93
- Manure + Fertilizer	7.02	5.67
- Manure - Fertilizer	2.06	1.28

separately to two different 1 ha fields would yield 10.9 t of maize over a three year cycle, while combining them on 1 ha would yield only 9.1 t (Table 1).

DISCUSSION

Continuous maize

The yield trends established in these experiments suggest considerable declines in maize productivity without fertilizer in less than ten years in fields that had a previous history of maize production. Grain yields have fallen from over 2 t ha^{-1} to around 1 t ha^{-1} on station, and from around 0.75 t ha^{-1} to below 0.5 t ha^{-1} on the farms. These trends in Fig. 1 are conservative estimates, since the high yielding 1993-1994 season was deleted from the trend analysis. Fertilizer appears able to maintain yield on farm over this time scale, but the N use efficiencies of the fertilizer were low, as found in other studies in sub-humid Zimbabwe by Mushayi *et al.,* (1999). Nevertheless, nine years is inadequate to see the nature and duration of these trends, and to measure them well we are planning to ensure these longer-term experiments can continue for at least another six years.

Groundnut rotation

The results given here on groundnut + maize rotations extend those in Waddington and Karigwindi (2001) that reported very low groundnut and maize yields and greater profitability with continuous maize than the rotation at the same on-farm sites in Zimbabwe. The productivity of the rotation is very sensitive to the performance of the groundnut crop, which is difficult to grow well on many fields. There was a slight improvement in groundnut crop performance during the second cycle of the rotation on farm, but groundnut yields remain so low that the rotation makes only a modest contribution to soil fertility or food security. Many soil, weather, input and management factors contribute to this, as discussed in Waddington and Karigwindi (2001). The far greater productivity improvement from the groundnut + maize rotation at a station representative of the soil type found on farm demonstrates the potential of the rotation. The challenge is how to reproduce that with farmers in economic ways.

Cattle manure

Low rates of a poor quality organic resource like smallholder cattle manure are known to give very variable and sometimes no maize yield response in Zimbabwe (e.g. Murwira *et al.* 1998). Given the pattern of crop response to the cattle manure we found in these experiments, farmers' practices of applying large rates of their low quality manure infrequently to a given field and avoiding or reducing fertilizer when manure is applied, appear rational.

Cattle manure appears to be a major contributor to sustained yield in this system. Whether its combination with fertilizer would be more beneficial at the lower rates of fertilizer that farmers now use needs investigation (Mugwira and Murwira, 1997). The combination of anaerobically composted cattle manure (with a higher N content) and small amounts of inorganic N also needs attention. Early results from work being led by TSBF and DR&SS in Zimbabwe indicate that anaerobic composting can double the N content of the cattle manure and almost double maize crop yields (Murwira and Palm, 1999). There is some interest by farmers in Zimbabwe to use this.

CONCLUSION

From these experiments, it appears that farmer's current practice with groundnut rotation and with cattle manure both contribute to the productivity and sustainability of this cropping system on farm. Measured for maize grain production without fertilizer, the cattle manure appears to be the greater contributor; providing 1.50 t ha^{-1} or 2.38 t ha^{-1} of additional maize over two years against just 0.21 t ha^{-1} or 0.38 t ha^{-1} from the groundnut rotation. However, in addition to maize, the groundnut + maize rotation provides some groundnut which has a high value for household food and for sale.

In conclusion, these experiments are beginning to generate some helpful data about the sustainability contribution of two of the most widely used soil fertility inputs into smallholder maize production in Zimbabwe. We will try to maintain the experiments in coming years to measure the trends. Meanwhile, opportunities for farmers to more routinely integrate and augment several soil fertility management strategies on their farms, focusing both on efficient use of external nutrient inputs and on nutrient cycling through organic matter, need to be vigorously explored.

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ENHANCING SOIL PRODUCTIVITY FOR SUSTAINED FOOD PRODUCTION FOR SMALL-SCALE FARMERS IN MALAWI: A SASAKAWA GLOBAL 2000 AND AGRICULTURAL EXTENSION PARTNERSHIP INITIATIVE

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ABSTRACT

Maize is the main staple food crop for the majority of Malawians. It is grown on 1.3 million hectares of land with a national average yield of 1.38 tonnes per hectare resulting in an estimated national production of 1.8 million metric tonnes. This is not adequate to feed a population that is currently estimated at 10.5 million and growing at the rate of 3.1% per year. Declining soil fertility, poor agronomic practices and low adoption rates of the recommended technologies have been singled out as the main factors constraining maize production in Malawi, especially under smallholder farm conditions. To address these problems, the Malawi Government, in partnership with Sasakawa Global 2000, initiated an agricultural project aimed at transferring and disseminating the recommended agricultural technologies to smallholder farmers, which have hitherto not been adopted by them. Through this partnership, staff of the Department of Agricultural Extension Services and smallholder farmers, established maize demonstration plots in Blantyre, Machinga, Lilongwe, Salima and Mzuzu Agricultural Development Divisions. The major objective in these demonstrations is to train farmers and field assistants in the proper use of hybrid maize seed, optimum plant populations, timely application of fertilisers and good cultural practices so as to increase maize yields per unit area. The concept of conservation tillage was also introduced and demonstrated to smallholder farmers in the country. Round up, a post emergence herbicide, and Bullet, a residual herbicide, were used to control weeds in maize plots. Yields averaging more than 5 tonnes per hectare have been obtained from both the conventionally tilled plots and the no-till (conservation) demonstration plots. Farmers are very enthusiastic about the good performance of the technologies and are quickly adopting these. This fast adoption rate can mainly be attributed to higher maize yields in the improved technology plots compared with the farmers' own traditional plots, and the subsequent economic benefits. The training offered to both extension field staff and farmers has been instrumental in imparting knowledge and skills in the technology transfer and delivery system.

Keywords: Agricultural extension, agronomic practices, partnerships, Sasakawa Global 2000, smallholder farmer, soil productivity.

INTRODUCTION

Maize is the most dominant and staple food crop for the majority of Malawians (Smale and Heisey, 1991; Ngwira *et al,* 1989; Mangison and Nankhumba, 1999). However, its total production and yields per unit area over the last 10 years have stagnated around 2.0 million metric tonnes and 1.0 tonne per ha, respectively (Steven Carr, personal communication). This can mainly be attributed to and associated with the problems of low adoption rates of new and improved production-increasing agricultural technologies. These problems include: (i) declining soil fertility owing to poor soil management practices, and continuous cultivation without added external inputs, (ii) use of unimproved crop varieties, (iii) non-use and/or low use of fertilisers, (iv) poor soil and water management practices, (v) frequent recurrent droughts, (vi) uncontrolled plant diseases, insect pests and obnoxious weeds, and (vii) poor crop husbandry practices (such as improper use of the recommended technologies, lack of know-how on land preparation, correct and optimum plant population densities, untimely weeding and fertilizer application).

National Agricultural Research Systems (NARS) and International Research Institutes (IRI) have developed agriculture production technologies that have been used by the various end-users to address these problems that constrain maize production in Malawi. One example of the use of this knowledge is the compilation of technologies by the MAI in Malawi in a Guide for Agriculture Production available for the general public (GAP) (ACB, 1994). Nonetheless, despite the availability of these guides for agricultural production, the rate of technology adoption by resource-poor smallholder farmers has been very low indeed. The low adoption rates of agricultural technologies can be attributed to many factors including widespread poverty among smallholder farmers, commitment from the parties involved in technology transfer, wrong interpretation of the technologies, misconception of labour demands, poor information about agricultural products demand and marketing and the use of top-down approaches that do not use the participatory approach since they do not involve stakeholders in the technology development and transfer process.

These problems have further been aggravated by the new challenges brought about by the democratisation in the new millennium. These include: (i) decentralisation where power is devolved to district level organisations, and empowerment of farming communities to demand the type of research and extension service that they require, (ii) market liberalisation that gives farmers greater options in the type of crop or livestock that they produce, (iii) HIV/AIDS pandemic that is changing the demography patterns of the farming communities, and (iv) decentralized coordination. Thus, the Government is faced with the task of addressing the agricultural problems to ensure food self-sufficiency to its population of 10.5 million and growing at the rate of 3.1% (NSO, 1999), against a background of deteriorating natural resources and increasing poverty.

In an effort to address these constraints, the Malawi Government is implementing many programmes aimed at increasing maize productivity. These include: the Maize Productivity Task Force (MPTF), the Targeted Inputs Programme (TIP), Agricultural Productivity Investment Programme (APIP), Chinese Maize Production Programme, the JICA Projects, and the Sasakawa Global 2000 initiatives. In this paper, we shall focus on the Sasakawa Global 2000 activities that were initiated during the 1998/99 cropping season. These initiatives are aimed at assisting the Malawi Government to transfer agricultural technologies to smallholder farmers, who constitute over 80% of the country's population, to achieve a sustainable growth in agricultural productivity. This will ultimately contribute to increased food security at both household and national levels, reduce poverty, and provide employment. These objectives are being realised through the implementation of the following project components: (i) crop intensification and diversification, (ii) soil and water conservation and soil fertility improvement, (iii) institutional support in technology adoption, and (iv) capacity building. However, this paper will only focus on crop intensification and water and soil conservation. Increased maize production in the project areas is being achieved by implementing the following strategies: (i) boxing and ridge spacing at 75 cm (ii) optimum plant population density targeting 53,000 plants per hectare, (iii) use of both organic and inorganic fertilizers to improve the chemical, physical and biological characteristics of the soil and (iv) reduced tillage practices by using herbicides to lessen labour requirements and increase in the future the organic matter content of the soil.

MATERIALS AND METHODS

Sasakawa Global 2000 (SG 2000), in partnership with the Ministry of Agriculture and Irrigation (MAI), extension staff of the Rural Development Projects (RDPs) of Blantyre Machinga, Lilongwe, Salima and Mzuzu Agricultural Development Divisions (ADDs), and farmers implemented a total of 5,426 maize management training plots (MTPs) starting from 1998/99 to 2000/2001 cropping seasons. During the 2000/01 cropping season, SG 2000 and Malawi Government, in collaboration with Monsanto (Malawi) Limited conducted 47 conservation tillage demonstrations as follows: 10 in Blantyre ADD, 18 in Machinga ADD, 8 in Lilongwe ADD, 5 in Salima ADD, and 5 in Mzuzu ADD. The traditional practices of growing maize by smallholder farmers constituted the control. The SG 2000 technological package for the maize management training plots is as follows: (i) use of hybrid maize seed; (ii) till the soil and make ridges at 75 cm apart; (iii) plant one seed at 25 cm apart per hole along the ridge; (iv) fertilise with 92 kg N and 21 kg P per hectare. From the total rate recommended, the basal application is composed of 50% of the N and 100% of the P. The top dress is composed of the remaining 50% of N.

The top dress is applied at knee high or at 21 days from planting; (v) maintain the plot weed free by weeding 2 to 3 times;(vi) harvest when the ears have reached physiological maturity and (vii) before drying the cob remove the husks, thresh the cob and after drying, apply super Actellic to control weevils and larger grain borer. Store the treated grain in sacs or in mud storage structures.

The technological package for conservation tillage plots is basically the same as above. The differences are as follows:(i) maintain residue on the surface without tilling the soil by killing the growing weeds with post emergence Roundup herbicide. (ii) and by applying Bullet a residual herbicide after planting in order to maintain the field weed free and (iv) maintain the residue on the surface without tilling the soil after harvesting the cobs.

The traditional technology is what most farmers are using and this technology is the: (i) use of un-improved varieties; (ii) planting of 3 seeds per hole at 90-100 cm on a ridge 90-120 cm apart; (iii) application of unknown rate of fertiliser when the maize is in reproductive phase; (iv) weeding once or twice if they do at all; (v) harvesting of the maize after drying in the field and (vi) storing the cobs with husks without chemical treatment in a granary.

All the participating farmers, and field extension staff in these areas, were trained in maize morphology, production technologies, crop management and conservation tillage principles, herbicide application methods and crop storage technologies. The site location and environmental characteristics of the study areas, where the demonstrations have been conducted, are presented in Table 1, whereas management information, in terms agronomic and crop husbandry practices, is given in Table 2. The fertilizers and the maize seed were provided to farmers on credit for the conventional and conservation tillage demonstrations. The plot sizes of both demonstration activities were either 0.1 ha or 0.2 ha, and the whole plot was harvested for crop yield determination. Roundup and bullet herbicides were provided to farmers demonstrating the conservation tillage technology free of charge. The Roundup, a post-emergence foliar herbicide, was applied before planting and was later followed by Bullet, a residual pre-emerge herbicide. Field days (Table 5) were conducted at different stages of the maize growth for farmers and the general public, as a training tool and also to make farmers participate with extension agents and officials in discussing their problems and to create awareness among the farming communities about their own agricultural problems.

The yield from each demonstration was determined after weighing the harvested grain from the whole plot from the conventional and conservation tillage plots. National crop production and yield estimates were used to come up with yields from the traditional plots. Economic analyses were also conducted for the three systems of maize production to determine the profitability of the introduced technologies.

RESULTS AND DISCUSSION

Maize grain yields

Conventional Management Training Plots (MTPs): Maize grain yields from the conventional MTPs for the 1998/1999; 1999/2000 and 2000/2001 cropping seasons are presented in Table 3. Maize grain yields are over 300% higher in SG 2000 maize demonstrations than the traditional maize farmers field (Table 4). These results show that the

Table 1. Ecology, soil type, latitude and longitude, elevation, temperature and annual rainfall for the ADDs and RDPs under SG 2000 Malawi project activities.

ADD/RDP	Natural ecology	Soil type	Latitude degrees	Longitude degrees	Elevation (masl)	Temper-ature (°C)	Annual rainfall (mm)
Blantyre							
Blantyre/shire	Shire highlands	Ferrallitic	15° 40′	35° 00′	2900 - 4000	15 - 18	875 - 1250
Mulanje	Lujeri basin	Ferrasol	16° 00′	35° 30′	2050 - 3650	15 - 21	>1750
Mwanza	Undulating plain	Ferrallitic / Ferruginous	15° 30′	34° 30′	1500 - 2500	21 - 24	1000 - 1375
Phalombe	Plain	Ferruginous / Ferrallitic	15° 30′	35° 30′	2200 - 3100	21 - 24	825 - 1000
Thyolo	Shire highlands	Lithosols / Ferruginous	16° 30′	35° 15′	2500 - 4500	16 - 21	1250 - 1750
Machinga							
Balaka	Plain	Ferruginous	15° 00′	35° 00′	1850 - 2200	21 - 24	750 - 875
Kawinga	Plain	Ferrallitic	15° 00′	35° 30′	2100 - 2700	21 - 24	875 - 1000
Namwera	Plain	Ferrallitic	14° 30′	35° 30′	2500 - 3300	18 - 21	1000 - 1250
Mangochi	Lake shore plain	Calcimorphic	14° 30′	35° 15′	500	21 - 24	800 - 1000
Zomba	Shire highlands	Lithosols	15° 30′	35° 30′	2900 - 4000	16 - 21	750 - 1000
Lilongwe							
Dedza hills	High altitude hill zone	Ferruginous / lithosols	14° 05′	34° 15′	4800	18 - 19	1000 - 1250
Lilongwe east	High altitude plateau	Ferruginous	14° 00′	34° 00′	3600 - 4200	20 - 21	1000 - 1250
Lilongwe west	Mid-altitude plateau	Ferruginous latosols	13°59	33° 38′	1100	18 - 21	800 - 1000
Ntcheu	High altitude hill zone	Ferrallitic Ferruginous	14° 30′ S	34° 30′		18 - 19	875 - 1250
Thiwi /Lifidzi	High altitude hill zone	Ferruginous latosols	14° 05 S	34° 10′	4800	18 - 26	750 - 1000
Salima							
Salima	Lakeshore plain	Calcimorphic	13° 40′ S	34°17′	500	24 - 25	800 - 1200
Mzuzu							
Rumphi	Nyika plateau	Ferrallitic	11° 00′ S	34° 00′	3000 - 5000	13 - 21	625 - 750
Mzimba centre	Vipya plateau	Ferrallitic and lithosols	12°05′ S	33° 29′	4000 - 5300	18 - 20	875 - 1000
Mzimba south	Vipya plateau	Ferrallitic	12° 05′ S	33° 29′	4000 - 4600	20 - 21	750 - 875

Table 2. Year, plot sizes, general agronomical information for the MTPs and number of farmers per ADD.

ADD/RDP	Year	Plot Size	Target plant population	Source of seed	Planting time	Fertilizer rate	Basal dressing	Top dressing	Number of farmers
		(ha)	(# ha^{-1})			- - - - - - - (kg N-P-K ha^{-1})	- - - - - - -		
Blantyre	1998 – 99	0.1	53,000	PANNAR	Nov - Dec	92-21-00	46-21-00	46-00-00	40
	1999 – 00	0.1	53,000	Seed Co.	Nov - Dec	92-21-00	46-21-00	46-00-00	692
	2000 – 01	0.1	53,000	Nat. Seed	Nov - Dec	92-21-00	46-21-00	46-00-00	890
Machinga	1998 – 99	0.1	53,000	Monsanto	Nov - Dec	92-21-00	46-21-00	46-00-00	50
	1999 – 00	0.1	53,000	PANNAR	Nov - Dec	92-21-00	46-21-00	46-00-00	589
	2000 – 01	0.1	53,000	Seed Co.	Nov - Dec	92-21-00	46-21-00	46-00-00	1020
Lilongwe	1998 – 99	0.1	53,000	Nat. Seed	Nov - Dec	92-21-00	46-21-00	46-00-00	99
	1999 – 00	0.1	53,000	PANNAR	Nov - Dec	92-21-00	46-21-00	46-00-00	509
	2000 – 01	0.1	53,000	Seed Co.	Nov - Dec	92-21-00	46-21-00	46-00-00	917
Salima	2000 - 01	0.1	53,000	PANNAR	Nov - Dec	92-21-00	46-21-00	46-00-00	50
Mzuzu	1998 – 99	0.1	53,000	Seed Co.	Nov - Jan	92-21-00	46-21-00	46-00-00	60
	1999 – 00	0.1	53,000	PANNAR	Nov - Jan	92-21-00	46-21-00	46-00-00	257
	2000 – 01	0.1	53,000	Monsanto	Nov - Jan	92-21-00	46-21-00	46-00-00	397

conventional technology out-yielded the traditional system of the farmers by more than three times in Blantyre, Machinga, Lilongwe and Mzuzu ADDs. However, in Salima ADD, the maize grain yields in SG 2000 plots were only 2.7 times higher than in the traditional system of the farmers, during the 2000/2001 cropping season. The lower average maize yields in Salima can be attributed to climatic conditions and management.

Conservation tillage management training plots: A comparison of maize grain yield obtained from conservation MTPs (Table5), traditional system of the farmers (Table 4) and those from conventional demonstrations (Table 3), reveal the following: maize grain yields from conservation tillage plots are 400% higher than traditional system of the farmers in Blantyre, Machinga, and Lilongwe ADDs. However, in Mzuzu ADD, the conservation tillage plots out-yielded the traditional system of the farmers by only 200%. Apparently, the late planting and the persistent rains affected the effectiveness of the Roundup and bullet herbicide. (E.C Kazira, personal communication). Generally, the conventional technology system and the conservation tillage system performed similarly, but were both better than the traditional farmers system. We expected this results since we

Table 3. Agricultural Development Divisions and Rural Development Project names, number of participating farmers, yield range and average maize yield for 1998 / 99, 1999 / 2000 and 2000 / 2001 seasons.

Agricultural Development Division	Rural Development Project name	1998 - 1999 Number of farmers	1998 - 1999 Yield Range	1998 - 1999 Average yield	1999 - 2000 Number of farmers	1999 - 2000 Yield Range	1999 - 2000 Average yield	2000 - 2001 Number of farmers	2000 - 2001 Yield range	2000 - 2001 Average yield
			- - - - (t ha^{-1}) - - - -			- - - - (t ha^{-1}) - - - -			- - - - (t ha^{-1}) - - - -	
Blantyre	BT/Chiradzulu	20	11.2 - 3.4	6.10	284	9.0 - 1.8	5.32	407	8.5 - 3.8	5.08
	Mulanje				70	5.5 - 3.7	4.77	65	4.7 - 1.1	3.02
	Mwanza				64	7.6 - 5.6	7.06	85	5.0 - 2.9	4.86
	Phalombe	20	9.2 - 3.3	6.70	139	8.1 - 1.6	4.29	206	8.1 - 2.9	4.61
	Thyolo				95	5.5 - 3.1	4.52	127	7.4 - 2.9	5.57
Machinga	Balaka				40	5.7 - 2.5	3.80	115	9.7 - 4.1	6.94
	Kawinga				30	5.1 - 3.7	4.41	67	5.7 - 3.4	4.53
	Namwera	50	9.0 - 2.7	4.60	381	7.8 - 3.2	5.41	411	7.9 - 1.8	4.77
	Mangochi				50	7.1 - 3.6	5.71	96	5.8 - 2.1	3.74
	Zomba				88	7.2 - 2.9	5.27	231	7.1 - 3.6	4.74
Lilongwe	Lilongwe W.	50	8.9 - 3.0	4.70	131	6.6 - 3.3	5.35	306	6.7 - 2.8	4.35
	Thiwi/lifidzi	49	8.7 - 2.1	4.80	189	8.5 - 3.3	5.76	220	5.1 - 1.6	3.66
	Dedza hills				60	5.8 - 2.7	4.64	134	6.7 - 2.1	4.14
	Lilongwe E				69	8.8 - 5.3	7.38	153	9.7 - 3.9	6.76
	Ntcheu				60	7.4 - 2.6	5.31	104	9.7 - 1.5	5.25
Mzuzu	Rumphi	20	10.5 - 1.0	5.80	89	15.0 - 4.2	7.05	45	6.4 - 2.5	4.61
	Mzimba c.	20	8.1 - 2.8	5.30	88	10.4 - 4.9	6.51	243	7.0 - 3.2	4.97
	Mzimba s.	20	8.5 - 1.5	4.70	80	9.6 - 6.1	8.47	109	6.0 - 3.1	4.38
Salima	Salima							50	6.2 - 3.6	4.70
Total		249			2,003			3,174		
Av. yield				5.1			5.61			4.80

Table 4. Comparison of maize yields (kg/ha) under traditional, conventional and conservation tillage management in different years and ADDs.

Agricultural Development Division	Type of Management training plot	Maize grain yields 1998/99	Maize grain yields 1999/2000	Maize grain yields 2000/2001	Average yield
		(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Blantyre	Traditional	1542	1530	1002	1413
	Conventional	4600	4920	4944	4821
	Conservation tillage	-	-	4290	4290
Machinga	Traditional	1683	1553	1002	1413
	Conventional	4600	4920	4944	4821
	Conservation tillage	-	-	4290	4290
Lilongwe	Traditional	1452	1569	1085	1369
	Conventional	4750	5688	4832	5090
	Conservation tillage	-	-	5380	5380
Mzuzu	Traditional	1986	1673	1254	1638
	Conventional	5267	7343	4653	5754
	Conservation tillage	-	-	3340	3340
Salima	Traditional	2125	1823	1182	1720
	Conventional	-	-	4700	4700
	Conservation tillage	-	-	5430	5430

had used the farmer field for one year only to demonstrate the conservation system. However, we expect that the differences between the two systems will be increased in favour of the conservation tillage after several years. The build-up of organic matter and the improvement of soil physical characteristics that is expected from the conservation tillage is a medium to long-term phenomenon that will probably start showing up several cropping seasons later. For this reason, the conservation tillage plot is maintained in the same land as long as we can convince the farmer to do so.

Table 5. Number of field days and number of participating farmers per ADD in 2000 / 2001 maize season.

Agriculture Development Division	Rural Development Project	Number of field days	Number of Participating farmers		Total Participants
			Female	Male	
Blantyre	Blantyre/Shire	22	367	388	755
	Chiradzulu	2	56	65	121
	Mulanje	5	188	133	321
	Mwanza	5	113	149	262
	Phalombe	15	474	442	916
	Thyolo	11	145	242	387
	Sub total	60	1,343	1,419	2,762
Machinga	Balaka	13	455	540	995
	Kawinga	7	310	342	652
	Namwera	29	1141	1218	2,359
	Mangochi	7	302	307	609
	Zomba	10	506	566	1,072
	Sub total	66	2,714	2,973	5,687
Lilongwe	Dedza	6	466	701	1,167
	Lilongwe east	10	283	650	933
	Lilongwe west	10	128	304	432
	Ntcheu	12	158	425	583
	Thiwi/Lifidzi	5	94	200	294
	Sub total	43	1,129	2,280	3,409
Salima	Salima	12	118	330	448
	Sub total	12	118	330	448
Mzuzu	Central Mzimba	65	444	1,115	1,559
	South Mzimba	16	392	420	905
	Rumphi	13			592
	Sub total	94	836	1,535	2,371
	Grand total	275	6,140	8,537	14,677

Economic Analysis.

The cost of producing maize in the conventional system, conservation tillage system and the traditional farmer system is presented in Table 7. Farm gate maize prices around harvesting time (June-July) are usually low. The supply of maize at this time of the year is greater than the demand. Later in the season, however, the farm gate prices increase, as supply dwindles and demand increases. During the 2000/2001 cropping season, the average farm gate price soon after harvest was around 3 to 4 Kwacha per kg (Exchange rate Kwacha 65 to US dollar). However, the official price was 5 Kwacha per kilogram. After 4 to 5 months the official price was increased to 8.5 Kwacha per kilogram when the maize was imported at 17 Kwacha per kilogram. Therefore, the marketing price for grain maize in Malawi is disturbing the annual consumption of improved seed and fertilisers by farmers and consequently the national production.

Regardless of the ups and downs of the maize price, a comparison of net income from the three production systems was made. The comparison indicates that at the farm gate prices of MK 10.00 per kg, a higher net income is obtained from the conservation tillage system (MK3, 394.00), followed by the conventional system (MK3,135.00) and then the traditional farmer system (MK18.00). The higher net income from the conservation system is a result of savings accrued from labour, indicating that the herbicides used in the conservation system are cost effective.

The farmers have accepted the technology applied in the conventional system and the conservation tillage system so that the demand from farmers to participate in the programme has increased. The increases in number of participating farmers were from 249 in 1998/1999 to 3,174 in 2000/2001(Table 3). The findings of an SG 2000 internal review conducted in July 2001 show an adoption rate of 90% by the graduated farmers (farmers who participated in the project from 1998 to 2000) who are continuing to practise the technologies demonstrated on their own farms. Some participating farmers are even expanding the use of it in their fields including dimba crops (out of season maize grown under residual moisture).

SUMMARY AND CONCLUSIONS

Generally, the project of Sasakawa Global 2000 in Malawi has shown that maize yield can be tremendously increased from the current national average yield of 1.38 tonnes per hectare to at least 3.0 tonnes per hectare (a 162 % increase). If the right environment is in place this increase per unit area can be easily achieved. Therefore the country can pass from importing maize to be self-sufficient and consequently she can use the excess for livestock and poultry production and for developing industrial uses.

Table 6. Average gain yield for conservation tillage management per Agricultural Development Division during 2000/2001 maize season.

Agriculture Development Division	Rural Development Project	Area (ha)	Number of field days	Yield range (t ha^{-1})	Average grain yield (t ha^{-1})
Blantyre	BT/Shire	0.1	1	NA	7.5
	Mwanza	0.2	2	3.5 – 3.5	3.5
	Phalombe	0.3	3	4.0 – 7.5	5.7
	Mulanje	0.1	1	NA	4.8
	Thyolo	0.3	3	4.0 – 7.5	5.7
	Totals	1.0	10	NA	
	ADD average				**5.0**
Machinga	Balaka	0.2	2	5.0 – 6.0	5.5
	Mangochi	0.2	2	3.0 – 3.6	3.3
	Nmwera	1.0	10	1.3 – 6.5	4.3
	Zomba	0.4	4	2.8 – 5.7	4.2
	Totals	1.8	18	NA	
	ADD average				**4.3**
Lilongwe	Lilongwe east	0.3	3	3.9 – 9.0	6.6
	Dedza Hills	0.2	2	7.0 – 7.7	7.3
	Lilongwe west	0.4	4	2.3 – 4.8	3.5
	Totals	0.9	9	NA	5.4
	ADD average				**5.4**
Salima	Salima	0.5	5	3.7 – 7.1	5.4
	ADD average				**5.4**
Mzuzu	Central Mzimba	0.5	5	2.5 – 4.3	3.3
	ADD average				**3.3**

Table 7. Average production costs associated with operations and inputs in traditional, conventional and conservation tillage plots in one tend of a hectare at Dowa west, Kasungu, Mzimba, Rumphi and Nkhota kota Rural Development Projects 2001 / 2002.

Operation / inputs (Data collected from 161 farmers)	Tillage system		
	Traditional Cost in MK	Conventional Cost in MK	Conservational Cost in MK
Clearing	100.0	100.0	0.0
Ridging	394.0	264.0	0.0
Seed	76.0	171.0	171.0
Round + labour	0.0	0.0	200.0
Planting	70.0	115.0	115.0
First fertilizer cost + labour	0.0	485	485.0
First weeding	115.0	115.0	0.0
Bullet + labour	0.0	0.0	200.0
Second weeding	180.0	180.0	0.0
2nd Fertilizer cost + labour	491.0	340.0	340.0
Harvesting	356.0	715.0	715.0
Total cost of production (MK)	1,782.0	2,485.0	2,226.0
Yield average obtained in kg / 0.1 ha	180	562.0	562.0
One kilogram of grain cost (MK)	10		
Gross income (MK)	1,800.0	5,620.0	5,620.0
Net income (MK)	18.0	3,135.0	3394.0

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SOIL FERTILITY MANAGEMENT IN MAIZE-BASED PRODUCTION SYSTEMS IN KENYA: CURRENT OPTIONS AND FUTURE STRATEGIES

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ABSTRACT

This paper analyzed the salient factors that affect the adoption of soil fertility management (SFM) technologies in the marginal and medium potential zones of Eastern and Western Kenya, respectively. Data from a survey of 120 smallholder maize farmers from each zone was analyzed using discrete choice (Multinomial logit and Tobit) models. Parameter estimates showed that farmers' resource endowments, costs of SFM technologies, access to cash and labour resources and human capital factors were significant in determining the uptake of SFM technologies. Manure use was restricted to livestock owners suggesting lack of viable alternatives and markets for the input. In the medium potential zone, 52 percent of the farmers were adopters of fertilizer but 70 percent of these adopters applied less than 15 kgN/ha against recommended levels of 55 kg/ha. Thirty-six per cent of the farmers in the marginal zone were adopters of fertilizer and applied an average of 8.6 kgN/ha against a recommended level of 50 kgN/ha. The foregoing results show that resource poverty coupled with low returns to SFM technologies' use were prominent reasons behind their sub-optimal adoption. Maize sector policy interventions should emphasize the provision of sustainable credit and development of low-cost SFM techniques for smallholder farmers in Kenya.

Key words: Adoption, multinomial logit, maize, policy options, soil fertility management, tobit model.

INTRODUCTION

Kenya's experience with maize research and technology development illustrates the need to put this vital sector on a high productivity path beyond what is currently attained. The maize sector in Kenya has experienced considerable breakthroughs especially in the spheres of varietal development. The use of improved varieties supplemented by purchased inputs especially fertilizers increased maize yields in the late 1960s to the mid 1970s. Maize yields grew at an average rate of seven percent annually over the 1963-1991 period, but declined significantly after the mid-1970s, falling 11 percent in the 1963-1974 period and four percent between 1985 and 1991 (Lynam and Hassan, 1998). Hassan and Karanja (1997) reported that by 1997, in most maize growing regions, average farm yields were about half of KARI's experimental yields and 25-50 percent lower than yields recorded for researcher managed trials in farmers' fields.

The trends in maize productivity have been noted to be on the decline especially in the decades following the 1970's. As such, farmers have not seen sustained growth in maize yields and the maize revolution has yet to fulfill its earlier promise. However, a huge potential exists for increasing maize production in Kenya through increasing the use of improved seeds, soil fertility management and appropriate crop husbandry. Muguneiri (1996) showed that smallholder farmers in Kenya are resource-poor, and emphasized better soil fertility management as a complement to improved maize seeds use. Moreover, past research in Kenya shows that farmers adopt new seed varieties, but consistently ignore extension recommendations on improved SFM practices (Rukandema *et al*, 1981). An understanding of the major factors behind the foregoing scenario of poor adoption of SFM practices is indispensable in an attempt to revamp the African maize systems. The present study is an attempt in this regard.

Technology adoption studies have become common in Kenya's maize sub-sector (Hassan, 1998). Analyzing factors that condition the uptake of technologies is an important link in the process of technology generation and dissemination. This is important when it is considered that the macro-economic, policy and institutional environment in which farmers operate affect their ability to adopt specific technologies. However, specific social, economic and other idiosyncratic circumstances at the individual level determine how each farmer responds to the macro environment in which all of them operate. Moreover once important micro level factors that constrain or foster adoption have been identified, it is possible to design policies that enable farmers to go around the constraints and take advantage of the favourable factors. The relevance of the present study can be seen in this light.

While adoption of soil fertility management practices especially fertilizers is low in the entire Kenyan maize sub-sector, the situation is more acute in the marginal areas of the country. These input use patterns have led many researchers to conclude that alternative strategies to fertilizer adoption, especially in the areas of resource management present more realistic strategies in creating sustainable maize systems in the country. In this regard, crop improvement and soil fertility management are essential for increasing crop productivity in most smallholder cropping systems in Africa. Moreover, studies documenting adoption of soil fertility management technologies in Kenya have been infrequent. The paucity of empirical economic studies on factors influencing the adoption of soil fertility management in Kenya justifies further studies. The present paper has made an attempt to study the adoption of organic manure in concert with inorganic fertilizers in Kenya.

Prominent issues that need attention in Kenya were highlighted by KARI (1994) and included such issues as low soil fertility, labour scarcities and crop pests and diseases. Use of inorganic fertilizer, farmyard manure, alley cropping, and use of herbicides in weed control to alleviate labour scarcities as well as the need to improve timeliness of farm operations were identified by KARI (1994) as SFM practices that could offset these constraints. Studies on soil fertility management should expand the range of practices examined to move beyond fertilizers alone and to include organic manures, crop rotations and agro forestry interventions. An attempt has been made to draw relevant lessons for Kenya as well in terms of future SFM research and extension policies necessary to kick-start smallholder maize productivity on a high productivity and sustainable pathway.

A survey of literature on maize technology adoption studies in Kenya shows that past adoption studies on soil fertility management (SFM) have dwelt on fertilizers alone. It is important, however, to recognize that farmers apply multiple SFM practices and, as such, in studying the adoption of SFM practices it is important to bear in mind the multiple choice scenarios that farmers face. The present study has developed a multinomial logit model and a simultaneous equation model to analyze the adoption of SFM techniques in Kenya.

Farmer's adoption patterns of SFM practices were characterized by socio-economic attributes. Other objectives included the determination of the factors affecting the adoption of fertilizers, organic manure and combinations of the two as distinct choices in Western Kenya, determination of the factors influencing the adoption of fertilizers in Eastern Kenya simultaneously with improved seeds, and coming up with recommendations regarding future policies necessary for generating, extending and fostering the adoption of soil fertility management practices in Kenya.

METHODOLOGY

Theoretical models.

Technology adoption can be modeled within frameworks that explain individual choice behaviour. The decision to adopt an innovation is a behavioural response arising from a set of alternatives and constraints facing the decision maker as illustrated by Leagans (1979). Technology adoption phenomena necessitate a different analytical approach from those used in consumer theory and hence discrete choice theory is a more appropriate basis for analysis (Ben-Akiva and Lerman, 1985). Based on this framework, discrete choice models were developed to analyze the adoption of various soil fertility management strategies.

Analytical models.

Descriptive and quantitative statistics were used in the analysis of the data. In analyzing the determinants of soil fertility management options, a multinomial Logit model was used in Western Kenya while a simultaneous equation Tobit model was used in Eastern Kenya.

Multinomial logit.

A multinomial logit model was used to analyze the factors affecting choice of the soil fertility management (SFM) option in Western Kenya. The multinomial logit model is based on the random utility model. The utility to an adopter of an alternative *(U)* is specified as a linear function of the individual and farm specific characteristics, the attributes of the alternative and other institutional factors as well as a stochastic component. In the present study use has been made of individual specific and institutional characteristics *(X)*.

$$U\ (alternative\ 0) = \beta_j X_0 + e_j$$
$$U\ (alternative\ 1) = \beta_j X_0 + e_j$$
$$U\ (alternative\ j) = \beta_j X_0 + e_k$$

Suppose the observed outcome (dependent variable) = *choice j*. If U (alternative j) > U (alternative k) $\forall$ j $\neq$ k, then

$$\beta_j X_j + e_j > \beta_k X_k + e_k.$$

The probability of choosing an alternative is equal to the probability that the utility of that particular alternative is greater than or equal to the utilities of all other alternatives in the choice set. The farmer maximizes utility from a technology choice in the sense that, that particular choice best minimizes the cost of production, maximizes profits or ensures achievement of a threshold level of subsistence or any other objective as the case may be.

The dependent variable was a discrete variable taking values 0, 1, 2 and 3 for cases where no fertilizer/manure, fertilizer alone, manure alone and fertilizer-manure combination was used by the farmer, respectively. The dependent variables (X_o) were as follows: Age of the farmer in years (AGE), level of formal schooling of decisionmaker in terms of number of years spent in educational institutions (EDUC), gender of the decisionmaker (1 if male and 0 if female) (GEND), the size of the farm household measured in persons (FMLY), presence of a cash-generating non-maize enterprise (0 if present and 1 if not) (ENTPRS), livestock ownership (LVSTK) with the value 0 if no livestock is owned and 1 if livestock is owned.

Other variables were farm size operated measured in hectares (FMSZ), use of machinery in land preparation (MACH) taking value 1 if tractor or ox-plough was used in land preparation and 0 if land preparation was done manually, credit participation (CRDT) taking value 1 if credit was accessed at least once in the two years prior to the survey and 0 if not. Extension contact (CONTACT) taking binary values 1 if farmer had ever had extension contact through various channels and 0 if not. Fulltime family labour (FLTIME) was also a variable included measured in the number of family members who work fulltime on the farm. Farmers' perception of the right planting time (PLTIME) was also included as a variable to assess its impact on SFM adoption. Variables reflecting cash and labour costs namely mandays per hectare used in planting operation (PLTLB), cost of tillage operations in Kenya shillings per hectare (CSTPRP) and cost of a single weeding operation measured in mandays per hectare (WDLB) were also included.

The simultaneous equation tobit model.

The Tobit model is as follows (McDonald and Moffit, 1980): Let IA = intensity of adoption of an improved technology; IA* = the solution to utility maximisation problem of intensity of adoption subject to a set of constraints per household and conditional on being above a certain threshold limit. IA_0 = the minimum technology adoption intensity per household. Here, IA = 0 amount of fertiliser applied per hectare of maize.

Therefore: $IA = IA^*$ if $IA^* > IA_0$
and $IA = 0$ if $IA^* \leq IA_0$

The equation above represents a censored distribution of intensity of adoption since the value of IA for all non-adopters is zero. This study treated the amount (kg) of inorganic fertiliser applied per hectare as the dependent variables. A set of independent variables capturing a variety of factors (individual, household, institutional and farm characteristics) was considered. To model the adoption of inorganic fertilisers (ADFRT), the following simultaneous equation was specified: -

$$ADFRT = \alpha\ ADIS + \beta X_i + \mu_{i.}$$

Where X was a vector of explanatory variables; α and β were parameter estimates of the respective variables and μ_i are random errors. The estimated parameters were;

$$ADFRT = \beta_0 + \beta_{11}\ ADIS + \beta_{21}EDC + \beta_{31}AGE + , \ldots, + \beta n_1 + \mu_{1.}$$

In analysing the adoption of inorganic fertilisers, the improved maize seeds are an endogenous factor and hence a simultaneous model was to solve for endogeneity and simultaneity.

The dependent variable for the model (ADFRT) was the amount of fertiliser applied per hectare (kgs/ha). The multidisciplinary independent variables included farmer/farm characteristics and institutional factors postulated to influence technology adoption. These variables included age (AGE), formal education level (EDC), gender (GND), farm size (FMSIZE), extension (EXT) and family size (FMLYSIZE) specified earlier. Other factors included off-farm income (OFFINC), membership of farmers groups (FMSGRP), attendance at field days (FLDDAY) and hired labour (HIREDLB) that were measured as dummies. Distance to the market (DTM) was measured in kilometres while experience (EXP) was measured in years. The proportion of the farm planted to improved seeds (ADIS) was measured in hectares.

The rationale for inclusion of these factors was based on *a priori* of agricultural technology adoption literature. Age, education and experience were hypothesised to positively influence the adoption of SFM technologies since as farmers acquire more of these factors, their ability to obtain, process and use new information improves and they are likely to adopt (Adesina *et al*, 1993). The effect of farm size and family size on adoption is not clear in adoption literature as they can influence adoption in both directions. Institutional factors were hypothesised to positively influence the adoption as these support services facilitate the uptake of new technologies.

Data sources and sampling procedure.

Field surveys were conducted in the two agro-ecological zones where 120 farmers in each zone were interviewed using semi-structured questionnaires. In Eastern Kenya, a two stage sampling procedure was used to select four work units within two divisions in Machakos district while a stratified sampling in Western Kenya similarly selected four work units within two divisions of Kakamega district.

RESULTS AND DISCUSSION

Descriptive analysis results showed that 36 percent of the farmers in the marginal Eastern zones of Kenya had adopted inorganic fertilizers. The average farm applied 8.6 kgN/ha and 10 kgN/ha as compared to 50 kgN/ha recommended by KARI for this area. This fertilizer was applied to 11 percent of the farm size. In Eastern Kenya, all the farmers interviewed in the survey year used farmyard manure as a fertility enhancing strategy at an average rate of 2.5 tones/ha and 54 percent of these farmers applied a combination of manure and fertilizers on their farms.

In the Western medium potential zones of Kenya, 52 percent of the surveyed farmers had adopted fertilizers but 70 percent of all respondents applied less than 15 kgN/ha as opposed to a recommended level of 55 kgN/ha. Further, nine percent of the survey farmers used none of the soil fertility management strategies while 39 percent used manure and 25 percent combined the use of manure with that of inorganic fertilizers. Fertilizer markets were relatively well developed whereas manure markets were undeveloped with the amount of manure available being dependent on the livestock numbers.

Farmer and farm characteristics were important determinants of the SFM strategy to apply. A majority of the farmers were middle-aged (31–50 years) with the average age being 45 years. Families had an average of seven persons and average years of formal education were eight years, which conformed well to a primary school level of education. In general, more male than female farmers were managers of their farms and owned more land, were better educated, had better access to extension and credit than female farmers. Institutional support in the form of credit and extension was generally weak and inaccessible in both regions.

The results of the multinomial logit analysis (Table 1) above indicated that a number of factors were significant in influencing the adoption of inorganic fertilizers, manure and combinations of these two practices. Formal schooling positively influenced the use of fertilizer alone, manure alone and their combinations. Education increases the speed with which new skills and techniques can be learned and adopted. Better-educated farmers are more likely to acquire, interpret and use technical advice from research allowing them to assess the relative benefits and risks from using alternative technologies (Nkonya *et al*, 1997).

Farm size positively influenced the probability of adoption of the three SFM options. The positive relationship is plausible because adoption costs, when considered as fixed expenses, may tend to discourage adoption by smallholders who are likely to face more severe resource constraints. Operators of larger farms are likely to have more opportunities to learn about new technologies, have more incentive to adopt and are able to bear the risks associated with early technology adoption (Feder and Slade, 1984; Feder et al, 1985).

Household size was negatively associated with the probability to apply the SFM options. This outcome may arise from the effect of household size on household disposable income and resource allocation behaviour. Larger households may have more subsistence requirements leaving proportionately fewer resources to finance the adoption of improved techniques. The number of family members working fulltime on the farm positively influenced use of fertilizer alone and manure alone since the more people available to work fulltime on the farm, the higher the likelihood that the farm household will have some of its labour constraints relaxed.

Table 1. The MLEs of the Multinomial Logit model of the factors affecting Choice of Soil Fertility Options on smallholder maize farms in Western Kenya.

Variable	Co-Efficient Estimates											
	Fertilizer Alone Chosen				Manure Alone Chosen				Fertilizer -Manure Combination			
	Estima	SE	t-ratio	p-value	Estimate	SE	t-ratio	p-value	Estimate	SE	t-ratio	p-value
Constant	0.04	3.00	0.01	0.99	2.90	2.80	1.02	0.30	-0.20	3.07	-0.06	0.95
AGE	0.02	0.05	0.40	0.67	0.04	0.05	-0.9	0.40	-0.03	0.50	0.60	0.60
EDUC	0.67	0.24	2.80	0.005***	0.60	0.23	2.40	0.02**	0.70	0.23	2.80	0.0045***
GEND	-3.7	1.60	-2.30	0.02**	-3.50	1.60	-2.30	0.02**	-3.20	1.60	-2.00	0.04**
FMLY	-0.90	0.30	-2.90	0.004***	-0.80	0.30	-2.62	0.01***	-0.90	0.30	-2.90	0.003***
ENTPRS	-1.20	1.50	-0.80	0.42	-1.20	1.44	-0.80	0.40	-1.75	1.50	-1.20	0.024
LVSTK	4.50	1.90	2.35	0.02**	5.00	1.90	2.60	0.01***	5.30	1.96	2.70	0.007***
FMSZ	2.07	0.84	2.50	0.01***	1.90	0.80	2.30	0.02**	2.20	0.80	2.63	0.008***
MACH	-0.27	1.4	-0.20	0.84	-1.60	1.40	-1.20	0.22	-0.12	1.50	0.09	0.94
CRDT	7.90	4.00	1.90	0.05**	8.10	4.06	2.00	0.04**	8.96	4.00	2.20	0.03**
CONTACT	0.90	1.20	0.80	0.43	-1.80	1.13	-1.70	0.10*	-0.50	1.20	0.42	0.70
FLTIME	0.90	0.50	1.70	0.09*	1.07	0.53	2.01	0.04**	0.74	0.56	1.33	0.18
PLTIME	2.71	1.40	1.94	0.05*	1.19	1.40	0.90	0.40	2.50	1.40	1.80	0.08*
PLTLB	0.06	0.07	0.91	0.40	0.05	0.06	0.70	0.50	0.08	0.07	1.10	0.27
CSTPRP	-0.0008	0.0005	-1.70	0.09*	-0.0008	0.0005	-1.73	0.08*	-0.0008	0.0005	-1.62	0.11
WDLB	-0.07	0.03	-2.16	0.03**	-0.08	0.03	-2.40	0.02*	-0.08	0.03	-2.40	0.02**

Unrestricted Log Likelihood –115.0 Restricted Log Likelihood –157.0 McFadden's R^2 0.27
Chi Squared 82.80 Degrees of freedom 45 Significance Level 0.01
*The asterixes *, **,*** refer to significance at 10%, 5% and 1% respectively*
Source: Authors survey 2000.

Table 2. Simultaneous equation Tobit maximum model estimates for the intensity of adoption of chemical fertilizers (ADFRT) in Eastern Kenya.

Variable	Coefficient	Std error	t- ratio	p-value	Total Change δE (IA)/δx	Change among Adopters δE (IA*)/δx	Change in Probabilityδ F (z)/ δx
CONSTANT	-21.797	25.80	0.845	0.39818	-	-	-
ADIS	-6.639	5.871	-1.131	0.25810	-2.390	-1.849	-0.422
AGE	-0.268	0.317	-0.846	0.39760	-0.096	-0.075	-0.017
GND	7.516	7.898	0.952	0.34129	2.705	2.094	0.478
EDC	2.811**	1.143	2.459	0.01394	1.012	0.783	0.179
FMSIZE	-0.643**	0.269	-2.388	0.01695	-0.231	-0.179	-0.041
FMLYSIZE	1.187	1.453	0.817	0.41389	0.427	0.331	0.076
OFFINC	-1.471	6.389	-0.230	0.81798	-0.529	-0.410	-0.094
DTM	-0.097	0.304	-0.318	0.75039	-0.035	-0.027	-0.006
EXFRT	1.424**	0.702	2.028	0.04257	0.513	0.397	0.091
FMSGRP	7.071	9.466	0.747	0.45511	2.545	1.970	0.450
FLDDAY	-11.094*	6.053	-1.833	0.06680	-3.994	-3.090	-0.706
EXT	7.486	9.332	0.802	0.42243	2.695	2.085	0.476
HIREDLB	12.948*	7.814	1.657	0.09752	4.661	3.607	0.823
FRTAREA	2.886***	0.875	3.299	0.00097	1.039	0.804	0.184
Log likelihood function (LnL_L)	-376.174	$Z = -0.35$ $F(z) = 0.36$ $f(z) = 0.38$ $\sigma = 5.9$					
Log likelihood function (LnL_0)	-434.085						
Likelihood ratio index	0.133						
Model size (observations)	121						

***, **, and * = Significance at 1%, 5% and 10% levels respectively.

Credit availability also positively related to use of the three SFM options. Capital in the form of either accumulated savings or access to capital markets is necessary to finance the uptake of new agricultural technologies. Farmers' extension contact was negatively working fulltime on the farm positively influenced use of fertilizer alone and manure alone since the more people available to work fulltime on the farm, the higher the likelihood that the farm household will have some of its labour constraints relaxed.

Credit availability also positively related to use of the three SFM options. Capital in the form of either accumulated savings or access to capital markets is necessary to finance the uptake of new agricultural technologies. Farmers' extension contact was negatively related to use of manure alone. Byerlee (1994) argued that extension credibility might suffer in situations where their recommendations to farmers are unsuitable for the farmers' conditions. Farmers' correct perception of the right planting time positively influenced use of fertilizer and fertilizer-manure combinations. A farmer's perception in this regard may be indicative of his/her overall correct understanding of soil management practices. Other significant but negative factors in determining SFM technologies use included the amount of labour used for one weeding operation and per hectare cost of a single land preparation operation suggesting that reductions in tillage costs might lead to resource savings that can be applied in the adoption of other SFM techniques.

Results of the simultaneous equation tobit model in the marginal zones of Eastern Kenya (Table 2) below indicated that formal education level, experience in use of fertilizers, hired labour, area receiving fertilizers, farm size and attendance at field days significantly influenced the intensity with which fertilizers were used. A positive significant relationship at a 0.01 level was observed between education and the intensity of fertilizer use in Eastern Kenya. An extra school year increased the probability of fertilizer use by 18 percent and would increase fertilizer application per hectare by one kilogram for the entire sample while the increase among adopters would be 0.78 kg. Highly educated farmers tended to adopt new technologies more quickly. The impact of education on adoption of SFM is positive in both cases showing the universal importance of education in technology adoption across agro-ecological zones.

The effect of farm size on the intensity with which fertilizers were used in the marginal zones was negative and significant at a 0.05 level. An increase in farm size by an extra hectare reduced the probability of fertilizer use by four percent while reducing its application by 0.18 kg/ha among adopters and by 0.23 kg/ha for the entire sample.

This relationship implied that producers farming less land used fertilizer more intensively per hectare and suggested that smaller farms were more likely to adopt SFM techniques. This was contrary to the influence of farm size in Western Kenya and might have arisen from greater risks associated with inorganic fertilizer application in the marginal zones.

Experience positively influenced the intensity of fertilizer use at the 0.05 level. An extra year of experience increased the probability of fertilizer use by nine percent while it increased its use by 0.51 kg/ha for the whole sample and by 0.4 kg/ha among adopters. This relationship implied that experienced farmers had better technical knowledge and were likely to apply improved SFM techniques. Experienced farmers were able to assess the risks and relative returns to investment in SFM techniques and were likely to be getting the highest possible returns from investments in SFM. As farmers gain experience, it is expected to positively influence their decision-making skills (Adesina *et al*, 1993).

Hired labour positively and significantly influenced fertilizer use in the marginal zones. This implied that farmers who could afford to hire labour were more likely to improve the management of their soils. Availability of fulltime family labour was also shown to positively influence adoption of SFM options for Western Kenya confirming the centrality of labour in the adoption of SFM techniques. Attendance at field days was also significant but negative. The negative relationship could be explained by the possibility that the field days that farmers attended were not specifically on soil fertility management. This is similar to the negative impact of extension contact for the Western zone. These outcomes provide a case for a fundamental reexamination of extension programmes serving Kenya's maize sub-sector.

CONCLUSIONS AND RECOMMENDATIONS

The results of the study showed that resource endowment factors such as farm size and livestock ownership, human capital factors such as the formal education level, experience and labour and factors that reflect costs of production such as land preparation significantly influence the techniques applied in soil fertility management in Kenya.

Policy interest should therefore be rekindled in the search for ways of providing sustainable credit sources to support smallholders in view of the importance of credit in fostering adoption of the practices considered in this study. This can be achieved by encouraging the formation of co-operative groups through which farmers can access credit and facilitate dissemination of information about new innovations.

Improvement of the literacy levels can greatly improve SFM. There is need for the government and other development agencies to invest more in village schools and other educational efforts such as adult education and provide free primary education. Extension programmes should focus more on education and skill building and problem solving approaches rather than the prescriptive role of offering pre-packaged recommendations that may not apply to all farmers with equal success.

It is now widely acknowledged that farmers are aware of the need for soil fertility management interventions in Kenya. However, soil fertility management patterns were sub-optimal due to resource poverty that was reflected in the inability of most of the farmers to acquire adequate quantities of fertilizers and manure to use.

The challenge facing researchers in the area of SFM in maize production in Kenya is that of finding cost-effective ways of increasing SFM interventions in the face of land, labour and cash constraints. Techniques that optimize the returns to the scant resources available to farmers and which rely on internally generated soil nutrient sources will find ready acceptance. Maize-legume rotations or intercrops and agro-forestry techniques will be important in this regard.

In the long run, the need for external nutrient inputs is inescapable. However, adequate use of these inputs will depend on the performance of the Kenyan economy. Prospects are now emerging that application of biotechnology in breeding of maize could lead to the development of low-nitrogen tolerant or nitrogen fixing maize varieties. If these prospects can be realized this will represent an enormous revolution (gene revolution) in the impoverished African maize systems, as it will largely reduce the need for costly external nitrogen.

Future soil fertility research policy options rest heavily on pragmatic breeding and biotechnology approaches for developing low N-tolerant maize varieties to lessen the need for costly external inorganic and organic interventions. Developing high-return maize-legume agronomic techniques and resource management technologies appear indispensable if sustainable maize productivity is to be achieved.

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THE USEFULNESS OF CHLOROPHYLL FLUORESCENCE IN SCREENING FOR DISEASE RESISTANCE, WATER STRESS TOLERANCE, ALUMINIUM TOXICITY TOLERANCE, AND N USE EFFICIENCY IN MAIZE.

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ABSTRACT

Plant breeders need to know which traits are the most highly associated with grain yield in order to concentrate breeding efforts. Plant production, driven by photosynthesis, is sensitive to abiotic (environmental) and biotic (diseases) stresses. Among all photosynthetic functions, *Photosystem II* (*PSII*) is believed to be the most stress sensitive. The *in vivo* chlorophyll fluorescence (*CF*) technique is a powerful nondestructive and fast method to detect changes in the photosynthetic activity in leaves influenced by changes in the environment or by natural and anthropogenic stress. The ratio Fv/Fm has been shown to be a reliable indicator of stress. We compared *CF* assessments and conventional approaches, for constraints such as drought stress, N deficiency and aluminum toxicity which have induced damage to the *PSII* apparatus, and these changes have permitted us to distinguish genotypes tolerant and sensitive for each mentioned stress. Also, the *CF* parameters have indicated that maize inbred lines L_4, L_1, and L_2 were resistant and line L_3 was susceptible to the two southern rust pathogen (*Puccinia polysora)* isolates. Finally, the results found in this study have shown that *in vivo CF* measurements can be a useful tool to help in the screening of maize germplasm for abiotic and biotic stress tolerance.

Keywords: Aluminium, drought, leaf disease, nitrogen, photosynthesis, quenching, screening technique, stress, thylakoid membranes, *Zea mays*.

INTRODUCTION

Maize (*Zea mays* L.) is cultivated across a wide range of environments, from extremely stressful to favourable. It is generally agreed that drought and low fertilizer input are the two major constraints in maize production in tropical and subtropical regions. Erratic rainfall patterns can expose the crop to varying intensities of drought stress. Very often, high temperature, low nutrient status of soils and diseases have worsened the deleterious effect of drought.

In tropical areas, experimental evidence leads to the conclusion that adaptation to aluminium stress, low phosphorus and/or nitrogen availability, and short periods of drought, may be controlled by mechanisms which are at least partially related. “Cerrado”, an acid savanna eco-region of Central Brazil, was considered, 30 years ago to be unsuitable for agricultural crop production. This area covers a region of 205 million hectares, from which approximately 112 million hectares are considered adequate for developing sustainable agricultural production. Incorporation of maize breeding efforts involving linked mechanisms that allow better responses under several constraints common in the “Cerrado”, may give rise to tolerant maize materials with higher yield stability and better average agronomic performance over many growing seasons. Efforts are being carried out on several fronts to integrate information and to understand plant traits related to maize productivity and mechanisms controlling this complex system. A better understanding of the mechanisms underlying multiple stress tolerance will allow the design of better selection strategies, speeding up the period for cultivar development in the future.

Several physiological traits have been associated with environment stress tolerance (abiotic and biotic stresses) in maize and other crops (Willman *et al*., 1987; Bolaños and Edmeades, 1993; Selmani and Wassom, 1993; Schussler and Westgate, 1995; Jackson *et al*., 1996; Tollenaar *et al*., 1997; Nissanka *et al*., 1997; Bänziger *et al*., 1999; Edmeades *et al*., 1999; Evans and Fischer, 1999; Loomis and Amthor, 1999; Wilhelm *et al*., 1999; Cárcova *et al*., 2000; Mu-Qing *et al*., 2000; Durães *et al*., 2000, 2001).

For plant improvement, information on photosynthetic performance cannot just be obtained by gaseous exchange measurements (Dwyer *et al*., 1992). In green tissue, photosynthetically active radiation is absorbed by chlorophyll and accessory pigments of the protein-chlorophyll a/b apparatus, and it migrates to the reaction centres of photosystems II and I, where the conversion of the quantum photosynthetic process takes place (Horton *et al*., 1996). Based on this knowledge, measurement of chlorophyll fluorescence (CF) is considered an important technique in ecophysiological studies of plants (Goedheer, 1972; Govindjee *et al*., 1981; Havaux and Lannoye, 1983; Krause and Weis, 1991). Use of CF parameters, such as Fo (initial), Fm (maximum), Fv (variable equal Fm-Fo), Fv/Fm evaluate intact leaves or chloroplast suspensions. Using the CF technique, it is possible to estimate the parameters of actual photosynthetic efficiency of the leaf, under various conditions at various times, and also the potential maximum of the quantum efficiency (Fv/Fm). The Fv/Fm ratio (the measurement of quantum yield potential of photosynthesis, or maximal photochemical efficiency of PSII) has been shown to be a reliable indicator of stress (Krause and Weis, 1991; Schreiber *et al*., 1994). The *in vivo* chlorophyll fluorescence is a powerful, nondestructive and fast method to detect changes in the photosynthetic activity in leaves influenced by changes in the environment or by natural and anthropogenic stress. The objective of this work was to demonstrate that *in vivo* CF measurements can be useful for screening maize germplasm tolerant to environmental stresses, with emphasis on stress due to water, Al and N, and a rust disease, caused by *Puccinia polysora* Underw.

MATERIALS AND METHODS

Abiotic Stresses:

Drought, N and Al: Water, nitrogen and aluminium stresses were imposed under greenhouse conditions on five different maize genotypes in three separate experiments. Chlorophyll fluorescence assessments of the different genotypes were used to characterize the phenotypic response to stress.

Water Regime-treatments: Three levels of water stress (RH1 = 100% FC, (field capacity), RH2 = 63% FC, RH3 = 50% FC) were imposed on 5 maize genotypes in potted soil (5.0 kg of *LEm* soil), from 21 to 35 days after germination, using three replications. See experimental details in Durães *et al*. (2000a, b).

N-treatments: Two levels of N stress (0 and 10 mg l^{-1} of N) were imposed on 5 maize lines at 14 days after the beginning of germination (paper towel), in nutrient solution, with three replications. The maize lines were pre-selected in the field under N stress, and were considered contrasting for N use efficiency and/or biological fixation of N (Marriel *et al*. 1998). See experimental details in Durães *et al*. (2001a).

Al-treatments: Two levels of aluminium stress (0 and 222 µmoles l^{-1} of Al) were imposed from 7 to the 14 days after the beginning of germination (paper towel), in nutrient solution (Magnavaca, 1982), using 5 experimental three-way maize hybrids, with three replications. The values of the relative length of the seminal root (RLSR) were obtained from the means of 3 plants of each experimental unit. Experimental details are described in Durães *et al*. (2000b).

Biotic Stresses

Plant Material and Treatments: Four maize lines (L1-1199, L2-527, L3-5128412891, L4-420) were cultivated in the greenhouse, using 3 plants per pot with 5.0 kg of a *LEm* soil, phase "Cerrado", with three replications. Twenty days after planting the young plants were inoculated with two isolates (I_1-08.99, of Goiânia-GO and I_2-05.99, of Jardinópolis, SP) of *Puccinia polysora,* as described by Robert (1962). Chlorophyll fluorescence assessments according to Durães *et al*. (2000) and visual scoring for pathogenicity were made 15 days after inoculation. Visual scoring was done for pathogenicity according to Robert (1962) using two modified classes of reactions: resistant (R) - chlorotic or necrotic punctuations without the formation of pustules or formation of small pustules with little sporulation, and susceptible (S) - pustules open with or without the chlorotic formation, with moderate to abundant sporulation.

Measures of chlorophyll fluorescence: Chlorophyll fluorescence was measured in each experiment after the imposition of the specific stress treatment using the adaxial surface of the most recently fully expanded leaf with visible ligule, using a PEA II (Hansatech Instruments Co., UK). Before making the measurements of the fluorescence parameters (Fo, initial; Fm, maximum; Fv, variable; tm and relationships), a portion of the chosen leaves for evaluation was adapted in darkness (with leaf clip) for a minimum of 30 minutes at normal temperature, in 3, 5 and 7 intact plants per experimental unit, for water regime, N and Al, respectively; and, for leaf disease caused by *Puccinia polysora*, in 3 intact plants of each one of the 3 replications. The intact leaf was coupled, in the darkness, to the probe of the fluorometer. For the calculation and definition of parameters in the analysis of quenching of the chlorophyll fluorescence, see Scholes and Horton, 1993 and Durães *et al*., 2000, 2001.

RESULTS AND DISCUSSION

Abiotic Stress

(Drought, N and Al): The results from the chlorophyll fluorescence parameters are shown in Tables 1, 2 and 3, respectively, for the treatments with water, N and Al stresses.

Water Regime-treatments: The results of classification for tolerance to drought through chlorophyll fluorescence parameters, point out the lines G5, G4 and G2 (tolerant) and the lines G1 and G3 (sensitive) (Table 1), in agreement with the criteria presented by Durães *et al.* (2000a).

N-treatments: The results of classification for N efficiency through the chlorophyll fluorescence parameters show the lines G1, G3 and G4 (N-efficient) and the lines G5 and G2 (N-inefficient) (Table 2), in agreement with the criteria presented by Marriel *et al*. (1998) parameters, point out the lines G5, G4 and G2 (tolerant) and the lines G1 and G3 (sensitive) (Table 1), in agreement with the criteria presented by Durães *et al.* (2000a).

N-treatments: The results of classification for N efficiency through the chlorophyll fluorescence parameters show the lines G1, G3 and G4 (N-efficient) and the lines G5 and G2 (N-inefficient) (Table 2), in agreement with the criteria presented by Marriel *et al*. (1998).

Al-treatments: The 5 genotypes used in the screening test differed in Al tolerance (Table 3) based on the RLSR parameter as described by Magnavaca (1982). The fluctuation percentage in the fraction Fv/Fm was shown to be correlated with the rate of toxicity injuries for the (RLSR). Among the tested genotypes, G5 and G12 were the most Al tolerant, and the genotypes G8, G6 and G18 (intermediary) were the most sensitive of the tested materials.

Biotic Stress (Leaf disease)

The results of the chlorophyll fluorescence parameters and pathogenicity reactions for *Puccinia polysora* are presented in Tables 4 and 5. In normal physiologic conditions, Fo is constant and not responsive to changes in the photosynthetic metabolism (Goedheer, 1972). However, under the pressure of P. *polysora* inoculations, Fo was increased in only 3/8 of the genotypes x inoculations, indicating damage in the functionality of the photosynthetic apparatus (Durães *et al*., 2001b). This phenomenon should

Table 1. Water regime effects over the chlorophyll fluorescence parameters (Fv/Fo e Fv/Fm), in percent of the Tester, in 5 maize lines. Embrapa Milho e Sorgo. MG, Brazil. November/2001.

Genotype	Fv/Fo			Fv/Fm		
	Soil Water Regime			Soil Water Regime		
	100% FC	63% FC	50% FC	100% FC	63% FC	50% FC
	Tester	% of the Tester	% of the Tester	Tester	% of the Tester	% of the Tester
G1- L1147		68.7	53.1		88.9	90.0
G2- L13.1.2 (T)		77.7	76.0		92.4	92.4
G3- L6.1.1	100	78.8	33.6	100	88.7	64.7
G4- L8.3.1		88.7	77.9		95.7	96.7
G5- L8.3.1a		96.9	91.5		99.2	95.5

FC, Field Capacity

Table 2. Nitrogen effects over the chlorophyll fluorescence parameters in 5 contrasting maize lines, for N efficiency. Embrapa Milho e Sorgo. Sete Lagoas, MG, Brazil. November 2001.

Genotype	Fv/Fo			Fv/Fm		
	Tester	N-treatment	% of theTester	Tester	N-treatment	% of theTester
G1- L55 N	3.407	3.623	106	0.772	0.782	101
G2- L100 N	3.112	2.905	93	0.755	0.744	99
G3- L9.1 N	3.124	3.439	110	0.756	0.774	102
G4- L7.1 N (T)	3.028	3.265	108	0.751	0.764	102
G5- L17.2 n	2.920	2.706	93	0.744	0.729	98

Tester (10 N, 7+7 days): maize young plant kept in nutrient solution with low N availability (10 mg l^{-1}), during 7 days and renewed for another 7 days; N-treatment (0 N, 14 days): maize young plant kept in nutrient solution (0 N) during 14 days.

Table 3. Aluminum effects over the chlorophyll fluorescence parameters in relation to RLSR, in 5 experimental maize lines. Embrapa Milho e Sorgo. Sete Lagoas, MG, Brazil. November/2001.

Genotype	Fv/Fo			Fv/Fm			% of the RLSR in relation to Al (0 μmoles l^{-1}) *
	Tester	Al-treatment	% of the Tester	Tester	Al-treatment	% of the Tester	
G5 (T)	2.654	3.170	119	0.718	0.754	105	47.6 (5.4)
G12	2.586	3.042	118	0.734	0.738	101	43.9 (4.4)
G8	3.695	3.150	85	0.786	0.758	96	23.5 (2.2)
G6	3.492	3.182	91	0.776	0.759	98	22.1 (0.6)
G18	3.282	2.947	90	0.762	0.744	98	20.1 (1.9)

* Mean standard deviation in parentheses; RLSR – Relative Length Seminal Root

Table 4. Resistance/Susceptibility effects to *Puccinia polysora* in maize, over chlorophyll fluorescence parameters. Embrapa Milho e Sorgo. Sete Lagoas, MG, Brazil. November/2001.

Treatment		Fv/Fo			Score Scale* (1 to 5)	Fv/Fm			Score Scale* (1 to 5)
Genotype	Isolate	1. NI (Tester)	2. I	% of the Tester		1. NI (Tester)	2. I	% of the Tester	
L_1-1199	I_1- 08.99	3.261	2.891	0.87	1	0.765	0.741	0.97	1
	I_2- 05.99	2.898	1.748	0.60	3	0.743	0.590	0.79	2
L_2-527	I_1- 08.99	2.565	1.423	0.55	4	0.716	0.489	0.68	3
	I_2- 05.99	2.730	1.940	0.71	2	0.732	0.657	0.90	1
L_3- 5128412891	I_1- 08.99	2.716	0.422	0.16	5	0.730	0.290	0.40	5
	I_2- 05.99	2.756	0.502	0.18	5	0.732	0.302	0.41	5
L_4-420	I_1- 08.99	3.161	2.473	0.78	2	0.759	0.712	0.94	1
	I_2- 05.99	2.726	2.590	0.95	1	0.732	0.721	0.98	1

* Plant per pot: *NI = No-inoculated leaf (tester)*, 1st. Superior leaf with visible ligule; and, *I = Inoculated leaf,* inferior. Scale of maize leaf disease *Puccinia polysora*: 1- resistant, 2- partialy resistant, 3- intermediate, 4- partially susceptible, 5- total susceptible (Robert, 1962).

have happened if the PSII reaction centers were damaged, or if the energy transference of excitement from the antenna to the reaction centers was impeded, as presented by Bolhar-Nordenkampf *et al*. (1989). Our results suggest that Fo was not a good parameter to evaluate the tolerance of the genotypes to the *P. polysora* isolates. In the sensitive genotype to *P. polysora*, the variable fluorescence (Fv) decreased about 5 and 9 times for the genotype L_3-5128412891 x Isolate I_1-08.99 and Isolate I_2-05.99, respectively (Durães *et al*., 2001b), indicating an inhibition site in the photo-oxidizer side of the PS II, in agreement with Govindjee *et al*. (1981) and Havaux and Lannoye (1983).

The data discussed in Durães *et al*. (2001b) showed a

Table 5 - Resistant/Susceptibility classification of maize lines to *Puccinia polysora*, based on fluorescence parameters (% of the Tester = I/NI) and pathogenecity visual scale. Embrapa Milho e Sorgo. Sete Lagoas, MG, Brazil. November/2001.

Genotype	Fluorescence parameters (% of the Tester)		Maize disease visual scale
	Fv/Fo	Fv/Fm	
Resistant	>0.80	>0.80	1
Intermediate	0.50-0.79	0.50-0.79	2 – 3 – 4
Susceptible	<0.50	<0.50	5

* Plant per pot: *NI = No-inoculated leaf (tester)*, 1st. Superior leaf with visible ligule; and, *I = Inoculated leaf,* inferior. Scale of maize leaf disease *Puccinia polysora*: 1- resistant, 2- partialy resistant, 3- intermediate, 4- partially susceptible, 5- total susceptible (Robert, 1962).

decrease in fractions Fv/Fo and Fv/Fm, suggesting that the two isolates of *P. polysora,* caused injury in the thylakoid structure and affected the photosynthetic electron transport, as it was also suggested by Havaux and Lannoye (1983) and Durães *et al*. (2000a) for tolerance to drought in maize.

The four genotypes used in the screening test differed in levels of resistance to *Puccinia polysora*, based on the phenotypic parameters (visual scale) and through the chlorophyll fluorescence. Table 4 displays the ranking for resistance to *P. polysora* among the treatments (lines x isolates), using some of the parameters of the screening method for chlorophyll fluorescence.

It is interesting that all the chlorophyll fluorescence ratios are in the same ranking as in the conventional screening techniques. Based on the two isolates and the four tested genotypes, L_4-420 was the most resistant and L3-5128412891 the most susceptible to *Puccinia polysora*. The other treatments (genotype x isolates), in other words, L_1-1199 I_2-05.99 and L_2-527 I_1-08.99, even though classified by the fluorescence technique as of intermediate resistance, were classified by the visual pathogenicity technique as resistant, considered as justification that the evaluated reaction just represents the result of a cycle of the pathogen in the plant. The data suggest that the defined criteria in Table 5 are useful in evaluating pathogenicity of *P. polysora* in field conditions, during the cycle of the maize crop.

Genotypes L_4-420 and L_1-1199 seem to have a potential for growth in conditions of infection by *P. polysora*, since its photosynthetic apparatus has shown marked rust resistance characteristics, as can be seen by the fractions Fv/Fo and Fv/Fm that were higher in leaves inoculated with *P. polysora* than in the testers (Table 4). This suggests that those genotypes exhibiting a better conversion of the photosynthetic quantum yield under influence of inoculation by *P. polysora* than without inoculation, in relation to sensitive genotypes, as for instance L_3-5128412891. The quantum yield (measured by Fv/Fm) is an indication of the efficiency by which the excitement energy picked up by the PSII antenna is transferred and used by the PSII reaction center for photochemical conversion (Baker *et al*. 1990, Durães *et al.* 2000a). The percentage decrease in Fv/Fm of the sensitive genotypes (L_3-5128412891) after inoculation with *P. polysora* (Table 4) indicates a decrease in the efficiency of the photochemical efficiency of PSII. The change in the fraction Fv/Fm was shown to correlate very strongly with the rate of injury evaluated by the visual index of pathogenicity.

In summary, our results show that measures of *in vivo* chlorophyll fluorescence can be used for screening maize genotypes tolerant to abiotic stresses such as Al, N, extreme temperatures, drought), which is similar to the observations of Havaux and Lannoye (1985). Additionally, chlorophyll fluorescence assessment of genotype resistance to *Puccinia polysora* were in agreement with the visual criteria of pathogenicity, suggesting chlorophyll fluorescence is a useful technique for screening of resistant maize lines to leaf diseases caused by *Puccinia polysora.*

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EFFECT OF *CASSIA SPECTABILIS*, COWDUNG AND THEIR COMBINATION ON GROWTH AND GRAIN YIELD OF MAIZE.

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ABSTRACT

Cassia spectabilis **prunings and cowdung as soil amendments were used to improve soil chemical properties and increase maize yield. Treatments to supply 1, 2, 3, or 4 t ha^{-1} of cowdung alone, 2 t ha^{-1} *Cassia spectabilis* alone and 2 t ha^{-1} *C. spectabilis* in combination with 1, 2, 3, or 4 t ha^{-1} cowdung were applied to a Clayey Kaolinitic Typic Haplustox at Misamfu. A grass mound was used as a control. A randomized complete block design with 4 replications was used. Maize (MMV 400) was the test crop. Soil samples collected at the beginning and end of the study were analyzed for pH, organic C, total available P, exchangeable K, Ca, Mg and Na. Plant height, dry matter, grain yield and nutrient uptake were assessed. Results showed significant increases in plant height (65 %, 59% and 13 %) at 3 growth stages with 99% grain yield increase over the control due to increased N (126.6 %), K, Mg uptake in treatments receiving *Cassia* + cowdung. In these treatments, soil C/N ratios decreased by 5.5% while N and P concentrations increased by 33.3 % and 10.4 % respectively, across all treatments. The study suggests the need for using animal and plant manures together to improve maize nutrition.**

Keywords: ***Cassia spectabilis*, *chitemene*, cowdung, *fundikila*, inorganic fertilizer, organic manure, soil fertility.**

INTRODUCTION

As small-scale farmers intensify crop production, land becomes more prone to soil degradation due to shorter or absence of fallow periods. To use this land continuously, deliberate soil management strategies that improve soil organic matter are required. Incorporating green manure to soil would provide multiple benefits of improving the soil chemical and physical status and in turn improve maize yield. The environment in the High Rainfall Zone (HRZ) of Zambia and the traditional practices of the people provide little support for permanent agriculture. The HRZ consists of highly weathered and strongly leached acidic soils that are low in native fertility (Brammer, 1976). Low pH, high aluminium and manganese concentrations are high on the list of major factors causing soil infertility. In order to overcome the above soil constraints to crop production, especially for maize which is a staple crop, farmers have traditionally practised forms of land husbandry such as *Chitemene* (slash and burn) and *Fundikila* (*Hyparhaenia* grass mound) and the use of cattle manure as coping strategies to replenish soil fertility (Mwakalombe and Mapiki, 1997). However, practices such as *Chitemene* are no longer sustainable due to increased pressure on land due to the rising population. The *Fundikila* practice is also of low productivity due to the poor quality of biomass used in the mounds leading to yield decline after only a few years of cultivation. The continuous use of inorganic fertilizers alone has proven unsustainable in smallholder agriculture. Not only is the material expensive, it is also often unavailable for timely application. Dalland *et al*. (1993) and Stocking (1988) have demonstrated that the continuous application of nitrogenous fertilizers has negative effects on the soil. They showed that as urea application in fertilized maize systems is increased, significant decreases in soil pH, Mg and K concentration and increases in Al concentration are recorded. They warned against the use of chemical fertilizers alone in improving soil fertility.

It has been established that the type and quality of organic resources used have an effect on the decomposition and nutrient release rates. Fast decomposers provide large amounts of nutrients in early stages of crop growth but may not influence soil physical conditions whereas slow decomposers have the opposite effect (Tian *et al*., 1993). Some green manure plants decompose faster and release nutrients much quicker in the early stages of plant growth thus contributing more to the initial supply of plant nutrients (Ladd *et al*., 1981). Farmyard manures on the other hand act as slow nutrient release fertilizers. This characteristic is desirable as there is a reduction in the leaching loss of N due to the slow decomposition rate and the slow release of ammonium N and its resulting slow conversion rate to nitrate (Murwira and Kirchman, 1993). Reddy *et al*. (1986) evaluated several tropical legumes as green manure for maize in the United States. The results showed that the yield of maize in green manure plots ranged from 3.4-5.7 t ha^{-1} with a mean of 4.2 t ha^{-1}, compared with 2.7 t ha^{-1} produced on the fallow plot.

Some work on the effect of organic manure on maize yields in Brazil showed that green manuring with legumes in general increased maize yield from 0.7 to 3.7 t ha^{-1} over the control (Bowen, 1987; Carsky, 1989). Maize yields of up to 6.3 t ha^{-1} were achieved using the legume green manure *Mucuna* as the N source.

The potential of optimizing cowdung use for maize was studied *by Munguri et al. (1996)* in Chinyika area in Zimbabwe. Their findings from on-farm trials on the effect of cattle manure quantity and application method showed little or no effect on maize grain yield. Station placement of manure gave the highest yield and was superior to broadcasting. However, results were similar to those of drilling in the planting furrow. Charreau (1975) found that fertilization with farmyard manure reduces or reverses acidification, increases Ca and Mg, reduces the content of Al and Mn and promotes root growth and uptake of P. Studies on plant-animal waste combinations conducted by Agbim (1981, 1985, 1988) produced positive responses and significant results on combinations of cassava peels and cattle dung on the yield of intercropped yam and bean.

MATERIALS AND METHODS

Location, climate and soils

The trial was conducted at Misamfu Research Centre in Kasama, Zambia. The area is in the high rainfall zone and receives an average of 1,200 mm of rainfall per annum. The approximate location is 10º 1' S and 31º 10' E at an altitude of 1,380 m above sea level. The area has a wet season from November to April and a dry season from May to October. The soil is Misamfu Red Series classified as a Clayey Kaolinitic Isohyperthermic Typic Haplustox (USDA, 1975). The average soil bulk density is 1.5 g cm^{-3} and has a pH $_{(CaCl2)}$ of 4.2. The experimental site was under a grass/shrub fallow for at least three years before the start of the experiment.

Trial design and management

A randomized complete block design (RCBD) with 10 treatments and 4 replications was used. The plot dimensions were 6 m x 5 m. The treatments were 1, 2, 3, or 4 t ha^{-1} of cowdung alone, 2 t ha^{-1} *Cassia spectabilis* alone and 2 t ha^{-1} *C. spectabilis* in combination with 1, 2, 3, or 4 t ha^{-1} cowdung. With an N concentration of 3.85 %, 2 t ha^{-1} *Cassia* was estimated to provide 77.0 kg ha^{-1} of N. At 1.12 % N concentration, varying rates of 1, 2, 3, and 4 t ha^{-1} cowdung were estimated to supply 11.2, 22.4, 33.6 and 44.8 kg ha^{-1} of N, respectively. All experimental units were subjected to uniform agronomic practices.

Ridging was done on 25th December, 1996. For plots that received *C. spectabilis* alone, the biomass was placed along the rows as marked and buried to make ridges. Where *C. spectabilis* and cowdung were combined, cowdung was placed on top of the *C. spectabilis* and ridges made. In the cowdung alone treatment the manure was placed along the rows and then buried under ridges. The control plots were prepared as farmers do by gathering the vegetative materials in rows and mounding them to form ridges. All plots were planted with an early maturing, open pollinated maize variety (MMV 400) as a test crop. All treatments in the experiment received half the recommended rate of 100 kg ha^{-1} of compound D (10 N, 20 P_2O_5, 10 K_2O) for basal and 100 kg ha $^{-1}$ of urea (46 % N) for top dressing

ANALYTICAL PROCEDURES

Soil chemical analyses

Soil samples for chemical analysis were collected at a depth of 0-20 cm at the beginning (November, 1996) and end (June, 1997) of the experiment. All analyses were done at Misamfu Research Centre, except for plant and soil N concentration, which was done at the University of Zambia Soil Analysis Laboratory. Total N was determined by the Kjeldahl method (Bradstreet, 1965) while available P was analysed by the Bray 1 method (Schuffelen *et al*., 1961) and the soil pH was measured in a 1:2 soil to $CaCl_2$ solution ratio. Organic C was determined by the Walkley Black method and K, Ca, Mg and Na were extracted in 1 M ammonium acetate (buffered at pH 7.0) and measured using by atomic absorption spectrophotometry.

Plant tissue analyses

Maize plant samples were collected thrice during the growing season, at the 4-6 leaf stage, ear leaf stage and at maturity stage. At the 4-6 leaf stage, six randomly selected plants were used for nutrient analysis. The whole plant portion above the ground was sampled and analyzed since the stems were too rudimentary to be separated from the leaves. A sub-sample was weighed and analyzed for N, P, K, Ca and Mg using methods described by Anderson and Ingram (1993). In the second sampling six randomly selected plants were sampled and the leaf immediately below the lowest cob was used for analysis. If no cob/ear had developed, samples were collected from the sixth leaf from the bottom of the plant. Samples were processed using the same procedure described above. In the third sampling, only selected treatments were used for both leaf and stem samples. Six randomly selected plants were taken for nutrient analysis. The leaf immediately below the lowest cob was used. For stem samples, four internodes were taken from the internode immediately below the lowest cob. The plant samples were processed using the procedures described above.

Plant nutrient uptake was calculated on the basis of plant dry matter and nutrient concentrations (Walsh and Beaton, 1983). The plant nutrient uptake at the ear-leaf stage was not calculated because the data on the nutrient concentrations for the whole plant at this stage were not collected.

Organic residue analysis

Leaf and twig samples taken from *Cassia* plants at the beginning of the trial were oven dried at 60º C and ground to pass through a 0.15 mm sieve. Cowdung samples were also collected from the heap prior to the commencement of the experiment and oven dried at 40º C to prevent volatilization of ammonium and ground to pass through 0.15 mm mesh. Carbon, N, P and K were analysed and the C/N ratio was calculated. All analyses were done according to procedures described above.

Plant height and dry matter assessment

Height measurements were done at three time intervals; at the 4–6 leaf stage, at the ear leaf stage and at the maturity stage. Ten randomly selected plants per plot were chosen as a sample for taking plant height. Dry matter assessment was done only for the above-ground biomass and at three time intervals as for plant height. For this assessment, six randomly selected plants were taken from each plot. The rest of the plants in the plot were cut from the crown of the stem at ground level and weighed to obtain the plot fresh weight. Sub-samples were collected for assessing the dry matter yield per hectare according to Anderson and Ingram (1993).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and means were separated using Duncan's Multiple Range Test and Orthogonal Contrasts.

Table 1. Selected chemical characteristics of the Misamfu Red soil at trial establishment

Depth	pH ($CaCl_2$)	Org. C	Total N	Available P	C/N	Exchangeable cations						CEC
						K	Mg	Ca	Na	Ex. acid	Ex. Al	
(cm)		---- (%) ----		(mg kg $^{-1}$)		---------------- (cmolc kg $^{-1}$) ----------------						
0-20	4.2	1.2	0.06	1.8	20	0.07	0.17	0.65	0.02	0.60	0.50	0.93

Table 2. Selected soil chemical properties of six treatments at the end of the trial as affected by *Cassia* and cowdung applications.

Treatments			pH ($CaCl_2$)	Org. C	Total N	Avail. P	C/N	Exchangeable cations						CEC
Grass fallow	Cowdung	*Cassia*						K	Ca	Mg	Na	Exc. acid	Ex. Al	
	(t/ha)	(t/ha)		(%)		(mg kg^{-1})		-------------- (cmolc kg $^{-1}$) --------------						
Control			4.6	1.8	0.08	6.7	23.4	0.12	0.48	0.24	0.01	0.83	0.27	0.85
	1		4.3	1.7	0.08	6.5	21.7	0.11	0.30	0.19	0.02	0.90	0.30	0.62
	2		4.4	1.7	0.10	7.4	17.5	0.11	0.28	0.16	0.01	1.13	0.33	0.62
		2	4.3	1.6	0.08	9.1	20.4	0.10	0.28	0.13	0.03	1.13	0.33	0.54
	1	2	4.4	1.5	0.08	5.9	19.5	0.14	0.38	0.19	0.04	0.83	0.27	0.75
	2	2	4.3	1.6	0.08	8.9	18.9	0.10	0.24	0.12	0.04	1.13	0.30	0.50
LSD(0.05)			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	Ns
CV (%)			4.7	12.1	16.18	43.5	26.3	22.3	45.1	49.9	26.0	31.5	30.4	22.8

ns=non significant at P = 0.05

Table 3. Chemical characteristics of organic residues used in the study.

Source	Org. C	N	P	K	C / N
	------------------- (%) -------------------				
Cowdung	38.9	1.12	0.40	0.06	34.7
C. spectabilis	47.6	3.85	0.37	0.16	12.4

RESULTS AND DISCUSSION

Soil chemical and organic residue analysis

There were no significant changes in soil chemical properties in the short run, but apparent changes in the soil nutrient status resulting from treatment effects were observed (Tables 1 and 2). In all the selected treatments, pH values were increased above those obtained before the treatments were imposed at the beginning of the experiment (Table 1 and 2). It was not well understood why the soil pH, organic carbon, Ca and Mg concentrations were highest in the control plot. There were no significant differences in soil N concentration, but appreciable increases from 0.06 % to 0.08 % were noticed. All the plots treated with either cowdung or *Cassia* were not different from each other in all parameters. The C/N ratio for the cowdung was 34.7 while that of the control was 12.4 (Table 3).

Effect of organic matter treatments on maize plant height as affected by different manure amendments.

Maize plant height at the 4-6-leaf stage, ear-leaf and maturity stages. At the various stages, significant height differences ($P \leq 0.05$) among the treatments were observed (Table 4). The general trend in growth was increasing height with increasing amounts of organic matter inputs. Plants treated with cowdung + *Cassia* were significantly ($P \leq 0.05$) taller than those in other plots. Plots treated with *Cassia* had plants that were taller than those treated with cowdung alone and those in the control plot. Generally, there was an added advantage of combining cowdung and *Cassia*, using cowdung alone or *Cassia* alone over the control.

Effect of organic matter treatments on maize dry matter production

Maize dry matter yield at the 4-6 leaf stage. The biomass production was unusually low because of the unexpected drought and poor growth conditions experienced in the 1996 season. The dry matter increased as organic manure inputs increased. The order of mean dry matter yield was cowdung + *Cassia* > *Cassia* > the cowdung alone plots and least in the control (Table 5). Generally, all plants with combinations of cowdung and *Cassia* had significantly more ($P \leq 0.05$) dry matter yield. All plants treated with cowdung alone, the control plots as well as those treated with *Cassia* alone did not show any significant differences in dry matter yield. The plants treated with *Cassia* alone responded much faster in dry matter build up than those amended with cowdung alone.

Maize dry matter yield at the ear-leaf stage. A combination of 4 t ha-1 cowdung with 2 t ha-1 Cassia green manure produced the highest DM yield whereas the lowest yield was obtained from the 1 ton ha -1 cowdung alone (Table 4). The trend shown at 4-6 leaf stage for cowdung + Cassia treatment was exhibited at the ear-leaf stage. Plants in plots with cowdung + Cassia had significant dry matter increases over the rest of the treatments. There was a tendency for the dry matter yield to increase as organic matter inputs increased. The plants amended with *Cassia*

Table 4. Height of maize plants at various growth stages in response to *Cassia* and cowdung applications.

Treatments			Plant height		
Grass fallow	Cow-dung	*Cassia*	4-6 leaf stage	Ear leaf stage	Matur-ity
(t ha^{-1})			(mm)		
Control			192	759	1513
	1		170	731	1460
	2		189	840	1507
	3		175	820	1438
	4		208	847	1519
		2	222	899	1557
	1	2	266	1084	1663
	2	2	310	1173	1673
	3	2	329	1231	1774
	4	2	361	134	1708
LSD (0.05)			39	160	176
CV (%)			11	11	7

alone generally gained more dry matter than plants in the control and the cowdung alone plots except for the 4 t ha^{-1} of cowdung. The results obtained by Reddy *et al.* (1986) in which green manure increased maize dry matter over the fallow is in agreement with these findings.

Maize dry matter yield at the maturity stage. There were no significant differences ($P \leq 0.05$) among the following treatments: the control, cowdung alone and the *Cassia* alone treatments. Plots with cowdung + *Cassia* gave significantly more dry matter yield over the control, the *Cassia* alone and the cowdung alone treatments (Table 5). The overall observation was that there were appreciable and in some cases significant dry matter yield increases in all manured plots.

Table 5. Dry matter of maize stalks for different *Cassia* and cowdung applications at various stages of growth.

Treatments			Dry matter		
Grass fallow	Cow-dung	*Cassia*	4-6 leaf stage	Ear leaf stage	Matur-ity
(t ha^{-1})			(kg ha^{-1})		
Control			67	1542	1409
	1		70	1494	1403
	2		83	1569	1590
	3		72	1616	1286
	4		96	1894	1467
		2	88	1747	1832
	1	2	151	2694	2189
	2	2	197	2363	2144
	3	2	202	2741	2931
	4	2	231	2757	2717
LSD (0.05)			35	490	683
CV (%)			19	17	25

Maize grain yield as affected by soil amendments of *Cassia* and cowdung. The average maize grain yields were slightly lower than expected for MMV 400 whose yield potential is 3,500 kg ha^{-1}. This could be attributed to late planting due to delayed onset of rains and the long drought experienced at the ear leaf stage. Generally, the grain yield increased as the amount of organic residues increased and was more pronounced in the *Cassia* + cowdung treatments (Table 6). The 4 t ha^{-1} cowdung + 2 t ha^{-1} *Cassia* produced the highest grain yield. The grain yield in the treatment of *Cassia* alone outyielded the control by 10.4 %, though not significant. This, however, is in accordance with Bowen (1987) and Carsky (1989) who found that green manuring with different legumes especially *Mucuna* increased maize grain yield from 700 to 3,700 kg ha^{-1} over the control. Our findings that cowdung application has no significant effect on the yield, are supported by Munguri *et al*. (1996) whose results on the effect of cattle manure on quantity and application method for cattle manure showed little or no effect on maize grain yield.

Table 6. Maize grain yield in response to different *Cassia* and cowdung applications.

Treatments			Grain yield
Grass fallow	Cowdung	*Cassia*	
(t ha^{-1})			(kg ha^{-1})
Control			1582
	1		1170
	2		1180
	3		944
	4		1182
		2	1195
	1	2	1874
	2	2	1906
	3	2	2534
	4	2	2585
LSD $_{0.05}$			1027
CV (%)			48

It was generally observed that the plants in the *Cassia* + cowdung plots were less affected by the long dry spells experienced at the ear leaf stage and subsequently gave higher maize yields than those in other treatments. The cowdung + *Cassia* (mean yield of 2,226 kg ha^{-1}) significantly more than doubled the yield over the control, and significantly almost doubled the yield over the *Cassia* alone and cowdung alone treatments. These results are supported by the findings of Agbim (1981, 1985, 1988) who obtained positive responses by combining plant and animal waste combinations of cassava peels and cattle dung on the intercropping yields of yam and bean. It is observed that the results show some possible synergistic effects. The combined effect of cowdung + *Cassia* seemed to be greater than the sum of their separate effects. For instance, the yield from the combined application of 4 t cowdung + 2 t *Cassia* was greater than the sum of individual treatments of 4 t cowdung and 2 t *Cassia*. It is expected that the release of nutrients from the *Cassia* with a low C/N ratio in the early stages was complemented by the continued release from the cowdung as a slow release fertilizer. Such treatments with a combined effect are more likely to synchronize the nutrient release from the organic residues with plant nutrient demand.

Nutrient concentrations in maize at the 4-6 leaf, ear leaf and maturity stages as affected by soil amendments of *Cassia* and cowdung

There were no significant effects of the organic matter treatments on the plant tissue concentrations of N, P, K, Ca and Mg at all the three growth stages(Tables 7).

Table 7. Mean nutrient concentrations in maize plants or components at various growth stages*

Whole plant or components	N	P	K	Ca	Mg
			(%)		
4-6 leaf stage	1.06	3.49	5.63	0.81	0.44
Ear-leaf stage	0.72	0.20	5.01	1.12	0.35
Stem at maturity	0.73	1.74	1.56	0.34	1.27
Leaf at maturity	1.15	2.30	2.05	0.91	1.68
Grain at maturity	1.66	0.12	0.06	0.18	0.09

* treatments effects not significant at p=0.05

Plant macro nutrient uptake by maize as affected by soil amendments of *Cassia* and cowdung

Plant macro nutrient uptake by maize at the 4-6 leaf stage. The uptake of nitrogen was lowest in the control and highest under 2 t ha^{-1} *Cassia* + 1 ton ha^{-1} cowdung. It was observed that plants treated with either *Cassia* alone, cowdung alone or a combination of cowdung + *Cassia* had higher uptake values than the control (Table 8). This perhaps suggests that organic manure contributed to the increased N uptake in the manured plots rather than the control though there could be other factors. The trend in the uptake of N within the cowdung alone or the cowdung + *Cassia* plots was not defined. Plants treated with cowdung alone and *Cassia* alone had similar N uptake. There was no trend in P and Ca uptake among all treatments though higher in the treatments with cowdung + *Cassia*. The uptake of P in the cowdung + *Cassia* plots was almost twice as much as that in the cowdung alone. There was a distinct trend in K uptake for all treatments that received of *Cassia* + cowdung manure. The uptake of K increased with increasing levels of organic manure application. A similar trend to that of K was observed for Mg. The uptake for the 2 t ha^{-1} *Cassia* + 4 t ha^{-1} cowdung was significantly higher than the control, the cowdung alone and the *Cassia* alone treatments. The significant increase in K and Mg uptake especially for the treatment with cowdung + *Cassia* might explain the plant growth vigour visually observed in these treatments.

Table 8. Plant macronutrient uptake by maize leaves for different *Cassia* and cowdung applications at the 4 - 6 leaf stage

Treatments			Nutrient uptake				
Grass fallow	Cow-dung	*Cassia*	N	P	K	Ca	Mg
	(t/ha^{-1})				(kg ha^{-1})		
Control			1.3	0.50	0.30	0.03	0.01
	1		2.2	0.32	0.28	0.02	0.01
	2		2.0	0.34	0.33	0.03	0.01
	3		1.5	0.33	0.29	0.02	0.01
	4		2.0	0.50	0.42	0.04	0.01
		2	1.7	0.45	0.35	0.03	0.01
	1	2	5.2	0.60	0.81	0.06	0.02
	2	2	3.1	1.20	0.94	0.07	0.02
	3	2	4.1	0.71	0.95	0.06	0.03
	4	2	3.5	0.54	1.10	0.06	0.03
LSD (0.05)			2.4	ns	0.33	ns	0.01
CV (%)			62	70	40	69	66

ns=non significant P = 0.05

Generally, the uptake of N, K and Mg were enhanced in treatments of *Cassia*, cowdung and their combination.

Plant macro nutrient uptake by maize at the maturity stage. There were no significant differences among the treatments in the overall plant nutrient uptake at the end of the growing season (Table 9). It is possible to obtain such results in the first cropping season when organic manures are incorporated until there is a build up effect in the long term. However, plant uptake in treatments of *Cassia* green manure and cowdung + *Cassia* were slightly more than the control for all the nutrients. The data generally indicate that there was some advantage in incorporating *Cassia* alone and also combining cowdung and *Cassia* manures to the soil. The uptake of all nutrients in the *Cassia* treatments was greater than that of cowdung alone treatment possibly because the contribution in terms of nutrient release from *Cassia* was more effective, being a relatively fast decomposer, than that from the cowdung, which, is a slow release fertilizer. The general performance of the maize from the combination of cowdung and *Cassia* was better than that of the other treatments possibly due to the combined effect of the two organic sources.

Generally, the uptake of N decreased while that of P, Ca and Mg increased with plant maturity. The N uptake could be lower probably due to leaching and volatilization losses as a result of long dry spells experienced at the beginning of the season followed by heavy rains received during the mid and towards the end of the season (Fig. 1).

CONCLUSION AND RECOMMENDATIONS

The potential for incorporating both plant and animal wastes to improve soil physical and chemical properties to provide a conducive maize growing environment exists. Appreciable increases in the soil pH, organic C, N, P, plant uptake of N, K, Mg, reduced exchangeable aluminium and significant increases in dry matter as well as grain yield observed in especially plots receiving cowdung, + *Cassia* are adequate indications of the importance of these organic amendments.

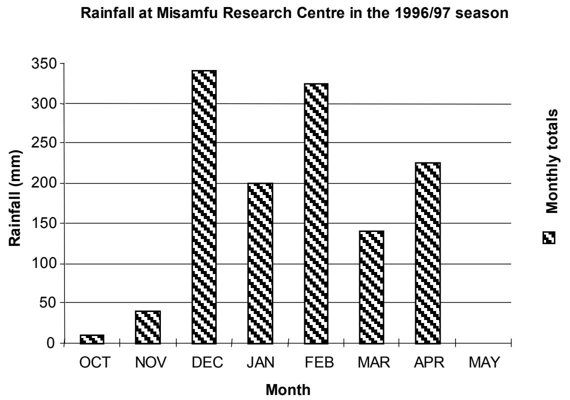
Studies to establish the true economic value of the organic materials used in the trial were not done. This therefore leaves room for future investigations to determine the socio-economic aspects of the various procedures of collecting, processing and distribution/application of organic fertilizers.

Table 9. Plant uptake of major nutrients in maize as affected by different *Cassia* and cowdung applications at the maturity stage

Treatments			Nutrient uptake				
Grass fallow	Cow-dung	*Cassia*	N	P	K	Ca	Mg
	(t/ha^{-1})				(kg ha^{-1})		
	Control		50	86	58	39	53
	1		47	73	52	26	43
	2		50	67	62	29	53
		2	58	85	72	36	66
	1	2	71	80	87	47	71
		2	64	69	70	41	62
LSD ($P \leq 0.05$)			ns	ns	ns	ns	ns
CV (%)			25	43	34	42	31

ns=non significant P = 0.05

Figure 1. Rainfall at Misamfu during the experimental period.



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THE USE OF ORGANIC/INORGANIC SOIL AMENDMENTS FOR ENHANCED MAIZE PRODUCTION IN THE CENTRAL HIGHLANDS OF KENYA.

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ABSTRACT

A study was conducted for four cropping seasons commencing March 1999 to determine the level of complementarity between organic and inorganic soil amendments that can be used to alleviate soil infertility for maize production. The sites of the study were at Kianjuki and Kivwe locations of Embu district in the central highlands of Kenya. The treatments consisted of organic, inorganic or combined organic/inorganic soil amendments. Soils at both sites are ando-humic Nitisols with a moderately acidic (pH = 5.3) reaction and low to medium levels of nitrogen (N) and phosphorus (P). Results of maize grain yield indicated that the use of combined organic/inorganic soil amendments appear to be superior to using either an inorganic or organic soil amendment source alone. Highest grain yields of 6.9 and 5.4 t ha^{-1} for Kivwe and Kianjuki, respectively, were obtained where combined cattle manure and inorganic fertilizer was applied during the 1999 cropping seasons. These yields were 2.0 and 1.5 times more than those obtained in the unfertilized check at Kivwe and Kianjuki sites, respectively. During the participatory farmers' evaluation of the treatments, combined organic/inorganic soil amendments were ranked higher than straight treatments of either cattle manure or a compound fertilizer.

Keywords: Ando-humic nitisols, central highlands of Kenya, farmer evaluation, maize, organic/inorganic soil amendments.

INTRODUCTION

Maize is the main food crop in central and eastern Kenya and is mainly cultivated in mid-altitude areas found in the Upper Midland (UM) 2, 3, and 4 as well as the Lower Midland (LM) 3 and 4 agro-ecological zones along the southern and eastern slopes of Mount Kenya. The crop is planted either as a sole crop or as an intercrop with beans (Jaetzold and Schmidt, 1983). Low soil fertility is one of the main constraints affecting cultivation of maize and other food crops in the mid-altitude areas of central and eastern Kenya. The mid-altitude areas of Mount Kenya region, like other parts of eastern African highlands, have suffered gross soil nutrient mining due to continuous cropping coupled with low levels of nutrient inputs and poor nutrient conservation practices accentuated by mounting population growth and land scarcity (Smaling, *et al*., 1993; Lynam, *et al.,* 1998). Studies conducted in Embu district have revealed that nutrient depletion in land use systems which are dominated by food crop production averages about 126, 14 and 104 kg ha^{-1} of N, P and K, respectively, annually (Gitari *et al,* 1999). In the central highlands of Kenya, long term trials have shown a decline in soil organic carbon (C) from 20 to 12 g kg^{-1} of soil. The decline has been greatest when no inputs are applied and is minimized when a combination of inorganic fertilizer and manure are used (Smaling *et al*., 1997). The result of this loss in soil productivity has been a continuous decline of maize yields in farmers' fields to less than 2.0 t ha^{-1} whilst the maize cultivars grown have a potential of producing >6.0 t ha^{-1} (Gitari *et al.*, 1996; Hassan *et al.,* 1998).

This paper focuses on the use of combined cattle manure and inorganic fertilizers soil amendments as a component of an integrated nutrient management strategy to improve maize yields in smallholder farms.

MATERIALS AND METHODS

The trial was carried out at Kianjuki and Kivwe locations of Embu district which is situated in the central highlands of Kenya within the administrative districts of Eastern province. The district lies on the eastern and southern slopes of Mount Kenya. The altitudinal gradient of the area ranges from 1,000 to 1,800 m above sea level. According to Jaetzold and Schmidt (1983) rainfall is bimodal and averages between 1,000 and 1,600 mm per year. There are two distinctive cropping seasons of March-July for the long rains (LR) and October-December for the short rains (SR). The main soil types are the humic Andosols in the tea land use zones found in Upper Highland (UH) 1 and UM1 agro-ecological zones. Nitisols and Ando-humic Nitisols are more prominent in the tea-coffee, main coffee as well as marginal coffee land use systems located in UM2 and UM3 as well as UM4 agro-ecological zones. The soil profiles are dark reddish-brown to brown friable and smeary clay loam with humic topsoil.

Farms are generally small, ranging from 0.5 to 4.0 ha with a mean of 1.5 ha per farm family. The region has a high population density which ranges from 230-730 persons per km^2 with an average of 450 persons per km^2 (Murithi, 1998). According to some participatory rural appraisals (PRA), which have recently been conducted in the maize-based land use systems of Embu district, the main farming constraints (as perceived by the farmers themselves) include soil erosion, low soil fertility and expensive farm inputs (Micheni *et al.,* 1999).

The trials were laid out and analyzed as a randomized complete block design with three and four replicates at Kivwe and Kianjuki, respectively. The trials commenced in March (long rains) of 1999 and planting was done by hand a few days before the onset of rains. Maize cultivar Pioneer hybrid 3253 spaced 75 cm by 30 cm - single plant per hill was planted on

Table 1. Soil and manure analyses for Kivwe and Kianjuki Sites.

Treatment	pH (H_2O)	Elemental content % N	% C	% P	% K
Kivwe site:					
Soil	5.41	0.28	2.54	0.14	0.09
Manure	9.29	1.45	11.65	0.37	0.20
Nutrients added with manure (kg ha^{-1})		102		26	14
Kianjuki site:					
Soil	5.45	0.29	2.39	0.09	0.17
Manure	7.21	1.05	11.18	0.06	0.75
Nutrients added with manure (kg ha^{-1})		74		4	53

Table 2. Effect of different soil amendments on maize grain and stover yields at Kivwe.

Treatment	Maize grain yield 1999	Maize grain yield 2000	Stover yield 1999	Stover yield 2000
	- - - - - (tons per hectare) - - - - -			
Inorganic at 50 kg ha^{-1} N and P_20_5	6.7	2.7	10.4	7.6
Farmyard manure at 7.0 t ha^{-1}	4.5	2.1	5.0	8.0
P only at 50 kg ha^{-1} P_20_5	4.3	2.8	5.7	6.8
N only at 50 kg ha^{-1} N	6.2	2.1	12.2	6.4
7.0 t ha^{-1} FYM + 50 kg ha^{-1} N and P_20_5	6.9	2.4	11.3	8.7
7.0 t/ha^{-1} FYM + 25 kg ha^{-1} N and P_20_5	6.7	2.8	9.2	7.0
3.5t/ha^{-1} FYM + 25 kg ha^{-1} N and P_20_5	5.8	2.5	8.0	7.3
Control	3.6	1.3	3.8	6.7
LSD (0.05)	1.3	0.7	3.0	1.3

a plot of 4.8m long by 4.5m wide. The net plot consisted of mid four rows per plot. Bio-physical data which were collected included stand count, stover weight, maize grain weight as well as grain moisture content. The final grain yield was corrected to 15% moisture content. Prior to planting, soil sampling was carried out in each of the eight plots and a composite sample from the three/four replicates taken for soil analysis. Soils were analyzed for pH, total N and total P as well as K (Table 1) at the Kenya Agricultural Research Institute laboratories at Muguga according to procedures outlined in Okalebo *et al.* (*1993*).

The following soil fertility amendment treatments were applied at each of the two sites:

1. Inorganic fertilizer (20:20:0) at the recommended dosage of 50 kg ha^{-1} N and P_2O_5
2. Farmyard Manure (FYM) at the recommended rate of 7.0 t ha^{-1}.
3. P only at 50 kg ha^{-1} P_2O_5.
4. N only 50 kg ha^{-1} N
5. Recommended rate of FYM + recommended rate of inorganic fertilizer
6. Recommended rate of FYM + half recommended rate of inorganic fertilizer
7. Half recommended rate of FYM + half recommended rate of inorganic fertilizer
8. Untreated check

In order to enhance the farmer awareness on the level of soil nutrient depletion as well as increase the level of technology adoption, a participatory farmer evaluation of the treatments was carried out at the grain-filling stage of the crop. Both pairwise and matrix ranking of the treatments was conducted on 23rd August 1999 at Kivwe trial site. During the matrix ranking, gender disparities were considered by having the male and female farmers conduct a separate evaluation.

RESULTS

The results of the soil analysis for the two sites are presented in Table 1. Soils at both Kivwe and Kianjuki were moderately acidic with medium to low nutrient stocks of N, P and K. Soils at the two sites had similar chemical characteristics. Characteristics of the animal manures (FYM) used differed at the two sites (Table 1). The Kivwe FYM was of higher quality with higher N and P content but lower K content. As a consequence, the amount of nutrients applied with the FYM treatments were substantially different between the two sites (Table 1).

Significant responses to inorganic and organic inputs were only observed at Kivwe in 1999, but at both Kivwe and Kianjuki in 2000 (Tables 2 and 3). At Kivwe in 1999 and Kianjuki in 2000, maize did not respond to P fertilizer in the absence of N fertilizer. However, maize consistently responded to N fertilizer without P application at both sites. FYM alone did not increase maize grain yield at Kivwe in 1999 but did so in 2000, presumably due to residual mineralization of orgaincally bound nutrients. There was no response to FYM alone at Kianjuki in either year; the year; the Kianjuki FYM was of lower quality and lower N and P content than the Kivwe FYM (Table 1). Combining FYM with N and P fertilizer did not elicit an additivie response in maize yields, which did not differ significantly from the NP fertilizer alone treatments (Tables 2 and 3). However, application of NP fertilizer at ½ the recommended rate in combination with FYM at the full or ½ recommended rates

Table 3. Effect of different soil amendments on maize grain and stover yields at Kianjuki.

Treatment	Maize grain yield		Stover yield	
	1999	2000	1999	2000
	- - - - - (tons per hectare) - - - - -			
Inorganic at 50 kg ha^{-1} N and P_20_5	4.3	4.4	14.3	4.7
Farmyard manure at 7.0 t ha^{-1}	5.0	3.4	17.5	3.7
P only at 50 kg ha^{-1} P_20_5	5.2	3.4	13.8	3.5
N only at 50 kg ha^{-1} N	3.9	4.0	16.0	4.9
7.0 t ha^{-1} FYM + 50 kg ha^{-1} N and P_20_5	5.4	4.5	18.5	4.8
7.0 t ha^{-1} FYM + 25 kg ha^{-1} N and P_20_5	5.1	4.3	16.5	4.3
3.5 t ha^{-1} FYM + 25 kg ha^{-1} N and P_20_5	5.4	4.3	19.3	5.0
Control	3.6	3.5	10.7	4.3
LSD (0.05)	2.7	0.4	6.2	1.3

Table 4. Pairwise ranking of crop performance with different soil amendments.

Treatment	Rec. NP	Rec. FYM	Rec. P_2O_5	Rec. N	Rec. FYM + Rec. NP	Rec. FYM + ½ rec. NP	½ rec. FYM + ½ rec. NP	Control	Score	Rank
Rec. NP		FYM	NP	NP	FYM + NP	NP	NP	NP	4	3
Rec. FYM			FYM	CAN	FYM + NP	FYM + ½NP	½FYM + ½NP	FYM	3	5
50 kg P_2O_5				CAN	FYM + NP	FYM + ½NP	½FYM + ½NP	P_2O_5	1	7
50 kg N					FYM + NP	FYM + ½NP	½FYM + ½NP	CAN	3	5
Rec. FYM + Rec. NP						FYM + NP	FYM + NP	FYM + NP	7	1
Rec. FYM + ½ rec. NP							FYM + ½NP	FYM + ½NP	5	2
½ FYM + ½ NP								½FYM + ½NP	4	3
Control									0	8

was as effective as the full NP rate. Similar effects fo FYM and NP fertilizer were observed on stover production (Tables 2 and 3). A higher level of moisture content at harvest may have been responsible for the higher stover yields at Kianjuki when compared with those of Kivwe.

Lower moisture regimes characterized the 2000 cropping seasons. The long (March) rains of 2000 completely failed since the crops which were planted dried soon after germination. This low moisture may in part have been responsible for the suppressed performance of the maize crop during that period.

The results of pairwise as well as matrix ranking shown in Tables 4 and 5 reveal that farmers gave high ranking to the combined inorganic/FYM treatments. The farmers rankings appear to closely agree with the final results of the actual grain yields. Apart from the rankings farmers also listed the merits and demerits of each of the treatments. Farmers indicated that the main drawback with the inorganic fertilizers-based treatments is the high cost of such inputs. With regard to the manure treatments, farmers felt that this was a feasible alternative although adequate quantities are normally not available for application in the entire farm.

DISCUSSION AND CONCLUSIONS

The foregoing results clearly indicate that the use of combined organic/inorganic soil amendments produce similar maize grain yields to those obtained where inorganic sources are used alone. These observations were more substantial during the wetter moisture conditions when moisture was not limiting the growth and development of the maize crop as occurred in the 2000 cropping season. These observations are in agreement with those made by Smaling *et al*. (1993) who noted that the response of maize and other annual crops to P

Table 5. Matrix ranking by male and female farmers of crop performance with different soil amendments.

Gender	Treatment	Rec. NP	Rec. FYM	Rec. P_2O_5	Rec. N	Rec. FYM + Rec. NP	Rec. FYM + ½ rec. NP	½ rec. FYM + ½ rec. NP	Control
Male	No. of people	10	0	1	5	9	2	2	1
	Rank	1	6	5	3	2	4	4	5
Female	No. of people	4	1	1	11	9	2	1	1
	Rank	3	5	5	1	2	4	5	5

and farmyard manure in different agro-ecological zones is vigorous with significant manure-fertilizer interactions. According to Msumari and Racz (1978) the negative effects of organic amendments occur when the organics are of low quality. Such negative effects are, however, offset by combining these organics with inorganic soil amendments especially N. In the case of the manure used in this study, it was of average quality. Thus, a great level of immobilization was not anticipated. An inventory of N, P, and K of cattle manures obtained in different parts of eastern and southern Africa by Palm *et al*. (1997) indicated that most manures in the region fall below the critical N and P contents and therefore immobilize these nutrients.

Participatory farmer evaluation of the treatments revealed that the farmers ranked the combined organic/inorganic treatments higher than the non-combined nutrient sources. The farmers listed the high cost of the inorganic fertilizers as the main constraint to the use of this particular farm input. These observations are in agreement with those obtained in Kiambu district of central Kenya by Makokha *et al*. (2000). Those authors conducted a formal survey among the smallholders to establish the determinants of fertilizer and manure use in maize production in Kiambu district. The results of the survey showed that 35% of the sampled farmers used manure alone, 27% used fartilizer alone, and 36% used both manure and fertilizer. The constraints to the use of fertilizers among the smallholders were identified as the high cost (45% of those sampled) while the main constraint of manure use was identified as the high cost of labour (42% of those sampled) required applying it.

In conclusion, this study has demonstrated that the ando-humic Nitisol type of soils found in the central highlands of Kenya have a good potential for maize cultivation. However, nutrient depletion especially with respect to N may hamper maize cultivation if some remedial action is not followed.

Combining organic and inorganic sources of nutrients appears to be advantageous because the inorganic and organic soil amendments will support the plant at the early and later maize crop development. The organics are more resistant to leaching but the release of nutrients may be too slow for an annual crop such as maize organic soil amendments will support the plant at the early and later maize crop development. The organics are more resistant to leaching but the release of nutrients may be too slow for an annual crop such as maize.

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EVALUATING THE AGRONOMIC POTENTIAL OF *TITHONIA DIVERSIFOLIA* PRUNINGS IN THE ACID SOILS OF NORTHERN ZAMBIA.

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ABSTRACT

Due to the high cost of inorganic fertilizer, small-scale resource poor farmers of Northern Zambia are unable to afford it. Cheaper alternatives are being sought. Addition of P alone tends to be ineffective as some of the P is fixed. Thus, use of *Tithonia* alone or in combination with sources of P was employed as this approach has been shown elsewhere to improve crop yield and available soil P better than inorganic P sources alone. This study evaluated *Tithonia* prunings as (1) a source of nitrogen for maize, alone or when combined with P sources and (2) its effects on soil acidity and fertility in general. Prunings were cut as fresh material and incorporated into the soil based on the maize recommended rate of N of 112 kg N ha^{-1} (McPhillips, 1987). Mixtures of *Tithonia* residue with P sources were made before incorporation (Malama, 1998). Northern Zambian *Tithonia* was found to be of high quality. *Tithonia* prunings had 2.5% N, 0.14% P, 4.20% K, 0.98% Ca, 0.32% Mg, 300 ppm Fe and 11 ppm Zn. Application of *Tithonia* improved available soil P and P uptake by maize. Thus, *Tithonia* appears to enhance P availability on these P-fixing acid soils. Exchangeable Al, acidity and Al saturation were reduced in all the *Tithonia* treatments. Both the stover and the grain yields were improved by the incorporation of *Tithonia. Tithonia* prunings were found to improve soil fertility and maize yield, alone or in combination with P sources (single superphosphate [SSP} or Ground Rock Phosphate [GRP]), and are a cheap and effective method of ameliorating soil acidity in Northern Zambia.

Keywords: Al-saturation, maize, P-fixation, soil acidity amelioration, *Tithonia diversifolia,* Zambia ground rock phosphate.

INTRODUCTION

Justification of this study is that due to the high cost of inorganic fertilizer, small-scale resource poor farmers of Northern Zambia are unable to afford it. Therefore, cheaper alternatives are being sought. Soils of northern Zambia are acidic and are of medium-to-high P fixing capacity (1-3 ppm Bray 1) (Soil Productivity Annual Reports, 1990, 1991, 1996). Thus addition of P alone tends to be ineffective as some of the P is fixed and therefore becomes unavailable to a crop. Use of mixtures of *Tithonia* alone, or in combination with inorganic sources of P or ground rock phosphate (GRP) has been shown in Kenya to boost crop yields and improve P availability better than inorganic P sources alone (Niang *et al*., 1999; Questions and Answers in Agroforestry Today, 1998; Buresh and Tian, 1998; Sanchez *et al*., 1997), in Zimbabwe (Jiri and Waddington, 1999) and Malawi (Ganuga, 1998). Past research work with Zambian GRP at Misamfu has shown that using GRP on its own, on annual crops, was not agronomically effective due to the slow rate of P release (Soil Productivity Annual Reports, 1990, 1991, 1996) and thus testing of Zambian GRP has shifted to perennial crops where it is believed that over the long-term, release of P would be beneficial to such perennial crops.

Tithonia diversifolia popularly known as the Mexican sunflower, is a common plant in the Isoka and Kasama Districts of Northern Zambia. It is mainly planted as a hedge around households in compounds as an ornamental. A few farmers plant it as a hedge around their fields in Isoka District. This plant is used as fish food (Fisheries Specialist, Dept of Fisheries Isoka District, pers comm., 2000). Fresh leaves are put into fish-ponds and within few days the leaves undergo decomposition, providing some valuable food. According to the Fisheries Specialist, the fact that *Tithonia* decomposed leaves makes the pond water green is an ideal environment because it provides camouflage for the fish. This makes the fish to feel good as the fish is thus protected from predators. Some farmers say they use it as a medicinal plant to treat various ailments. However, when farmers were asked if they have used it for soil fertility improvement the answer was no. Even those few farmers who have planted it as a hedge around their gardens do not know that it can be used for soil fertility improvement. When asked what the prunings were used for, they responded by saying that they threw away the prunings. Apparently pruning were carried out on average 3 times during one rain season (Malama and Kapekele, 2001).

Therefore this study was conducted in order to evaluate the *Tithonia* prunings as a source of plant nutrients on the performance of maize, when used alone or when combined with P sources and its effects on soil acidity and fertility in general.

MATERIALS AND METHODS

Prunings were cut as fresh material (small twigs and leaves). These were incorporated into the soil using a hand hoe as intact unground fresh leaf materials based on the recommended rate of N of 112 kg N ha^{-1}, which translates into 4.5 t ha^{-1} fresh matter of *Tithonia*. Mixtures of *Tithonia* residue with either SSP or GRP where made by mixing residues with these P sources and then incorporated into the soil. The rate of P applied was the recommended rate of 60 kg P ha^{-1} and 20 kg P ha^{-1}, respectively, at Misamfu Regional Research Center (10^{o} 10$^{'}$ S 31^{o} 12$^{'}$ E) and Mungwi (10^{o} 10$^{'}$ S 31^{o} 15$^{'}$ E) District, both in Northern Zambia. This difference in rate being due to differences in fertility status between the two sites as has been shown by previous soils data from these sites. Misamfu soil is an oxisol, a Kandiustults. Mungwi soil is classified as udandic Kandiustults.

Treatments:

1. Control (no *Tithonia*, no fertilizer)
2. NKP compound fertilizer
3. *Tithonia* alone
4. *Tithonia* + ¼ recommended rate of P as SSP
5. *Tithonia* + Full recommended rate of P as GRP
6. *Tithonia* + ¼ recommende rate of P as GRP

Design: RCBD replicated four times.

Grain yield: Grain harvest was recorded from plants in an area with borders 0.5m from the edge of each plot. Seed was allowed to dry in the sun after shelling of the cobs. A sub-sample of about 100 g was taken for moisture content determination using a Dole 400 moisture Tester (1987) in order to see whether the grain had reached 12% moisture content after which yield measurement (t ha^{-1}) were corrected for moisture content based on the entire plot harvested area rather than cropped area**.**

Soil nutrient analysis: Soil samples were collected from the depth of 0 –15 cm in each harvested area per plot using a standard auger at the time of harvesting maize. The samples were put into polythene bags and taken to the laboratory for analysis. They were air dried and sieved to pass 1 mm sieve

Exchangeable bases Ca, Mg, K, Na and Al were extracted by 0.1 N ammonium acetate (pH 7); Ca and Mg were determined on a Perkin Elmer atomic absorption spectrophotometer and K on a flame photometer. Available P was analysed by Bray-1; total N by the regular Macro–Kjeldahl Method, Organic C by Walkley and Black, effective cation exchange capacity (ECEC) was found by adding the exchangeable bases and the exchangeable acidity (H^+ and Al^{3+}). Al and H cations were extracted in 1 M KCL solution. CEC was estimated from ECEC based on the pH. Base saturation was calculated by adding the exchangeable bases multiplying by 100 and dividing by CEC. Aluminium saturation was calculated by multiplying exchangeable acidity by 100 and dividing by ECEC (Laboratory methods, 1985).

Tithonia leaf analysis: Fully matured leaf samples were sampled at random. Samples were oven-dried at 60° C for 48 hours and ground to pass a 1 mm sieve before sending them to Mount Makulu Research Station, Lusaka for nutrient analysis. The mineral nutrients were extracted from the leaf material in 1 N HNO_3. Concentrations of N, K Ca, Mg, Fe and Zn were determined in a similar way as described above for soil analysis. P was determined with HCl and NH_4F as extractants (Lab. Methods, 1985).

Statistical analysis: Analysis of variance was performed on all parameters using SAS Software (2000).

RESULTS

***Tithonia* residue characterization:** *Tithonia* prunings had 2.5% N, 0.14% P, 4.20% K, 0.98% Ca, 0.32% Mg, 300 ppm Fe and 11 ppm Zn (Table 1).

Lignin and polyphenols were not determined as neither the laboratory at Misamfu or Mt. Makulu have ever carried out such specialized techniques but these parameters shown in Table 1 are extrapolated from TSBF organic database (Mutuo *et al*., 2000).

Table 1. Chemical characterization of *Tithonia* from Northern Zambia

N	Lignin	Poly-phenols	P	K	Ca	Mg	Fe	Zn
- - - - - - - - - - - - - - - - - - (%) - - - - - - - - - - - - - - - - - -							(ppm)	
2.7	13.16	3.83	0.14	4.2	0.98	0.32	300	11

Note: Lignin and Polyphenol values are averages from TSBF Organic database, (Mutuo, *at el*., 2000).

Available soil P: At Misamfu the available soil P (Bray 1) was significantly different (P<0.05) between the NPK fertilizer treatment and the rest of the treatments. All the treatments, except NPK fertilizer were around and below 0.1% available P. The control was significantly different (P<0.05) from *Tithonia* alone, *Tithonia* combined with ¼ rate P as SSP or as GRP (Table 2). At Mungwi, available soil P was higher than at Misamfu, except in the treatment where NPK fertilizer was added. The highest was NPK fertilizer. There were no significant differences at Mungwi.

Exchangeable acidity: At Misamfu all treatments with *Tithonia* were not significantly different (P<0.05) from one another, but all were significantly different from the control and NPK fertilizer treatment. The latter produced the highest exchangeable acidity (Table 2). At Mungwi there were no significant differences between the treatments which was caused by high CV due to some plots recording zero exchangeable acidity.

Exchangeable acidity was relatively lower than at Misamfu by comparing the control treatments only at these two sites.

Exchangeable aluminium: At Misamfu, exchangeable Al was significantly different (P<0.05) between control and all the treatments receiving *Tithonia* and between NPK fertilizer and all treatments receiving *Tithonia*, with NPK fertilizer being the highest (Table 2).

At Mungwi, there were no significant differences between treatments due to high CV as a result of some plots recording zero exchangeable Al.

Aluminium saturation: At Misamfu Al saturation was highest in the control treatment. The latter was significantly different (P<0.05) to the rest of the treatments. NPK fertilizer treatment was the second highest and was significanlty different (P<0.05) to all treatments receiving *Tithonia*. The lowest were *Tithonia* alone and *Tithonia* combined with ¼ P as GRP. These latter two treatments were not significantly different from each other. At Mungwi Al saturation was highest in the NPK fertilizer treatment. *Tithonia* alone was the lowest. At this site Al saturation levels were lower than at Misamfu (Table 2). There were no significant differences between treatments due to high variations as a result of some plots recording zero Al saturation.

P uptake: At Misamfu, the P uptake by maize was significantly different (P<0.05) between the NPK fertilizer treatment and the rest. All the *Tithonia* treatments were not significantly different from each other. The control was not significantly different from all *Tithonia* treatments (Fig. 2). At Mungwi, there were no significant differences between all the treatments due to the fact that P seems not to be limiting, which also confirms the available soil P results above.

Table 2. Effect of treatments on available P (Bray-1 P) and exchangeable acidity at the time of harvesting maize at (a) MRRC, Kasama, and (b) Mungwi District, Northern Zambia.

Treatment	Bray P		Exch Al+H		Exch Al		Exch Al Satn	
	MRRC	Mungwi	MRRC	Mungwi	MRRC	Mungwi	MRRC	Mungwi
	- - - - (ppm) - - - -		- - - - - - - - - - (cmol kg^{-1}) - - - - - - - - - -				- - - - - (%) - - - - -	
1. Control (no *Tithonia*, no fertilizer)	0.06	0.22	0.45	0.25	0.35	0.12	20	3.6
2. NKP compound fertilizer	0.61	0.38	0.58	0.50	0.45	0.28	15	9.0
3. Tithonia alone	0.10	0.28	0.33	0.22	0.25	0.05	8	1.0
4. Tithonia + ¼ recommended rate of P as SSP	0.11	0.32	0.35	0.25	0.25	0.08	10	2.4
5. Tithonia + Full recommended rate of P as GRP	0.09	0.26	0.40	0.30	0.22	0.20	10	6.0
6. *Tithonia* + ¼ recommended rate of P as GRP	0.11	0.20	0.35	0.15	0.20	0.12	6	3.0

Figure 1. Effect of treatments on P concentration in maize at harvest at (a) MRRC and (b) Mungwi.

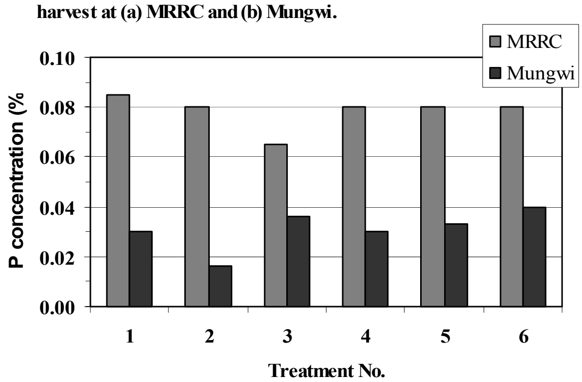


Figure 2. Effect of incorporating Tithonia prunings on maize grain and stover yield at MRRC stover.

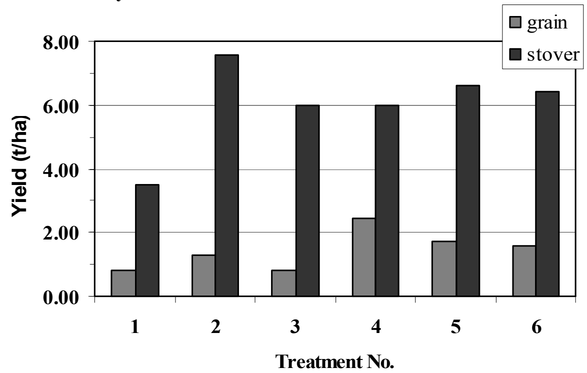
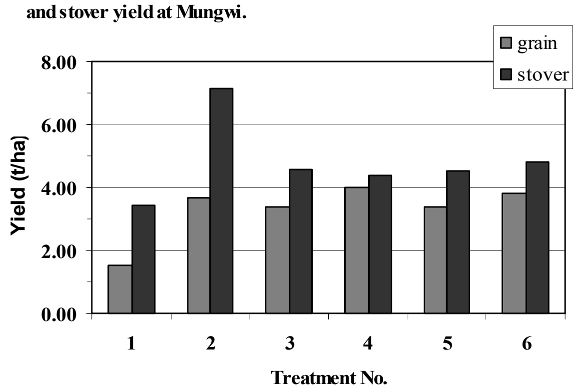


Figure 3. Effect of incorporating Tithonia prunings on maize grain and stover yield at Mungwi.



Grain yield: At Misamfu, the stover yield showed that the control treatment was significantly different ($P = 0.05$) from the rest of the treatments. There was no significant difference ($P = 0.05$) between the NPK fertilizer treatment and treatments receiving *Tithonia* either alone or in combination with SSP or GRP on stover yield. There were no significant differences between the control and NPK fertilizer on grain yield, as well as among treatments receiving *Tithonia* combined with P sources (SSP and GRP). The treatment receiving *Tithonia* combined with ¼ rate P as SSP, produced the highest grain yield at Misamfu (Fig. 3) while *Tithonia* alone produced the lowest grain yield.

These results also showed that at Mungwi stover yield was significantly different ($P = 0.05$) between the control and the rest of the treatments. There was no significant difference ($P = 0.05$) in terms of stover yield between the NPK fertilizer treatment and the treatments receiving *Tithonia* alone or in combination with either SSP or GRP. The grain yield also showed that there was a highly significant difference ($P = 0.05$) between the control and the NPK fertilizer treatments (Table 2). Among the treatments receiving *Tithonia,* there were no significant differences ($P = 0.05$) on grain yield (Fig. 3).

DISCUSSION

Tithonia residue contained adequate concentration of N, very low concentration of P, higher concentration of K, very high concentration of Ca and some adequate amount of Mg, as well as high quantities of Fe and some Zn (Table 1). At Misamfu grain yield data showed that P was the most limiting nutrient element (this is confirmed by previous soils data, where available P (Bray 1) = 1 ppm, (data not shown), because despite providing recommended N rate in form of *Tithonia*-N (*Tithonia* tissue-P was 0.14%), the grain yield was not significantly different to the control (Table 2).

According to Buresh (1999) upon decomposition, *Tithonia* residue would be expected to release its tissue-P readily if the latter concentration was equal or more than 0.25% P. The evidence from the data from this experiment suggests that this assertion does not perhaps hold for the acid soils of Northern Zambia since it is clear that there was a response to grain yield at Mungwi where *Tithonia* alone was not significantly different from *Tithonia* combined with ¼ rate P as SSP (Table 2). When recommended NKP fertilizer was applied at Misamfu without *Tithonia*, it appears the applied P was fixed, thus the grain yield was significantly different to that of *Tithonia* combined with quarter rate P as SSP (Fig. 3). This implies that *Tithonia* perhaps helped to make the applied P available to the maize only in the presence of inorganic source of P as SSP, and that even with P concentration of 0.14%, some solubilization or desorption appeared to have occurred. The presence of *Tithonia* appears to also make available P from rock phosphate as can be seen from the two treatments with *Tithonia* combined with GRP which were significantly different to *Tithonia* alone (Fig. 3). The high SED obtained at Misamfu was due to poor germination (caused by drought) which occurred at the time of planting. The biggest improvement in terms of grain yield was with *Tithonia* combined with ¼ rate of P as SSP. This is desired because it involves using a cheap material – *Tithonia*, with the addition of a small quantity of expensive inorganic P fertilizer.

The maize grain yields are higher at Mungwi than has previously been found (by Soil Productivity Research Programme (1990, 1991, 1996) which was based at Misamfu) when GRP was used on its own on maize. SPRP yields were around 2 t ha^{-1} while in this study the yield was around 4 t ha^{-1} indicating that perhaps *Tithonia* helped to solubilize the added rock P to some extent, may be not to a degree as with inorganic P source on the Mungwi site where the acidity was lower than at Misamfu. However, both treatments with GRP had relatively low grain yield compared to *Tithonia* combined with quarter rate P as SSP, due probably to the relatively low solubility of the GRP compared to inorganic SSP (Fig. 3).

These results are in agreement to those of Ganunga (1998) who also showed that at three sites in Malawi, *Tithonia* combined with inorganic P source was able to produce comparable grain yield with inorganic fertilizers alone or produced even better yields (Table 2). In this study the NPK treatment produced comparable grain yield with *Tithonia* combined with GRP (Fig. 3). These results are similar to those obtained in studies in Kenya (Niang *et al*., 1999; Question and Answers) where yield of maize was shown to be boosted by applying *Tithonia* combined with rock phosphate.

The Misamfu soil (an oxisol) was relatively poor in fertility terms compared to the udandic Kandiustults soil at Mungwi. The latter had all soil parameters, except for exchangeable Al and Al saturation, higher than the former site (Table 3). The soils at Mungwi are more fertile than those at Misamfu as indicated by high pH, available P (Bray 1), organic matter and CEC (from previous data not shown). These differences in soil fertility status explain why at Mungwi both stover and grain yield were higher than at Misamfu. This is why a lower rate of P was applied at this site.

Mungwi soils seem not to represent the major soil types of Northern Zambia, so the challenge to attain food security at household or the village level lies with options such as use of *Tithonia* combined with judicious amounts of inorganic P or with GRP on these acid soils typically represented by Misamfu soil.

These results show that a resource-poor farmer of Northern Zambia can grow and produce adequate maize

Table 3. Initial chemical soil properties (0-15 cm depth) of the experimental sites

Soil characteristics	Misamfu	Mungwi
pH ($CaCl_2$)	4.5	4.7
CEC (cmol (+) kg^{-1})	3.72	6.8
Org. C (%)	0.60	1.31
Total N (%)	0.05	0.11
Bray-1 P (mg kg^{-1})	1.07	2.65
Exch. K (cmol (+) kg^{-1})	0.47	0.97
Exch. Ca (cmol (+) kg^{-1})	0.28	0.84
Exch.Mg (cmol (+) kg^{-1})	0.03	0.08
Exch. Al^{3+} (cmol (+) kg^{-1})	0.36	0.13
Al^{3+} Saturation (%)	20	3.5
Base Saturation (%)	41	48

grain yield to attain household food security merely by using either *Tithonia* combined with judicous quantities of inorganic fertilizer (which is desirable because inorganic fertilizer is costly) or some full to quarter rate P as GRP and this practice is even more desirable as *Tithonia* is cheap and readily available locally and GRP is a cheaper source of P if only the deposits found in Northern Zambia can be exploited as this is readily available in this province. This is more applicable on the less fertile Misamfu soil, which is one of the dominant soil types in Northern Zambia. On the more fertile Mungwi soil, a resource-poor farmer would easily attain household food security by applying *Tithonia* alone or combined with cheap and locally available GRP, or if he/she can afford a little amount of inorganic P. The control shows a somewhat high grain yield at Mungwi (Fig. 3), perhaps this could be attributed to some residual P effect.

Al saturation

The pattern of Al saturation results is a mirror image of the pattern of the grain yield produced at Misamfu, implying that clearly Al saturation was the most limiting parameter to increased maize grain yield at this site (Table 2). The other soil parameters (Exchangeable acidity and Al, available P and P uptake) consistently showed that Mungwi soil was relatively more fertile than Misamfu soil. Yield data confirmed this quite accurately. Hence the discussion has dealt mostly with yield data and the soil available P, the latter being a crucial element in these soils due to its unavailability, which is directly influenced by the soil acidity. Exchangeable acidity and Al, as well Al saturation merely help to show the degree of acidity.

In general pH was lowest in fertilizer treated plots at both sites (4.4 at Misamfu and 4.5 at Mungwi), confirming the soil degradation which seems to be caused by the application of fertilizers on these soil as has been shown by other workers (e.g. Dalland *et al*., 1993; Singh and Goma, 1995; Stocking, 1988), as also shown by the exchangeable acidity, exchangeable Al and Al saturation.

CONCLUSIONS

(1) Maize stover and grain yield obtained from the application of *Tithonia* leaves alone or in combination with both P sources, were comparable with yields obtained with inorganic NPK fertilizer treatment at Mungwi site; at Misamfu, the NPK fertilizer was able to give grain yield comparable to *Tithonia* combined with GRP. (2) Soil acidity

was reduced and there was an overall improvement in soil fertility as a result of applying *Tithonia.* (3) GRP appears to be agronomically effective on the performance of some annual (short-duration) crops such as maize if it is incorporated together with *Tithonia* prunings (contrary to the sole application of GRP) before application on the acid soils of Northern Zambia. This work has not only verified that *Tithonia* does work in improving maize yield, which has been shown elsewhere in Kenya, Malawi and Zimbabwe, but the most significant added piece of knowledge is the acid ameliorating effect. This latter aspect is particularly pertinent to Northern Zambia where acid soils are widespread and will no doubt go along way in solving the acidity problem and the associated crop production constraints.

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RESPONSE OF MAIZE (*Zea mays* L.) CULTIVARS TO DIFFERENT LEVELS OF NITROGEN APPLICATION IN SWAZILAND

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ABSTRACT

Nitrogen (N) is one of the most deficient elements in highly weathered tropical and subtropical soils. Yet, N is one of the most important nutrients for maize growth and development. If deficient, maize yields are reduced. A field experiment was conducted to determine the response of four maize cultivars to different nitrogen levels at the Lowveld Experiment Station, Big Bend, Swaziland. Four Nitrogen rates consisting of 0 kgN/ha^{-1}, 50 kgN/ha^{-1}, 100 kgN/ha^{-1} and 150 kg/ha^{-1} and four varieties (PHB3435, SNK2943, CG4141 and PAN6479) were used in this study. The experimental design was a randomised complete block (RCB) with 4x4 factorial treatment arrangement and 4 replications. The data collected were subjected to analysis of variance (ANOVA) and means were separated by the Least Significant Differences (LSD) test. Grain yields were further analysed using the Yield Fit Model to obtain both the Most Economic Yield and the Most Economic N rate. The ANOVA showed that the grain yield varied significantly (P>0.05) with both varieties and nitrogen level. However, there was no significant variety by nitrogen interaction, suggesting that all varieties responded similarly to N application. In general, grain yield and total dry matter increased with increase in N applied up to 100kg N/ha^{-1}. There was very little or no further grain yield increase beyond 100kg N/ha^{-1} application. PAN6479 was the highest yielding variety while CG4141 was the lowest. Based on these findings the three (PAN6479, SNK 2943 and PHB3455) highest yielding varieties may be recommended to be grown in this region of the country. However, based on the Yield Fit Model the variety PAN6476 would be the most economical to grow in this region of the country.

Keywords: Most Economic N Rate, Most Economic Yield, Nitrogen Uptake, Nitrogen Use Efficiency, Varieties, Yield fit model.

INTRODUCTION

Nitrogen (N) is the most important element for plant growth and development. Nitrogen is an integral component of many compounds essential for plant growth processes including chlorophyll and many enzymes. Nitrogen also mediates the utilization of potassium, phosphorus and other elements in plants (Brady, 1984). The optimal amounts of these elements in the soils cannot be utilised efficiently if nitrogen is deficient in plants. Therefore, nitrogen deficiency or excess can result in reduced maize yields. Maize nitrogen requirement can be as high as 150 to 200 kg N per hectare. However, nitrogen requirement and utilization in maize also depends on environmental factors like rainfall, varieties and expected yield.

Research results elsewhere have shown that various hybrids of maize (*Zea mays* L) differ markedly in grain yield response to N fertilization (Bundy and Carter, 1988). These findings are supported by studies conducted by Kamprath *et al*. (1973), Beauchamp *et al*. (1976), Balko and Russell (1980), and Nxumalo *et al*. (1993). According to Kamprath *et al*. (1982) the increase in maize grain yield after N application is largely due to an increase in the number of ears per plant, increase in total dry matter distributed to the grain and increase in average ear weight.

In the industrialised countries nitrogen deficiency is alleviated by the addition of inorganic fertilizers. This is not possible in the least developed countries where inorganic fertilizers are either not available or are very expensive for small-scale subsistence farmers. In Swaziland, even though inorganic fertilizers are available, the majority of farmers cannot afford to buy them. More often farmers apply less than the recommended amount of inorganic fertilizers thus resulting in low maize grain yields. According to Dlamini (1990), Swazi Nation Land (SNL) farmers only apply on average seven kg N/ha^{-1} while the recommended rate is 65-75kg N/ha^{-1} in order to obtain good yield in the range of 3.5-5.0 t/ha^{-1}. This practice by SNL farmers is attributed to lack of funds and knowledge of the role of nitrogen in maize grain production.

Maize is the major food crop grown by SNL farmers in Swaziland. According to the Central Statistics Office (1987), about 90% of maize in Swaziland is produced by SNL farmers while the remaining 10% is produced by farmers in Title Deed Land (TDL). The average maize yield from SNL is about 1.5-2.0 t /ha^{-1} while that from TDL can be as high as 6.0 t/ ha^{-1} (Dlamini, 1990). The big difference in grain yields can be attributed to management, input availability especially inorganic fertilizers, the lack of technical and production skills. Despite planting improved seed, SNL farmers continue to obtain low grain yields mainly because they either do not apply or apply less than the recommended amount of inorganic fertilisers.

Most of the research conducted in Swaziland to determine high yielding maize varieties has been done under high moisture, optimum inputs and good management. No or little research has been done under low input agriculture. Dlamini (1990) reported that most of the research in Swaziland was geared for commercial farmers. Therefore, there is a need for more research under low input agricultural systems such as those practised by small scale farmers in the SNL. The need is further justified by the observation that the bulk of maize in the country is produced by smallholder farmers. It is very important to identify maize varieties that are able to produce high grain yield under low management cropping systems as practised by smallholder farmers. The varieties that is suitable for such systems should in addition to high grain yields absorb and utilize nitrogen efficiently even at low N rates.

The objectives of the study therefore were to: (1) determine the grain yield response of four maize cultivars to four levels of nitrogen, and (2) determine nitrogen uptake, nitrogen use efficiency, the most economic nitrogen rate and the most economic yield among four maize varieties.

MATERIALS AND METHODS

Experiment site

The experiment was conducted at Big-Bend, Lowveld Experimental Station which is located in the Lowveld region of Swaziland. This region is in the driest part of the country receiving highly variable rainfall averaging about 660 mm per year. The region has mean annual temperature of about 22^0 C. Summer temperatures in this region sometimes reach 35^0 C resulting to high evapotranspiration (Table 1). The soil type is black vertisol which is very low in nutrients and organic matter (Murdoch, 1973).

Table 1. Mean temperatures in degrees celsius for the maize growing period at BigBend experiment

	Month			
	May	**June**	**July**	**August**
Long Term Mean Temperature	19.1	15.8	16.0	18.4
Actual Mean Temperature	18.7	5.9	12.9	17.2

Experimental Design

The experimental design was a randomized complete block (RCB) with 4x4 factorial treatment arrangement and 4 replicates. The plot sizes were 4.5 m X 6.0 m with four rows. Four commercial maize varieties consisting of PHB3435, CG4141, SNK2943 and PAN 6479 were used as test varieties. The four varieties were chosen at random among the recommended varieties in the country. However, their drought, pest and disease tolerance were also taken into consideration during the selection. Nitrogen treatments consisted of four rates of 0, 50, 100 and 150 kg N ha^{-1}.

Ploughing was done using a mouldboard plough while planting was by hand. Inter-row and intra-row spacing was 90cm and 25 cm, respectively. Weeds were controlled by the application of GARDOMIL, which is a mixture of Metolachlor, Terbuthylazine and Atrazine. The herbicide was applied post emergence at a rate of 1 L ha^{-1}. Hand weeding was also carried out whenever necessary. Plant population counts were conducted 5 weeks after emergence and at crop harvest.

Prior to planting, soil tests were conducted to determine the available N, P and K. The soil pH was also determined so that adjustments could be made if necessary. Nitrogen was determined following the Kjeldahl method (Bremner and Mulvaney, 1982), while the soil pH was measured in $CaCl_2$ solution using a glass electrode (McLean, 1982). Phosphorus and K were determined following the methods of Olsen and Sommers, (1982) and Knudsen *et al*., (1982), respectively. Nitrogen fertilizer was applied as a split application during planting together with P and K and at 5 weeks after planting. Phosphorus and K were applied according to soil analysis results. The amounts applied were 39kgha^{-1} and 26kg ha^{-1} for P and K, respectively. The N source was lime ammonium nitrate (28% N) while the P source was triple super phosphate and that for K was muriate of potash. No adjustments were made on the pH since it was within the normal range for maize (6.1).

The experiment was irrigated once a week using overhead sprinklers to ensure that water was not a limiting factor. Over application of water was avoided to minimise nutrient leaching especially N. At 9, 13, and 16 weeks after planting and just before crop harvesting, whole plant samples were taken at random from each plot (2 outside rows) oven dried at 65□C and total nitrogen content was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). At crop maturity (5 months after planting) the 2 centre rows X 6m per plot (10.8 M^2) comprising of at most 24 plants were hand harvested. Ear number, cob weight, total above-ground dry matter and grain yield were recorded.

The harvest index, total N uptake and N use efficiency were calculated. The harvest index was calculated as grain yield/total dry matter while the N uptake was calculated as total N in grain plus N left in the stover at harvest. The N use efficiency was calculated as grain yield/nitrogen used (Bundy and Carter, 1988).

The Most Economic Yield (MEY) and the Most Economic Rate (MER) of nitrogen were determined using the statistical Yield Fit Model (Barreto and Westerman, 1985). The model uses data such as price of N fertilizer, price of maize, grain yield, N level applied, and fixed costs to calculate the MEY and MER. In this experiment the price of maize grain was calculated to be E 0.54/kg and that of fertilizer N was E 2.93/kg. The fixed costs were estimated to be E 200 ha^{-1}.

Statistical Analysis

Total dry matter, grain yield, plant nitrogen content, ear number, cob weight, nitrogen uptake, cob number, nitrogen use efficiency, harvest index and plant population data were subjected to analysis of variance using SAS Statistical procedures. Mean separation was done using the LSD test at 5% probability level (Montgomery, 1991). The grain yield data for each cultivar at each nitrogen level was further analysed using the Yield Fit quadratic model to determine both the Most Economic Yield (MEY) and the Most Economic Nitrogen Rate (MER).

RESULTS AND DISCUSSION

The analysis of variance mean squares of grain yield, total dry matter, nitrogen uptake, cob number, nitrogen use efficiency and harvest index are presented in Table 2. The grain yield and the total above-ground dry matter was significantly ($P > 0.5$) affected by both the variety and nitrogen level. However, the variety by nitrogen interaction was not significantly different ($P>0.05$) from zero for both grain yield and total above-ground dry matter.

The cob number, nitrogen use efficiency and the harvest index were all significantly different ($P>0.05$) for station, Swaziland, 1994 the varieties. The nitrogen effects were not significantly different ($P> 0.05$) for the varieties for cob number, nitrogen use efficiency and harvest index. Similarly there were no significant differences (P. 0.05) for the varieties for their interaction with nitrogen. This finding indicates that the performance of the varieties is independent from the nitrogen levels applied in this study. This result

Table 2. Analysis of variance showing mean squares for grain yield, total dry matter, nitrogen uptake, cob number, nitrogen use efficiency and harvest index of four maize varieties evaluated at Big Bend experiment station, Swaziland.

Sources of variation	df	Mean Squares					
		Grain yield	Total dry matter	Nitrogen uptake	Cob number	Nitrogen use efficiency	Harvest index
Varieties	3	9879207*	28893719*	2176*	175803576*	158.3*	0.0288*
Nitrogen	3	3476528*	26798497*	1818*	3335584	25.7*	0.0019
Varieties X Nitrogen	9	8060876	6592580	223	109764672	22.9	0.0090
Error	48	905716	6219415	314	59980695	24.1	0.0099

* = significant at 0.05 probability level

may suggest that the experimental plot might have had adequate amount of soil nitrogen.

The cultivar and nitrogen level had a significant effect on the nitrogen uptake. As nitrogen level increased the nitrogen uptake also increased with all cultivars. There was no significant cultivar X nitrogen interaction.

NITROGEN EFFECTS

Grain yield was significantly affected by the nitrogen level (Table 2). The grain yield increased as nitrogen level increased up to 100kg N/ha. This was in agreement with results reported by Bundy and Carter (1988) and Kamprath *et al*. (1982). On the contrary, Nxumalo *et al*. (1993) found no significant effect of N level on grain yield. The highest grain yield (4.7 t/ha) occurred when 150kg N/ha was applied while the lowest (4.0 t/ha) occurred when no nitrogen was applied. The other two rates (50 and 100kg N/ha) recorded mean grain yields of 4.3 and 4.6 t/ha, respectively.

The least significant difference (LSD) test showed that the mean grain yields achieved with 0 and 50kg N/ha were not significantly different. The yields for 50, 100 and 150kg N/ha were also not significantly different from each other (Figure 1). The cultivars PHB3435 and PAN6479 reached maximum grain production when 100kg N/ha was applied while those of CG4141 and SNK2943 had a slight grain yield increase when 150kg N/ha was applied (Figure 2).

The total above-ground dry matter was significantly affected by the nitrogen level (Table 2). The total above-ground dry matter was 9.2 and 11.0 t/ha for the 0 and 100kg N/ha treatments, respectively. The other two nitrogen levels 50 and 150 kg/ha achieved 10.2 and 10.6 t/ha total dry matter, respectively. In general, as nitrogen level increased the total dry matter also increased up to 100kg N/ha then declined (Figure 3). Kamprath *et al*. (1982) also observed the same trend. In their study they found that the total dry matter and grain yield increased as nitrogen level increased from 56 to 168kg N/ha but no further dry matter increase was observed with the application of 280kg N/ha. This coupled with the fact that there was no significant difference between the grain yields from nitrogen levels of 100 and 150kg N/ha may suggest that the minimum nitrogen level required by these cultivars to achieve maximum yields is about 100kg N/ha. Dlamini (1990), reported that 65 to 75kg N/ha was required to obtain a good maize yield (3.5 to 5.0 t/ha) in Swaziland.

The cob number, nitrogen use efficiency and harvest index were all not significantly affected by nitrogen level. However, nitrogen uptake was significantly affected by nitrogen level and cultivar (Table 2). This was in agreement with results reported by Bundy and Carter (1988). In general, as nitrogen level was increased more nitrogen was taken up by the plants. The highest mean nitrogen uptake (96 kg/ha) was achieved when 100kg N/ha was applied. After that it declined. When 0, 50 and 150kg N/ha were applied the mean nitrogen uptake was 83, 87 and 95kg N/ha, respectively. However, there was no significant difference between 0 and 50, or 100 and 150kg N/ha applied (Figure 4).

The soil analysis conducted before planting showed that there was, on average, 40 kg/ha of available N in the soil measured to a depth of 15 cm. The high residual available nitrogen is not surprising because the field used for this experiment has always been used for experimental purposes and fertilizers have been applied almost every year. Therefore, the high nitrogen uptake even when no nitrogen was applied may be attributed to the high residual nitrogen during planting and high mineralization rate of organic nitrogen during the growing season.

CULTIVAR EFFECTS

The mean grain yield differed with each cultivar. Cultivar CG4141 produced the lowest mean grain yield (3.2 t/ha) while PAN6479 produced the highest mean grain yield (5.0 t/ha) at all N levels. Cultivars SNK2943 and PHB3435 produced grain yields of 4.5 and 4.7 t/ha, respectively. There were no significant differences amongst the grain yields of SNK2943, PHB3435 and PAN6479. The grain yield of CG4141 was however, significantly inferior compared to the other three cultivars (Figure 5). This supports the observation that genetics plays a major role in grain yield production. Nxumalo *et al*. (1993), Bundy and Carter (1988) and Kamprath *et al*. (1982) all reported that cultivars differ in grain yield production.

The cob number (prolificacy) was significantly affected by cultivar (Table 2). Some cultivars were more prolific than others; i.e. they produced more than one cob per plant. The cultivar PAN6479, having produced the highest grain yield, had the highest number of cobs (37,161/ha) which was significantly higher than that of the other three cultivars (Figure 6). However, the total grain yield of this cultivar was not significantly different from that of SNK2943 and PHB3435. Anderson *et al*. (1984) and F.A.O. (1980) suggested that less prolific cultivars produce fewer cobs with greater grain weight. This might have been the case in this experiment. Studies undertaken by Kamprath *et al*. (1982) and Nxumalo *et al*. (1993) revealed similar results. This suggests that prolificacy is a genetically controlled trait. The

Table 3: Means of most economic yield (kg/ha) most economic nitrogen rate (kg/ha) regression coefficient of the four maize varieties evaluated at Big Bend Research Station, Swaziland, 1995.

Cultivar	M.E.Y.	M.E.R (kg/ha)	R^2 (kg/ha)	Net profit E/ha*
CG4141	2264	21	0.869	961
SNK2943	4114	106	0.404	1711
PHB3435	5687	104	0.904	2566
PAN6479	5308	74	0.644	2450

*E stands for Emalangeni which is the Swaziland currency. During the time of the study one US dollar was equivalent to 3.5 Swaziland Emalangeni

other three cultivars CG4141, SNK2943 and PHB3435 produced 31,485, 29,710 and 30,520 cobs/ha, respectively which were not significantly different from each other.

The nitrogen use efficiency and harvest index differed amongst the cultivars (Table 2). The cultivar CG4141 had the lowest mean nitrogen use efficiency (44kg grain/kg N), which was statistically inferior compared to the other three cultivars. The most efficient cultivar (51kg grain/ kg N) was PH3435 while the other two cultivars had efficiencies of 50 kg grain/ kg fertilizer N. (Figure 7).

The cultivar PAN6479 had the highest harvest index (0.49), which was significantly different from the other cultivars. The lowest harvest index (0.40) was recorded by the cultivar CG4141 while the other two cultivars recorded harvest indices of 0.44. Many researchers have reported high harvest indices for maize grown under high management and input agricultural systems. F.A.O. (1980) reported that the harvest index for maize could range between 0.37 to 0.74. The generally low harvest indices in this experiment may have been caused by the frost kill, which affected the maize crop on the last day of June. The minimum temperature for that day was -11^{O}C. The maize at that time was about 6 weeks old. All the leaves were killed but the experiment recovered enough to warrant analysis of the data. This might have had an effect on the grain yield. The mean temperature data for the growing period is shown in (Table 2). The data shows that the actual mean temperatures were below normal during the months of May, July, and August.

Nitrogen uptake was highly influenced by the cultivar and nitrogen level (Table 2). The cultivar PAN6479 absorbed the largest mean amount of nitrogen (102kg N/ha), which was significantly higher than that absorbed by cultivars CG4141 and SNK2943. This corresponded with this cultivar (PAN6479) producing the highest mean grain yield. The cultivar CG4141 absorbed the least nitrogen and ended up with the lowest grain yield averaged over all N levels. The other cultivars SNK2943 and PHB3435 absorbed 90 and 96 kg N/ha respectively, which were not significantly different from each other (Figure 8). This supports the suggestion by Beauchamp *et al*. (1976) that cultivars differ in their ability to absorb nitrogen from the soil.

The cultivars PAN6479 and PHB3435 reached a maximum nitrogen uptake of 116kg N/ha when 100kg N/ha was applied then declined. However, N uptake continued with cultivars CG4141 and SNK2943 even when 150kg N/ha was applied (Figure 9). This coupled with the fact that there was no significant difference in grain yield at 100 and 150kg N/ha applied may suggest that these two cultivars PAN6479 and PHB3435 require at least 100kg N/ha to maximize grain yield production while the cultivars SNK2943 and CG4141 may require more.

The most economic yields and most economic nitrogen rates for each cultivar are presented in Table 3. The most economic yield of cultivar PHB3435 was the highest at 5,687 kg/ha followed by that of PAN6479, which was 5,308 kg/ha. The economic nitrogen rates for these cultivars were 104 and 74 kg/ha, respectively. The most economic yields of the other two cultivars CG4141 and SNK2943were 2,264 and 4,114 kg/ha and their most economic nitrogen fertilizer rates were 21 and 106kg N/ha, respectively. The cultivar PHB3435 was the most profitable to grow followed by the cultivar PAN6479 while the cultivar CG4141 was the least profitable.

CONCLUSION

The grain yield of maize was significantly affected by cultivar and nitrogen level. Cultivars SNK2943, PHB3435 and PAN6479 produced grain yields which were not statistically different. Their nitrogen uptake and nitrogen use efficiency was also not statistically different but significantly different from that of CG4141. The cultivar CG4141 was the lowest yielding and absorbed the lowest amount of nitrogen from the soil. These results suggest that cultivars SNK2943, PHB3435 and PAN6479 had several advantages over CG4141 i.e. higher grain yield and higher nitrogen use efficiency. These cultivars also had higher economic yields and higher net profit than CG4141 (Table 3). These cultivars were developed much more recently than CG4141. The objective in most corn breeding programmes is to select materials, which perform much better than the highest yielding locally grown cultivar. Although CG4141 was at one time elite, new cultivars now have a yield advantage over it.

Since there was no significant difference on the grain yield realised when 50, 100 and 150kg N/ha was applied the present nitrogen recommendations i.e 65-75kg N/ha for a maize yield between 3.5 to 5.0t/ha seem to be satisfactory. However, the results of this experiment show that at least 50kg N/ha should be applied in order to get maize yields between 3.0 and 5.0t/ha. The MER however, for cultivars PHB3435 and SNK2943 (i.e. 104 and 106kg N/ha) respectively are higher than the recommended rate. On the other hand, that for cultivar PAN6479 (i.e. 74kg N/ha) is within the recommended level.

From the results of the experiment it may be recommended that the three highest yielding cultivars be grown in this part of the country. But, based on the MER values the cultivar PAN6476 would be the most economic for SNL farmers. However, since the study was conducted in one location, it is suggested that the research be conducted in several locations to come up with recommendations that would apply in the whole country.

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EVALUATION OF COMPOST FOR MAIZE PRODUCTION UNDER FARMERS' CONDITIONS

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ABSTRACT

A study was carried out to evaluate the integrated use of compost and low rates of NP fertilizers under farmers' conditions in western Oromia. Training was organized for the farmers, development agents and subject matter specialists on the method of compost preparation and its use. The treatments used were no NP and compost, 0/0 N/P + 5 tons (t) compost ha^{-1}, 25/11 kg N/P +5 t compost ha^{-1}, 55/10 kg N/P + 5 t compost ha^{-1}, and the recommended rate of NP (110/20 kg N/P ha^{-1}) in a randomized complete block design with three replications. The experiment was conducted on four different locations for two cropping seasons using a hybrid maize (BH-660) variety. Laboratory analysis of the compost showed that 171 kg total N, 41 kg total P, 11 kg exchangeable K, 21 kg exchangeable Ca, and 8 kg exchangeable Mg ha^{-1} in addition to the micronutrients were applied from the 5 t compost. Statistical analysis for each location revealed significant differences ($p \leq 0.05$) among the treatments on the maize grain yield. The 5 t compost ha^{-1}, 25/11 kg N/P plus 5 t compost ha^{-1}, 50/10 kg N/P plus 5 t compost ha^{-1} and the recommended rate of NP (110/20 kg N/P ha^{-1}) provided 5.38, 6.34, 6.88, and 7.42 t ha^{-1} of average grain yield, respectively, as compared to 3.97 t ha^{-1} under the control treatment. Likewise, the economic analysis showed that the highest marginal rate of return (382%) was recorded for the use of 5 t compost ha^{-1} alone, followed by 151% for the 55/10 kg N/P + 5 t compost ha^{-1} treatment, and 136% for the application of 5 t compost ha^{-1} + 25/11 kg N/P ha^{-1}. Except for the control treatment and the recommended rate of NP fertilizers, the use of 5 t compost ha^{-1} alone or integrated with low rates of NP fertilizers considered in this study is economical for maize production in western Oromia.

Key words: Compost, economic analysis, integrated nutrient management, Ethiopia

INTRODUCTION

Maize is a staple food and cash crop in western Oromia, Ethiopia. However, its production in the region is limited among other factors by low soil fertility (Legesse *et al*, 1987; Asfaw *et al.*, 1997). Composting of decomposable materials and returning them back to the soil is an historic method for maintaining soil fertility through natural nutrient cycling (Inckel *et al.*, 1996). For instance, in Korea, compost applied to upland soils that are low in organic matter and cation exchange capacity and subjected to severe erosion often results in higher crop yields than applying undecomposed rice straw with supplemental N (Parr, 1975). Moreover, Japanese farmers strongly believe that the application of compost is one among the most important practices to maintain and improve soil fertility (Egawa, 1975). As a result, the practice of applying compost and other organic fertilizer sources has continued even with the increasing supply of cheap chemical fertilizers.

Various studies have shown the importance of organic nutrient sources in improving crop yields and land productivity. Their integrated use with inorganic fertilizers was shown to increase the potential of the organic fertilizer sources under Ethiopian conditions (Asfaw et al., 1997; Asfaw et al., 1998; Heluf et al., 1999; Heluf, 2002).Thus, Asfaw et al. (1998) reported significant increases in the grain yields of maize grown on a Typic Ustorthent and a Typic Pellustert in the Alemaya area due to crop residue application. Similarly, Heluf (2002) reported an increment of 0.47 t ha^{-1} in grain yield of maize on Vertisols of Hirna valley in western Hararghe zone during the first year due to application of farmyard manure compared to no manure application. Moreover, in the same report, increasing farmyard manure rates from 0 to 20 t ha^{-1} increased wheat grain yield from 1.97 to 3.31 t ha^{-1}, while increasing N and P fertilizer rates from 0 to 92 kg N ha^{-1} and 40 kg P ha^{-1} increased the same wheat yield from 1.77 to 3.68 t ha^{-1} and from 2.38 to 2.88 t ha^{-1}, respectively (Heluf, 2002).

With regard to the integrated use of organic sources with mineral fertilizers, crop residues in combination with freshly applied and residual NP fertilizers increased maize grain yields by 1.31 and 0.54 t ha^{-1}, respectively, on Vertisols and by 0.85 and 0.57 t ha^{-1}, respectively, on Inceptisols of Alemaya region (Heluf et al., 1999). According to Asfaw et al. (1998), crop residues increased maize yields on Inceptisols in eastern Ethiopia by 0.58 t ha^{-1} (26%) more when planted on a field with residual NP fertilizers than when planted on a field without residual NP fertilizers. With sorghum, crop residues applied with recommended rates of NP fertilizers increased grain yields on a Typic Ustorthent and a Typic Pellustert near Alemaya by 52 and 47%, respectively, over the effect of crop residues applied without NP fertilizers (Asfaw et al., 1997).

Since western Oromia receives rainfall from April to December, it is among the wettest parts of Ethiopia, allowing the growth of considerable amounts of decomposable materials. However, due to lack of awareness and technical know-how, these materials are usually wasted and not put to proper use despite the declining rapidly soil fertility in the region. The low rates of NP fertilizers currently being used for maize production under farmers' conditions have aggravated the situation of soil fertility degradation and reduction of maize production, leading soil scientists at the Bako Agricultural Research Center to seek for alternative sources of fertilizers such as green manure, compost,

Table 1. Selected soil physicochemical properties of the experimental sites

Soil property	Location			Soil property	Location		
	Anno	Kejo	BRC		Anno	Kejo	[1]BRC
Sand (%)	31.0	47.0	37.0	Na ($cmol_c kg^{-1}$)	1.81	0.44	0.43
Silt (%)	38.0	24.0	24.0	K ($cmol_c kg^{-1}$)	1.94	2.08	0.55
Clay (%)	31.0	29.0	39.0	Ca ($cmol_c kg^{-1}$)	5.34	6.79	4.58
Textural Class	CL	SCL	CL	Mg ($cmol_c kg^{-1}$)	2.67	2.08	1.42
pH (H_2O), 1:2.5	5.30	5.61	4.99	Acidity ($cmol_c kg^{-1}$)	0.40	0.24	0.44
Organic C (%)	3.27	2.53	1.60	Al ($cmol_c kg^{-1}$)	Trace	Trace	Trace
Total N (%)	0.30	0.19	0.15	TB ($cmol_c kg^{-1}$)	11.76	11.39	6.98
C:N ratio	11.0	13.0	11.0	CEC ($cmol_c kg^{-1}$)	32.20	23.40	17.80
Olsen P, mg/kg	8.88	4.94	10.54	PBS (%)	37.00	49.00	39.00
Bray II P, mg/kg	8.10	4.40	8.70	pH (KCl), 1:2.5	3.46	4.30	3.93

BRC = Bako Research Center, TB = Total exchangeable bases, PBS = Percent base saturation
CL = Clay loam, SCL = Sandy clay loam, CEC = Cation exchange capacity, Acidity = Total acidity

farmyard manure, bone meal, rock phosphate and agroforestry systems to sustain maize productivity. At the beginning of the 1990s, the possibility of using compost along with low rates of NP fertilizers to improve the production of maize and hot pepper was investigated at the Bako Agricultural Research Center. Based on the results of on-station studies, Tadesse and Abdissa (1996) recommended the integrated use of 25/11 kg N/P fertilizer and 5 t compost ha^{-1} as economical for maize production. The objective of this study was to evaluate the feasibility of using compost or its integration with NP fertilizers for economically profitable and sustainable maize production under farmers' conditions in western Oromia.

MATERIALS AND METHODS

Description of the study area

The study sites are located in East Wollega Zone of Oromia National Regional State, western Ethiopia, in the sub humid agro-ecology of the country at 260-290 km west of Addis Ababa. The locations lie within a 30 km radius of 9° 6' N latitude and 37° 9' E longitude with altitude range of 1650-2000 m.a.s.l. Long-term weather data (1961-2001) at the Bako Agricultural Research Center indicates a unimodal rainfall pattern and annual total rainfall was 1244 mm. The rainy season occurs from April to December and maximum rain is received in the months of June, July and August. The minimum, maximum and average air temperature is 14.1°, 27.9° and 20.6°C, respectively. The average soil temperature at 1-m soil depth was 24°C (Zewude, 2001 personal communication). Soils in the study area are Alfisols with clayey, acidic reaction, low total N, organic carbon and available P (Wakene, 2001).

Sampling and laboratory analysis of soils and compost

Composite soil samples were collected from the plow layers of each experimental site before the application of the treatments. Standard laboratory procedures were followed in analyzing the soil samples and the compost. Accordingly, determination of soil particle size distribution was carried out using the hydrometer method, soil pH was measured potentiometrically using digital pH meter in 1:2.5 soil to solution ratio with H_2O and 1 *M* KCl solution.

Exchangeable bases were extracted with 1.0 *M*-ammonium acetate at pH 7. Ca and Mg in the extract were measured by atomic adsorption spectrophotometry while K and Na were determined using flame photometry. Cation exchange capacity (CEC) of the soil was determined with the ammonium acetate saturated samples using Na from percolating NaCl solution to replace the ammonium ions. The displaced ammonium was measured using the modified Kjeldahl procedure (Chapman, 1965) and reported as CEC. Percent base saturation was calculated from the sum of exchangeable bases as a percent of the CEC of the soil. Exchangeable acidity was determined by extracting the soil samples with M KCl solution and titrating with sodium hydroxide as described by McLean (1965).

Organic carbon was determined following the wet digestion method as described by Walkley and Black (1934). Total nitrogen in both soils and compost was determined by the Kjeldahl procedure as described by Jackson (1958). Available P in the soil samples was determined by the Olsen (Olsen et al., 1954) and Bray II (Bray and Kurtz, 1945) methods whereas only the Bray II method was used for available P in compost. Total P in the compost was extracted using aqua regia digestion technique. The P different extracts was measured by spectrophotometer following the procedure described by Murphy and Riley (1962). Available Fe, Mn, Zn and Cu in the composts were extracted with DTPA as described by Lindsay and Norvell (1978) and were measured by atomic absorption spectrophotometry.

Treatments and experimental design

The study was initiated in 1999 with the training of farmers, development agents and subject matter specialists in the area on the use and the methods of compost preparation.

Table 2. Composition of the compost used and amounts of nutrients applied in compost in the experiments

A) Nutrient Element Composition of Compost										
Available nutrients (mg kg^{-1})							Exchangeable bases ($cmol_c kg^{-1}$)			
TN (%)	Total P	Bray II	Fe	Mn	Zn	Cu	Na	K	Ca	Mg
3.42	8220.0	92.0	25.6	52.2	16.8	2.5	0.5	5.8	20.7	13.8
B) Quantity of nutrients (kg) in the 5 t compost ha^{-1}										
TN (%)	Total P	Bray II	Fe	Mn	Zn	Cu	Na	K	Ca	Mg
171.00	41.10	0.46	0.13	0.26	0.08	0.01	0.55	11.42	20.20	8.44

TN = Total Nitrogen, Bray II P = Available P extracted with Bray-II method

Table 3. Effects of compost and NP fertilizers on the maize grain yield (t ha^{-1}) under different locations and cropping seasons

N/P (kg ha^{-1})	Compost (t ha^{-1})	Bako Research Center		Kejo		Anno		Dambi Dima	Mean
		2000	2001	2000	2001	2000	2001	2001	
0/0	0	3.97 c	4.08 b	1.75 c	5.59 c	3.61 d	3.86 d	4.92 d	3.97 e
0/0	5	4.46 bc	6.44 a	3.10 bc	7.58 b	4.46 c	4.99 c	6.66 c	5.38 d
25/11	5	5.24 abc	6.44 a	4.59 ab	8.60 ab	5.59 b	5.77 bc	8.15 b	6.34 c
55/10	5	6.33 a	7.65 a	3.82 b	8.41 ab	6.78 a	6.23 b	8.94 b	6.88 b
110/20	0	5.91 ab	7.07 a	5.85 a	8.84 a	6.45 a	7.25 a	10.59 a	7.42 a
LSD (5%)		1.49	2.24	1.87	1.10	0.67	0.90	1.40	0.47
CV%		15.31	18.75	25.99	7.46	6.61	8.49	8.54	13.09

Means within a column followed by the same letter(s) are not significantly different at 0.05 level

The selected trained farmers and their families undertook the preparation of compost with the supervision of technical assistants and researchers. The compost was made from any decomposable material including weeds, grasses, leaves of trees and shrubs, ashes, farmyard manure, and crop residues. Compost preparation was carried out from September to October when considerable amounts of decomposable materials were available. The treatments used were: (1) no NP fertilizer or compost, (2) 0/0 N/P + 5 t compost ha^{-1}, (3) 25/11 kg N/P + 5 t compost ha^{-1}, (4) half the recommended N/P rate (55/10 kg ha^{-1}) + 5 t compost ha^{-1}, and (5) the recommended N/P fertilizer rate (110/20 kg ha^{-1}). The compost and the P fertilizer were applied at planting while N fertilizer was applied in split, half at planting and the remaining half at 30 to 40 days after planting. The experiment was laid out in a randomized complete block design with three replications using BH-660 hybrid maize as the test crop. The recommended cultural practices for hybrid maize production were adopted during the execution of the experiment. Analysis of variance was carried out using MSTATC computer soft ware and the methods described by CIMMYT (1987) were used for the economic analysis.

RESULTS AND DISCUSSION

Soil physical and chemical properties

Selected physicochemical properties of the soils on which the on-farm experiments were conducted are presented in Table 1. The texture of the soils varied from sandy clay loam at Kejo to clay loam both at Anno and Bako Research Center (BRC). The soil was very strongly acidic (pH in H_2O: 4.99) at BRC to moderately acidic (pH in H_2O: 5.63) at Kejo. According to the limits suggested by Landon (1991) for tropical soils, soil organic carbon was low at Anno and Kejo and very low at Bako Research Center. The total N contents of the soils were medium at Anno, and low at Kejo and Bako Agricultural Research Center. The soils at Anno also had the highest CEC (32.2 cmol$_c$kg^{-1}) followed by the soils at Kejo (23.4 cmol$_c$kg^{-1}). Although organic carbon, total N and CEC, were higher in the farmers' fields than at the BRC, both the Olsen and Bray II extractable P were highest in the soils of the research fields at BRC followed by the farmers' fields at Anno (Table 1).

The relatively poor soil organic carbon and N fertility of the fields at BRC compared with the farmers' fields could be attributed to the continuous monocropping and cultivation through heavy applications of NP fertilizers and intensive mechanized tillage practice at the research center. All these enhanced soil acidity, loss of organic carbon and leaching of the exchangeable bases. The lowest values of Olsen and Bray II extractable P were recorded at the Kejo site. The available soil P contents of the other two sites are also unsatisfactory for maize production. The generally low available soil P is presumably attributable to the high P fixing capacity of the Alfisols in these areas, which in turn is accounted for its strongly acidic nature. In line with this, Wakene (2001) reported results indicating considerable fixation of available P by Al, Fe, and Ca in the Alfisols of the same region.

Chemical composition of compost

The chemical composition of the compost used in the experiment was characterized (Table 2) through laboratory

Table 4. Partial budget analysis for compost and NP fertilizers in maize production

Description	Treatments (N/P, kg ha^{-1} + Compost, t ha^{-1})				
	0/0 + 0	0/0 + 5	25/11 + 5	55/10 + 5	110/20 + 0
Average yield (kg ha^{-1})	3970	5380	6340	6880	7420
Adjusted yield (kg ha^{-1})	3600	4842	5706	6192	6678
Gross field benefit (0.76 Birr/kg)	2736	3680	4337	4706	5075
Cost of compost preparation (3.50 Birr/Man day)	0	175	175	175	0
Cost of Urea (2.39 Birr/kg)	0	0	130	287	574
Cost of DAP (2.50 Birr/kg)	0	0	138	125	250
Cost of compost application (3.5 Birr/Man day)	0	21	21	21	0
Cost of Urea/DAP application (3.5 Birr/Man day)	0	0	11	14	28
Total cost that vary	0	196	474	622	852
Net benefit (Eth. Birr)	2736	3484	3862	4084	4224

Table 5. The marginal rate of return for compost and NP fertilizers in maize production

N/P, kg ha^{-1} + Compost, t ha^{-1}	Costs that vary	Marginal cost	Net benefits	Marginal net benefits	Marginal rate of return (%)
0/0 + 0	0	-	2736	-	-
0/0 + 5	196	196	3483	748	382
25/11 + 5	474	278	3862	378	136
55/10 + 5	622	147	4084	222	151
110/20 + 0	852	230	4224	140	61

analysis. The compost contained considerable amounts of essential macro and micronutrients. For instance, it contained 3.42% total nitrogen, 0.82% total P and 92 mg kg^{-1} available P. The implication is that the application of 5 t ha^{-1} of compost has supplied the soil with 171 kg ha^{-1} of total N and 41 kg ha^{-1} of total P (Table 2).

The exchangeable Ca, Mg and K contents of the compost were 20.7, 13.8 and 5.8 cmol$_c$kg^{-1}, respectively. Accordingly, the quantities of exchangeable Ca, K and Mg applied per ha of land from the application of compost at a rate of 5 t ha^{-1} were 20, 11 and 8.4 kg ha^{-1}, respectively (Table 2). In addition, the compost had supplied the soil with minor amounts of micronutrients such as Mn, Fe, Zn, and Cu. This implies that compost is a source of most essential plant nutrients and, thus a complete fertilizer to be used for sustaining maize and other crops production and productivity provided that other abiotic and biotic factors are favorable.

Maize grain yield

The effects of integrated use of compost and low rates of NP fertilizers on maize grain yields four sites in western Oromia are presented in Table 3. The difference in maize grain yield between and within location and cropping season as affected by applied compost and NP fertilizers were statistically significant ($p<0.05$). The statistical analysis at each location and the combined statistical analysis over locations indicated that there were significant ($p\leq0.05$) differences among the treatments on grain yield. The application of 5 t compost ha^{-1} without NP fertilizer increased maize yield by 1.41 t ha^{-1} while the recommended fertilizer rate (110/20 N/P kg ha^{-1}) increased the yield by 3.45 t ha^{-1} over the control treatment. The treatments involving combinations of NP fertilizers and compost produced intermediate yields. Application of the recommended rates of NP fertilizer gave the highest average maize grain yield followed by the application of half of the recommended rates of NP fertilizers plus 5 t compost ha^{-1} (Table 3).

The results of this study are in agreement with those various other studies which have also revealed the importance of organic nutrient sources particularly when integrated with mineral fertilizers in improving crop yields and land productivity under Ethiopian conditions (Asfaw et al., 1997; Asfaw et al., 1998; Heluf et al., 1999; Heluf, 2002). Generally, the wide gaps between the maize grain yields produced on the control plots and the treatments supplied with compost alone or together with NP fertilizers across locations and cropping seasons have attracted the attention of the farmers and helped them to understand more and easily about the value of compost in maize production.

Economic analysis

Partial budget analysis (Table 4) and marginal rate of return (Table 5) were carried out for the integrated use of compost and NP fertilizers in maize production. As indicated in the Table 4, the highest net benefit (4224 Eth. Birr ha^{-1}) was recorded for the application of the recommended rates of NP (110/20 kg N/P ha^{-1}) fertilizers followed by the application of half the recommended rates of NP (55/10 kg N/P ha^{-1}) plus 5 t compost ha^{-1} (4084 Eth. Birr ha^{-1}). However, the highest marginal rate of return (382%) was registered for the sole application of 5 t compost ha^{-1} followed by 55/10 kg N/P ha^{-1} plus 5 t compost ha^{-1} (151%). The recommended NP fertilizer rate (110/20 kg ha^{-1}), which provided the highest net benefit, was least in marginal rate of return (61%), far below the minimum rate of return (100%). Therefore, the added benefit of the recommended rate of NP fertilizers is not economical for maize production according to this finding. Although the monetary value was not determined, the macro- and micronutrients supplied by the compost are also highly invaluable for maintaining soil fertility and sustaining crop production in particular and land productivity in general.

CONCLUSION

The study revealed that the highest net benefit is not profitable. The integrated use of 5 t compost ha^{-1} either with 55/10 kg N/P ha^{-1} or 25/11 kg N/P ha^{-1} appeared to be economical. Moreover, the resource poor farmers could use sole application of 5 t composts ha^{-1} in the absence of inorganic fertilizers for maize production. The use of high doses of NP fertilizers were shown to be not feasible economically. As indicated in its chemical composition, the applied compost supplied the crop with considerable amounts of different essential macro- and micronutrients. Therefore, the integrated use of compost and low rates of inorganic fertilizers should be used to sustain maize production and productivity, thereby ensuring that organic matter as well as essential plant nutrients are replenished in these depleted acid soils. However, compost technology is new to Ethiopian farmers in general, and to the region in particular, therefore, advising, training and assisting the farmers in using any locally available decomposable materials for soil fertility management is of paramount importance.

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DETERMINATION OF OPTIMUM FARMYARD MANURE AND NP FERTILIZERS FOR MAIZE ON FARMERS' FIELDS

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ABSTRACT

A study was initiated in 1997 to introduce the culture of supplementing low rates of NP fertilizers with farmyard manure (FYM) in the maize based farming systems of western Oromia. The treatments were 0/0, 20/20, 40/25 and 60/30 kg N/P ha^{-1} and 0, 4, 8, and 12 t FYM ha^{-1} in factorial arrangement in a randomized complete block design with three replications. The experiment was conducted at Laga Kalla, Walda, Shoboka, Harato, and Bako Research Center using BH-660 hybrid maize. The FYM used for the experiment was well decomposed under shade and spot applied together with the P fertilizer at planting; N was applied in split form. The residual effects of FYM were investigated for Laga Kalla, Walda and Shoboka during the 1998 cropping season. Statistical analysis revealed that the N/P fertilizers and FYM significantly ($p<0.05$) increased grain yield in all locations except for Walda in 1997. Interactions of FYM and NP fertilizer rates were significant ($p\leq0.05$) at all locations except for Shoboka. The application of FYM alone at rates of 4, 8, and 12 t ha^{-1} produced average grain yields of 5.76, 5.61 and 5.93 t ha^{-1}, respectively, compared to 3.53 t ha^{-1} for the control treatment. Laboratory analysis confirmed that considerable amounts of macronutrients and small amounts of micronutrients were supplied by the FYM. There were significant residual effects of FYM and NP fertilizers applied in 1997 on maize grain yields in 1998. Based on the results of this study, the integrated use of properly managed FYM and low rates NP fertilizers could be used for maize production in the areas under consideration. Moreover, sole applications of FYM on relatively fertile soils like Walda and Harato are useful in maintaining soil fertilty and are encouraging for resource poor farmers.

Key Words: Farmyard manure, integrated nutrient management, NP fertilizers, residual effects, Ethiopia

INTRODUCTION

Low soil fertility is one among the major factors limiting maize production and productivity in western Oromia, Ethiopia. This is common in many tropical cropping systems where fertilizer use is low and little or no agricultural residues are returned to the soil for maintaining soil fertility. Alfisols that are moderately acidic in reaction are the dominant soil type in the region. These soils are characterized by low cation exchange capacity (CEC), and low contents of organic matter, available phosphorus (P) and total nitrogen (N) (Asfaw et al., 1997; Wakene, 2001). Moreover, the soils are fragile and easily affected by intensive cultivation and continuous use of inorganic fertilizers. As a result, considerable areas of land at the Bako Agricultural Research Center have been abandoned from production during the past three decades (Wakene, 2001). Several other natural and socioeconomic factors are also involved in aggravating the decline in soil productivity under the farming community in the region with the result that the relatively common practice of sole application of NP fertilizers has not sustained maize production and productivity in the region.

The recommended rates of inorganic fertilizers for hybrid maize production in western Oromia are 110 kg N and 20 kg P ha^{-1}. The recommendation was initially adopted by the well-to-do farmers but when the fertilizer subsidy was removed by the Government and the price of inorganic fertilizers doubled, the farmers failed to use even one-third of the recommended rates. Therefore, to maintain soil fertility and enhance their productivity, the use of other alternative options of soil fertility replenishment is indispensable. Farmyard manure (FYM) is one potential source of nutrients as a result of the high cattle population in the region where on average there are 6.1 cattle per family (Legesse et al., 1987).

There exists a large volume of literature reporting the the efficiency and effectiveness of FYM and other organic nutrient sources in maintaining soil fertility, improving crop yields and sustaining productivity, and that display their increased potential when integrated with inorganic fertilizers (Grant, 1981; Mugwira, 1985; Lyimo & Temu, 1992; Inckel et al., 1996; Asfaw et al., 1997; Asfaw et al., 1998; Heluf et al., 1999; Heluf, 2002; Wakene et al., 2002). Studies in Zimbabwe indicated that manure alone generally resulted in low crop yield indicating a need to supplement with inorganic fertilizers on soils low in fertility (Grant, 1981; Mugwira, 1985). At Uyole in Tanzania, application of low rates of NP fertilizers with FYM produced 7.10 t ha^{-1} of maize grain compared to 4.03 t ha^{-1} when the same rates of NP were used alone (Lyimo & Temu, 1992). Heluf (2002) reported an increment of 0.47 t ha^{-1} in grain yield of maize due to application of FYM during the first year over no FYM, whereas increasing FYM applications from 0-20 t ha^{-1} increased wheat grain yield from 1.97 to 3.31 t ha^{-1} on Vertisols of Hirna valley in western Hararghe zone, Ethiopia.

The potential of organic sources increases when used together with mineral fertilizers. While evaluating the potential of compost and its integration with low rates of NP fertilizers for improvement of maize production in western Oromia, Wakene et al. (2002) observed a higher marginal rate of return (MRR) when half the recommended N/P fertilizer rate was combined with 5 t compost ha^{-1} compared to MRR for the recommended NP rate alone (MRR of 151% vs. 61%, respectively). The use of crop residues with freshly applied and with residual NP fertilizers increased maize grain

Table 1. The soil pH, texture, total N (TN), organic carbon (OC) and available P of the experimental sites before and after treatments application

Location	Yr	N/P	+ FYM	pH (1:2.5)		OC	TN	Particle size (%)			Texture	Avail P (mg kg^{-1})	
				H_2O	KCl	(%)		Sa	Si	Cl		Olsen	Bray
Bako Research Center	97	0/0	+ 0	5.24	4.10	2.03	0.18	39	29	32	CL	2.68	2.80
	99	0/0	+ 12	5.17	3.99	2.15	0.18	40	31	29	CL	4.18	5.20
	99	60/30	+ 0	5.05	3.67	1.56	0.13	33	29	28	CL	9.48	10.12
	99	60/30	+ 12	5.65	4.30	1.88	0.14	38	25	27	SCL	7.62	8.33
Shoboka	97	0/0	+ 0	5.30	4.04	2.57	0.22	29	37	34	CL	3.06	2.80
	99	0/0	+ 12	5.05	4.00	1.76	0.14	30	36	34	CL	4.21	6.71
	99	60/30	+ 0	5.20	4.12	1.76	0.13	31	37	32	CL	3.86	4.20
	99	60/30	+ 12	5.42	4.20	2.35	0.23	29	38	23	L	3.10	4.21
Laga Qalla	97	0/0	+ 0	5.25	4.35	2.17	0.20	39	33	28	CL	3.86	4.50
	99	0/0	+ 12	5.73	4.24	2.87	0.26	40	32	28	CL	4.46	12.41
	99	60/30	+ 0	5.71	4.42	2.85	0.24	38	36	26	L	7.64	7.26
	99	60/30	+ 12	5.33	4.21	3.25	0.33	39	34	27	L	10.3	8.25
Walda	97	0/0	+ 0	5.64	4.12	2.21	0.24	39	31	30	CL	3.20	2.50

CL = Clay loam, SCL = Sandy clay loam, L = Loam, S = Sand, Si = Silt, C = Clay, Bray = Bray II method, Tex = Textural class, Yr = year, 97 = 1997 = soil samples collected before treatments application, 99 = 1999 = soil samples taken after treatments application

Table 2. The exchangeable bases, exchangeable acids, CEC, percent base saturation of the experimental sites before and after treatments application

Location	Yr	N/P	+ FYM	Exchangeable bases, acid and CEC ($cmol_c$ kg^{-1})							PBS (%)
		(kg	+ t ha^{-1})	Na	K	Ca	Mg	Acid	Al	CEC	
Bako Research Center	97	0/0	+ 0	0.44	0.47	4.59	1.92	0.56	Tr.	24.6	30
	99	0/0	+ 12	0.63	1.38	4.99	1.33	0.45	Tr.	25.2	33
	99	60/30	+ 0	0.39	0.72	2.94	0.83	0.36	Tr.	15.0	40
	99	60/30	+ 12	0.79	1.99	3.79	1.25	0.52	Tr.	19.4	62
Shoboka	97	0/0	+ 0	0.38	1.23	15.0	6.50	0.12	Tr.	37.2	62
	99	0/0	+ 12	0.39	0.59	4.14	1.08	0.32	Tr.	20.2	31
	99	60/30	+ 0	0.47	0.87	3.99	1.00	0.51	Tr.	21.0	30
	99	60/30	+ 12	0.55	1.28	7.88	2.50	0.40	Tr.	33.8	36
Laga Qalla	97	0/0	+ 0	0.31	1.91	4.69	2.08	0.16	Tr.	23.2	30
	99	0/0	+ 12	0.87	2.32	7.83	1.83	0.23	Tr.	31.4	39
	99	60/30	+ 0	0.63	1.79	8.78	2.08	0.12	Tr.	30.6	31
	99	60/30	+ 12	0.79	2.09	6.24	1.75	0.21	Tr.	35.0	41
Walda	97	0/0	+ 0	0.40	1.64	8.48	2.25	0.24	Tr.	24.0	53

PBS = percent base saturation, Yr = year, 97 = 1997 = soil samples collected before treatments application, 99 = 1999 = soil samples taken after treatments application, Tr = trace

yields by 1.31 and 0.54 t ha^{-1}, respectively, on Vertisols (Typic Pellusterts), and by 0.85 and 0.57 t ha^{-1}, respectively, on Inceptisols (Typic Ustorthents) in the Alemaya area of Ethiopia (Heluf et al., 1999). Asfaw et al. (1998) also reported significant increases in maize grain yields on Inceptisols and Vertisols in the Alemaya area due to crop residue application. Crop residues applied with recommended NP fertilizers produced 52% more sorghum grain on Inceptisols in the Alemaya area than crop residues applied alone (Asfaw et al., 1997).

Despite the high number of cattle per household (average of 6.1) and the availability of cheap family labor that could be used for FYM collection, incubation and transportation (Legesse et al., 1987), the use of FYM for soil fertility maintenance is not a common practice in western Oromia. Besides, due to the relatively higher availability of firewood, unlike the central and eastern highlands, FYM is not used for fuel in the region. These and the low rates of NP fertilizers currently being used for maize production under farmers' conditions have aggravated the situation of soil fertility degradation and declining maize production. Consequently, training the farming community on the proper handling and use of FYM together with low rates of inorganic fertilizers could be one alternative solution for the resource poor farmers in the region. The objective of this study was to introduce the culture of integrating FYM and NP fertilizers for maize production in western Oromia.

MATERIALS AND METHODS

Description of the study area

The study sites are located in East Wollega Zone of Oromia National Regional State, western Ethiopia, in the sub humid agro-ecology of the country at 260 km west of Addis Ababa. The locations lie within a 30 km radius of 9º6' N latitude and 37º 9' E longitude with altitude range of 1650-2000 m.a.s.l. Long-term weather data (1961-2001) at the Bako Agricultural Research Center indicates that the study area has a unimodal rainfall pattern and average annual total rainfall of 1244 mm. The rainy season occurs during April to December and maximum rain is received in the months of June, July and August. The minimum, maximum and average air temperature is 14.1º, 27.9º and 20.6ºC, respectively. The average soil temperature at 1-m soil depth is 24ºC (Zewude, personal communication). The dominant soil type in the study area is Alfisols with clayey texture, acidic reaction, low total N, organic carbon, and available P (Wakene, 2001).

Sampling and laboratory analysis of soils and farmyard manure

Composite soil samples were collected from the plow layers at each experimental site before applications of the treatments in 1997 and from the plots that received 12 t FYM ha^{-1}, 60/30 N/P kg ha^{-1} and 60/30 N/P kg ha^{-1} plus 12 t ha^{-1} of FYM at the end of the experiment in 1999. Standard laboratory procedures for each parameter were followed in analyzing the composite surface soil samples and the FYM. Determination of soil particle size distribution was carried out using the hydrometer method. Soil pH was measured potentiometrically using digital pH meter in 1:2.5 soil to solution ratio with H2O and 1 M KCl solution.

Exchangeable bases were extracted with 1.0 M-ammonium acetate at pH 7 for both soil and FYM samples. Ca and Mg in the extract were measured by atomic adsorption spectrophotometry while K and Na were determined using flame photometry. Cation exchange capacity (CEC) of the soil was determined with the ammonium acetate saturated samples using Na from percolating NaCl solution to replace the ammonium ions. The displaced ammonium was measured using the modified Kjeldahl procedure (Chapman, 1965) and reported as CEC. Percent base saturation was calculated from the sum of exchangeable bases as a percent of the CEC of the soil. Exchangeable acidity was determined by extracting the soil samples with M KCl solution and titrating with sodium hydroxide as described by McLean (1965).

Organic carbon was determined following the wet digestion method as described by Walkley and Black (1934). Total N in both soils and compost was determined by the Kjeldahl procedure as described by Jackson (1958). Available P in the soil samples was determined by the Olsen (Olsen et al., 1954) and Bray II (Bray and Kurtz, 1945) methods whereas only the Bray II method was used for available P in compost. Total P in the FYM was extracted using aqua regia digestion technique. The P different extracts was measured by spectrophotometer following the procedure described by Murphy and Riley (1962). Available Fe, Mn, Zn and Cu in the composts were extracted with DTPA as described by Lindsay and Norvell (1978) and were measured by atomic absorption spectrophotometry.

Treatments and experimental design

The experiment was conducted during the 1997 and 1998 cropping cropping seasons in five locations (Shoboka, Laga Kalla, Walda, Harato, and Bako Agricultural Research Center) in the maize-based farming system of western Oromia. The treatments used were 0/0, 20/20, 40/25, and 60/30 kg N/P ha^{-1} and 0, 4, 8 and 12 t FYM ha^{-1} in factorial arrangement using the BH-660 hybrid maize. Treatments were laid out in arandomized complete block design with three replications.

The FYM used for the experiment was well decomposed under shade and applied all at planting in spots with P fertilizer; N fertilizer was applied in split form with half of the dose applied at planting and the remaining half at 30 to 40 days after planting. The residual effects of FYM on maize grain yields at Shoboka, Laga Kalla and Walda were evaluated during the 1998 cropping season. All the necessary cultural practices recommended to the hybrid maize production were used for the management of the experimental plots throughout the cropping seasons. The farmers with the close supervision of the technical assistants and researchers managed the experimental fields. The yield data were subjected to statistical analysis using MSTATC computer software and the least significant difference (LSD) was used to separate significant treatment means.

Table 3. Elemental composition of the FYM used as organic fertilizer in the experiment

A) Nutrient Element Composition of the FYM

Nutrient (FYM)	Total N (%)	Total P (mg kg^{-1})	Available nutrient content (mg kg^{-1})					Exchangeable bases ($cmol_c kg^{-1}$)			
			Bray-II P	Fe	Mn	Zn	Cu	Na	K	Ca	Mg
	2.34	6780	427	31	145	29	3.5	0.88	17.12	15.26	15.74

B) Quantity of nutrient (kg) in the 4, 8 and 12 t ha^{-1} of Applied FYM

FYM, t	Total N	Total P	Bray-II P	Fe	Mn	Zn	Cu	Na	K	Ca	Mg
4	94	27	1.7	0.13	0.58	0.12	0.01	0.8	27	12	8
8	187	54	3.4	0.26	1.16	0.24	0.03	1.6	54	24	15
12	281	81	5.1	0.39	1.74	0.36	0.04	2.4	80	37	23

Table 4. Main effects of FYM and NP fertilizers on maize grain yield (t ha^{-1}) during the 1997 cropping season

Main effect	BRC	Walda	Shoboka	Harato	Laga Kalla	Mean
N/P (kg ha^{-1})		(t maize grain ha^{-1})				
0/0	3.61 c	6.14	6.08 b	6.51 b	3.70 b	5.21 c
20/20	5.37 b	6.69	7.16 a	7.35 ab	4.28 b	6.17 b
40/25	5.32 b	6.67	7.44 a	7.35 ab	5.06 a	6.37 b
60/30	6.09 a	6.97	7.12 a	8.07 a	5.54 a	6.76 a
LSD(.05)	0.62	NS	0.91	NS	0.66	0.36
FYM (t ha^{-1})						
0	3.38 c	6.00	6.13	7.19	4.03 b	5.35 c
4	4.78 b	6.71	7.43	7.29	4.24 b	6.09 b
8	6.18 a	6.97	7.12	7.40	5.07 a	6.55 a
12	6.05 a	6.79	7.14	7.41	5.24 a	6.53 a
LSD(.05)	0.62	NS	0.91	NS	0.66	0.36
CV (%)	14.5	16.9	15.6	16.6	17.1	16.4

Bako Research Center, means within a column followed by the same letter(s) are not significantly different at 0.05 levels

RESULTS AND DISCUSSION

Soil physical and chemical properties

Laboratory analytical results of selected physicochemical properties of the soils on which these on-farm experiments were conducted are presented in Tables 1 & 2. Soils in the study areas are dominantly clay loams while some are loamy in texture and vary from medium to moderately acidic based on pH (H_2O). The use of acid forming inorganic fertilizers in the region could lead to soil acidity constraints in the weakly buffered Alfisols.

Based on criteria defined by Landon (1991), the soil organic carbon contents at all locations are low whereas total N was medium except for the Bako Agricultural Research field, indicating the low fertility status of the soils. This could be due to the high temperature, continuous cultivation, and lack of incorporation of organic materials into the soils.

The cation exchange capacity of the soils ranged from 15.0 cmol$_c$ kg^{-1} at the Bako Agricultural Research Center to 37.2 cmol$_c$ kg^{-1} at Shoboka (Table 2). Exchangeable bases at all sites were sufficient for crop production, although the lowest was recorded in the soil of the Research Center. This could be attributed to the cropping history of the Center, which is quite different from that of the farmers' fields. In both the farmers' fields and the research station, available P (Olsen and Bray II extractable P) was deficient. In general, the low available soil P is presumably attributed to the high P fixing capacity of the Alfisols in these areas. In line with this, Wakene (2001) reported results indicating considerable fixation of available P by Al, Fe, and Ca in Alfisols of the same region.

Chemical composition of farmyard manure

The chemical composition of the FYM used in the field experiments is shown in Table 3a. The FYM contained considerable amounts of essential macronutrients and small amounts of micronutrients. In terms of total nutrients applied per hectare (see Table 3b), 4 t-FYM ha^{-1} supplied 85% of the recommended fertilizer N rate (110 kg ha^{-1})and 136% of the recommended fertilizer P rate (20 kg ha^{-1}) as well as asubstantial proportion of the maize crops K and Mg requirements. However, not all of the total N and P are immediately available for crop uptake. In terms of available P, 4 t FYM ha^{-1} supplied only 9% of the recommended P rate from inorganic fertilizer; 12 t FYM ha^{-1} thus supplied only 26% of the requisite available P. However, much of the P in unavailable forms is expected to become slowly available both during the current growing season to the crop to which it is applied as well as to subsequent crops through residual effects. The FYM supplied the soil with rather minor amounts of the micronutrients, in each case never more than 1 kg nutrient ha^{-1} (Table 3b). Thus, FYM is a source of most essential plant nutrients and, hence, is a complete fertilizer for sustaining production of maize and other crops provided that other abiotic and biotic factors are favorable. Moreover, FYM application helps to maintain soil organic matter content and soil biological activity. In other words, the application of FYM continuously could improve the soil physicochemical properties and sustain production and productivity.

In the present study, the application of FYM alone or with low rates of NP fertilizers did not bring about significant changes on the selected soil properties. This may be due to the treatments were spot applied to feed the crop, not to feed the soils. Soil sampling did not target the spot application points.

Maize grain yield

The grain yields of maize produced under different integrated rates of FYM and NP fertilizers at five locations in western Oromia are presented in Tables 4, 5, 6 and 7. Maize grain yields at all locations in 1997 cropping season were significant ($p \leq 0.05$) affected by both applied FYM and NP fertilizers except for Walda and Harato (Table 4). Except for Shoboka, interactions between FYM and NP fertilizers on maize grain yield were also significant ($p \leq 0.05$) (Table 5). The combined statistical analysis over locations also revealed significant main effects of FYM and NP fertilizers ($p \leq 0.05$) and interactions between these factors (Tables 4 and 5).

The average grain yield of maize increased consistently with increasing rates of NP fertilizers and FYM. Yields of control plots ranged from <1.0 t ha-1 at BRC to almost 6.0 t ha-1 farmers' fields at Harato (Table 5), indicating a fairly

Table 5. The effects of FYM and NP fertilizers on maize grain yield at five locations in the 1997 cropping season

N/P	+ FYM	BRC	Walda	Shoboka	Harato	Laga Kalla	Mean
(kg ha^{-1}	+ t ha^{-1})			(t maize grain ha^{-1})			
0/0	+ 0	0.90 h	4.68 c	4.44	5.79 d	1.86 f	3.53 g
0/0	+ 4	3.61 g	6.68 ab	6.43	7.72 abcd	4.37 cde	5.76 ef
0/0	+ 8	4.87 cdef	6.50 abc	6.52	5.74 d	4.41 cde	5.61 f
0/0	+ 12	5.05 cde	6.71 ab	6.95	6.78 d	4.17 de	5.93 def
20/20	+ 0	3.79 fg	6.70 ab	6.88	6.20 d	4.75 bcd	5.66 ef
20/20	+ 4	4.69 defg	7.44 ab	7.82	6.96 cd	3.27 e	6.04 def
20/20	+ 8	6.50 ab	6.88 ab	7.44	8.94 abc	4.35 de	6.82 bc
20/20	+ 12	6.50 ab	5.76 bc	6.52	7.28 bcd	4.75 bcd	6.16 cdef
40/25	+ 0	4.33 efg	6.12 abc	6.70	9.06 ab	4.46 cde	6.13 cdef
40/25	+ 4	5.05 cde	5.71 bc	8.00	6.78 d	4.66 bcd	6.04 def
40/25	+ 8	5.96 bc	7.98 a	7.64	7.57 abcd	5.67 abc	6.96 ab
40/25	+ 12	5.96 bc	6.88 ab	7.44	6.00 d	5.44 abcd	6.34 bcde
60/30	+ 0	4.51 efg	6.52 abc	6.52	7.68 abcd	5.04 bcd	6.06 def
60/30	+ 4	5.77 bcd	7.05 ab	7.47	7.68 abcd	4.67 bcd	6.53 bcd
60/30	+ 8	7.40 a	6.52 abc	6.88	7.34 bcd	5.85 ab	6.80 bc
60/30	+ 12	6.78 ab	7.80 a	7.64	9.58 a	6.61 a	7.68 a
LSD (5%)		1.24	1.86	NS	2.02	1.32	0.72
CV (%)		14.54	16.87	24.00	16.59	17.05	16.45

BRC = Bako Research Center, means within a column followed by the same letter(s) are not significantly different at 0.05 level

high level of soil fertility at some sites. This could be due to the differences in cropping history, cropping systems, land management and variations in socio-economic circumstances among the farmers. For instance, the host farmer from Walda was educated to a certain level, and knows the consequences of soil degradation on crop productivity. At Harato monoculture of maize is not commonly practiced; farmers are accustomed to growing diversified crops which help to maintain soil fertility.

No significant response to NP or FYM was observed at Shoboka. At Walda, Harato and Laga Kalla, the first 4 t ha^{-1} increment FYM alone was generally sufficient to achieve maximum maize yield; only at BRC did maize respond to higher rates of FYM without NP fertilizer application (Table 5). Similarly, there was generally no significant response to increasing rates of NP fertilizer alone beyond the first increment of 20/20 kg NP ha^{-1}. At the least fertile (most responsive) sites, maximum yield was only obtained with combined application of NP fertilizer (sub-optimal levels) and FYM. This implies that nutrients (especially N and P) in FYM are not immediately available during the season of application to fully nourish a maize crop even though the total quantities applied were in excess of recommended requirements based on inorganic NP fertilizer rates. Low sub-optimal rates of NP fertilizers alone were as effective as high rates of N and P from heavy FYM applications. Under conditions of low soil fertility, combined application of NP fertilizer and FYM are most effective because the supply of nutrients from both sources is additive (Paustian et al., 1992). Moreover, a readily available supply of N and P from fertilizer may enhance mineralization of unavailable organic N and P forms supplied in FYM providing a synergy in which the whole is greater than the sum of the parts.

There were significant main effects on grain yield in 1998 of NP fertilizer and FYM residues applied in 1997 at two of the three sites observed (Table 6). NP fertilizers showed significant residual effects ($p<0.05$) on grain yield at Walda and Shoboka whereas FYM produced significant residual effects on grain yield at Shoboka and Laga Kalla (Table 6). However, interactions of the residues of NP fertilizers and FYM on maize grain yield were not significant at any site (Table 7).

Table 6. Main effects of FYM and NP fertilizer residues applied in 1997 on maize grain yield in the 1998.

Main effect	Walda	Shoboka	Laga Kalla	Mean
N/P (kg ha^{-1})		(t maize grain ha^{-1})		
0/0	5.82 b	3.31 c	4.35	4.49 b
20/20	6.81 a	4.48 b	4.67	5.32 a
40/25	6.77 a	5.18 ab	4.95	5.63 a
60/30	6.86 a	5.64 a	4.30	5.60 a
LSD(.05)	0.78	0.92	NS	0.47
FYM (t ha^{-1})				
0	6.45	3.64 c	3.88 c	4.66 c
4	6.36	4.85 ab	4.25 bc	5.15 b
8	6.41	4.38 bc	4.95 ab	5.25 b
12	7.04	5.74 a	5.19 a	5.99 a
LSD(.05)	NS	0.92	0.80	0.47
CV (%)	14.27	23.67	21.06	19.05

Means within a column followed by the same letter(s) are not significantly different at 0.05 probability level

Table 7. Interactions of FYM and NP fertilizer residues applied in 1997 on maize grain yield in the 1998.

N/P	+ FYM	Walda	Shoboka	Laga Kalla	Mean
(kg ha^{-1}	+ t ha^{-1})		(t maize grain ha^{-1})		
0/0	+ 0	5.05	2.24	2.99	3.43
0/0	+ 4	5.41	3.54	3.74	4.23
0/0	+ 8	6.32	2.61	4.67	4.53
0/0	+ 12	6.50	4.85	5.98	5.78
20/20	+ 0	7.04	3.36	4.67	5.02
20/20	+ 4	6.68	4.29	4.11	5.03
20/20	+ 8	6.86	5.04	5.05	5.65
20/20	+ 12	6.68	5.22	4.86	5.59
40/25	+ 0	7.04	4.48	4.11	5.21
40/25	+ 4	7.04	5.97	5.42	6.14
40/25	+ 8	6.14	4.29	5.24	5.22
40/25	+ 12	6.86	5.97	5.05	5.96
60/30	+ 0	6.68	4.48	3.74	4.97
60/30	+ 4	6.32	6.00	3.74	5.35
60/30	+ 8	6.32	6.00	4.86	5.73
60/30	+ 12	8.12	6.90	4.86	6.63
LSD (.05)		NS	NS	NS	NS
CV (%)		14.27	24.00	21.00	19.05

Means within a column followed by the same letter(s) are not significantly different at 0.05 level

In agreement with the results of this study, various other studies have also shown the importance of organic nutrient sources particularly when integrated with mineral fertilizers in improving crop yields and land productivity under Ethiopian conditions (Asfaw et al., 1997; Asfaw et al., 1998; Heluf et al., 1999; Heluf, 2002). The findings of the present study indicate that the potential of FYM or organics improves when used together with mineral fertilizers. It has similarly been found that the use of crop residues with freshly applied and with residual NP fertilizers has significant effects on maize grain yields under Ethiopian conditions. Generally, the wide gaps between the grain yields of maize produced on the control plots and on the treatments supplied with FYM alone or together with NP fertilizers across locations and cropping seasons in this study is expected to attract the attention of the farmers and help them to have a better understanding about the value of FYM in sustaining maize production.

CONCLUSIONS

According to the study, the integrated use of various rates of FYM and low rates of N/P fertilizers are better than the application of either NP fertilizers or FYM alone. However, the sole application of FYM at the rates of 4-12 t ha^{-1} is also encouraging for resource poor farmers on relatively fertile soils like Walda and Harato areas. As indicated in its chemical composition, the applied FYM supplied the crop with considerable amounts of different essential macronutrients and small amounts of micronutrients usually deficient in acid soils. However, in this study, the FYM was applied in spots with the maize seed with the intention to feed the crop. Therefore, it is not expected to bring significant change on soil physicochemical properties after crop harvest. As a long-term strategy in the future, locally available sources of organic fertilizers should be used on a continuous basis for replenishing the degraded physicochemical properties of the soils in the region.

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THE EFFECT OF LOCAL ROCK PHOSPHATE FERTILIZER ON YIELD OF MAIZE IN P-DEFICIENT SOILS OF THE CENTRAL PLATEAU OF MADAGASCAR

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ABSTRACT

Orthic Ferralsols of the moist Mid-Altitude Central Plateau of Madagascar are characterized among other things by low pH, low exchangeable bases especially Ca, and high deficiency in P and N. Low and declining fertility from soil nutrient mining without replenishment are responsible for the poor production levels of smallholder farms with limited cash access. Local rock phosphate named Barren hyperphosphate or simply Barren Phosphate (HB) can be an alternative to imported phosphate fertilizers, whose purchase price is not affordable by resource-poor peasants for alleviating soil Ca and P depletion. An experiment consisting of three trials was conducted at Ankazobe site (18°99'S, 47°07'E) located at 100 km north of Antananarivo, over two consecutive cropping seasons to investigate the effect of local rock phosphate fertilizer on maize grain yields. The experiment was laid out in RCBD with 4 replications. In the first trial, HB fertilizer was evaluated (direct and residual effects) in comparison with two imported P-fertilizers : Reno Hyperphosphate (HR) and NPK at the rate of 300 kg ha^{-1}, for two seasons (1997/1998-1998/1999). In the second trial, the direct and residual effects of cattle manure at the rates of 5 and 10 t ha^{-1} supplemented with HB at the rate of 150 and 300 kg ha^{-1} were evaluated over the same seasons. In the third trial, four application methods (two broadcasting and two station placement) were investigated over the next two campaigns (1999/2000 – 2000/2001). Results showed that during the first season (direct effect evaluation) there was no significant grain yield difference between the two rock phosphates (HB and HR) without N/NK supplement and the unfertilized control : HB and HR supplied alone were equivalent and had no direct effect in the first year of application. Supplementing rock phosphate fertilizers with top-dressed NK (45 : 60) doubled the yield (6.4 t ha^{-1} with NK against 3.6 t ha^{-1} without) : effectiveness of P-fertilizers was enhanced by the presence of NK-fertilizer. There was no significant grain yield difference between HB (300 kg ha^{-1}) + NK (35 : 45) applied at planting time and the compound P-fertilizer NPK (300 kg ha^{-1}). Results of the second trial showed that HB was inefficient in the first year without manure: there was effectively no significant yield difference between HB (150 kg ha^{-1}) without cattle manure and the unfertilized check. The best yield (7.0 t ha^{-1}) was obtained from combination of the highest rates of manure (10 t ha^{-1}) and HB (300 kg ha^{-1}). Results of rock phosphate fertilizers residual effect investigation during the second season showed that there was no significant yield difference (i) between HB alone, HR alone and unfertilized control, that is rock phosphate fertilizers without supplement had no residual effect in the second year, (ii) between the two rock phosphates with or without top-dressed N/NK. Concerning the 'Manure x HB' trial, there was no significant yield difference between HB without manure for 2 years and unfertilized check : there was virtually no residual effect of HB alone in the second year. Results of the third trial highlighted the superiority of station (hole) placement over the other methods. To sum up, the four seasons' experimentation showed that (i) during the first two years rock phosphate fertilizers applied alone have no effect, (ii) to get adequate maize grain yield it is necessary to supplement rock phosphates with urea or with FYM, (iii) station placement of phosphate fertilizers is recommended.

INTRODUCTION

Maize (*Zea mays* L.) is the second cereal crop after rice grown in the Central Plateau of Madagascar with an elevation ranging from 1,000 to 1,800 masl which belongs to the Moist Mid-Altitude. It is mainly used for animal feed (poultry, pigs) directly as whole grains or more frequently as feed meal. Maize is cultivated rainfed by resource-poor smallholder farmers on depleted soils formed on acid basal crystalline parent materials (migmatite, gneiss) highly desaturated with low pH (4.5 – 5.0), very low in exchangeable bases especially in Ca and Mg, highly deficient in P and N as shown by the analysis results of soil samples taken at test sites situated around Antananarivo (Table 1). These reddish-brown soils are very deep, well drained, in general well structured, with silt clay sand texture near the surface becoming more clayey in depth. Average near the surface (2.5 – 3 %), organic matter content decreases rapidly in sub surface (0.5 – 1 % at 1.5m). Cationic exchange capacity (4 – 8 cmol(+) kg^{-1}) and the saturation rate of the absorbing complex (8 – 15%) are obviously very low. If the total P content is moderate (450 – 1,000 mg kg^{-1}), on the contrary the assimilable P content is very poor : Olsen–P (15 – 50 mg kg^{-1}), Saunders-P (150 – 250 mg kg^{-1}) and Truog-P (3.5 – 5 mg kg^{-1}).

Table 1. Mean base content (cmol(+) kg^{-1}) of an Orthic Ferralsol sample from Ampangabe experimental site.

	Ca	Mg	K
Total bases *	0.17	0.24	0.29
Exchangeable bases **	0.09	0.06	1.10

(*) Extracted from boiled concentrated nitric acid, (**) and from ammonium acetate. (Source: Arrivets, 1977)

Table 2. Results of subtractive tests carried out on field at Ampangabe site (t ha^{-1} maize grain) and on 'Vase de végétation' (dry matter weight as % of FC)

	FC*	-P**	-Ca	-Mg	-K	-S	-CaMg
Field test	5.4	1.4	-	-	1.1	-	2.7
Vase test	10.0	2.1	2.1	4.8	3.8	4.0	-

(*) FC : with all major nutrients (Fumure complete), (**)-P : without P (Source: Velly et al, 67)

Table 3. Maize grain yield of the basal P-fertilizer field test carried out at Iboaka site on third year's cropping

P rate (kg-P_2O_5 ha^{-1})	0	100	200	300	400	1000
Grain yield (t ha^{-1})	2.1	2.4	3.0	3.6	4.3	4.7

Source: Truong Binh et al, 71

Subtractive test in 'Vase (pot) de végétation' (Chaminade procedure) and in field clearly showed (Table 2) that soil main nutrient deficiencies are P, Ca and the secondary deficiencies are K and Mg. Therefore without major nutrient supply especially P, Ca, Mg (and N) these soils yield virtually nothing. Field P response curve tests have shown (Table 3) that yields increase with P- fertilizer rates denoting that these soils did not strongly fix P despite the high fixing capacity of tropical soils.

Table 4. Maize grain yield of basal and annual P-fertilizer field tests carried out at Ampangabe (5 years' mean)

Basal P-fertilizer	Annual P-fertilizer	Total P_2O_5*	Grain yield
(P_2O_5 kg ha^{-1})	(P_2O_5 kg ha^{-1})	(kg ha^{-1})	(t ha^{-1})
90	0	90	1.7
90	45	270	2.7
90	90	450	3.3
180	0	180	2.6
180	45	360	3.2
180	90	540	3.8

(*) Amount of P_2O_5 supplied for 5 years
Source: Arrivets et al, 77

There is a good response of maize to P-fertilizer application as shown in Table 4. Supplying of P-fertilizer whether as basal fertilizer at high rate (which could be brought once in the first year or spread over years) or as annual fertilizer at moderate rate proved to be essential for intensive and sustainable farming of highly depleted upland Ferralsols. Since purchased imported P-fertilizers as single (superphosphate, hyperphosphate) or compound (DAP, NPK, ...) inorganic fertilizers are at the present time out of reach of most smallholder purchasing power. An alternative to this problem of cash shortage is the replacement of imported P-fertilizer by rock phosphate produced on the spot, readily available in the market place, which is 3 to 4 times less expensive and whose efficiency is comparable or higher than equivalent imported P-fertilizers, like 'Reno Hyperphosphate' (HR), a soft rock phosphate from GAFSA (Tunisia) available in Madagascar, or other West African P-sources such as TAÏBA (Senegal), TILEMSI (Mali), TAHOUNA (Niger) rock phosphates. Happily our country has one sizeable deposit of phosphatic ore that is referred to as 'phosphorite' in islands which make up the Barren Archipelago in the Mozambique channel, off the western coast of Madagascar. The quantity of the material is estimated at 525,000 metric tons, with an average content of 9 % P_2O_5 which corresponds to 55,000 metric tons of P_2O_5 in the form of tricalcic phosphate. P_2O_5 content of the deposit varies greatly (0.15 to 45%) with the island and its location within the island. Phosphorite came from sea birds' droppings (guano) which under rain and water runoff actions on the coral reef substratum resulted in rock phosphate. Barren rock phosphate is commercially exploited under the name of Hyperphosphate Barren or simply Hyper Barren (HB), with P_2O_5 and CaO contents ranging from 25 to 30% and 45 to 50%, respectively. The following element contents are from analysis of ten HB samples by the FOFIFA pedology laboratory : 24 – 30% P_2O_5, 45-50% CaO and 0.8 – 1.5% MgO. Hyper Barren fertilizer had been widely tested under different agro-ecological conditions (soils, climates, crops, ...) in a number of areas of the country. Testing results were absolutely comparable to those of imported hypersoluble phosphate, like Hyper Reno (HR) or even those of more soluble phosphate, like bicalcic phosphate and superphosphate, as shown in Table 5.

HR is an imported rock phosphate available in the market place whose certified contents are : 30% P_2O_5, 45% CaO, with 90 % grains passing through number 300 sieve (50 micron meshes) and at least 60% of the total P_2O_5 are soluble in 2% formic acid solution and 2% citric acid solution.

As HB fertilizer had not been yet tested in the Northern part of the Central Plateau which makes up a vast erosion surface referred to as 'Plateau or Pénéplaine d'Ankazobe', a migration area with good prospect for maize production, but with very poor soils highly deficient in P, Ca and N, we thought it right to establish experimentation in this area to study the value of HB as P-fertilizer.

MATERIALS AND METHODS

A researcher-managed experiment whose aim is to investigate the effect of HB on maize yield was established over 4 consecutive cropping seasons (1997/1998 – 2000/2001) at testing site of Ankazobe (18°99'S, 47°07'E) situated at 100 km North of Antananarivo with an elevation of 1,225 masl. Climate is of 'Tropical d'altitude' type. Rainfall is of unimodal pattern lasting 6 to 7 months with an annual average of 1,458 mm (88 days). Annual mean temperature is 19.6°C, annual maximum is 25.8°C and annual minimum 13.5°C. Monthly rainfall data are given in Table 6.

Table 5. Maize grain yield from rock phosphate comparison test on Orthic Ferralsols of a number testing sites around Antananarivo – Results of third year's experiment

Rock phosphate	Site			
	Betsiz.	Am/koho	Anta/ka	Four site average
	(t ha^{-1})			
00	1.6	0.8	0.6	1.3
HR	3.5	1.3	2.4	2.5
HB	4.3	1.1	2.1	2.3

Source: Rajaonarison et al, 80

Table 6. Monthly mean rainfall (mm) recorded at Ankazobe meteorological station (30 years' average)

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jnr	Feb	Mrs	Apr	May	Jun	Total
Amount	5	8	12	41	165	297	361	275	228	51	11	4	1,458

Source: Oldeman, 80

The site soils are of Ferrallitic type formed on acid materials (migmatite, gneiss) from basal crystalline rocks. They are classified as Orthic Ferralsols (FAO/UNESCO) with reddish-brown colour, very deep (> 10m), highly acidic (pH<5), highly deficient in exchangeable bases and available P. In the French classification (Bourgeat, 70) the site soils belong to the Ferrallitic class and the 'Sols acides anciens et profonds' sub-class, with a very clayey lower horizon and destructured top horizon especially on the preserved 'surface d'érosion' referred to as 'Pénéplaine d'ankazobe'. Because of their top horizon characteristics these soils are prone to crusting after heavy rain.

Study of the value of HB as P-fertilizer makes up the first experimentation set, whose specific objective is to determine the phosphate effect on maize yield under two aspects : (i) *per se* in comparison with other P-fertilizers, (ii) in combination with inorganic (N, NK) or organic (cattle manure) fertilizers. For this purpose two field trials were conducted over two cropping seasons (1997/1998 – 1998/1999) : (1) testing of the intrinsic agronomic value of HB in comparison with HR and the compound fertilizer NPK 11:22 :16, (2) manure supplementation with HB. The trials were laid out as a RCBD with 4 replications. Gross plot was five 5-m rows spaced 0.80m apart (20m² area). Yields were recorded from 3 centre rows with ears from plants on two external hills discarded (7m² area).

In the first trial (1), there were nine treatments : (1) HB, (2) HR, (3) NPK [all without supplement], (4) HB, (5) HR [both with top-dressed N supplement],(6) HB, (7) HR [Both with top–dressed NK], (8) HB with NK supplement at planting time, and (9) non-fertilized control ; HB, HR, NPK rate was 300 kg.ha^{-1} and NK rate was 45N and 60K$_2$0, respectively. Therefore total amount of P_2O_5 : N : K_2O, supplied to the plots was 90 : 45 : 0 for (4) and (5) ; 90 : 45 : 60 for (6) and (7) ; 90 : 35 : 45 for (8) ; 66 : 33 : 48 for (3).

In the second trial (2), there were nine treatments too : Manure alone at the rate of 5 t ha^{-1} (1) and 10 t ha^{-1} (2) ; HB alone (3) and HR alone (4) at the rate of 150 and 300 kg ha^{-1} respectively ; Manure at the rate of 5 t ha^{-1} supplemented with 150kg ha^{-1} (5) and 300kg ha^{-1} (6) of HB respectively ; Manure at the rate of 10 t ha^{-1} supplemented with 150kg ha^{-1} (5) and 300kg ha^{-1} (6) of HB respectively ; Manure at the rate of 10 t ha^{-1} supplemented with 150kg ha^{-1} (7) and 300kg ha^{-1} (8) of HB respectively ; and lastly non-fertilized check (9).

Table 7. Maize grain yields on trial (1) in 1997/98 and 1998/99 (residual effect).

Fertilizer	Amount			Grain yield§	
	N	P_20_5	K_20	97/98	98/99
	(kg ha^{-1})			(t ha^{-1})	
00 (control)	0	0	0	3.2 d	1.6 c
HB	0	90	0	3.4 d	1.9 bc
HR	0	90	0	3.7 cd	1.9 bc
NPK	33	66	48	4.6 b	2.0 bc
HB+N*	45	90	0	6.2 a	2.1 b
HR+N*	45	90	0	6.5 a	2.1 b
HB+NK*	45	90	60	6.7 a	2.2 b
HR+NK*	45	90	60	6.6 a	2.2 b
HB+NK **	45	90	45	4.1 bc	2.6 a

(*) N and K top-dressed, (**) NK applied at planting time. §Grain yields followed by same letter are not significantly different according to Duncan's MRT.

Study of HB placement methods constitute the third trial (3). As HB is not soluble in water, it should be placed near the root system to be taken up by the maize plant. Four treatment factors were tested (1) broadcasting before planting followed by burying with a spade, (2) placement of fertilizer in planting holes before sowing, (3) spreading of fertilizer along the rows followed by incorporation into soil before the making of planting holes, (4) thoroughly mixing of HB with manure before placement in planting holes. HB rate was 300kg ha^{-1} which correspond to 90kg ha^{-1} P_20_5. All plots received 67kg ha^{-1} N as urea applied in two splits at knee-high stage and at the beginning of male flowering. All trial fields were mouldboard ploughed and levelled with the help of spade. Improved OPV (Volasoa) was sown in rows spaced 0.80 m apart with in-between hills of 0.50 m, with 3 to 4 seeds per hill thinned to two plants per hill at five-leaf stage. Soils and seeds were treated with chemical insecticide (Lindane) against seed-borne insects (white grubs, cutworms). Harvest was performed manually at maize maturity and weight adjusted to 15% M.C.

RESULTS AND DISCUSSION

Results obtained on trial (1) over the first growing season are given in Table 7. Yield level was high in spite of lack of rain over flowering stage. Yield of non-fertilized treatment was relatively high. Without mineral supplement there was no significant (P>0.05) yield difference between HB, HR and the control, this proves the inefficiency under the area agro-ecological conditions of P-fertilizer applied alone. P-fertilizer plots supplemented with N or NK yielded about twice more (6.6 t ha^{-1} on average) than plots with P-fertilizer alone (3.6 t ha^{-1} on average), this shows once more the advantage of supplementation. There was no significant yield difference between NPK and HB + NK at planting, which yielded 4.6 and 4.1 t ha^{-1}, respectively ; both formulae brought approximatively the same quantity of nutrients. Results obtained on trial (2) over the first season are presented in Table 8.

Table 8. Maize grain yield on trial (2) in 1997/1998 and 1998/99 (residual effects).

Fertilizer		Grain yield§	
Manure	HB	1997/98	1998/99
(t ha^{-1})	(kg ha^{-1})	(t ha^{-1})	
0	0	1.1 d	0.5 h
5	0	2.7 c	1.2 f
10	0	3.9 c	1.6 cd
0	150	1.4 d	0.7 fg
0	300	2.8 c	0.9 fg
5	150	3.4 c	1.6 e
5	300	5.0 b	1.9 bc
10	150	5.5 b	1.7 cd
10	300	7.0 a	2.3 a

§ Grain yields followed by same letter are not significantly different according to Duncan's MRT.

Table 9. Maize grain yield in trial (3) during two seasons.

Treatment	Maize grain yield	
	1999/00	2000/01
	($t\ ha^{-1}$)	
1 HB broadcast	1.9 c	2.5 b
2 HB placement in holes	3.0 a	3.5 a
3 HB banding in row	2.1 b	2.5 b
4 HB mixing with manure	2.9 a	3.3 a
mean	2.5	2.9

Inherent poor fertility of the trial field partly accounted for the low yield of non-fertilized control. There were no significant (P>0.05) yield difference between HB (150kg ha^{-1}) and the check, this proves once more the inefficiency of HB applied alone. The highest manure rate (10 t ha^{-1}) supplemented with the highest rate of HB (300 kg ha^{-1}) differed distinctly from the others , with an excellent yield (7.0 t ha^{-1}) which represents an additionnal yield of 6.0 t ha^{-1} relative to the check treatment. Supplementing 5 t ha^{-1} manure with 150kg ha^{-1} HB did not much improve yield. All things considered, to get good yield there are two possibilities : whether applying high rate of manure supplemented with high or moderate rate of HB, or supplying high rate of HB combined with average rate of manure.

The residual effect of fertilizers brought in the first year was investigated over the second cropping season (1988/1999) keeping the same design without providing P-fertilizer this time. On trial (1) all plots were uniformelly supplied with 10 t ha^{-1} cattle manure during the second campaign and those that had received N or NK the previous year were provided with these nutrients at the same rate. The trial results are given in Table 7.

Yield level was fairly low (2.1 t ha^{-1} on average), this could be attributed to bad rainfall (delay, shortage) combined with insect pests outbreak (white grub, ear worms). Concerning P-fertilizer residual effect, there was no significant (P>0.05) yield difference between P-fertilizers alone and control : this means that P-fertilizer alone did not show residual effect yet. If treatment control is put aside we could not find difference, as far as residual effect is concerned, between P-fertilizers whether supplemented with top-dressed N/NK or not, this could be attributed to poor assimilation of N/NK applied at male flowing stage during which time there occured a severe water shortage, resulting in poor ear fertilization (abortion, poor ear filling). Only HB + NK applied at planting time seems to be having a fairly neat residual effect, maybe because NK supplied at planting with well watered condition was properly assimilated by maize plants. Whatever that may be, its yield was not so good.

On trial (2) during the second season plots were supplied with the same rate of manure as during the first one. Below are shown maize grain yields obtained from the trial and means ranking.

Yield level was very low (1.4 t ha^{-1} on average). The highest rate of HB supplementing the highest rate of manure gave the best residual effect. There was no significant (P>0.05) yield difference between plots not supplied with manure on first year (although they have received 150 and 300 kg ha^{-1} the same year) and check plots, their yields came in at the tail-end (0.5 to 1.2 t ha^{-1}), that is, there was virtually no HB residual effect. In short HB residual effect appeared only with HB at high rate combined with manure at high rate.

Results obtained on trial (3) over the first season are given in Table 9.

In spite of the prevailing bad cropping conditions occuring during the campaign that account for the fairly poor yield level of the trial, analysis of variance showed a significant (P<0.01) yield difference between treatments, with a 6% CV.

Higher yields (2.5 t ha^{-1} on average) came from placement into hole methods, the lowest were recorded on broadcasting method (1.9 t ha^{-1}).

Trial (3) was carried out again during season 2000-2001 with the aim of trying to differentiate broadcasting treatment effects. Results are given in Table 9.

Yields were slightly higher than of the previous year's trial. There were highly significant (P<0.01) yield differences between treatments, but this time the two broadcasting methods did not differ from each other. In short, the best application method of HB is station (hole) placement. Broadcasting proved to be less interesting.

CONCLUSION

At the end of this four years investigation on local rock phosphate effect on maize yields, we could assert that under the particular agroecological conditions of the study area, Hyper Barren (HB) rock phosphate is not really efficient without N-mineral fertilizer supplement. It is true that fields of our trial site were among other things highly deficient in P, Ca and N. Supplementing farmyard manure (FYM) with HB proved to be beneficial. Manures produced on smallholder farms, because of shortage and bad quality of litter, are in general low in most of major nutrients. With the high quantity of lime (45% – 50% Ca0 on average) and phosphorus (25% – 30% P_20_5 on average) that HB brings, this fertilizer can advantageously compensate the imbalance of FYM on these two major nutrients. As the phosphorus of HB fertilizer is soluble in a progressive and sustainable manner in acidic soils such as those of the Central Plateau, crops could benefit from the relatively long residual effect of local phosphate. What's more, these soils did not fix too strongly phosphorus in spite of the high fixing capacity of tropical soils. Lastly, station (hole) placement of phosphate fertilizer is the application method to be recommended which is not difficult to perform as farmers in the area are used to this practice when fertilizing their crops. In addition to its agronomic interest, HB rock phosphate is economically attractive because this fertilizer is reasonably priced and readily available in the market place. On the other hand, macroeconomically speaking, substitution of imported rock phosphate by a local one would allow substantial foreign currency savings.

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SESSION VI:

Linking research with farmers

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DIRECT ESTIMATION OF MAIZE CROP LOSSES DUE TO STEM BORERS IN KENYA, PRELIMINARY RESULTS FROM 2000 AND 2001

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ABSTRACT

Maize is the major food crop in Kenya, where 2.4 million tons are produced yearly for 28.6 million people (85 kg/person). Population is growing rapidly (2.9%/year) and the increased population pressure on the land has resulted in increased pest pressure on crops. Stem borer is one of the most important pests of maize. Previous research with artificial infestation established clear links between incidence or damage factors and yield losses These results cannot be extrapolated to estimate crop losses under natural infestation, although it is precisely those estimates that are needed in order to estimate impact and to set research and extension priorities.

Therefore, to estimate the potential impact of the Insect Resistant Maize for Africa (IRMA) project, a representative sample of maize fields was selected during 1999 and 2000 for each of Kenya's 5 major agro-ecological zones. Half of each field was protected against stem borers using a systemic insecticide, and the other half was left for natural infestation, and the comparison of yields gives an estimate of crop loss. Total loss in Kenya due to stem borers is thus estimated at 13.5 % (valued at between US$25 and US$ 59.8 million), ranging from 11% in the highlands to 21% in the dry areas. More than half of the losses occur in the moist transitional zone. This area also has a high adoption rate of improved varieties (95%) making this area a promising target for insect resistant varieties. In the dry areas, losses are relatively high (21%), but its low yields reduce potential benefits but those benefits would go to more resource-poor farmers.

Keywords: Crop loss, maize, Kenya, stem borer.

INTRODUCTION

Maize is a major food crop in Africa, especially in the eastern and southern regions of the continent. For many people, it is the main staple of their diet, as evidenced by annual consumption levels of 79 kg/per capita in the region and 105 kg/per capita in Kenya (Heisey and Edmeades, 1999). Food production has not kept up with population growth, and most suitable land has been brought in production, leading to serious problems in food security. Agricultural intensification generally leads to higher pest pressure, and stem borers are one of the most important problems in cereal production in Eastern Africa. In Kenya alone, farmers estimate crop losses due to stem borers at 15% of their harvest, amounting to 400,000 tons of maize (Hassan, 1998). At current prices this represents a value of US $90 million (De Groote, 2000).

To tackle this problem, the Insect Resistant Maize for Africa (IRMA) project was launched in 1999, by the International Maize and Wheat Improvement Center (CIMMYT) and the Kenya Agricultural Research Institute (KARI), with financial support from the Novartis Foundation. The project goal is to increase maize production and food security through the development and deployment of insect resistant maize, thereby significantly reducing crop losses.

To assess the potential demand for these varieties, an estimation of crop losses due to stem borers is necessary by region. In combination with an estimation of adoption of new varieties, this will allow for an overall assessment of the potential benefits of this new technology, to which the cost of the development can then be compared.

So far, no systematic study of stem borer damage has been undertaken in Eastern Africa. In Kenya, the most important species are the spotted stem borer *Chilo partellus* (Swinhoe) in the warmer and lower areas, and *Busseola fusca* in the cooler and higher altitudes. A third, but less important species is, *Sesamia spp.,* found up to 2,600 masl. The attack of the spotted stem borer starts with the eggs being deposited on maize leaves (Ajala and Saxena, 1994). The first instar larvae move into the leaf whorls where they feed and develop on the bases of the leaves, causing lesions. The late third or early fourth instars bore into the stem, feeding on tissues and making tunnels. When the larvae, either in the leaf whorl or stem, cut through the meristematic tissues, the central leaves dry up to produce the "dead heart" symptom, resulting in the death of the plant.

In artificial infestation tests with 30 first instars at 3 weeks, links between yield reduction (in %) and damage parameters such as foliar lesions (on a 1-9 scale at 4 weeks after infestation), dead heart (%) and stem tunneling (% plant height) were examined (Ajala and Saxena, 1994), in combination with morphological parameters such as plant height and number of ears per plant. Reduction in the number of ears harvested due to larval infestation was found to be the primary cause of grain yield loss, primarily due to stem tunneling of the plants. Yield losses from the artificial infestation were estimated to fall between 34% and 43%.

A number of studies in Eastern Africa have demonstrated high losses of maize due to stem borer after artificial infestation. Alghali (1992) shows how the yield loss depends on cultivar, time of infestation and number of larvae. Seshu Reddy and Sum (1991) find a linear relationship between infestation and yield loss, and an increasing loss with earlier infestation. This allows for a calculation of Economic Injury Level, for example cv. Katumani shows an EIL of 3.2 and 3.9 larvae/plant for 20- and 40-day old plants, respectively. Tests with other varieties show similar results, but depending on variety (Seshu Reddy and Sum, 1991)

The extrapolation of artificial infestation trials, however, can be dangerous. The grain yield of the Katumani variety, for example, is significantly reduced under artificial infestation, but under natural infestation it escapes due to its early maturity (Kumar and Saxena, 1994). Therefore, systematic measurements under natural infestations are needed to obtain accurate crop loss estimates. Similarly, planting time can have a significant effect. Tests in Ethiopia, using different planting times under natural infestation, indicated a positive correlation between crop loss and late planting (Gebre-Amlak, 1989). Second generation larvae caused crop loss ranging from 22.5 to 100% while it was only 0-22.6% due to the first generation. It is therefore important to estimate crop losses under farmers' conditions, in farmers' fields.

The only national crop loss assessment from natural infestation in Africa so far was done by Cardwell *et al.* (1997) in Cameroon. Across ecological zones and surveys, *B. fusca* accounted for 95% of all the species found on maize, followed by *E. saccharina*. In the first cropping season, the mean percent borer infestation was similar in lowland and highland with a mean of 43%. Borer incidence was higher during the second cropping season. In both low and mid-altitude fields, 52-56% of the plants were infested, resulting in a calculated cob weight loss of 9 g per plant. At that time, the average plant loss from dead hearts across zones was 11%. The authors, however, do not translate these figures into crop losses for different areas; neither do they estimate the economic value of those losses.

Building on this past experience, the present study therefore intends to estimate the economic value of crop losses due to stem borers in Kenya, based on natural infestation in farmers' fields. In this paper, the preliminary results of the first 3 seasons (two in 2000, one in 2001) are presented.

METHODOLOGY

Conceptual framework

Several methods of estimating crop losses from insect pests exist. In the direct method, actual crop losses are measured in the field. In indirect methods, costs are reduced by linking number of insects some indicators such as exit holes (Walker, 1991b), and link yield to incidence or to damage factors such as length of tunneling (Walker, 1991c). Some of these functions have been developed for stem borers (Walker, 1991a).

The more precise method of estimating crop losses is through direct measurement of the actual losses. Crop loss can be defined as the difference between the potential yield Y_p (the yield that would have been obtained in the absence of the pest under study) and the actual yield Y_r . It is convenient to express this proportionate to the potential yield, to obtain a proportional crop loss r :

$$r = \frac{Y_p - Y_a}{Y_p}$$

The ratio r can be calculated from crop loss trials in a representative sample of fields. In each field i, potential yield y_{pi} is obtained from protecting half of the field against the pest, and actual yield y_{ai} from the other, unprotected half. Crop loss in the field can be calculated by:

$$r_i = \frac{y_{pi} - y_{ai}}{y_{pi}}$$

Although these ratio's cannot be averaged to obtain a ratio for a region or country. Regional or national ratios would be obtained by first estimating total potential production x_{pi} of the farms by multiplying yield by area z_i:

$$x_{pi} = \frac{y_{pi}z_{pi} - y_{ai}z_{pi}}{}$$

The regional ratio can than be estimated by:

$$r = \frac{\sum x_{pi} - \sum x_{ai}}{\sum x_{pi}}$$

Crop loss for an area or for a country can be defined as the difference between potential production X_p and actual production X_r (expressed in kg or tons). When r is known, we can use a similar formula to estimate absolute crop losses:

$$X_p - X_r = X_r \frac{r}{1-r}$$

Finally, economic evaluation can be obtained by multiplying crop loss by prices.

The accuracy (deviation from the population mean), as well as the precision (size of deviations from the mean by repeated sampling) of indirect yield loss measurement, can than be compared to the direct measurement method by calculating the mean square error (Cochran, 1977), which combines bias and standard error in a measure of total survey error. It is possible to develop cost functions to calculate the cost of obtaining a crop loss estimate within a given error margin (De Groote, 1996). By developing these cost functions for the different estimation methods, the least expensive way to obtain estimates within a given error margin can be calculated.

Data collection and analysis

The study was executed by at team of CIMMYT and KARI economists, collaborators of the IRMA project, in consultation with entomologists of both institutes. After a literature review, discussions with key informants and a preparatory workshop, the methodology was decided upon. It was decided to start with the direct yield measurements, while collecting at the same time other indicators found in the literature such as exit holes and the number and length of tunneling. Only the direct measurements are discussed in the paper.

The most important point in crop loss assessment is to obtain a representative sample, necessarily based on a correct sample survey design (Church 1971). Previously, a stratified two-stage sampling design was used to select 43 sublocations for a Participatory Rural Appraisal (De Groote *et al*., 2001, Odendo *et al*., 2001), 5-7 for each of the six major maize producing agro-ecological zones (classification by Hassan, 1998). The sampling procedure was a stratified two stage sampling, with the production zones as strata. The first stage of the sampling was formed by sublocation. For the crop loss assessment, 5 sublocations were selected for each zone. A sampling frame was first be established with all the sublocations of the zone, and sublocations were to be drawn at random. Similarly, a sampling frame of all farmers (men as well as women) was composed, and 5 farmers drawn at random. For the crop loss assessment, 5 sublocations were maintained in each zone. . If a farmer has more than one field, one of his or her suitable fields (large enough area without trees) was drawn at random and five farmers selected at random from a list of volunteers. From each farmer a field was chosen randomly among those that were sufficiently large and without trees, a total of 150. However, due to poor rains in some areas and logistical problems in others, data from only 51 fields were collected in the first season, the long rains of 2000. The next season, short rains of 2000, that figure was increased to 69, and reached 74 in the last season covered, long rains of 2001. The selected villages are represented in the map in Figure 1.

All the villages had previously been visited for the PRA. For the crop loss assessment, an introductory meeting was organized to explain the purpose and to select the farmers. During each season, the farmers were visited three times. During an introductory visit, the field was agreed upon with the farmer, and a small questionnaire administered with farm and farmer characteristics, as well as some data on the field and its crop management. Two adjoining plots of 50 m^2 were staked out. During a second visit, one subplot was treated with a systemic insecticide for borer control (Bulldock, Bayer: active ingredient: *beta cyfluthrin*), at about 2-3 weeks or at the 6-leaf stage. If necessary, the treatment was repeated. During this visit plants and dead hearts were counted, and damage parameters observed.

During the last visit, both plots were harvested. The harvest of cobs was weighed and moisture content sampled. Length of tunneling and number of exit holes were also measured. For this paper, only the harvest was analyzed. The field weight (FW) was measured as the weight in kg of the harvested cobs, on a plot of size PS. The field weight needs to be adjusted for shelling percentage (assumed to be 80%) and the average moisture content (AMC), adjusted to a standard 15%, resulting in an Adjusted Field Weight (ADFW):

$$ADFW = \frac{FW(100 - AMC)\,80 \bullet 10{,}000}{(100 - 15) \bullet PS}$$

The adjusted yields of the two subplots were compared and the difference was attributed to loss from stem borers. Using secondary data on maize production and prices, the crop loss was extrapolated over the different zones and its value calculated.

BACKGROUND: MAIZE AND STEM BORERS IN KENYA

Over the last three years (1998-2000) Kenya produced on average 2.3 million tons of maize, on an area of 1.5 million ha (2 seasons) (Ministry of Agriculture, unpublished data). This production has remained fairly constant over the last 10 years. During the same period, the population has increasing by 2.9% per year, reaching 28.7 million in 1999 (CBS, 2001). Average production per capita is therefore estimated at 81 kg/capita, while consumption is estimated at 103 kg/per capita (Pingali, 2001).

Maize research, especially the introduction of hybrid varieties, was highly successful in 1960s till 1980s. Since then, however, very few new varieties have been introduced, and even fewer were widely adopted.

In Kenya, six major agro-ecological zones for maize production can be identified (Hassan, 1998). Moving from east to west, there are the Lowland Tropics (LT) on the coast, followed by the Dry Mid-altitudes and Dry Transitional zones around Machakos. These three zones are characterized by low yields (less than 1.5 t/ha); although they cover 29% of maize area in Kenya, they only produce 11% of the country's maize. In Central and Western Kenya, we find the Highland Tropics (HT), bordered on the west and east by the Moist Transitional (MT) zone (transitional between mid-altitudes and highlands). These zones have high yields (more than 2.5 t/ha) and produce 80% of the maize in Kenya on 30% of the area (see Table 1). Finally, around Lake Victoria, is the Moist Mid-altitude (MM) zone, which produces moderate yields (1.44 t/ha), covers 22% of the area and produces 9% of maize in the country.

The most important species of stem borers are the spotted stem borer *Chilo partellus* (Swinhoe), found in the warmer and lower areas around the coast and Lake Victoria, and *Busseola fusca* Fuller, found in the cooler and higher altitudes (Mulaa, 1995). A third, less important species is *Sesamia calamistis* Hampson, found at elevations up to 2,600 m. For the first two species, four major areas of distribution can be distinguished, (William Overholt, pers. comm.). The first area is situated in the southeast , where *C. partellus* is important, and it covers the lowland tropics and most of the dry areas. The second area covers the highlands and the eastern moist transitional zone and is distinguished by *C. partellus* below an altitude of 1,500 m, and *B. fusca* above that. The third area, around Lake Victoria, has a mixture of the two species, and covers the moist mid-altitudes and the southwest of the moist transitional zone. The fourth area covers the northwest corner of the highlands and moist transitional zones and is dominated by *B. fusca*.

RESULTS

The average yields of treated and untreated plots, as well as the difference, are presented in Table 1, by season and zone. As such, the figures are not easy to interpret since simple arithmetic means cannot be used to calculate averages over seasons. Moreover, several regions faced crop failures in some seasons. The moist transitional zone had no harvest in the first season, and the dry areas had no harvest in the first and last season. Still, we can clearly see that the short rainy season of 2000 has a lower crop loss than the other, long rainy seasons. The long rains of 2001 also clearly had less crop loss.

Table 1. Crop loss assessment of three seasons: long rains (LR) and short rains (SR) of 2000, long rains of 2001.

Year	Season	Agroecological zone	Yield (kg/ha) Treated	Yield (kg/ha) Non-treated	Yield (kg/ha) Difference	Loss (%)
2000	LR	LT (lowland tropics)	2252	1891	361	16.0
2000	LR	MM (moist mid-altitudes)	2089	1725	364	17.4
2000	LR	HL (highland tropics)	4831	4280	551	11.4
2000	SR	LT (lowland tropics)	1019	957	62	6.1
2000	SR	DM and DT (dry mid and transitional)	1731	1585	146	8.4
2000	SR	MM (moist mid-altitudes)	1518	1433	86	5.6
2000	SR	MT (moist transitional)	3106	2659	515	16.6
2001	LR	LT (lowland tropics)	1530	1370	160	10.5
2001	LR	MM (moist mid-altitudes)	2340	2134	206	8.8
2001	LR	MT (moist transitional)	2425	1962	471	19.4
2001	LR	HL (highland tropics)	4443	4152	291	6.6

Source: IRMA crop loss data

Table 2. Crop loss estimates, based on field data for:

	Major season					Second Season					Total			
	Area	Yield	Prodn.	Loss		Area	Yield	Prodn.	Loss		Prodn.	Loss		
	1000 ha	(t/ha)	1000 ton	%	1000 ton	1000 ha	(t/ha)	1000 ton	(%)	1000 ton	1000 ton	(%)	1000 ton	previous estimate (%)[a]
Lowland Tropics	33	1.36	45	9.0	4	8	0.99	8	6.1	0.5	53	8.5	5	25
Dry Mid-altitude	118	1.03	122	17.0[a]	25	48	0.83	40	8.4	3.7	162	15.0	29	17
Dry-Transitional	37	1.21	45	26.0[a]	16	29	1.08	32	8.4	2.9	76	19.8	19	26
Moist Mid-altitude	118	1.44	170	13.1	26	55	1.11	62	5.6	3.7	231	11.3	29	26
Moist-transitional	424	2.76	1170	16.6	233	42	1.50	64	16.6	12.7	1234	16.6	245	14
Highlands	307	2.91	893	9.0	88	9[b]	1.73	16	9.0	1.6	909	9.0	90	11
Total	1037	2.31	2395	14.1	392	207	1.33	276	8.4	25.1	2671	13.5	417	15

Source of loss estimations: IRMA crop loss survey (2000: long and short rains, 2001: long rains), except [a] Source: De Groote (2001), with calculations based on farmers' estimates (Kenya Maize Data Base), [a]based on major season estimate. Source of production data: Hassan (1998)

To calculate the actual losses of the different seasons, we have to apply the loss rates to the production statistics. Only the production data for 2000 are available, and only at the district level. These need to be disaggregated over smaller geographical units to fit the definitions of the agro-ecological zones.

Until these data become available, we use here the average production data as calculated by Hassan (1998), and presented in Table 2. For each of the seasons and zones, we calculated the average yield loss, as a percentage and in absolute quantity. Since we had no data on crop loss for the long rains in the dry area, we used previous estimates based on farmers' perception (De Groote, 2001). In the major season (long rains), an average of 2.3 million tons of maize is produced. We calculate that this production would increase by 0.4 million ton if stem borers were controlled. This comes to a loss of 13.5% of the potential production. The second season is relatively minor, with a production of only 0.3 m ton. Crop loss was also found to be less, calculated at 8% (for the short rains of 2000 only).

Since we have no measured data for the long rains in the dry areas, we will not speculate on the relative importance of the losses by zone and by season, but only discuss the overall losses, regardless of season. Overall loss was estimated at 13.5%, slightly less then the previous calculation of 15% based on farmers' perceptions. It should be noted that measured crop losses are generally lower than farmers' perceptions (last column in Table 2), at least in the seasons covered, except for the moist transitional zone.

The highest measured losses occur in the moist transitional zone (16%), that also has the highest production (1.2 m ton). As a result, this zone accounts for an enormous 59% of all losses attributed to stem borers in Kenya. The second most important zone are the highlands, with 22% of the national losses. The coast accounts for only 2% of the losses, and the other zones between 4 and 7%. To give these comparisons some perspective, stem borer losses estimated in the moist transitional area (245,000 tons) are five times the size of the whole maize production at the coast (53,000).

To calculate the economic value of these losses, they need to be multiplied by maize prices. The value for 1999, used in the previous calculation, was estimated at US$230/ton., resulting in an estimated crop loss of $91 million. In 2000, the value of maize was estimated at $160/ton (Pingali, 2001). No price statistics are available for 2001 yet, but anecdotal evidence indicated that farmers were getting as low as 400 Kenyan shilling per bag of 90 kg (at 75 Ksh/US$ this would be $60/ton), while the intervention price of the National Cereal and Produce Board (NCPB) in December 2001 was set at 1000 Ksh/bag ($160/ton). We conclude that, depending on the price used, the crop losses can be valued at between $25 million and $60 million.

However, these crop loss figures need to be interpreted with caution, especially since variance is high and sample size small. The key variable is the difference between treated and untreated plots. As Table 3 (column 4) shows, this difference is substantial, on average 300 kg/ha (between 62 and 551). The standard deviations, however, are much larger than the mean, with a Coefficient of Variation between 1.4

Table 3. Precision of the crop loss data.

Year	Season	Agroecological zone	Mean	Standard Deviation	C.V.	N	% of sample > 0	Standard Error	Relative standard error RSE(%)
2000	LR	LT	361	1128	3.1	12	75	326	0.90
2000	LR	MM	364	789	2.2	21	81	172	0.47
2000	LR	HL	551	1250	2.3	18	67	295	0.54
2000	SR	LT	62	232	3.7	8	63	82	1.33
2000	SR	DM and DT	146	564	3.9	23	52	118	0.81
2000	SR	MM	86	179	2.1	19	79	41	0.48
2000	SR	MT	515	714	1.4	19	74	164	0.32
2001	LR	LT	160	243	1.5	15	73	63	0.39
2001	LR	MM	206	683	3.3	25	60	137	0.66
2001	LR	MT	471	835	1.8	21	86	182	0.39
2001	LR	HT	291	1044	3.6	13	62	289	0.99
	Overall		301	770	2.6	194	70	55	0.18

and 3.9. A variable with a higher variance requires a larger sample size to be measured with the same precision than a variable with low variance. Sample sizes are relatively small: between 8 and 25 fields for each of the regions and seasons. The precision, with which a variable, in this case the mean yield difference, is estimated, can be expressed by the standard error. For a simple random sample, the standard error is obtained by dividing the standard deviation by the square root of the sample size. Dividing this by the mean results in the relative standard error (RSE), similar to the CV. For an estimate to be significantly different from zero, its SRE needs to be smaller than 0.5. This is only the case for 5 of the 11 situations in Table 3. And this is still a conservative estimate, since it does not yet take into account the two stage sampling, which is less efficient than the simple random sampling.

CONCLUSIONS

This paper presents the preliminary results of the first national field survey on crop losses caused by maize stem borers in Kenya. The results indicate that stem borers are a very important pest, causing losses of 13.5% of maize production nation wide, or 0.4 million ton. Measured crop losses vary from 8.5% in the lowlands to 16% in the moist transitional zone, which is also the most important maize growing area. As a result, this area accounts for 59% of crop losses in the country, followed by the highlands (22% of national losses). It follows that the potential impact of insect resistant maize is by far highest in the moist transitional zone, followed by the highlands. Moreover, these high potential areas have much higher adoption rates than the low potential areas. Estimated losses at the coast, by contrast, only amount to 5,000 tons. Given the low adoption rate in those areas, impact can only be small.

The value of crop losses is heavily influenced by the high fluctuation of the market price, between $60 and $150/ton, leading to an estimated loss between $25 and $60 million.

The precision of the estimates is still limited. If the project wants to document a decrease in crop loss due to stem borers, an increase of the sample size is necessary. Indirect measures of damage such as number of exit holes and length of tunneling also need to be analyzed and compared to yield measurements, to find the most cost efficient way to obtain precise crop loss estimates. Moreover, links have to be established with marketing information services to obtain accurate price estimations.

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IMPACT OF SELF-HELP GROUPS CREDIT ON INPUT USE IN MAIZE PRODUCTION IN SIAYA, KENYA

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ABSTRACT

Maize is the major food crop in Kenya, and most of it is produced by small-scale farmers. One of the major production constraints is inadequate production credit. This study analyzes how self-help credit and saving groups can relieve that constraint. In Ukwala Division, Siaya District, 37 groups and 90 farmers were interviewed to establish the groups' credit impact on improved input use and maize production. These farmers were found to have no access to formal credit, while more than 90% of them consider credit shortage the major constraint to improved input use. About two thirds of households are member of a self-help group. These groups have an average of 19 members, 94% of them women. Members meet on average twice a month, and each one contributes on average 106 Kenya Shillings (KSh) per person per meeting, or a total of 4,000 KSh per month per group. From these contributions, 46% is set aside to meet members' loan demands, while 44% is given to members in a rotating fashion. About 46% of the loans were used for agriculture, in particular for fertiliser and seed. As a result, farmers who borrow from the groups use significantly more fertiliser than non-borrowers (19.4 vs 6.0 kg/ha) as well as more hybrid seed (4 vs 2 kg/ha), leading to higher maize yields (845 vs 616 kg/ha). However, the members' contributions are not cover the demand for credit, leading to rationing (on a first-come first-served basis) and high interest rates (14% per month). Linking formal and informal credit markets should increase the available capital and hence decrease rationing and interest rates, while preserving the strengths of informal systems, in particular concerning client information and provision of flexible services with low transaction costs. The major challenge, however, is to determine in how far external capital can be used without changing the essential features that determine the sustainability of the informal groups.

Keywords: **Impact, indigenous self-help groups, informal credit, production technology adoption.**

INTRODUCTION

The majority of Kenyans live in rural areas with agriculture as their main occupation. Over 70 % of the farming households (about 2.7 million) are small-scale farmers, who produce 75% of maize in the country (Government of Kenya, 1996). Maize is the main food crop, and also doubles as a cash crop. Therefore, it has been a government policy to promote maize production as an effort towards food self-sufficiency. However, during the last 10 years, Kenya imported on average 350,000 tons per year (FAOSTAT, 1992-2000).

Despite the effort by small-scale farmers to attain food self-sufficiency and food security, they are constrained by lack of adequate production capital. A number of farmers have resorted to credit to augment their personal savings in order to remain in production. Studies on production have shown that credit programmes can help small-scale farmers. Early studies encouraged tying credit to improved input technologies such as use of purchased hybrid seeds and inorganic fertiliser (Mckinnon, 1973), although this view has been criticized later (Adams and Graham, 1984).

In Kenya, credit has been a major problem among small-scale farmers, particularly from the formal sector such as commercial banks and the government's Agricultural Finance Corporation (AFC). In 1998, 99% of AFC credit was made to large-scale farmers in the Rift Valley Province and those in the Central Highlands (Argwings-Kodhek, 1999), yet they account for less than 30% of the total maize production, and constitute less than that proportion of the farming population. The remaining 1% of the loans were made to medium and small-scale farmers with a further bias towards cash crops.

In Siaya district in Western Kenya, small-scale farmers basically have had no access to formal credit. The only available sources of credit are found in the informal sector, in particular self-help groups referred to as '*Nyoluoro'* , which are referred to in the literature as Rotating Savings and Credit Associations (ROSCAs). These groups have impressively struggled to bridge financial shortfalls for a number of farmers, and are known to exist in the area and the district as early as 1980s (Government of Kenya, 1986). In Malawi, similar groups have been found to mobilise savings and substantially invest (72.7%) in farming, with fertiliser accounting for 64.9% (Chipeta and Mkandawire, 1991). Other similar groups have been reported in West African countries, such as the *'susu'* of Ghana (Aryeeta, 1992), '*tontines'* of Cameroon and '*esusu'* of Nigeria (Bauman, 1994). In Ghana, the groups have managed to form a strong financial base and registered as '*susu'* company (Aryeetey *et, al.* 1991). Similar groups have also been operational in Ethiopia (known as *iddir),* South Africa (known as *stokvel*) , Malawi (Chipeta and Mkandawire, 1991), Tanzania, Zambia and Zaire (Slover, 1992). In Kenya, apart from the groups in the study area, Buckley (1993) reported existence of ROSCA-like groups, although clearly donor driven, among the urban slum dwellings of Kibera, known as '*Tano Tano'*.

Despite these few studies, the groups' contribution to agricultural development is not clearly understood by policymakers. The informal sector is in a way still a "black box" in many countries. Conventional wisdom had it that these endeavours were comprised of exploitative loans and that credit lent by the informal sector never promoted development. Politicians and policymakers fretted about informal lending and these concerns have had a negative effect, preaching against informal finance, trying to regulate it or creating credit programmes targeted to or substituting for it.

Adams and Fitchett (1992) pointed out that ROSCAs successfully pool small-resources and also resolve the loan collateral and bridge borrower information problem, by enrolling members who have mutual confidence in each other. Apart from developing countries, ROSCAs were found among the employees of the International Monetary Fund (IMF) in Washington DC., indicating that many people use this type of informal credit to bridge the gap between income and expenditures or to obtain assets that they cannot afford at a particular time.

The present study was launched to understand and support innovative rural financial systems, using a bottom-up approach building upon existing indigenous groups. The groups not only provide credit but also insurance through risk pooling services (Adams and Graham, 1984). As we will show, the groups can play an important role in agricultural production in Kenya. Formal financial systems should be encouraged to collaborate with small-scale farmers through their informal groups, to increase sustainable productivity.

This study had following objectives:

a) To identify the groups and establish their organisation and management structures
b) To establish the extent the groups' credit impacts on purchased input use in maize production.

Description of the study area

Ukwala Division is located in Siaya District, in the corner formed by Lake Victoria and the Uganda border, right above the equator (between latitude 0^0 and 0^0 34' N). The division is bordered to the North by Busia District, to the South by Uranga Division, Ugunja Division and Nzoia River (Fig. 1). It has an area of 319.5 km^2 and is divided into 28 administrative sub-locations. The total population is 99,000 people, living in 24,725 households, with an population density of 310 persons km^2 (Central Bureau of the Census, 2001). Arable land is estimated at 29,000 hectares (Government of Kenya, 1996), about 90% of the total. The division falls in the Lake Victoria basin, with an elevation from 1,100 to 1,300 meters above sea level (masl), and an average annual temperature of 25 ^{0}C. The division falls in the Lower Midland (LM) agroecological zone (according to the general zoning by Jaetzold and Schimdt, 1983)and is divided over three subzones in function of humidity: LM1 (humid, surgarcane zone), LM2 (semi-humid, marginal sugarcane zone) and LM3 (sub-humid, cotton zone). In the maize agroecological zoning (Hassan, 1998) the division falls in the Moist-Midaltitudes. The main food crops are maize, sorghum, beans, cassava and potatoes. Cattle, sheep, poultry and goats are the major livestock. Rainfall is bimodal, with a long and a short rainy season. The long rainy season falls in the months of March to July with the highest rainfall month being

April, and the short rain season occurs between August and December. Annual rainfall averages between 1,200 – 1,300 millimetres per year. Table 1 shows a detailed month by month rainfall distribution.

Both the government and agricultural non-governmental organisations provide agricultural extension services. However, at the time of this study, the 28 sub-locations only counted 9 government extension agents, as a result of the government retrenchment programme of 2000. Nevertheless, the Non-Governmental Organisations (NGOs), particularly Sustainable Community Development Programme (SCODP), conduct extensive extension operations and supply improved inputs in the division. The Sustainable Rural Christian Community Development Programme (SURUC - CODEP) has also opened an office in Ukwala Division to promote the use of organic farming.Similar organisations work in the neighouring divisions. In the neighbouring Busia District, more specifically in the market center of Bar Ober, two other organizations are active: the Ugunja Community Resource Centre (UCRC) and the Appropriate Rural Development Agricultural Programme (ARDAP).

On credit supply, apart from the contribution of self-help groups in the district, the formal credit market to agriculture is distinctively lacking. The only active semiformal credit institution in the area is Western Development Company (WEDCO), a local NGO linked to the international NGO CARE. Still, WEDCO only started operating in the year 2000, and has not yet established itself in the area.

MATERIALS AND METHODS

Ukwala Division was selected for this study for several reasons. First, maize is a major food and cash crop in the area. Besides, many small-scale farmers belong to the self-help groups. The groups have been established to exist in the district as early as the 1980s (GOK, 1986). Therefore, the division provides a suitable case for this study and is applicable to similar groups of farmers in other parts of Kenya.

The research was conducted at two levels: a survey of existing informal savings and loan associations, combined with a survey of farm households, all conducted from June to August 2001. For both survey levels a two-stage approach was used. In the first stage, six sub-locations were randomly selected out of the 28 in the division, this number being determined by limitations in time and finance. In each sublocation a list of all the existing groups (67 in total) was established with key resource people. For each sublocation, 6 groups were selected randomly, and 7 for one sublocation with a particular large number of groups. All 37 groups were visited with a structured questionnaire, and a discussion was organized with the groups' committee (chairman, secretary and treasurer). In almost all cases, several group members also assisted. The discussion covered the group's leadership and organization, the mobilization of their funds, and the criteria and amounts in their lending program.

For the second stage of the household survey, a list of households for each sublocation was assembled and 15 households were selected from each sublocation (or 90 in total), using a stratefied random sampling design. First, all households were split according to their membership of an informal credit and savings association.Since one third of the households belonged to such a group, they consisted the first stratum, and 5 households were selected randomly from that stratum for each sublocation. The group discussions had revealed that about one third of the household members were able to secure a loan from the group each year. Therefore, the member households were split into another two strata: those members who had borrowed during 2000, and those first stratums for each sublocation, and three from the second

Table 1: Average monthly rainfall in Ukwala (1990- 1998)

Month	J	F	M	A	M	J	J	A	S	O	N	D
Mm	56	115	156	264	191	89	61	120	141	171	158	94

Source: Ukwala Division Agricultural Office.

Table 2: Funds mobilisation by the groups

Variable	Mean	Minimum	Maximum	Std.
Number of members	19	5	45	10
Meeting frequency per month	2	1	3	1
Rotation funds contributed/ person/meeting (Ksh)	43.0	0.0	150.0	38.0
Loan funds contributed/person/ meeting (Ksh)	63.0	13.3	400.0	66.6
Rotation funds contributed/ group/meeting (Ksh)	808.0	0.0	4,100.0	948.1
Loan funds contributed/group/meeting (Ksh)	1,208.0	116.7	4,500.0	1,167.4
Total funds contributed/group/meeting (Ksh)	2,015.8	233.4	8,200.0	1810.3
Percentage funds set aside for rotation/group (%)	42.3	0.0	78.7	20.5
Percentage funds set aside for loan demands/group (%)	57.7	21.3	100.0	20.5

stratum. The topics addressed in the questionnaires were household profile, farm profile, households' credit and savings profile, credit access and borrowing status, inputs use, farm costs and maize production.

A Chi-square test was used to establish the independence of the groups of farmers with respect to input use. To test for differences in input use and yields, a t-test of independent samples was performed.

RESULTS OF THE GROUP SURVEY

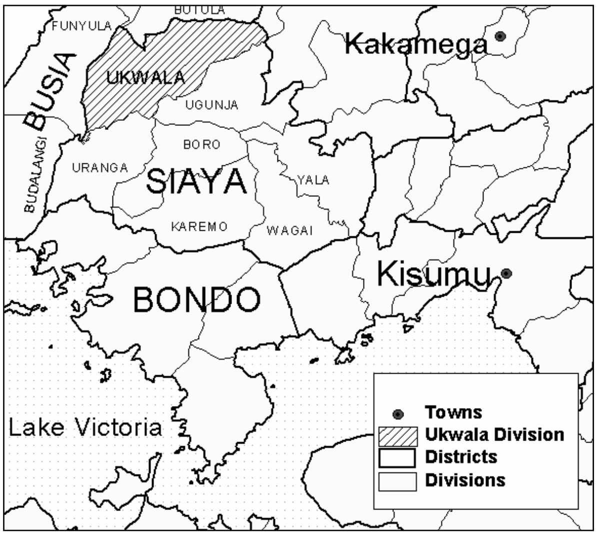
Groups' organisation and management structure

All groups interviewed had the same basic structure. The management of the group is in hands of the credit committee, which is composed of three people: a chairperson, a treasurer and a secretary. This committee also doubles as signatories to any official transactions in the group. Apart from this committee, the groups also have an organising officers, who organises and facilitates contacts and meetings with external parties.

Group size varies between 5 and 45 members, with an average of 19 members. Women constitute the large majority of members (94%). Despite the government requirement that self-help groups register with the Ministry of Culture and Social Services, by the time of this survey, only 54% of the interviewed groups had done so. On average each group met twice a month, with each member at a meeting contributing an average of 106 Kenya Shillings (KSh) per person. Out of this, 46% was set aside to meet members' loan demands, while 44% was given to members in a rotating fashion (Table 2). Annual allowable credit to a member was KSh 3,073. Interest rates are very high (14% per month) compared to rates in the formal sector. Borrowers did, however, not complain of high interest rates. They instead pointed out that the convenience and ease with which group credit is issued outweigh any disadvantage arising from the interest rates. Besides, borrowers indicated that because the loan amounts are small and with short repayment periods (six months or less), the impacts of interest rates are not severe.

Unlike the commonly-held notion that informal finance only meets consumption and social needs, of the loans extended to members, farming accounted for 46% of the loans, with the rest going to different expenditures such as school fees, medical expenses, consumption and off-farm business investment.

Figure 1. Map of Ukwala Division, Siaya District.



Operations

Typically, groups do not screen individual loans, but rather membership application. This amounts to determining whether a person can be trusted to regularly meet his or her obligations to the group. So most of their screening has to be done before members join up This screening is based on the groups' observations of an individual's habits and the group's obligations towards applicants. Leaders interviewed pointed out that each group is aware that their members joined because of the possibility of borrowing. Therefore, in screening applicants, emphasis is not necessarily on whether members can pay back loans they have taken, but on the commitment of members to the groups' goals. Hardly any group attempted to monitor the use of loans by their members. The leaders stated that they are aware that most borrowers use credit for various purposes and not only limited to the intended purpose. Knowing this does not raise much concern in many cases, as they believe that members are adequately covered by group pressure. In the event of default, a member's household property equivalent in value to the loan is auctioned, usually with the assistance of village elders or the sub-chiefs.

RESULTS OF THE FARMERS' SURVEY

Demographic and Socio-economic characteristics

From the 90 farm households in the sample, there were slightly more there were more female-headed household (52%) than male-headed households (48%). Average age of the household head was 45 years, with an average farming experience of 17 years, implying that a substantial number started farming in their late twenties (see Table 3 for a summary of the farm household information). Education level was on average low (8 years). More so, many respondents did not have any formal education. Farm sizes were on average less than 2 hectares.

Table 3: Demographic Characteristics of the sample

Variable	Mean	Minimum	Maximum
Age of the farmer in years	45	19	76
Years of formal education	8	0	14
Number of household members	7	1	10
Experience in farming in years	17.4	1	67
Farm size in hectares	2.0	0.2	5
Gender of the farmer: Male	43 (48%)		
Female	47 (52%)		

The crops grown are mainly food crops, but maize dominates in land allocation (85%) and is considered as a staple food as well as a cash crop. A large majority of farmers (95%) use hand hoes as the main farm tool. Other farm tools are ox-plough, axe, machetes and knives for different farm operations. Maize is grown in pure stands as well as intercropped with beans and sorghum. More farmers (95%) grow pure maize stand than intercropped (50% of the farmers). Moreover, the pure stands are generally on larger plots. Given its dominance, as well as for ease of calculations, this study only took into consideration pure maize stands.

In the livestock sector, farmers mainly keep indigenous breeds, with each household keeping an average of 5 head of cattle, 6 goats, 2 sheep and a flock of 10 poultry.

Access to extension and credit

The number of farmers that received extension over the last year clearly indicates the decreasing role of the government as compared to the local NGOs, in this case SCODP.

While only a quarter (27%) received extension from the government, almost half (42%) received extension from SCODP, with 14% receiving extension from both (Table 4). The largest group of farmers (46%) did not receive any extension services at all.

Of all interviewed farmers, none had access to formal credit. Farmers in the division have to rely on informal or semi-formal credit. More than 90% of farmers (so even those who borrowed) indicated a credit constraint. The sample contains 20% of non-borrowing members. It should be noted that most of these farmers do not receive credit because the groups do not generate enough savings to serve all demand. Still, group credit was the most important source of credit, with 47% of interviewed farmers who constitute the borrowing members in the sample. The second source of credit, with 27% of the farmers, was other informal credit. No farmers from the borrowing members took part in it, but

Table 4. Farmers access to extension during the year 2000

Source of extension	% of the sample
None	46.5
SCODP	27.8
Government & SCODP	14.4
Government	12.2
Total	100

Table 5. Sources of credit in the study area (in % of farmers in the sample) for members and non-members of credit groups

Credit source	Non-members (G1) (33%)	Members: Non-borrowing (G2) (20%)	Members: Borrowing (G3) (47%)	Total (100%)
Group credit	0	0	100	47
Other informal credit	46	5	0	27
Semi-formal credit	0	0	12	6
None	54	95	0	21
Total	100	100		100

46% of the non-members, and 5% of the non-borrowing members did (Table 5).

Despite the availability of group credit, only 10% of all the sampled farmers, borrowers as well as non-borrowers, indicated that credit is not a constraint in input use (Table 6). Both hybrid seed use and yield are higher on non-constrained farms, indicating problems in input acquisition for credit-constrained farmers.

Cash flow problems were therefore cited as a major problem, resulting in inadequate or untimely purchase of inputs, particularly fertiliser and hybrid seeds. Institutions like commercial banks tended to cater to the medium and large-scale farmers only. While the Agricultural Finance Corporation (AFC), the main agricultural finance institution in Kenya, has had extremely poor experience with the small-scale farming community. The few farmers (5.6%) who used semiformal credit were groups that had been financed by WEDCO (Table. 5).

ANALYSIS ON FACTOR USE AND OUTPUT DIFFERENTIALS BETWEEN GROUPS OF FARMERS

To analyse the effect of credit, input use and outputs of the different groups of farmers are compared (Table 7). Group members who borrowed (G3 in the Table) clearly used more improved inputs, fertiliser as well as hybrid seed, than non-members (G1) or non-borrowing members (G2), and also obtained higher maize yields. Statistical analysis, using a t-test of independent samples, showed significant differences between the borrowing members (G1) and the other groups, taken separate (G3 vs. G2, and G3 vs. G1) as well as together (G3 vs. G1 and G2 combined). To properly quantify the effect of credit on maize production through increased input use, however, an appropriate multivariate

Table 6: Input use in credit constrained and not-constrained farmers

Credit constrained	% of farmers	Farmer category	Fertilizer (kg)	Hybrid seeds (kg)	Pesticides (litres)	Hired labour (man-days)	Land under maize (%)	Yield (kg/ha)
No	9.1%	Non-borrowers	0.06	3.50	0.00	6	52	695
		Borrowers	20.40	8.63	0.27	14	58	1176
		Total	14.45	6.06	0.14	11	62	943
Yes	89.9%	Non-borrowers	7.85	3.07	0.35	8	53	575
		Borrowers	34.12	6.36	0.24	10	79	810
		Total	20.28	4.55	0.36	9	64	702

Table 7: Comparative analysis of different groups of farmers in factor uses and yields.

Input/output	Units	Non-members (G1)	Non-borrower members (G2)	Borrower members (G3)	Non-borrower farmers (G1+G2)	t-test G2 vs G3	t-test G1 vs G3	t-test (G1+G2) vs G3
Fertiliser	kg/farmer	9.13	7.06	32.68	8.35	2.0**	2.3**	3.0***
Hybrid seeds	kg/farmer	2.83	3.36	6.58	3.03	3.0***	4.3***	4.9***
Hired labour	days/farmer	7	10	10	8	1.1	2.0*	1.5
Farm labour	Days/farmer	100	106	109	102	0.2	1.2	0.8
Pesticides	Litres/farmer	0.68	0	0.24	0.4	0.7	-0.8	0.4
Fertiliser	Kg/hectare	8.13	3.8	19.4	6	4.0***	2.5**	3.0***
Hybrid seeds	Kg/hectare	1.75	2.08	4	2	2.0**	2.6**	5.0***
Maize hectares	% of farm	49	63.36	78.47	56.2	2.1**	4.1***	3.3***
Maize yield	Kg/hectare	671	520	845	616	3.3***	4.0***	3.7***

*** = Significant at 0.01, ** = Significant at 0.05, * = Significant at 0.10.

econometric model needs to be developed and applied.

There was no significant difference between the groups in the use of other inputs, in particular the use of labour and pesticides. The insignificant difference between the groups of farmers on pesticide use is likely due to low pesticide use by the sample farmers on food crops, also observed by Saito *et al.* (1994). The non-significant difference in labour use can also be explained by the to low use of hired labour in general. Most farms (both borrowing and non-borrowing) have sufficient family labour available: average farm size is two hectares while the average household is composed of 7 members, with 4 aged above 14 years.

CONCLUSIONS

The results of this study show that group credit has a positive and significant impact on the use of improved inputs such as improved maize seed and fertilizer, and that yields from borrowers are significantly higher than non-borrowers. However, this trend is not followed in pesticides and labour use. The significant difference in use of fertiliser and hybrid seeds between the two groups of farmers depicts the influence of credit (formal or informal) on adoption of improved input technologies. Similar findings have been reported by Nkonya *et al.* (1998), Yadav and Rahman (1994), and Chipeta and Mkandawire (1991).

The study also shows that financial self-help groups are very important financial institutes for small-scale farmers. They successfully tap the meagre financial resources and help build funds, which meet credit demands among poor rural farmers. Credit amounts are however small and quite often inadequate, leading to high interest rates and credit rationing. The interest rates charged (14% per month), are much higher than those in the formal sector. Similar rates were reported among the '*tontines*'- self-help groups (who charge 10% interest rates per month) in Cameroon (Bouman, 1994). The high interest rates do not seem to suppress demand because of the convenience and ease with which group funds are accessible to members. More so, they are indigenously established groups, deeply rooted in the communities, have knowledge of each member and members' cohesiveness inhibits unprecedented defaults in obligations such as savings and credit repayments. The credit rationing, common in most groups, denies other willing borrowers credit. From this perspective, external financial support would help to serve demand.

Small-scale farmers critically need convenient, cost-effective and sustainable financial services. Formal credit is distinctively lacking with very limited participation of semi-formal credit participants, while the available informal sources such as groups are quite inadequate. Availability of inputs and technologies is to no avail unless farmers have the means to obtain and use them. If properly designed and complemented by the formal financial market participants, and also, given an enabling policy environment, group credit can act as a catalyst to overcome such obstacles and help neglected small-scale farmers in uplifting their productivity.

The key institutional challenge is to link the informal and formal financial sectors, drawing on the strenths of each, but without destroying the former. Proper links should increase the available capital and hence decrease rationing and interest rates, while preserving the strengths of informal systems, in particular concerning client information and provision of flexible services with low transaction costs. The major challenge, however, is to determine in how far external capital can be used without changing the essential features that determine the sustainability of the informal groups. To reach a proper balance, innovative thinking is needed, preferably within a framework of institutional experimentation in small pilot projects. These projects should encourage strong interactions between the farmers on the one hand, and practioners and scientists of relevant disciplines (finance, economics, sociology, and agriculture) on the other hand. Lessons drawn from such pilot projects could then be used to improve the financial services available to small-scale farmers and thereby, as this paper showed, increase food security for the poor.

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IMPROVING GRAIN YIELD OF SMALLHOLDER CROPPING SYSTEMS: A FARMER PARTICIPATORY RESEARCH (FPR) APPROACH WITH LEGUMES FOR SOIL FERTILITY IMPROVEMENT IN CENTRAL MALAWI.

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ABSTRACT

Low crop yields associated with predominantly nutrient-related soil constraints to crop production constitute an undoubted characteristic of subsistence cropping systems throughout Malawi. Nitrogen (N) is singled out as the most limiting nutrient element followed to some extent by phosphorus (P). Continuous monocropping of maize (*Zea mays* L.) with little or no fertilizer inputs has contributed to the fall in crop yields. Yet, fertilizer recommendations for smallholder farmers developed in the 20th century have become grossly uneconomic due to escalating fertilizer prices *vis-a-vis* declining real prices of maize grain. An innovative approach to develop assess and disseminate legume intensified crop production systems as a low-cost measure to counter the risk of diminishing soil fertility and low crop yields, including the criteria governing farmers choice of intensified legume technologies, is described. Using continuous unfertilized maize as a control, the paper outlines maize yield gains resulting from soil nutrient replacement through inputs of intensified legume technologies based on four years (1997-2001) of experimentation with farmers in Central Malawi. Intensified legume technologies resulted in significant ($p \leq 0.05$) grain yield increments over control maize. Technologies identified to offer substantial soil fertility benefits included one year fallows with *Mucuna pruriens* (about 1,135 kg/ha increase in maize grain in Chisepo and 3,515 kg/ha increase in Bembeke averaged over 4 years), maize/pigeonpea intercrop, doubled-up legume intercrop maize rotations (involving improved medium duration pigeonpea variety (ICP 9145), improved groundnut variety (CG7), soyabeans) and maize/*Tephrosia vogelii* relay intercrop systems. Technologies that offered multiple benefits including reduced demand on household labour were most preferred for adoption by smallholder farmers. Future research in pursuit of improving availability of seed of improved varieties, produce outlets and integrated nutrient management strategies tapping on farmer innovations is urgently required to ensure sustainability of the production system.

Keywords: Cropping system, fallow, legumes, soil fertility

INTRODUCTION

Maize (*Zea mays* L,) dominates the subsistence agricultural landscape of Southern Africa, in general, and particularly, nowhere more so than in Malawi where it covers about 80% of the smallholder farm land (Wendt *et al*., 1993). The reliance of the country's growing population on maize portrays a cropping system susceptible to biological and socio-economic instability. Smallholder farmers' average maize yields continue to dwindle below 0.4 t ha^{-1} partly due to predominantly nutrient-related soil constraints (Kanyama-Phiri *et al*., 2000). Among other things; uninterrupted annual cropping of sole cereals coupled with limited use of inorganic fertilizer characterize a farming system already constrained by limited land, depleted soils, inadequate farm labour and cash resources. Additionally, the prevalence of the HIV/AIDS pandemic and its devastating effects on human health continues to present serious consequences on labour availability for farming activities. Research on crop nutrition has documented nitrogen (N) and phosphorus (P) as major limiting nutrient elements on growth and productivity of maize (Kumwenda *et al*., 1997). However, fertilizer recommendations of the 1990s generally targetted sole-cropped maize and lack economic relevance considering recent escalating inorganic fertilizer prices and declining real grain price (Snapp *et al*., 1998; ICRISAT/MAI, 2000). Consequently, smallholder farmers continue to experience diminishing soil fertility, declining crop yields, food shortages and unsustainable livelihoods.

An opportunity exists to improve crop yields by diversifying with nitrogen-fixing leguminous plants as the availability of improved varieties grows. Crop diversification has been an explicit goal of agricultural policy in Malawi (Kumwenda *et al*., 1997) promoted to enhance human nutrition through protein-rich crops and soil fertility through biological processes. Surprisingly, the uptake of legume technologies by smallholder farmers has remained low and puzzling to the research community. This paper outlines efforts by ICRISAT and its collaborative partners to develop, test and disseminate legume technologies and practices to improve soil fertility and maize productivity while stimulating farmer experimentation and developing farmers' absorptive capacities to adopt and apply such practices through farmer participatory research (FPR).

MATERIALS AND METHODS

Selection of trial sites, villages and farmers

Farmer participatory research (FPR) work using the mother-baby trial approach to develop, introduce, assess and disseminate technologies was initiated by ICRISAT in collaboration with the national agricultural research system in Malawi during the 1997/98 cropping season. The partnership was extended to other institutions and non-governmental organisations particularly CIMMYT in Chisepo, Kasungu and Concern Universal in Bembeke area in Dedza. The mother-baby trial approach served to improve the flow of information from research to farmers and vice versa about how suitable and efficient a technology was performing

Table 1. The biophysical and socioeconomic characteristics of case study sites for farmer participatory research in Malawi.

Site	Altitude (m) asl	Annual rainfall (mm)	Annual temperature (°C)	Rainfall pattern	Soil texture	Organic carbon (mg/kg)	pH	Farm size (ha)	Major field crops
Chisepo	1000-1300	600-800	18	Nov.-Apr	Sand Sandy loam	15	6.4	2.6	Maize Tobacco Groundnut
Bembeke	1400-1700	800-1000	15	Nov.-Apr	Loamy sand Sandy clay	12	5.5	1.2	Maize Common bean

under farmers' conditions (Snapp, 1999). The approach involved the establishment of two types of trials one being a subset of the other. The mother trial was designed and managed on-farm by the researcher incorporating a range of legume options conforming to scientific data requirements (ICRISAT, 2000), whereas the baby trial was limited to 4 treatments chosen by the farmer from the mother trial to facilitate farmer involvement, participation and evaluation. Each site had one mother trial while farmers established several baby trials. Mother trials had at least 4 replications per site and compared about 9 technologies in 36 plots. Technologies in both types of trials involved legume systems including continuous control maize. Farmer assessment of trials was done during field days, focus group discussions and trial monitoring on the basis of overall desirability and potential for adaptation and incorporation into the existing farming system.

Chisepo is located in the relatively dry, mid-altitude central plains of Malawi and 90% of farmers in this area cultivate tobacco with minimum use of inorganic fertilizers on their small land holdings. The area is relatively food insecure and experiences considerably high levels of malnutrition. Host farmers in Chisepo were randomly selected from 4 villages based on results of a farmer characterization survey that was conducted prior to trial implementation. While 3 villages hosted trials, 1 was set aside as a control. Trials were either researcher-designed farmer-managed or farmer-led trials. All trials focused on legume best bets (pigeonpeas, groundnuts *Tephrosia vogelii* and *Mucuna pruriens*) as intercrops or in rotation with maize with little or no fertilizer.

On the other hand, Bembeke is located within the relatively cool high altitude central highlands. Host farmers were spread across 5 villages selected based on results of a participatory rural appraisal (PRA) exercise carried out to characterize the cropping system and identify critical problems affecting farmers. Three villages hosted farmer-led farmer-managed trials while 2 villages hosted researcher-led farmer-managed trials. Farmers were given legume seed (*Mucuna pruriens*, pigeonpeas and *Tephrosia vogelii*) of their choice through Concern Universal to plant as sole crops, intercrops or in rotation with maize in farmer-led trials. Unlike in Chisepo, trials in Bembeke included beans and soyabeans as the main cash income earners in the area The biophysical and socio-economic characteristics of the sites for farmer participatory research activities in Malawi are given in Table 1.

The gross plot size for the legume best bet trial plots at both Chisepo and Bembeke measured 7.2 m x 0.91 m x 8 ridges while agronomic data were collected from a net plot of 6 ridges discarding 1 planting station on each end of the ridge. Data collected included grain yield, farmer

Table 2. Details of treatments in mother and baby trials conducted in Chisepo and Bembeke from 1997-2001.

Within site replicated mother trial Plant density = (x 1000)	One farmer, one replicate baby trial Plant density = (x 1000)
1. Maize (Mz) control (continuous unfertilized; hybrid-MH 18, 37 plants/ha) Current farmer practice in Malawi	1. Mz control (continuous unfertilized; hybrid (MH 18), 37 plants/ha) Current farmer practice in Malawi
2. Mz + fertilizer (hybrid - MH 18; 37 plants/ha plus area specific recommendation; 69 kg N/ha, 20 kg P_2O_5/ha)	2. Mz/pp (1:1 ratio)
3. Maize + Pigeonpea (pp) intercrop (37:37 plants/ha, MH18:ICP 9145)	3. Groundnut (gnut) + pp or pp/ soyabean intercrop rotated with maize (74 + 37 plants/ha, CG 7: ICP 9145)
4. Mz + pp + fertilizer	4. Mz/*Tephrosia vogelii* (tp), relay intercrop broadcast at first weeding, 20 kg/ha
5 Groundnut (gnut) + pp or pp/ soyabean/common bean intercrop rotated with maize (74 + 37 plants/ha, CG 7: ICP 9145)	
6. Maize phase of legume intercrop	
7. Maize + tp relay intercrop (broadcast at first weeding, 20 kg/ha)	
8. *Mucuna pruriens* (mucuna) :74	
9. Maize phase of green manure (mucuna) rotation	

perceptions on the performance of the technologies and adoption constraints and opportunities identified by farmers.All data were analysed using Genstat 5 after which a partial budget analysis was conducted using present value cost of seed, fertilizer and opportunity cost for farmers' labour. Details of the treatments are given in Table 2.

RESULTS AND DISCUSSION

Performance of mother trials at Chisepo and Bembeke (1997-2000)

The performance of the legume technologies was generally superior to continuous unfertilized control maize over the four seasons. The intensified legume systems (without fertilizer) significantly ($p \leq 0.05$) increased maize grain yield from as low as 1.0 t/ha in the first season to as high as over 3.5 t/ha in the third season in Chisepo (Fig. 1) and from below a t/ha to as high as over 4.0 t/ha in Bembeke (Fig. 2). The highest yield increase was obtained from the maize/pigeonpea intercrop plus specific fertilizer recommendation in the third season in Chisepo. The increase

Figure 1. Grain yield response for technologies tested in the mother trials in Chisepo from 1997-2001.

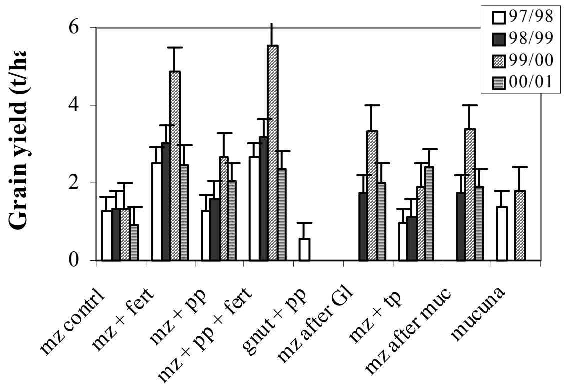
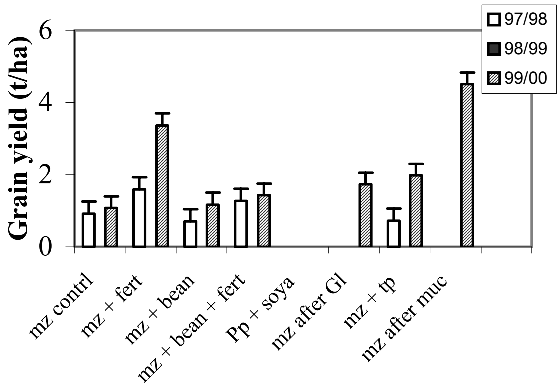


Figure 2. Grain yield response for technologies tested in the baby trials in Bembeke from 1997-2001.



(Fig. 2). The highest yield increase was obtained from the maize/pigeonpea intercrop plus specific fertilizer recommendation in the third season in Chisepo. The increase in maize yield was likely due to the nitrogen replenishing ability of the legumes through biological nitrogen fixation and nitrogen release from incorporation of the residues from legumes which resulted in residual soil fertility for the subsequent crops in rotation. Previous studies reported a wide range of legume intensified technologies for improving soil fertility and observed that performance of different technologies tends to vary with individual farmer management techniques, quality of cropping season and soil types (Myers *et al*., 1997). The mother trial data for Bembeke were not available for the 1998/99 and 2000/2001 seasons due to other unforeseen project logistical setbacks. The performance of the technologies was highly variable between the sites with a much more stable yield response in Chisepo than in Bembeke.

For treatments tested in baby trials in Chisepo, the maize/*Tephrosia vogelii* system gave the highest maize yields in the third season followed by maize/pigeonpea intercrop and maize after grain legume rotation system (Fig. 3). The continuous unfertilized maize control gave the lowest maize grain yields over the seasons. The differences in field management by different farmers constituted the most critical issue to support the variations in maize yield between the sites. Residual fertilizer from the maize rotation with tobacco contributed to large volume of biomass production by legumes in Chisepo as opposed to Bembeke where tobacco is not traditionally grown due to low temperature and poor soils. As in the mother trial, different technologies exhibited different trade-offs between maize grain and legume grain, labour requirements andtimeliness in weed control and other benefits including fuelwood and hanging poles for tobacco from farmers' observations during field days. In Bembeke there were a variety of baby trials deviating from the expected baby trial treatments especially by farmers from the farmer-led villages. It was interesting to note that innovative farmers in these villages implemented a wide range of baby trials using beans and soyabean seed that Concern Universal distributed through its community seedbank initiative. The maize after legume system gave the highest yields followed by the maize/*Tephrosia vogelii* then the maize/pigeonpea intercrop (Fig. 3). Yield response to all technologies was more variable at the wetter central highland site of Bembeke with inherently acid soils than in Chisepo which produced relatively stable and increased yields. Trial performance was generally poor with low yields across the two sites during the 2000/2001 season due to heavy rains that were evenly distributed across the growing season resulting in waterlogging and leaching of nutrient elements.

The average grain yield data over the four years of production for best bet technologies indicated an overall increase in the production and productivity of the maize-based cropping system in both sites with an associated increase in the number of participating farmers (Table 3). The increase in the number of participating farmers implied the attractiveness of the technologies to the farmers considering the high market and food values offered by the legume grain (ICRISAT, 2000) compared to maize.

Farmer perceptions, assessment and ranking of technologies tested in the trials during the 1997-2001 period in Chisepo and Bembeke.

Over the years farmers assessed and ranked technologies tested in baby trials starting with maize/mucuna then pigeonpea/groundnut or soyabean intercrop-maize rotation as the best system, followed by maize/pigeonpea intercrop and maize/*Tephrosia vogelii* relay intercrop, during field days and focus group discussions. Farmers from Chisepo considered the maize/pigeonpea intercrop as the best technology to adopt due to combined harvest of both cereal and legume grain for consumption and for cash sales. Farmers felt convinced that this technology requires little labour input at weeding due to the weed suppressive effect of the plant canopy arising from increased plant density. Farmers also observed that the maize/pigeonpea technology reduces labour required during banking operations since the deep-rooted pigeonpea acts as a biological plough that effectively loosens the soil. The system also requires less labour to harvest compared to maize/*Tephrosia vogelii* system. For farmers with a little more land to afford crop rotation, the pigeonpea/groundnut intercrop maize rotation was perceived best for business oriented farmers (Snapp, 1998; Snapp, 1999). The yield that was expected to rise over the seasons by incorporation of a blend of nutrient-rich *Tephrosia vogelii* and maize residues meant that maize yield was the only product of the maize/*Tephrosia vogelii* relay intercrop green manure system within the scope of the trials. Farmers generally perceived maize/*Tephrosia vogelii* as a low-return system due to high labour required for harvesting, reduced and delayed biomass incorporation eventually resulting in low maize response. In Bembeke, farmers were

Figure 3. Grain yield response for technologies tested in baby trials in (a) Chisepo and (b) Bembeke from 1997-01.

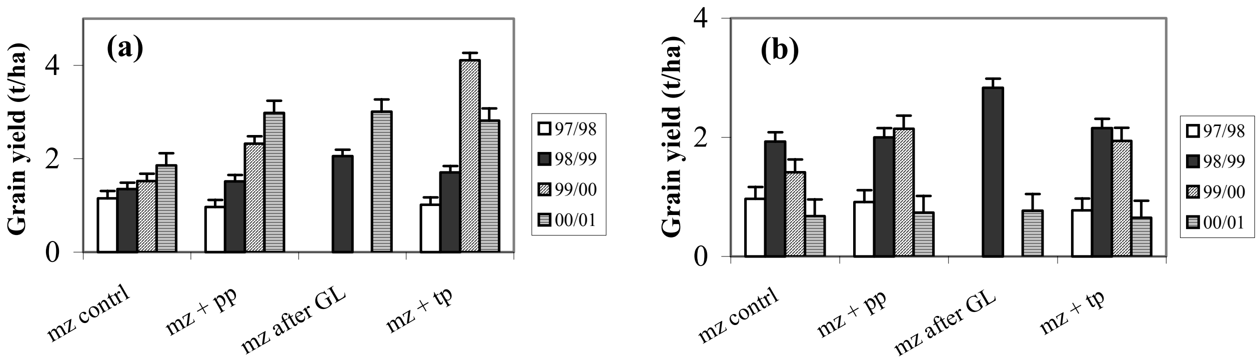


Table 3. Grain yields of maize and legumes from baby trials conducted in Chisepo and Bembeke from 1997-2001 in Central Malawi.

Location	Chisepo		Bembeke	
Technology	Maize	Legume kg/ha	Maize	Legume
1998	N=23		N=19	
Sole maize	1152	NA	969	NA
Maize/pp	963	155	913	227
*Double legume/ maize rotation	NA	1442	NA	867
Maize/tp	1016	NA	773	NA
1999	N=19		N=21	
Sole maize	1350	NA	1929	NA
Maize/pp	1514	224	1996	348
*Double legume/ maize rotation	2056	NA	2828	NA
Maize/tp	1704	NA	2152	NA
2000	N=39		N=34	
Sole maize	1521	NA	1411	NA
Maize/pp	2321	ND	2144	ND
*Double legume maize rotation	NA	2715	NA	1267
Maize/tp	4109		1939	NA
2001	N=11		N=70	
Sole maize	1857	NA	676	NA
Maize/pp	2982	ND	734	ND
*Double legume maize rotation	3006	NA	766	NA
Maize/tp	2812	NA	651	NA

* = this year's phase of the rotation, from which grain yields are reported.
NA = not applicable
ND = no data available

most attracted to the *Mucuna pruriens* rotated with maize, with the maize/pigeonpea intercrop ranked second, hence a greater motive for innovation and a wide range of adaptation of the baby trials into the existing cropping system.

Farmer assessment and ranking of intensified legume technologies during field days and focus group discussions roughly revealed interesting aspects about smallholder farm-level investment decision-making in soil fertility management. Farmers consistently ranked maize after *Mucuna pruriens* as the best technology of all treatments in the mother trial as well as the baby trials across the two sites. Farmers noted that *Mucuna pruriens* is a heavy biomass producer, provides ground cover for moisture retention, and suppresses persistently troublesome weeds especially sedges (*Cyperus* sp.), *Eleusine indica* and witchweed (*Striga* sp.). Weed control could thus be achieved without any cash expenditure. Farmers also observed that degraded land patches in the field, where further cultivation does not yield anything as a result of soil fertility depletion, may be reclaimed by establishing a continuous *Mucuna pruriens* rotation system with maize in a way that involves little opportunity cost of labour and cash resources. However, the low food value of *Mucuna pruriens* seed due to the presence of a poisonous chemical substance often reduces farmers' preference for this technology. Farmers in Chisepo ranked maize/pigeonpea as the second best technology after *Mucuna pruriens* rotation with maize. Farmers felt that maize/*Tephrosia vogelii* system did not offer substantial benefits despite the fact that that *Tephrosia vogelii* stalks could be used as fuelwood and tobacco curing sticks.

Farmers in Bembeke ranked maize/soyabeans and maize/pigeonpea intercrop systems as the next two best liked technologies after *Mucuna pruriens* rotation with maize. The farmers, however, expressed concern that unless animals are restrained until the pigeonpea attains harvest maturity, the technology may not offer its intended soil fertility benefits. Goats often browse on the pigeonpea especially if planted in homestead fields. Farmers in both sites also observed that the new groundnut variety (CG7) brought to the sites by ICRISAT tolerates drought and matures early resulting in stable seed yield, and biomass production that, if incorporated, benefits the maize rotation crop. The risk-averse farmers, especially the women folk, observed that intercrops were labour-saving and minimized risk due to combined yields and the fact that if one crop failed another could be harvested. The maize/*Tephrosia vogelii* relay intercrop got a low rank from the farmers' point of view because of the little biomass produced to benefit the subsequent season's crop. However, due to the problem of goats browsing on pigeonpeas, the more innovative farmers at both sites resorted to experimenting with this system by leaving the *Tephrosia vogelii* to grow for over a season and coppicing considerable volumes of fuelwood and leaf litter from the plots afterwards.

CONCLUSIONS AND FUTURE RESEARCH NEEDS

The FPR initiative led to the identification of potential legume intensified 'best bet' systems for soil fertility improvement that smallholder farmers in Malawi could adopt. Potential legume technologies that offer multiple benefits stand a better chance for adoption by smallholder farmers and these included maize/pigeonpea intercrop, pigeonpea/groundnut intercrop rotated with maize, one year fallow with *Mucuna pruriens* rotated with maize, pigeonpea/bean intercrop rotated with maize and the maize/pigeonpea intercrop plus fertilizer for those few farmers to whom the area specific fertilizer recommendation is affordable. In addition to improving soil fertility, these technologies also reduced labour requirement for weeding by suppressing weeds while contributing substantially to the profitability of the maize-based cropping system and household food security. The research has also showed that maize/pigeonpea and pigeonpea/groundnut technologies could only become attractive for adoption if the institutional capacity of the rural community adopts an organized leadership structure to strengthen and implement regulations that restrain livestock from browsing on crop fields until pigeonpea attains harvest maturity. Future research should strive to further develop and strategize dissemination channels to reach more of the smallholder population. By virtue of their living in the remote world, smallholder farmers marginally access information about upcoming technologies that may influence their production and investment choices. The research and development institutions should urgently pursue ways to link farmers to seed suppliers and produce markets while integrating nutrient management strategies, with a strong focus on farmer innovations that have arisen out of the current work to ensure sustainability of maize-based cropping systems.

ACKNOWLEDGEMENTS

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ON-FARM SEED MULTIPLICATION OF OPEN POLLINATED MAIZE VARIETIES USING FARMER GROUP APPROACH

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ABSTRACT

Maize (*Zea mays* L.) is a priority crop in the smallholder farming community in Eastern Tanzania. One of the major constraints limiting optimum production of maize is the use of low quality planting seed. To date, only 2-4% of the farming community in the rural areas can access improved commercial varieties. High cost of certified seed, limited distribution and limited awareness of the existence of good quality seed are among the reasons for low availability of improved seed in rural Tanzania. Poor road conditions contribute to low accessibility as well. On-farm seed production introduced in Central and Northern Kilosa used farmer group approach. Three-year experience indicated that it is possible to produce seed of open pollinated maize varieties on-farm. In maize-dominated cropping systems, a modified isolation by distance technique of saturating the 200-meter isolation with the same seed quality can be used. However, this technique requires large amounts of seed and hence the initial cost for procuring seed is also high. The paper suggests that the areas of seed storage, distribution and marketing be given due attention.

Keywords: Farmer groups, isolation, maize, on-farm seed multiplication

INTRODUCTION

Maize is a first priority crop of the farmers in the Eastern Tanzania (Moshi *et al*, 1997 and Kaliba *et al*, 1998). The crop is used for food as well as for cash. Maize is grown during the short rains that normally start in October and end in December, during the main rains that commence in February and go up to June and also during the dry season by utilizing residual moisture in the low-lying valley bottoms. The average grain yield in farmers' fields ranges between 0.5 to 1.0 tons per hectare.

Participatory Rural Appraisal Studies (Kadeng'uka *et al.*, 1996 and Akulumuka *et al.,* 1998) showed that limited accessibility of the improved seed is among the major contributing reasons for low grain yield of maize. Moshi *et al* (1997) and later Seed Unit (2001) indicated that only 2-4% of the improved seed of the released commercial open pollinated varieties reach the farmers in the rural areas. The contributing factors for low diffusion of the released improved open varieties of maize included high price of seed offered by the seed vendors, limited availability at planting time, little awareness of the existence of the improved commercial open pollinated varieties in the rural community and poor rural road conditions.

This paper describes three-cropping seasons' experience of on-farm seed multiplication of open pollinated maize varieties carried out in Central and Northern Kilosa District within Eastern Tanzania. The study started in 1998/1999 and ended in 2000/2001 cropping seasons.

The objectives of the study were to introduce simple techniques of producing quality seed of open pollinated varieties of maize to the smallholder farmers, to make available the improved seed of maize to the farmers which is accessible when needed and affordable and to contribute to the increase of maize production per unit area through the use of improved varieties of maize.

METHODOLOGY

Experiences gained by various workers in the informal seed multiplication sector led into conceptualizing on-farm seed multiplication into the following seed multiplication continuum (Fig 1). Basically, two phases of on-farm seed multiplication are envisaged. Phase one starts at a point where farmers produce seed from their own harvest. Then on-farm seed multiplication using improved seed takes off from this point. This phase ends at a point where farmers meet their requirement for improved seed. Phase two begins when farmers begin to multiply improved seed specifically for sale. At this stage, farmers must have acquired a considerable amount of entrepreneurship.

Farmer participation

On-farm seed multiplication in central and northern Kilosa used the farmer group approach when carrying out this activity. Farmer groups used are of two categories. The first category was those farmer groups formed at the beginning of the seed multiplication activity. Three farmer groups were formed. One in central Kilosa and two in northern Kilosa.

Category two involved farmer groups that existed before the start of the project. In this category, central Kilosa had one farmer group and five farmer groups in northern Kilosa. A total of nine farmer groups participated, two in central Kilosa and seven in northern Kilosa. The minimum farm size for farmer groups in central Kilosa was 2.5 ha and maximum farm size was 5 ha for new and old farmer, groups respectively. Each group had a total of 10 members. Table 1 provides information on the farmer groups that participated in the activity.

Figure 1. Informal Seed Multiplication Continuum.

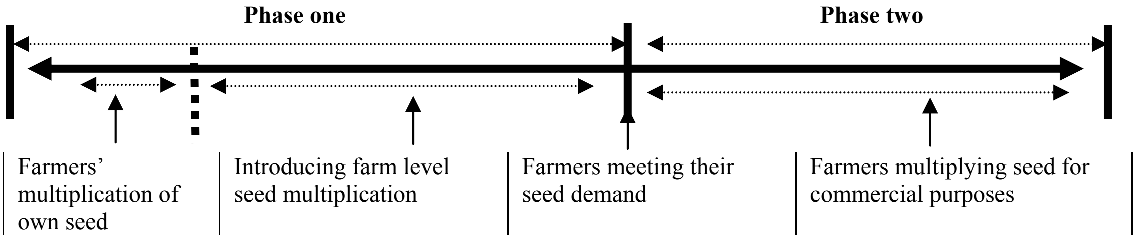

Table 1. Farmer Groups Involved in On-farm Seed Multiplication in Central and Northern Kilosa, Eastern Tanzania

Agro-ecology	Name of Farmer Group	Total members	% of women
Central Kilosa	Kimamba	10	90
	Pangawe*	10	20
Northern Kilosa	Ihanda*	5	60
	Kwipipa*	10	20
	Jitegemee	12	100
	Chikiende	9	100
	Chiwetuma	8	100
	Muungano	11	34
	Shuhudieni	10	10

* New farmer groups

Table 2. Mean Seed Yield of maize (t/ha) recorded in 1997-1999 Cropping Seasons in seed plots of two farmer groups in Central Kilosa, Eastern Tanzania

Farmer Group	Variety Name					
	TMV-1			Staha		
	Cropping season					
	97/98	98/99	99/00	97/98	98/99	99/00
Kimamba	2.5	2.8	1.1	1.7	2.9	1.1
Pangawe	1.2	0.8	0.5	1.1	1.4	0.9
Mean	1.9	1.8	0.8	1.4	2.2	1.0

Isolation techniques

One of the complicating factors in open pollinated maize seed multiplication is maintaining seed quality by minimizing contamination from undesirable pollen since maize is a highly cross-pollinated crop. To do so, the seed field had to be isolated typically by a distance of 200 m. Several isolation procedures were discussed with the farmers. Then farmers selected an appropriate procedure based on the availability of land and the existing cropping systems in the particular location.

In central Kilosa, for example, farmers opted for isolation by distance. This is because it is easier to get a seed plot that can be isolated by a distance of 200 m. Practically, farmers had to go far away from their usual maize plots. Sometimes this complicated the management of the seed farm.

Farmers in northern Kilosa had different limitations. Fallow land is scarce in the field site and almost all farmers plant maize during the cropping season. Thus, isolation by distance seemed not to be possible due to non-availability of land without maize crops.

Considering the above facts, the best alternative selected was to modify isolation by distance. The modification made involved encircling the seed field by saturating the 200 meters' area with the same type of seed. Figure 2 illustrates this procedure. The saturated area acted as a barrier that protected maize in the seed field from getting unwanted pollen from other maize.

The seed plot belonged to the farmer group involved in the seed production. The encircled area belonged to farmers who were none members of the farmer group. Again, this is another complication faced by the seed production group. Through several consultation meetings, farmers in the saturated area agreed to adhere to the same principles observed by the farmers within the seed field.

Maize varieties used in central Kilosa included TMV-1 (110 days) and Staha (120 days) while in northern Kilosa they used TMV-1, Staha and Kilima-ST (135 days). Farmers selected these varieties from previous on-farm variety testing experiments carried out in previous seasons. In the first year, the seed grade used to plant in the seed plots was Foundation Grade obtained from Msimba Foundation Seed Farm. In second and third year, farmers planted seed selected from their seed plots. Cost of foundation seed offered to research by the Foundation Seed Farm was Tanzanian shillings 5,000 (equivalent to $6) per kilogramme.

RESULTS AND DISCUSSION

This paper discusses the results obtained in the 1998/1999, 1999/2000 and 2000/2001 cropping seasons in terms of seed yields, seed distribution and acquisition model and farmer assessment on the techniques used to produce seed on-farm.

A summary of seed and grain yields are presented in Tables 2 and 3 for central Kilosa and Tables 4 and 5 for northern Kilosa. Central Kilosa had fairly good mean seed yield of 1.5 t/h (TMV-1 and Staha) across seasons. Farmers obtained relatively low yield in the third cropping season as compared to the other two seasons. This could be attributed to poorly distributed rainfall whereby most of the maize plants suffered terminal drought at the flowering stage.

In northern Kilosa, farmers obtained higher mean seed yield (1.8 and 1.9 t/h of TMV-I and Staha, respectively) in 1998/1999 cropping season than the following seasons. This could be attributed to a number of reasons. Erratic and poorly distributed rainfall that followed is among the major contributing factors to low seed and grain yields. Late planting associated with late on set of first rains and heavy infestation of stalk borer added to obtaining the low seed and grain yields. Stalk borer infestation was more severe in the third season. Usually farmers do not apply any chemical intended to control the stalk borer.

Figure 2. Modified isolation by distance method used to isolate seed maize from undesirable pollen.

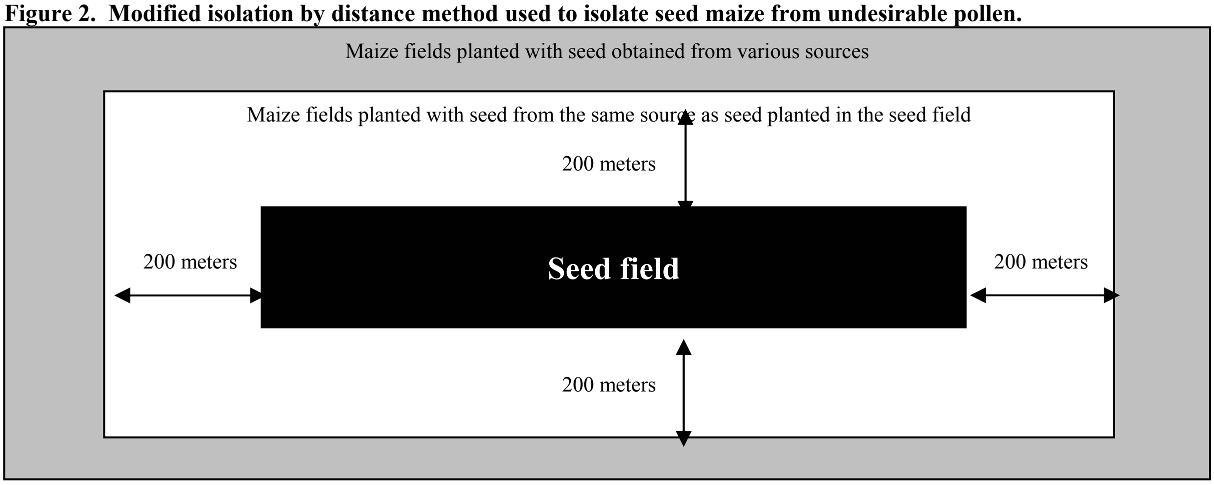

Table 3. Mean Grain Yield of maize (t/ha) recorded in 1997-1999 Cropping Seasons in seed plots of two farmer groups in Central Kilosa, Eastern Tanzania

Farmer Group	Variety Name					
	TMV-1			Staha		
	Cropping season					
	97/98	98/99	99/00	97/98	98/99	99/00
Kimamba	3.0	3.1	1.4	3.3	3.6	1.8
Pangawe	1.7	1.6	1.2	2.0	1.8	1.4
Mean	2.4	2.4	1.3	2.7	2.7	1.6

Table 4. Mean seed yield of maize (t/ha) of seven farmers groups in 1998-2001 cropping seasons in northern Kilosa, Eastern Tanzania

Farmer Group	Variety Name					
	TMV-1			Staha		
	Cropping season					
	98/99	99/00	00/01	98/99	99/00	00/01
Ihanda	1.5	1.0	0.8	-	-	-
Kwipipa	1.4	0.8	0.9	1.6	0.8	0.5
Jitegemee	1.6	1.2	1.1	2.0	0.9	0.6
Chikiende	1.9	1.3	0.7	1.8	1.1	0.9
Chiwetuma	1.4	0.9	0.5	1.5	1.0	1.2
Muungano	-	0.7	0.3	-	1.1	1.1
Shuhudieni	-	1.1	0.4	-	0.9	0.9
MEAN	1.8	1.0	0.7	1.7	1.0	0.9

- The farmer group was not involved in producing seed

Table 5. Mean grain yield of maize (t/ha) of seven farmers groups in 1998-2001 cropping seasons in northern Kilosa, Eastern Tanzania

Farmer Group	Variety Name					
	TMV-1			Staha		
	Cropping season					
	98/99	99/00	00/01	98/99	99/00	00/01
Ihanda	1.7	1.4	1.1	-	-	-
Kwipipa	1.6	1.3	1.2	1.8	0.9	0.7
Jitegemee	1.8	1.8	1.5	2.2	1.0	0.8
Chikiende	2.0	1.5	1.2	2.0	1.2	1.1
Chiwetuma	1.8	1.3	1.0	1.9	1.1	1.2
Muungano	-	1.2	0.7	-	1.4	1.2
Shuhudieni	-	1.7	0.5	-	1.3	1.0
MEAN	1.8	1.5	1.0	2.0	1.2	1.0

The farmer group was not involved in producing seed

In the first cropping season, farmers adhered to all agronomic practices needed for multiplying seed. However, in subsequent years, farmers could not follow some of the agronomic practices such as uprooting the volunteer plants. None uprooting of volunteer plants is a common farmer practice in northern Kilosa. Farmers reasoned that since the volunteer plants came from the same source of seed planted in the previous cropping season, then there was no need of removing them since they will not affect the quality of seed. Experience of the farmers on volunteer plants in their normal common grade maize production is of producing bigger cobs. Replanting is a common practice especially in years where first rains are not enough to allow all planted seeds to emerge and grow normally. Thus, erratic rainfall necessitated replanting in the seed farms and in most cases this resulted in the maize plants having different maturity stages. The situation was worse for the surrounding farmers because they used more than one variety to gap fill and hence affected the ultimate quality of the harvested seed.

Seed distribution and acquisition

Farmers used several models to dispose of surplus seed. The distribution models included exchanging maize grain to maize seed, selling on direct cash and on credit. Exchange of seed to grain only happened between seed producers and those farmers encircling them. Other farmers had to buy seed from the seed producers. The price of seed ranged from Tanzanian shillings 250 to 500 ($0.3 to $0.6) per kilogramme. The price of improved seed in a normal market is between Tanzanian shillings 800 and 1,000 equivalent to $0.9 and $1.1. In simple terms, on-farm seed multiplication managed to avail seed to farmers in the participating and few neighbouring villages at a price, which is 30% to 50% cheaper.

Table 6 provides indication of the amount of seed produced by the farmer groups. Old farmer groups produced higher amount of seed than the new ones. Jitegemee farmer group produced a total of 14.3 tons followed by Kimamba farmer group (12 tons), Chikiende (8.8 tons) and Chiwetuma (8.3 tons). These farmer groups had high composition of female farmers (see Table 1). This could be one of the reasons that enabled them to produce a higher amount of seed, but again the groups had large areas devoted to seed production.

Two constraints faced the farmer groups after harvesting their seed. Demand for seed is usually higher at planting time. The gap between harvesting and planting time is almost four to six months for northern and central Kilosa, respectively. This time gap calls for good storage structures and strategies. Farmer groups were not prepared for that and hence they stored seed the way they store their normal maize. Despite treating the seed with actellic super dust still the seed was attached by Larger Grain Borer (*Prostephanus truncatus*) and Grain Weevil (*Sitophillus spp*). The damage sometimes caused up to 50% seed loss.

Jitegemee farmer group produced a large amount of seed. They were able to satisfy their demand for seed for their seed plots and other plots as well as plots that encircled them. Still, they had quite a significant amount of seed remaining in their stores after the planting time came to an end. Simply, there were no strategies for advertising the availability of seed beyond village boundaries.

Simple analysis of the initial cost of seed particularly in the first year indicated that producing seed in northern Kilosa could be too expensive (Table 7). One needed to spend Tshs 1,800,000 (about $2,000) to buy seed (foundation grade) needed by Jitegemee farmer group to initiate on-farm seed multiplication. Surely, farmers on their own cannot afford to spend this amount of money to start a seed production system without external support. But again, is the isolation method selected in northern Kilosa the only appropriate one. Our observation on the plant performance indicated that maize plants in the seed plots and encircled plots matured earlier than other maize surrounding them. Technically, the maize in both plots (seed and encircled) was not in danger of being contaminated by undesirable pollen. This learning point has been discussed with farmers and other professionals in the seed industry. We now think that we can distribute good quality seed to a large number of farmers (be it individuals or groups) let's say 100 farmers and let them plant the seed in the way they plant normal maize. Then a vigorous selection of those plots that will mature early so that the surrounding maize within a distance of 200 meters will then be qualified as seed for the next planting season.

Table 6. Total Seed Yield of Maize in Tons Produced by Farmer Groups in 1997/1998 to 2000/2001 Cropping Seasons

Agro ecology	Name of Farmer Group	Area under seed in ha	Total Seed Yield			
			1*	2	3	Total
Central Kilosa	Kimamba	2	4.4	5.5	2.0	12.0
	Pangawe	1	1.1	1.2	0.8	3.1
Northern Kilosa	Ihanda	1	1.5	1.0	0.8	3.3
	Kwipipa	1.5	2.3	1.2	1.1	4.6
	Jitegemee	4	7.0	4.2	3.1	14.3
	Chikiende	2	3.8	2.5	2.5	8.8
	Chiwetuma	2	3.7	2.4	2.2	8.3
	Muungano	2	-	2.6	2.0	4.6
	Shuhudieni	1.5	-	3.0	1.5	4.5

* represents year of start:
For central Kilosa, started is 1997/98 and ended in 1999/00
For northern Kilosa, started is 1998/99 and ended in 2000/01

Table 7. Amount of Seed in Kg Used in Seed Plots of Various Farmer Groups and their Encircled Plots and the Associated Cost of Seed in Tshs

Farmer Group	Amount of Seed Planted in Seed Plots	Amount of Seed Planted in Encircled Plots	Total cost of seed in '000
Kimamba	20	0	100
Pangawe	10	0	50
Ihanda	10	240	1250
Kwipipa	15	260	1375
Jitegemee	40	320	1800
Chikiende	20	280	1500
Chiwetuma	20	280	1500
Muungano	20	280	1500
Shuhudieni	15	260	1375

Note: In first year, Foundation Seed Grade was used to plant in the seed plots and encircled plots. The cost of foundation seed offered to research institution by national seed farms is Tshs 5,000 ($6) per kilogramme

CONCLUSIVE REMARKS

The farmer group approach was found to be effective in the adoption of the modified method on seed multiplication of open pollinated maize varieties. Thus, it is possible to produce open pollinated varieties of maize by using farmers under their conditions

Farm level seed multiplication of open pollinated varieties can be expensive. Since farmers did not incur the initial cost involved in initiating this project, farmers were able to proceed with the process of multiplying the seed. We further suggest that there is a need of carrying out a thorough study on the cost of producing seed on-farm so as to establish the opportunities and constraints.

Enough time needs to be allocated to establish a strong informal seed multiplication, distribution and marketing system.

As illustrated in Figure 2, multiplication of cross-pollinated crops required heavy initial investments in terms of seed requirement. There is a need of making careful assessment of the existing methods used to produce seed under farmers' conditions in order to come up with a method that will meet minimum standards of seed quality at low initial cost. Presently, we think that by providing good quality seed to many farmers (about 100) can help to cut down the initial cost but also avail quality seed to farmers.

Lastly, Larger Grain Borer and Grain Weevil are major insect pests in the stores. There is a need to look into the issue of seed storage on-farm so that seed losses can be minimized.

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PARTICIPATORY DECENTRALIZED SECONDARY IMPROVED MAIZE (*Zea mays* L.) SEED MULTIPLICATION IN THE CENTRAL RIFT VALLEY OF ETHIOPIA

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ABSTRACT

Despite a far-reaching demand for improved seed of maize varieties by households in the drought-prone farming systems, the formal seed sector has been incapable of providing good quality seed in the required amounts and in a timely manner. In pursuit of narrowing the gap and to improve localized seed availability and to stabilize and increase maize productivity, a pilot scale progressive farmer participatory decentralized secondary seed multiplication scheme was initiated in 1995 in the drier farming Central Rift Valley areas of Ethiopia. During 1995 to 2000, 119 pilot seed growers from five districts produced 41.12 tons of pure maize seed (Katumani and Melkassa-1) on 29.75ha. Pilot growers maintained seeds for the subsequent season cropping cycle, shared and lent seed with neighbours, friends, relatives, exchanged for other grain food crops and sold at higher price proving a farmer-to-farmer exchange method within the localized social networks to be the most efficient in addressing localized pure seed availability and ensuring seed security. Learning from our pilot experience, we strongly recommend the scaling-up of the approach through establishing suitable linkage mechanisms between the localized seed system and the formal seed sector and provision of technical and financial backstopping of the informal sector in order to ensure localized seed security and speed up the strides towards the attainment of family food self-sufficiency and national food security goals.

Keywords: Decentralization, drought, exchange food security, family food self sufficiency, farmer-to-farmer extension, farming systems, local social networks, progressive farmer participatory, seed, seed security.

INTRODUCTION

The hallmark of crop production in the dry land areas of Ethiopia that cover over 66.6% of the country's arable land (MOA, 1998) is extreme variability in rainfall coupled with near total unpredictability (Belay, 1993). In the dry land Central Rift Valley, where rainfall in any given season could be low, moderate or high, severe drought constantly menaces the success of maize production and the livelihood of resource-poor farmers inhabiting the area (ICRA, 1999; Reddy and Kidane, 1993).

It has been widely recognized that the genetic potential of the seed used, agronomic practices employed and the energy available for photosynthesis to be the major determinants of the level of crop productivity. In the drought-prone Central Rift Valley, maize productivity is generally low, averaging 1.2t/ha due to moisture stress exacerbated by poor water holding soils that are of degraded fertility and tilth. Thus, yields are more often capped by the absence of drought- and low N-tolerant maize verities in addition to fodder scarcity and weak draft oxen, lack of cash and poor credit systems and limited use of yield improving inputs which also profoundly hamper maize productivity. It has long been generally recognized that more than any other input, improved seeds hold the key to enhanced productivity and increased income generation (CTA, 2000). However, due to lack of good quality seeds in desired amounts and periods, food production greatly lags behind the ever-escalating human population leaving the majority of dry land resource-poor farm households to constantly suffer from food insecurity (Fujisaka *et al*., 1996; ICRA, 1999).

In order to alleviate maize production bottlenecks, Melkassa Agricultural Research Center (MARC) of the Ethiopian Agricultural Research Organization (EARO) has been undertaking considerable breeding efforts in collaboration with regional and international research organizations and has developed and released stress-tolerant maize varieties for drought-prone farming zones (Deressa and Seboka, 1995; Deressa and Seboka, 1996).

However, the formal seed sector in the country has been incapable to provide cheap good quality seeds, in the required amounts in a timely fashion despite considerable interests in, and a far-reaching demand, for improved maize seed. One of the major limitations to poor farmers' access to improved seeds has been the long chain linking the formal seed sector to the ultimate user in the distribution of improved seeds. Hence, in each new growing season, greater demand is posed on MARC from farmers, GOs and NGOs for large quantities of improved maize seeds. Unfortunately, MARC could only supply a low amount of improved seeds, far less than required. Consequently, the majority of farmers must continue to rely on and gamble with low yielding medium and long maturing local maize cultivars that are not suited to the prevailing rainfall uncertainties and low resource base of the diverse, complex, risk-prone Central Rift Valley agro-ecosystems (Ransom, *et al*., 1997). Thus, the majority of farmers remain ever desirous of improvements from research (Fujisaka *et al*., 1996; ICRA, 1999).

In view of the unsatisfactory services of the formal seed sector, a pilot scale progressive farmer-participatory decentralized secondary maize seed multiplication scheme was initiated in 1995 in pursuit of narrowing the ever-widening gap and improve localized seed security to stabilize and increase maize productivity. In this paper, experiences gained from implementing a community-based seed multiplication scheme involving 119 pilot progressive farmers in five districts of the Ethiopian Central Rift Valley dry land farming systems is presented and few suggestions are also in order for future scaling up of the approach on a sustainable basis.

Variety Development, Seed Multiplication and Distribution Systems in Ethiopia

Over the past few decades, EARO, agricultural universities and colleges have been developing agricultural technologies including crop varieties in collaboration with regional and international organizations (Seboka and Deressa, 2000). However, the varietal development and release system has been reported to be tedious and time consuming and has been blamed for being rigid and too restrictive of varietal release domains in which varieties that would have performed well were limited for release to fewer areas for unsatisfactory reasons thereby denying farmers rapid access and opportunities to produce improved varieties (IAR, 1996).

It is evident that the supply of seed depends on the availability of seed sources and the capacity to develop and provide seed of the varieties needed by farmers. In this respect, the National Seed Council was established in 1978 and on its recommendations the Ethiopian Seed Corporation, and then the Ethiopian Seed Enterprise (ESE) as autonomous national organizations with a mandate to multiply and distribute (sell) basic seeds of improved and released varieties from EARO centres, universities and colleges. However, due to limited institutional capacity, the ESE used to produce and supply seeds of a few cereal crops, often in limited quantity.

The seeds produced are then sold to state farms, the Agricultural Input Supply Corporation (AISCO) of the MOA (which has a monopoly on distribution of inputs (seeds, fertilizers, and pesticides to the peasant sector), and NGO's. For instance, over the past 13 years, seed sales, mostly wheat, by ESE averaged about 5% of the potential annual requirement and only a small percentage of seeds produced by ESE has been directed to farmers, with an overwhelming proportion of seeds being sold to state farms and NGO's mainly for relief purposes (Agrawal and Mariam, 1995). In addition, unavailability of farmers' preferred seeds in required amounts and quality, poor seed marketing and distribution network, non-existence of seed quality standards, inefficient seed promotion and extension activities are other weaknesses of the seed sector in Ethiopia. Also, the ESE being the only actor in the seed sector until 1990, and due to absence of a legislation permitting the participation of the private sector in the business, only about 2% of Ethiopian farmers use improved seeds. Added to this , although Ethiopian farmers have demonstrated a high level of technical intelligence in localized bio-diversity conservation and management that have produced practical developments in Ethiopian food production, the roles farmers could have played in alleviating the seed shortage has been typically by-passed. Thus, the denial of farmers' continuous availability of improved seeds would mean that the attainment of food security would remain a dim and far from being attainable goal in the foreseeable future.

In recognition of the difficulty faced by the formal sector to satisfy the national seed demand, legislation was set forth in the 1990s inviting the private sector to participate in seed production, processing and marketing. Consequently, a National Seed Industry Agency (NSIA) was established in 1993 to provide policy and national guidance on all matters related to the seed industry and to develop a national seed industry in which both the public and private sectors could co-exist to play their roles in increasing food production. To this end, NSIA initiated a secondary seed system development project where a secondary seed multiplication scheme was launched to develop and expand the informal seed multiplication and supply system to ensure the availability of seeds for farmers (Dhabii, 1996). However, this effort has not been supported with empirical evidence and remains still under question for its effectiveness in addressing the seed problem.

Informal Seed Systems

A farmer-to-farmer-seed exchange mechanism is the predominant seed system in developing countries (CTA, 2000) in general, and in Ethiopia in particular, whereby farmers mainly obtain seeds from local sources (Seboka and Deressa, 2000). According to Teshome (1998), about three quarters of the world's farmers save seed. According to Hailye *et al*. (1998) this informal supply system contributes over 80% of the national seed demand of the country. The share of formal sector (seed companies/enterprises, research organizations and universities) in total seed supply stands low as compared to local seed sources (farmers saved seeds, market and NGO's) (Seboka and Deressa, 2000). Though very efficient, the informal seed system has been reported to be very vulnerable to risks from weather and civil disorders and, thus, cannot escape dependency on the formal sector, and thus needs improvements in order to improve efficiency of their operational modalities (Sebeka and Deressa (2000).

Community-Based Farmer Participatory Decentralized Improved Seed Multiplication

In recent years, research, extension and development programmes have adopted community-based participatory approaches that unify the efforts of various stakeholders concerned with agricultural development with the aim of overcoming formal research-extension weaknesses and improve localized seed availability on a sustainable basis. One of these approaches has been community-based secondary seed multiplication schemes whereby farmers' roles are shifted from passive recipients to that of active seed producers and eventually serve as secondary seed sources and disseminators. Such efforts have been proven to greatly reduce farmers' dependency on the research and extension and formal agencies for seed. The schemes have been reported to increase access of many farmers within the shortest time and at low cost for they are essentially grafted onto the local social networks and farmer-to-farmer extension approaches (Sebeka and Deressa, 2000).

In view of the above-described scenarios, MARC launched decentralized maize and haricot bean seed multiplication schemes in 1995 in the Central Rift Valley of Ethiopia with eighty pilot bean seed growers (the results of the findings from this has been reported elsewhere by Abera and Beyene, 2000) and with 119 maize farmers, the findings of which are the subject of this paper.

MATERIALS AND METHODS

Pilot Site and Grower Selection and Training of Growers

The pilot experiment was carried out in collaboration with 119 progressive farmers who were drawn from 5 districts through assistance of MOA DAs at each locale (Development Agents). The main consideration in selecting sites and pilot growers include interest to grow pure seeds, with access and willingness to offer isolated fields, good field commitment and family size, and access to oxen.

In addition, farmers should be willing to take seeds and fertilizers on loan and pay back immediately after harvest. Also,

Table 1. Quantities of improved maize seed produced by pilot farmers, 1995-2000, Nazreth Ethiopia, 2001.

Year	Variety	Sites	No. seed Growers / District	Total area planted (ha)	Quantity of seed multiplied per grower (tons)	Total seed produced (tons)
1995	Katumani[1]	Dera / Ataye	11	2.75	0.44	4.8
1996	Katumani	Adama / Dera / Ataye	16	4.00	0.44	7.0
1997	Katumani	Adama / Dera / Ataye	58	14.50	0.26	14.9
1998	Katumani	Adama / Boset	29	7.25	0.31	9.1
2000	Katumani	Adama / Boset	2	0.50	0.35	0.7
2000	Melkassa-1	Adama / Bose t/ Lome	3	0.75	0.94	4.7
Total	Katumani		116	29.00	0.36	36.5
	Melkassa-1		3	0.75	0.94	4.7
Grand Total			**119**	**29.75**	**0.35**	**41.1**

sites with large population and settled in marginal areas and with poor access to improved seed and experiencing frequent failures from use of local cultivars, and with access to market and infrastructure such as storage facilities, etc. were included.

An interdisciplinary team of MOA DAs, breeders, research-extension staff, agronomists, pathologists and economists trained the selected pilot seed growers in improved breeder seed production field techniques including basic agronomy as well as crop protection measures. Then the team, together with seed growers at the site, selected isolated fields and pilot growers were provided with seeds (6.25kg) and fertilizer (25kg DAP and 12.5 kg Urea) on loan for a quarter of a hectare of land. The number of farmers who participated in the pilot programme and the experimental sites are shown in Table 1.

Supervision, Exchange Visits and Field Days

After planting, field supervision visits were organized by the extension division to ensure proper management and observe the conditions of seed germination, seedling emergence and stand establishment with a follow-up visit at thinning, cultivation, first hand weeding, and top dressing and while the crop is at the rapid vegetative growth stage, pollination (tasselling and silking) and at maturity stages. Finally, the crop was harvested and yields were determined together with farmers.

Exchange field visits were organized for participating growers in 1995-1997, and 1999-2000 during which growers shared their experiences among each other. Field days were organized for non-grower community members in each site and their perceptions were gathered during which experiences gained from implementing the seed multiplication scheme were disclosed. Invited stakeholders included National and regional MOA extension staff, Eastern Shoa Zone and district MOA extension staff, SMSs and village-based DAs, zonal, district administrators and PA chairman's and local leaders, zonal planners, and district administrators and politicians, National Seed Industry Agency and Seed Enterprise staff and NGO's such as UNDP, SG-2000, World Vision International, CARE, CCF, and GTZ staff all concerned with agricultural development in the Central Rift Valley and other parts of the country. In addition, extension researchers from various research centers were also invited and participated in the field day.

In the year 2000, the participating growers at each location were interviewed in order to assess their perceptions of the programme and the pattern of seed diffusion as well as the survival of pure seeds in the community. In addition, towards the end of the year 2001, assessment was also made of nearby local markets in order to observe the availability of the seed and the price situation.

RESULTS

Quantitative Assessment of Improved Seed and Local Diffusion Mechanisms

During 1995 to 2000, about 41.12 tons of pure seeds of maize (Katumani and Melkassa-1) were produced by 119 pilot seed growers on a total of 29.75ha of land in the five districts (Table 1) out of which, 116 pilot seed growers produced about 37 tons of Katumani seeds during 1995-1998, and 2000 cropping seasons on 29ha area and the rest of the Melkassa-1 seeds were produced by 3 farmers in three districts on 0.75ha area during the year 2000. The average Katumani maize seed multiplied per grower ranged from 0.26t-0.44t and 0.94t for Melkassa-1.

Out of the total seeds multiplied, the largest amount (~16t) was sold on the local market and the remaining seeds were partly reserved as seed for the next season and/or as grain for local consumption, and exchanged between farmers. About 33% of the multiplied seeds entered the local seed system (Table 2).

The majority of growers mentioned that they were obliged to sell the bulk of the seeds immediately after harvest as the varieties were susceptible to storage pests and also for cash purposes. This implies the need for assisting farmers with infrastructure such as storage facilities and pest control chemicals in order to ensure survival of improved seed that enters the local seed system. Most farmers could sell the seeds at relatively high prices. One participant farmer could sell 3.0 tons of basic seed from what he had produced to an NGO at 200 Ethiopian Birr/100kg seed (1USD~8.50 Ethiopian Birr), which

Table 2. Quantity of maize seed marketed and exchanged by pilot growers

Utilization method	Quantity (t)	% of the total
Marketed	16.04	39
Reserved	11.51	28
Exchanged	13.57	33
Total	41.12	100

Table 3. Seed transfer from pilot growers to non-growers (N=119)

Type of relation	Number of growers who transferred seed to others	%
Neighbour	69	58
Friend	31	26
Relative	19	16

is 100 % above the current market price of maize at relatively high prices. One participant farmer could sell 3.0 tons of basic seed from what he had produced to an NGO at 200 Ethiopian Birr/100kg seed (1USD~8.50 Ethiopian Birr), which is 100 % above the current market price of maize.

The farmer could then buy a diesel engine and irrigation accessories and launch an off-season pure seed multiplication. The seeds produced were bought by an NGO at the indicated price who in turn distributed the seeds in the remotest areas where farmers have little access to improved maize seed. Thus, the scheme was confirmed to increase farmers' access to improved seeds in marginalized areas which had not been possible for the formal sector hitherto.

Table 3 shows that the majority of seed growers interviewed transferred small quantities of their seed to their neighbours, 26% to their friends and 16% to their relatives. This was very similar in pattern to those of localized farmer-to-farmer diffusion of haricot bean seed reported elsewhere by Seboka and Deressa (2000). The rate of diffusion is indicative of the efficiency of local social networks and farmer-to-farmer approaches and the need for strengthening informal seed systems through devising mechanisms that link them to the formal sector in order to address the chronic dearth of seed. Informal discussion with non-growers who received the improved seeds from fellow friends mentioned that they could exchange the seeds easily with growers and trust the quality of the seeds more than those obtained from MOA or the market. Assessment made of the local seed exchange methods revealed lending, selling, bartering and gifts to be the most common methods for seed transfer. The cross tabulation of farmers' seed exchange methods by social networks presented in Table 4 indicates that 50% of the seed growers (59 of 119 farmers) transferred their seed by lending to others, 27% by selling, 12% by means of exchange with seeds of other grains like haricot bean and10% transferred as gifts mainly to their relatives. The results show lending and selling to be the predominant method of transfer between seed growers and their neighbours indicating farmer-to-farmer seed exchange to be the more efficient in neighbourhoods than on either friend or family relation-based type of social network.

Table 4. Cross tabulation of farmers' seed exchange methods by social networks (N=119)

Type of relation	Number of growers who transferred seed to others using different seed exchange methods				%
	Lend	Sell	Exchange	Gift	58
Neighbours	31	23	9	6	26
Friends	17	8	3	3	16
Relative	11	3	2	3	
%	50	27	12	10	100

Source: Survey data

Lending proved to be the most efficient method for seed transfer from seed growers to their neighbours whereby farmers could easily obtain seeds from neighbours trustfully without cash in hand compared to the often problematic loan system adopted by the MOA extension system. In addition, this also saves farmers time which is often wasted in looking for good quality seed. Such a seed supply system based on local social networks and exchange methods ensures social equity of technologies in that all farmers with varying socio-economic status benefit, which has not been possible to date for the formal sector. Since farmers have familiarity with the producers and share information and have the opportunity for direct observation of the production fields, they could judge the adaptability and quality of seeds and have more confidence than those obtained from outside the community. A detailed strength and weakness of such system has been reported elsewhere for haricot bean by Seboka and Deressa (2000).

Farmers Perceptions and Challenges and Prospects of Decentralized Seed Multiplication Scheme

Concerning the extent of input and intensity of operation involved in pure seed production and maintenance as compared to their local practices of grain production, all participating farmers mentioned the exercise as feasible and profitable. As a result, they promised to continue the production of the seeds if they continue to obtain technical backstopping. They also mentioned their intention to expand the area if there will be any GO or NGO to assist them establish a central store and create a suitable seed marketing system. Due to the farmer-to-farmer-exchange system, the gamble with longer cycle local cultivars under intermittent rainfall conditions was substantially minimized. In addition, farmers reported that the scheme would increase their management flexibility in that they could sow high yielding local varieties with early rains, and could perform other farm operations in time for sowing other enterprises. Above all, when improved short maturity cultivars are in hand, farmers reported that they would become daring enough to take risks of rainfall to sow longer maturing varieties with early rains since they could use shorter maturity cultivars when stands of the earliest sown cultivar turn out to be poor from intermittent rains. Consequently, the experience was vital as farmers' worries for seeds were minimized through breaking the queues usually experienced at MARC and MOA gates as each crop season approaches. Thus, they could save time and resources from use of short cycle cultivars that demand farmers to re-plow fields to re-sow when failure of long maturing cultivars becomes inevitable

Furthermore, the potentials of various stakeholders are better utilized than was possible hitherto in isolation in addressing shortage of improved seeds and much time and physical effort and manpower resources turn productive.

Due to the extensive nature of the approach, and once participating farmers are trained, they became well versed with field techniques, and the programme has been implemented with lower cost and with many farmers in several zones This would ultimately mean reduced impacts of shortages of improved seed while also enhancing adoption through farmer-to-farmer exchange mechanisms.

However, market price and storage pests remain the challenges which indicate the need to establish local seed storage facilities and availing storage chemicals so that the bulk of seed produced could be utilized and farmers could benefit from better price usually towards the budding of a new cropping season when prices are good.

CONCLUSIONS AND RECOMMENDATIONS

The major question underlying this paper whether the present formal seed operational mechanism will bring the desired seed security given the problematic bureaucratic channels on the one hand the urgency of attaining family food self-sufficiency and national food security goals. As discussed earlier, the farmers in the drought-prone Central Rift Valley area strongly favour the improved varieties of short cycle maize since the chance of harvest from use of medium and longer duration local cultivars is increasingly becoming a challenging task with the erratic and uncertain rainfall. Due to the frequent failure of these cultivars in low rainfall seasons, the consequences have been horrible. Also, the frequent failure makes overall average potential yields low. Short cycle maize varieties developed in the past decades could have greatly contributed to improving maize productivity in the system had it not been for the poor access of farmers to these varieties due to non-availability of farmer's preferred seeds in required amounts and quality, poor seed marketing and distribution network, non-existence of seed quality standards, inefficient seed promotion and extension activities. Undoubtedly, this weakness of the formal seed sector in Ethiopia has left farmers desirous of improved seeds and consequently searching for the possibility of stabilizing maize productivity in the area.

Thus, a participatory decentralized secondary improved maize seed multiplication scheme can undoubtedly contribute a lot to the goals of the formal seed sector in reaching farmers with the required amount of improved seeds and make them self-reliant. It offers great opportunities for managing localized seed supply shortfalls and maximize returns from and thus stabilize the maize production. In addition, it is an encouraging approach worth adopting by the formal seed sector, private investors and NGO's to in order to bridge the present gap between supply and demand.

Such a scheme thus fosters and enables dry land farmers and formal seed sectors and NGO's in concert to improve on the weaknesses of the past approach to seed multiplication and dissemination and slashes the chances of hazards posed by uncertain rainfall in Ethiopia's recurrent drought zones from use of longer duration unimproved local cultivars of maize.

Hence, we recommend the establishment of linkage mechanisms whereby the formal seed sector could join hands with the informal seed system and encourage and provide the necessary technical and financial assistance to improve farmers' access to seeds thereby stabilizing yields and ultimately ensuring localized seed security and family food self sufficiency and national food security and ultimately to the well-being of farm families.

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SUSTAINABILITY OF FERTILIZER USE ON MAIZE PRODUCTION IN WESTERN KENYA THROUGH PROVISION OF CREDIT

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ABSTRACT

A fertilizer credit study was conducted among maize farmers in Yala, Western Kenya in 1999-2001. Participating farmers were members of three active women-groups. The objective was to kick-start fertilizer use and its sustainability by giving credit to resource-poor farmers who currently contribute 70-80% of maize in Kenya. Each farmer was given 50 kg of Di-Ammonium Phosphate (DAP) and 50 kg of Calcium Ammonium Nitrate (CAN) fertilizer. Every farmer availed 0.4 ha piece of land and maize seed for the study. Apart from land preparation, other agronomic practices were collectively done by the group. There was strict supervision to ensure that fertilizer provided was not diverted to other uses. The group acted as security for the loan that was repaid with part of the produce at the end of the season. Maize yield increased from the traditional 0.5 t ha^{-1} to 3. 0 tha^{-1}, with a loan recovery rate of 95%. Households had adequate maize to meet their annual needs. Participating farmers were able to sustain fertilizer use in the subsequent seasons. There is need to subsidize the cost of fertilizer to make it affordable to the majority of farmers in order to increase maize productivity. Financial lending institutions can also play a role by giving credit (for inputs) without imposition of collateral which is beyond the reach of small-scale farmers.

Keywords: Credit, fertilizers, maize, sustainability, women-groups

INTRODUCTION

Previous surveys and Participatory Rural Appraisal (PRA) conducted in the low and mid-altitude zones of western Kenya have revealed that maize (*Zea mays* L.) is the most important crop enterprise in the area (Howell et al., 1999). Currently, maize production in the area stands at a low 0.2–0.4 t ha^{-1} while research indicates up to 3.8 – 4.0 t ha^{-1} can be achieved. These studies further revealed that low maize production in the area is caused by a combination of two factors: low soil fertility and widespread use of non-improved varieties. Field site diagnosis indicated that factors contributing to low soil fertility in the area include limited use of inorganic and organic fertilizers, lack of crop rotation due to reduced land sizes and removal of crop residues for livestock feed. The majority of farmers are resource-poor and hence lack the ability to purchase adequate amounts of the required inorganic fertilizers. Credit facilities available in Kenya are structured to mostly benefit large-scale rather than small-scale farmers. Formal financial lending institutions charge exorbitant interest rates besides demanding huge collateral as a condition for lending, hence eliminating potential small-scale borrowers.

Less than 40% of maize farmers in the low and mid-altitude zones of western Kenya use either inorganic or organic fertilizers (CMRT, 1994; MDB, 1993). Where fertilizer is applied, the rate is far below the recommended rates and often too late for optimum timing of applications (Swinkels *et al*., 1997). In Kenya, where the geographic regions with favourable climatic conditions for cereal production (especially maize) are limited, rapid population growth has resulted in more intense land use patterns. Western Kenya has one of the densest rural populations in the world: 500-1,000 people km^{-2} (Hoekstra and Corbett, 1995). Exacerbating this problem in recent years has been the relationship between the cost of fertilizer and maize market price, which have led to a sharp decline in the rates of fertilizer applied per unit area.

While the market value of maize has been held at artificially low levels by the Government purchasing agencies, the price of imported fertilizer has doubled between the year 1982 - 1990 and again by >50% in 1993 (CBS, 1996). In the densely populated parts of western Kenya, this economic disincentive to the use of inorganic fertilizers has resulted in both permanent loss of soil productivity, as well as in a reduction of maize productivity, resulting in a vicious cycle of poverty among the small-scale farmers.

Average rate of fertilizer use in Africa in general, and Kenya in particular, is significantly below consumption rates in other developing countries such as China and India, as well as below the world average. Five African countries (Egypt, South Africa, Nigeria, Morocco and Zimbabwe) accounted for over 70% of the fertilizer consumed in Africa in 1993/94 (FAO/IFDC/IFA, 1994). While these countries used more than 50 kg ha^{-1} of fertilizer on average, 28 other African countries used less than 10 kg ha^{-1}. Bumb (1991) reported that statistical projections suggest that Africa must increase its food production by 4% per year for the next 25 years to match the growth in food demand. Even with optimal management practices for recycling animal manure and compost, organic sources of soil nutrients will not be sufficient to raise production levels to meet the need. With rising population, pressures on land and average land holdings diminishing in size; the practice of fallows and rotation is disappearing, and crop residues are increasingly being used for fuel and fodder rather than being reincorporated into the soil to recycle nutrients. Consequently, such high food production targets can only be achieved by raising the rates of application of inorganic fertilizers 18% per year to an average rate of 50 kg ha^{-1} (Power *et al*., 1997).

In comparison to other developing countries of the world, annual rates of increase in food production in Kenya are falling behind annual rates of population growth (UNDP/WB, 1992). Historically, crop production has been increased by either expanding the acreage cultivated or intensifying production on acreage already under cultivation. With limited opportunity to expand cultivation to highly productive environments, Kenya must rely on intensifying production through the judicious use of agro-chemical inputs if the rates of food production are to keep pace with the growth of food demand. Use of inorganic fertilizers will be vital to this effort.

Studies conducted in western Kenya have underscored the important role played by inorganic fertilizers in boosting maize productivity. Ojiem *et al*., (1996) reported that use of inorganic fertilizers had a 3 ton grain yield ha^{-1} advantage over where fertilizer was not used. In a related study, Achieng' *et al.,* (unpublished) reported that hybrids showed a 50% yield reduction when fertilizer was not used, compared to a 35% reduction on the non-improved varieties.

An aggressive use of inorganic fertilizers on maize production can be enhanced by availing credit to resource-poor farmers to enable them to acquire the necessary farm inputs. Unfortunately, the loaning conditions currently imposed by the formal financial lending institutions in Kenya are too harsh for the small-scale farmers. The conditions include surrendering of title deeds of parcels of land not less than 2 ha as collateral, with an interest rate for repayment being >30% (Salasya *et al.,* 1998). Such conditions, besides being unaffordable to the majority of the small-scale farmers, scare away potential borrowers, with a resultant low productivity every season.

Elsewhere, Sasakawa Global 2000 (SG 2000) pilot projects demonstrated that provision of credit for agricultural inputs is one of the most effective strategies for improving productivity among the small-scale resource-poor farmers. When credit was provided by the project (SG 2000) in Togo and Benin, maize grain yield increased two and three fold, respectively, with a loan recovery rate of over 85% in both countries (Galiba, 1993). In Tanzania, farmers who used the SG 2000 improved technology increased their yields by up to four times compared to those obtained by farmers using traditional production practices (Foster *et al*., 1993).

The objective of this study was to formulate a viable sustainable programme for use of inorganic fertilizers and to test farmers' loan repayment ability when provided with credit in order to kick-start fertilizer use on maize production among small-scale resource-poor farmers of western Kenya.

MATERIALS AND METHODS

The study was conducted for three years beginning 1999. It was located in Yala Division, western Kenya. The site, with an elevation of 1,200 m, receives about 1,200-1,600 mm of rainfall annually with a bimodal pattern of distribution. The average land size in the area is about 0.5-1.0 ha per household with an average production of 0.5 t ha^{-1} and a consumption rate of >1,000 kg of maize per year. About a third of family land is normally under maize. Participating farmers were members of active women-groups whose objectives included agricultural development in the area. Endeley (1993) observed that women farmers constitute more than half the agricultural labour force in many African countries. As dominant actors in the traditional food sector, they are vital to alleviating food insecurity in Africa. For projects that give credit/loan such as this, working with women-groups makes loan recovery much easier since the group acts as collateral for loans. Besides, the groups have rules governing them and hence can deal with defaulting members. Furthermore, members interact more frequently to assess the technology.

Three women-groups and a primary school participated. The groups were selected with the help of the area agricultural extension officers. Tatro Women-Group, with a membership of 35 (30 women and 5 men) participated in 1999, while Gongo (31 women and 12 men), Uzima (17 women and 4 men) and Gongo Primary School participated in 2000. For purposes of this study, the school was affiliated to the Gongo Women-Group.

Each participating farmer availed to the project a 0.4 ha (1 acre) piece of land and 10 kg of maize seed for establishment of the activity. The plot size (0.4 ha) was big enough, not only to assess the technology, but also to bring comfortable returns to the farmer. Area extension officers helped farmers to accurately measure the plots. Where no single plots measuring 0.4 ha were available, several pieces were added together to give the required hectarage. Each farmer was given 50 kg of Di-Ammonium Phosphate (DAP) and 50 kg of Calcium Ammonium Nitrate (CAN) fertilizer as credit. The fertilizer was adequate to plant 0.4 ha plot at an application rate of 54 and 57 kg ha^{-1} of N and P_2O_5, respectively. Fertilizer was purchased and distributed by the project. Farmers were not allowed to handle money for fertilizer for fear that they could divert it to other uses. The group ensured that the fertilizer was available for both planting and top dressing.

Planting was done soon after the onset of the long rains at spacing of 75 cm x 60 cm; three seeds were planted per hole but later thinned to 2 plants per hill. Commonly adopted non-certified "local" maize varieties were planted because farmers lacked cash to purchase certified seeds. Traditionally, in this area, maize is intercropped with field beans (*Phaseolus vulgaris* L.). Farmers who preferred to intercrop were allowed to do so. The crop was weeded two times: the first at three weeks after emergence and the second about four weeks later.

Groups met frequently to monitor activities on each individual member's farm. A field day was organised on one farm selected by the group members. All agronomic activities, except land preparation were done collectively by the group under strict supervision of the research team. The project was evaluated jointly by the farmers, research team and scientists from CIMMYT- Nairobi at the end of each season.

The crop was harvested at physiological maturity (determined by the presence of the black layer at the base of the kernel). The whole plot was harvested and, average moisture content, shelling percentage and field weight immediately taken in order to calculate the preliminary grain yield. The actual grain yield was obtained later after the cobs had been shelled and dried. Estimation of preliminary yield was necessary in order to avoid hoarding of the produce or cheating by farmers about the number of bags of grain harvested so as to be exempted from loan repayment. Loan repayment was done in kind soon after harvest.

Each group participated for only one season. Participating farmers graduated at the end of the season but their progress was monitored for the next two seasons. The project identified new sets of farmers who subsequently benefited from the repaid loan. During the monitoring period, data was collected on the number of farmers continuing with fertilizer use, maize grain yield, number of farmers adopting improved maize varieties, and improvement in family livelihoods.

Sustainability Plan

It was hypothesised that if farmers were given credit and skills for good agronomic management, up to 18 bags of maize grain could be harvested on an 0.4 ha plot in Yala (1 bag = 90 kg). From the harvest, the group, on behalf of each farmer was expected to repay the credit by giving to the project 3 bags of maize. Out of the remaining 15 bags, the group was to take 3 bags, sell it immediately and purchase fertilizer (50 kg DAP and 50 kg CAN) on behalf of the farmers for planting the following season. The remaining 12 bags were to be left with the farmer for domestic use. The market value of the loaned fertilizer was Kenya Shillings 2,500 (US$34.6), while the value of 3 bags for loan repayment was Kenya Shillings 3,000 (US$40.0), hence farmers were charged an interest rate of 15% on the loan. Participating farmers graduated at the end of the season; from then on, it was the responsibility of the group to ensure continuity of fertilizer use among the members. The project, on the other hand, turned the savings from the recovered loan into a revolving fund to benefit the next set of women-groups.

RESULTS AND DISCUSSION

Tatro Women-Group. There was a marked increase in maize grain yield from the traditional 0.5 t ha^{-1} - 2.9 t ha^{-1} among the participating farmers of Tatro. Grain yield target 3.6 t ha^{-1} was not achieved due to severe *Striga* weed infestation on some farms. The group registered a loan recovery rate of 90%. Farmers who were severely affected by *Striga* were exempted from full loan repayment. The group graduated at the end of 1999, but their progress was continuously monitored and evaluated by the project for the next two years. Monitoring in the year 2000 indicated that all members applied adequate amounts of inorganic fertilizers on maize as was recommended by the project. Good maize yield obtained by the farmers due to fertilizer use encouraged them to expand plots under the crop. Besides purchasing fertilizer, about 60% of them bought and planted improved maize seeds instead of the traditional local varieties. In 2001, it was reported that all the farmers continued to use adequate amounts of inorganic fertilizers, with about 60% adopting improved maize varieties. These follow-up activities indicated that farmers' resource base appeared to have increased after being kick-started to enable them to purchase both fertilizer and hybrid seeds. With the savings made in year 2000, the group started a scheme to give credit to neighbouring women-groups.

Gongo and Uzima Women-Groups: Gongo and Uzima Women-Groups participated in the project in the year 2000. Part of the loan recovered from Tatro group (the previous year) was used to benefit these two groups. Maize yield of 3.2 t ha^{-1} and 3.4 t ha^{-1} was obtained by Gongo and Uzima, respectively. A loan recovery rate of 94% and 100% was recorded. Some farms belonging to Gongo group were affected by *Striga* weed and hailstorm. Consequently, the affected farmers were exempted from full loan repayment. The groups graduated at the end of year 2000 season. Monitoring in year 2001 indicated that both groups used adequate amounts of inorganic fertilizers. Field observations indicated well managed maize crops implying that agronomic skills learnt during the project were well mastered. About 50% of the farmers planted improved maize varieties up from the previous 7-9%.

In general, this study demonstrated that it is possible to raise the level of maize production within the mid and low altitude zones of Western Kenya from the traditional average of 0.5 t ha^{-1} to about 3.0 t ha^{-1}. Provision of credit to kick-start aggressive fertilizer use among the resource poor farmers is necessary to enhance productivity in the region. The farmers showed willingness to repay the loan even when there were no collateral attached. This is clearly demonstrated by a loan recovery rate of about 95%. These results are comparable to what was been reported elsewhere in Africa. Sasakawa Global 2000 (SG2000) project in Tanzania provided agricultural inputs and reported an increase in maize yield from 1.5 t ha^{-1} to more than 4 t ha^{-1}, with some farmers reaching 8-9 t ha^{-1} (Swegle and Dowswell, 1993). In Benin and Togo, SG2000 reported yield gain of between 90%-328% and 111%-112%, respectively. A loan recovery rate of 85% was recorded in Benin (Galiba, 1993). Grameen Bank in Bangladesh reported a loan recovery rate of 90% (Gladwin *et al*., 1997).

The mode of loan repayment in this project contributed to the high recovery rate. Repayment in kind was a preferred option compared to cash option. But still there were farmers, who despite the good harvest, preferred not to part with maize, and hence paid using cash. While formal financial lending institutions in Kenya currently charge an interest rate of >30%, the project charged only 15%. High interest rates charged by such institutions merely serve to discourage resource-poor farmers from applying for loans. Grameen Bank charged an interest rate of 20% and subsequently became very popular with farmers (Khandler *et al*., 1995).

Use of inorganic fertilizers on maize production enabled participating households to have enough maize to last them throughout the year. Without the use of any soil improvement measures, farmers' harvest do not normally last for more than 3-4 months. The impressive maize yield due to fertilizer subsequently encouraged farmers to embark on aggressive fertilizer use. With good returns, farmers get addicted to use of fertilizer.

Sustainability of fertilizer use among the resource-poor farmers is closely linked to provision of credit in order to kick-start them (farmers). Formal financial lending need to redesign their loan terms to favour such farmers. Imposition of collateral which is clearly beyond their reach, and very high interest rates charged discourage farmers from borrowing. Policy-makers need to identify ways of making fertilizer affordable to the majority of smallholder farmers who produce 70-80% of maize in Kenya. With only US$35 (as credit) to small-holder maize farmers, maize production can be enhanced, poverty reduced, and indeed, Kenya can become a net exporter of maize in the region.

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ON-FARM EVALUATION OF PERFORMANCE OF SELECTED IMPROVED MAIZE VARIETIES IN THE FOREST ZONE OF CENTRAL CAMEROON.

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ABSTRACT

Part or full adoption of a technology package by farmers may depend upon the way they perceive not only the production performance of the crop, but also its profitability and consumption qualities. On-farm experiments were carried out for three consecutive seasons in 13 villages in the forest zone of central Cameroon to assess the above parameters. The treatments evaluated were three improved maize varieties (CMS 8501 and CMS 8704 developed by IRAD, and AK 9522-DMR developed by IITA) plus a local check used in the village. A one-farmer one-replicate approach was used with the varieties being arranged in a randomized complete block design. Results showed that improved varieties were significantly less infested than the control. Mean grain yield was significantly higher for improved varieties than for the local check. However, no significant difference could be found among the high yielding varieties although the mean grain yield differed in the order CMS 8704 > AK 9522-DMR > CMS 8501. The same trend was observed for the marginal cost benefit ratio (MCBR) as derived from the partial budgetary analysis. These results suggest that CMS 8704 performed best as compared with the other varieties tested. However, based on farmers' perception of production and taste characteristics, AK 9522-DMR was the best, followed by CMS 8704, CMS 8501 and local variety. This suggests that if these varieties were to be adopted by the farmers of Cameroonian forest zone, the adoption would follow the same sequence.

Keywords: Central Cameroon, consumption qualities, forest zone, maize performance, on-farm trial.

INTRODUCTION

Maize is actually one of the main grasses all over the world (Rouanet, 1984). In Africa, for instance, maize is the main cereal consumed by smallholders. In Cameroon, about 500,000 ha are grown to maize by at least 90% of the smallholdings (PNUD/FAO, 1989; FAO, 1992). Yet, maize production is still low (about 1,800 kg per hectare according to FAO (1992)) as it is limited by many factors such as low soil fertility, pests and diseases, etc. The results of a participatory diagnosis done in 1998 in farmers' fields indicated that maize stem borers are the major limiting factor to maize production in the forest zone of Cameroon (Anonymous, 1998). The main species identified are *Busseola fusca* Fuller, *Sesamia calamistis* Hamps, *Eldana saccharina* Walker and *Mussidia nigrivenella* Ragonot (Aroga, 1987a, 1987b). *B. fusca* is the species causing most damage in the forest zone of central Cameroon (Aroga and Coderre, 2000; Cardwell *et al*., 1997). To mitigate this problem, high yielding varieties (early, intermediate and late maturing) with a certain level of tolerance to stem borer attacks have been developed by IRAD, IITA, CIMMYT and other research institutions (IRA, 1993; Enyong *et al*., 1997). Although their production performance has extensively been tested, little is known about the ability of these tolerant cultivars to resist *B. fusca* infestation, hence the very urgent need to evaluate these varieties and the associated crop management practices under farmers' conditions, with the participation of local farmers. This may lead to a higher rate of adoption and acceptability of the new technologies designed to significantly increase maize yield. The objectives of this study were therefore (i) to compare improved and local varieties under farmers' crop management conditions and get farmers' appraisal, (ii) to show the superiority – if any – of tolerant varieties in resisting stem borer attacks on maize (iii) to increase maize production as a result of low level of damage of stem borers, and (iv) to hasten the adoption of the newly developed high yielding varieties through good crop performance and consumption qualities, and increase their rate of dissemination.

MATERIALS AND METHODS

The field experiment

The experiment was planted in 5 villages in 3 ecological zones of Cameroon: Nkolnda in the subhumid forest zone, Nkue and Mbomnjok in the humid forest zone, and Gah and Do-Mbara in the transitional zone. The experiment was managed by 9 farmers without interference for three consecutive cropping seasons: the second cropping season of 1999, and the first and second cropping seasons of 2000. After clearing the bush fallow (mostly *Chromolaena* fallow) and burning the biomass, the 9 fields, 32 m x 12 m each, were laid out into 4 experimental plots of 96 m^2 (12 m x 8 m) each, then tilled with hand hoes and planted to maize according to the treatments at a population density of 50,000 plants per ha with two plants per hill (spacing 80 cm between rows and 50 cm between hills). Thirty days after planting, all the 4 experimental plots per farmer were fertilized with the compound NPK20-10-10 in a band at the rate of 500 kg ha^{-1} that was immediately incorporated into the soil. To avoid interference with the maize varieties' tolerance to stem borers, no chemicals were applied to control pests and diseases. However, weeds were controlled by manual weeding as necessary.

The experimental design was a randomized complete block with four treatments, using a one-farmer, one replicate approach (Mutsaers and Walker, 1990; Mutsaers *et al*., 1997). The treatments included three improved varieties

Table 1. Type and number of participants in the field days organized in the forest zone of Cameroon.

Location	Date	Type and number of participants†					Total	Number of hours
		♂F	♀F	Researcher	Research support	Extension agents		
Mouko	01/12/99	0	11	5	1	0	17	5
Mouko	06/01/00	4	21	4	2	3	34	6
Nkolnda	12/01/00	17	3	2	3	0	25	6
Nkolngok	12/07/00	15	13	4	2	0	34	7
Kiki	04/07/00	13	34	1	2	1	51	5
Nindjé	05/07/00	39	10	0	2	0	42	7
Total		88	92	16	12	4	203	36

† ♂**F** = male farmers; ♀**F** = female farmers; Among researchers were Entomologists (3), Breeders (2), Plant pathologist (1), Physiologist (1), Soil scientists (2), Agro-Economist (1), Agro-Sociologists (2) and Veterinary (1).

(CMS 8501 and CMS 8704 developed by IRA, and AK 9522-DMR developed by IITA) and a local variety (used as control) abbreviated as LOCAL. However, the local check was tested only in 2000.

Observations were made on crop yield, profitability of new varieties through a simple cost-benefit analysis, number of plants with borer leaf feeding using a rating scale of 1 to 9 (with 1 = tolerant, and 9 = susceptible), number of dead hearts, percentage of infested plants, and stem tunneling (i. e. average percentage of 10 tunneled stems per plot). Whereas the number of dead hearts and the number of plants with borer leaf feeding and the average percentage of infested plants were determined 6 weeks after planting (WAP), the average stem tunneling was recorded and crop yield and profitability calculated at harvest.

The farmers' field days

Following maize harvest, an assessment survey was conducted to evaluate the production performance and consumption qualities of the tested varieties. To this end, farmers' field days were organized in five villages (Table 1) that involved neighbouring farmers in the assessment of the varieties. During each field day, the objectives of the activities implemented were communicated to the participants. The opportunity was also given to the farmers who collaborated in the study to bear witness to the work they did in their fields and to display the harvested products with the aim to attract new volunteers to join the group. In addition to this, palatability tests were carried out at harvest with green and dried cobs from each maize variety. Seven local dishes were cooked by farmers with green maize from each of the 4 varieties tested, and evaluated for their colour and taste.

Participants in the evaluation were allowed to taste all the dishes from all the varieties and make their evaluation. One dish (the so-called "fufu" corn) was also made from dry maize grains and evaluated as described for green maize. Both crop performance and consumption qualities as perceived by farmers were assessed by ranking where 1 = best and 4 = least good.

Table 2. Stem borers infestation on maize varieties tested on farmers' fields in the forest zone of Cameroon.

Treatments (Varieties)	% Infestation†		
	2nd season 1999	1st season 2000	2nd season 2000
CMS 8501	26.7 ab	10.8 a	16.0 a
AK 9522-DMR	28.0 a	10.8 a	14.0 a
CMS 8704	19.0 b	9.3 a	17.0 a
LOCAL	-	7.6 a	35.5 b

† Average of 9 replications. Any two means followed by the same letter are not significantly different within columns at 5% level of probability.

RESULTS

Stem borer infestation

In 1999, the level of infestation of maize by stem borers was significantly lower for CMS 8704 as compared with AK 9522-DMR, but no significant difference was found between the first and CMS 8501 (Table 2). The level of infestation in the 2000 first season was low for all the varieties tested and was not significantly different among varieties. However, this level was higher in the 2000 second cropping season and no significant difference could be found among improved varieties although AK 9522 DMR was found slightly less attacked than CMS 8501 and CMS 8704. Besides, the local check was significantly more attacked than the other varieties (Table 2).

Comparing the ecological zones to each other showed that the level of infestation in the second cropping season was significantly higher in the humid forest zone than in the other zones (Table 3). In the first zone, the level of infestation was lower in the first growing season than in the second while the difference among seasons was fairly low in the other ecological zones. These results suggest that the humid forest could be the best area for testing tolerance to stem borers, and the second cropping season could be the best period for this test.

Table 3. Stem borers' infestation on maize in different ecological zones of Cameroon.

Ecological zones	% Infestation†		
	2nd cropping Season 1999	1st cropping Season 2000	2nd cropping Season 2000
Humid forest	27.2 a	3.6 a	47.5 a
Sub-humid forest	6.3 b	14.8 a	9.5 b
Forest savanna transition	13.8 c	10.6 a	-

† Average of 9 replications. Any two means followed by the same letter are not significantly different within columns at 5% level of probability.

Table 4. Dead Hearts, leaf feeding rating and percent tunneling on improved maize varieties tested in farmers' fields of the forest zone of Cameroon.

Treatments (Varieties)	% Dead Hearts†		Leaf feeding rating†		% Tunneling†	
	1999	2000	1999	2000	1999	2000
CMS 8501	3.6a	2.5 a	3.7a	4.6a	6.5a	3.4a
AK 9522 DMR	3.6a	7.5 a	3.6a	4.7a	4.7a	2.6a
CMS 8704	3.5a	7.5 a	3.5a	4.0a	4.8a	3.0a
LOCAL	4.7a	10 a	3.3a	4.3a	3.3a	2.3a

† Average of 9 replications. Any two means followed by the same letter are not significantly different within columns at the 5% level of probability.

Table 5. Grain yield of maize varieties tested on farmers' fields in the forest zone of Cameroon.

Treatments	Grain yield (tons.ha^{-1})†			
	2nd season 1999	1st season 2000	2nd season 2000	Mean
CMS 8501	3.3 a	4.9 a	2.7 a	3.6 a
AK 9522-DMR	3.5 a	5.2 a	2.8 a	3.8 a
CMS 8704	3.8 a	5.1 a	2.9 a	3.9 a
LOCAL	-	2.5 b	1.6 b	2.0 b

† Average of 9 replications. Any two means followed by the same letter are not significantly different within columns at the 5% level of probability.

Table 6. Farmers' preference for green maize of the varieties tested in the forest zone of Cameroon

Dishes		Treatments (Varieties)	Colour		Taste	
			% Respondents	Ranking	% Respondents	Ranking
1.	Pkidim*	8501	24	2	12	4
	Komba*	8704	**40**	**1**	20	2
	Ekomba*	9522	20	3	52	**1**
	N=25	LOCAL	16	4	16	3
2.	Koki	8501	0	-	1	2
	Koga	8704	**100**	**1**	33	1
		9522	0	-	33	1
	N = 6	LOCAL	0	-	33	1
3.	Kinuk	8501	15	4	5	4
	Nsock	8704	30	2	16	3
	Bouillie	9522	**35**	**1**	47	**1**
	N = 19	LOCAL	20	3	32	2
4.	Boiled maize	8501	0	4	13	3
		8704	**44**	**1**	20	2
		9522	32	2	54	**1**
	N = 15	LOCAL	24	3	13	3
5.	Roasted maize	8501	6	4	0	4
		8704	**47**	**1**	27	2
		9522	27	2	60	**1**
	N = 15	LOCAL	20	3	13	3
6.	Souga	8501	6	4	11	3
		8704	**66**	**1**	11	3
		9522	17	2	28	2
	N = 18	LOCAL	11	3	50	**1**
7.	Kpwem	8501	0	4	8	4
		8704	**75**	**1**	25	2
		9522	8	3	50	**1**
	N = 12	LOCAL	17	2	17	3

N.B.: N = total number of respondents; Dish name with a (*) in the first column is a local name.

Dead hearts, leaf feeding rating and percent tunneling

The percent of dead hearts, the leaf feeding rating and the percentage of tunneling on tested maize varieties in farmers' fields of the forest zone of Cameroon are presented in Table 4. Given the low level of infestation in the first season, only the second cropping seasons results were considered and presented. The results showed no significant difference among varieties.

Maize grain yield

In 1999 second cropping season, there was no significant difference between the 3 varieties tested in that season. However, the yield ranked as follows: CMS 8704 > AK 9522-DMR > CMS 8501 (Table 5). In the 2000 first season, the improved varieties performed significantly better than the local check, but no significant difference was found among them. A similar trend was observed in the 2000 second cropping season. However, the overall yields were lower than those obtained in the preceding seasons.

In the humid forest ecological zone, the 2.1 tons ha^{-1} obtained in the 1999 second cropping season was significantly lower than the mean grain yields recorded in the other ecological zones (4.5 and 2.8 tons ha^{-1} for the sub-humid forest and the forest-savanna transitional zones, respectively). Still in the humid forest ecological zone, mean grain yields of the second cropping season were significantly lower than those

Table 7. Farmers' evaluation of palatability of improved versus local maize varieties tested in the forest zone of Cameroon.

Treatments (Varieties)	Green maize		Dry maize (fufu)	
	Colour † (Ranking)	Taste† (Ranking)	Colour † (Ranking)	Taste † (Ranking)
CMS 8501	4	3	2	2
CMS 8704	1	2	3	4
AK 9522-DMR	2	1	1	1
LOCAL	3	4	2	2

† Ranking from 1 to 4 with 1 = good and 4 = least good

of the first season (2.1 against 3.8 tons.ha^{-1}). In the sub-humid forest ecological zone, mean grain yields remained high in both 1999 second season (4.5 tons.ha^{-1}) and 2000 first season (5.05 tonsha^{-1}).

Performance of improved maize varieties as perceived by farmers

From the results of Table 6, it appears that farmers have preferred the colour of variety CMS 8704 in 6 of the seven dishes tasted, followed by AK 9522-DMR. As for the taste, AK 9522-DMR was preferred over the other varieties in 6 dishes out of seven followed by CMS 8704. The colour and taste of AK 9522-DMR were preferred when maize was dry (Table 7).

Table 8 suggests that AK 9522-DMR performed better than the other varieties with respect to selected production characteristics such as plant growth, cob aspect and yield (visual estimation in the field by farmers) and taste. On the other hand, CMS 8704 ranked first with respect to borer infestation, cob colour and grain yield whereas the local check outyielded the improved varieties for the plant aspect. Besides, results in Table 8 show that with respect to production and taste characteristics, farmers' preference for AK 9522-DMR was higher, followed by CMS 8704, CMS 8501 and LOCAL in this order (Table 8).

Economic analysis

Table 9 summarizes the partial budgetary analysis done and shows – among other parameters – the net revenue per hectare as calculated for each of the different varieties tested. It appears that a net revenue of 449.29 to 1,118.59 US$ ha^{-1} can be obtained from those varieties. CMS 8704 and AK 9522-DMR yielded the highest net revenues (1,118.59 and 1,082.88 US$.ha^{-1}, respectively) followed by CMS 8501 1,011.45 US$.ha^{-1}) and LOCAL (only US$ 449.29 ha^{-1}). Furthermore, the Marginal Benefit-Cost Ratio (MBCR) obtained was 3.7, 4.0, 3.9 and 1.7 for CMS 8501, CMS 8704, AK 9522-DMR, and LOCAL, respectively

Table 8. Farmers' assessment of the production performance of improved versus local maize varieties (matrix scoring).

Treatments (Varieties)	Plant growth N=51	Plant aspect N=49	Cob aspect N =51	Resistance to borers	Yield† N = 50	Yield (t/ha)	Color N=110	Taste N=110	Priority ranking
CMS 8501	3	3	2	3	2	3	4	4	3
CMS 8704	4	4	3	1	3	1	1	2	2
AK9522 DMR	1	2	1	2	1	2	2	1	1
LOCAL	2	1	4	2	4	4	3	3	4

N.B.: N = number of respondents; †Yield estimation at the field level

Table 9. Partial budget analysis for 3 improved maize varieties and a local check tested in the forest zone of Cameroon

Parameters	Variety			
	CMS 8501	AK 9522-DMR	CMS 8704	LOCAL
a) Maize mean yield (t ha^{-1})	3.60	3.90	3.90	2.00
b) Revenue (US$ ha^{-1}) ≈ 0.36*a	1285.74	1357.17	1392.88	714.30
c) Costs of fertilizers (US$ ha^{-1})	142.86	142.86	142.86	142.86
d) Cost of seed (US$ ha^{-1})	18.57	18.57	18.57	9.28
e) Land preparation (US$ ha^{-1})	42.86	42.86	42.86	42.86
f) Planting (US$ ha^{-1})	21.43	21.43	21.43	21.43
g) Weeding (US$ ha^{-1})	28.57	28.57	28.57	28.57
h) Applying fertilizers (US$ ha^{-1})	11.43	11.43	11.43	11.43
i) Harvesting (US$ ha^{-1})	8.57	8.57	8.57	8.57
j) Total Costs (US$ ha^{-1}) = (c+..+i)	274.29	274.29	274.29	265.00
k) Net income (US$ ha^{-1}) = (b – j)	1011.45	1082.88	1118.59	449.29
l) l. MBCR = k/j	3.70	3.90	4.00	1.70

It is assumed that the maize is sold immediately after harvest. Therefore, storage loss is nil and measured maize yield is treated as net yield;
Maize price = 0.36 US$/kg in the local market;
Cost of fertilizer = 0.29 US$/kg in the local market;
Cost of labour for planting: 1.43 US$/ man-day x 15 man-days/ha = 21.43 US$;
Cost of labour to apply fertilizer: 1.43 US$/ man-day x 8 man-days/ha = 11.43;
Cost of labour for weeding: 1.43 US$/ man-day x 20 man-days/ha = 28.57 US$;
Cost of labour for land preparation: 1.43 US$/ man-day x 30 man-days/ha 42.86 US$;
Cost of labour for maize harvest: 1.43 US$/ man-day x 6 man-days/ha = 8.57 US$.
NB.: 1.00 US$ = 700 FCFA.

DISCUSSION

The above results have shown the superiority of CMS 8704 over the other improved varieties with respect to resistance to stem borers (Table 2). In fact, while in the 1999 second cropping season, CMS 8704 was followed by AK 9528-DMR, the latter slightly out-yielded it including the other varieties. Based on this, it is suggested that CMS 8704 is the most tolerant among the varieties tested followed by AK 9522-DMR. The local check was the most attacked as it is the least tolerant, particularly in the second cropping season when the level of infestation is usually high.

Stem borer infestation was significantly severe in the humid forest ecological zone as compared with the other zones, with the highest level recorded in the second cropping seasons (Table 3). These results tend to suggest the humid forest ecological zone as the best area for tests of tolerance to stem borers, and the second season as the best period for this test. Our results confirm reports by Girdling (1980), Bosque-Pérez and Mareck (1990, 1991) and Aroga (1997a, 1997b) who observed the most severe infestations in the second cropping season rather than in the first in Ghana, Nigeria and Cameroon.

Mean grain yield obtained with improved varieties was significantly higher than that obtained from the local check (Table 5). These results confirm the superiority of CMS 8501, CMS 8704 and AK 9522-DMR over LOCAL, support those by Moussie (1995) who reported that the yield potential of improved varieties CMS 8704 and CMS 8501 was at least 40% higher than the local. However, no significant difference could be found among improved varieties although CMS 8704 ranked first followed by AK 9522-DMR and CMS 8501 in this order. Mean grain yields in the second season were significantly lower in the humid forest ecological zone than in the other zones for all the varieties tested. This result was to be expected given the high level of infestation recorded in that ecological zone. Mean grain yields were higher in the sub-humid forest ecological zone than in the other zones irrespective of the cropping season, suggesting that the sub-humid forest zone could be the best area for maize production in any of the two cropping seasons of the forest zone of Cameroon. Besides, mean grain yields in the second season were lower than those of the first season for all the varieties (Table 5). This result is partly explained by the severe infestations of stem borers recorded in the second cropping season as stated above (Table 3).

According to Onyibe *et al*. (1999), Arokoyo *et al*. (1996) and Eyong *et al*., 1997, farmers' adoption or preference for a variety is hinged on criteria such as grain yield, grain colour and taste, to name but a few. Therefore, the results of the participatory evaluation of consumption qualities of varieties presented in Tables 6 and 7 clearly indicate that farmers preferred CMS 8704 for its colour in dishes where it was used fresh. AK 9522-DMR for its part, was preferred for its sweet taste in all dishes except the "souga" where farmers' preference was still directed towards the local variety. Similarly, AK 9522-DMR was preferred for its colour and taste in dishes where it was used dry.

The results in Table 8 indicate that AK 9522-DMR performed better for 4 out of 8 criteria considered while CMS 8704 was the best only for 3 out of 8 criteria. The local check was better only when the plant aspect was concerned. CMS 8501 had the poorest performance according to the farmers. Based on the above, it may be concluded that because of its highest level of tolerance to borers and grain yield, CMS 8704 is the most suitable for commercial production. However, AK 9522-DMR was preferred by the farmers for subsistence production because of its good appearance (plant and cob aspect) and taste, suggesting that if the varieties tested were to be adopted by the farmers in the Cameroonian forest zone, the adoption sequence would rank AK 9522-DMR first, followed by CMS 8704 (second) and CMS 8501 (third).

The partial budget analysis summarized in Table 9 shows a higher MBCR of 3.7 to 4.0 for the improved varieties as compared with the local check that yielded only 1.7. These MBCRs are even higher than the 2.5 considered as the minimum required before recommending a new technology. The MBCR signifies the increased revenue to the farmer per additional dollar to plant the improved varieties. From the MBCR perspective, CMS 8704 and AK 9522-DMR are the best varieties to be recommended to farmers in the collaborating areas. In fact, according to Coulibaly (1995), higher returns are an important factor in adopting a new technology. The local check had the lowest net income, with a MCBR under the acceptable level. These results clearly indicate that the adoption of improved varieties to optimize maize production in the forest zone of Cameroon is possible. However, many other constraints like seed scarcity of improved varieties and difficult access to credit (as the production cost seems to be too high and non-affordable by some resource-poor farmers) need to be taken into consideration.

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THE DETERMINANTS OF FERTILIZER AND MANURE USE IN MAIZE PRODUCTION IN WESTERN OROMIYA, ETHIOPIA

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ABSTRACT

A survey of 95 farmers selected from three agro-ecological zones (highland, lowland and mid-altitude) was conducted in two areas of western Ethiopia in year 2000. The objective of the study was to assess the determinants of fertilizer and manure use for maize production. Results showed that the agro-ecology in which the crop grows, the presence of other soil fertility management practices such as crop rotation, educational status, farm area allocated to maize production, and the number of livestock owned were factors which significantly influenced the use of chemical fertilizer. Results also revealed that the use of manure was significantly affected by the number of active family members (age 17-60 years), agro-ecological zone, and the number of cattle owned. The results imply that, in addition to further strengthening extension advice on the use of organic manure to supplement chemical fertilizer, more extension efforts should be directed especially to low and high altitude farmers to improve the adoption of maize technologies. There is a need to conduct more research on soil fertility mining and supplementation of chemical fertilizer with different sources of organic manure to reduce the volume of chemical fertilizer and cost of production for enhancing and sustainable utilization of maize technologies.

INTRODUCTION

Low soil fertility has been recognized as one of the major biophysical constraints affecting agriculture in sub-Saharan Africa. According to Sanchez et al (1997), soil fertility depletion in smallholder farms is the fundamental biophysical cause of declining per capita food production. This depletion is mainly due to intensive and continuous cropping with low application of fertilizer, causing a negative balance between nutrient supply and extraction.

In Ethiopia, land holdings are small because of land fragmentation due to an increasing population pressure. Unless land is intensively and more productively used, it is unlikely to provide enough food for consumption and sale. Land productivity could improve if soil fertility were improved. To overcome the soil fertility problem, farmers in western Oromiya use mainly chemical fertilizer and manure for crop production. For instance, in the mid-altitude areas like Bako, more than 80 percent of the farmers use chemical fertilizer (Abdissa et al, 1998). The other 20 percent do not use it mainly because of problems with availability, accessibility, affordability and awareness. However, in highland areas, the use of manure instead of chemical fertilizer is more common especially for maize production. The aim of this study was to identify factors determining the use of chemical fertilizer and manure for maize production, and to draw useful lessons for research, extension and policy.

MATERIALS AND METHODS

Data were gathered at the farm level using a semi-structured checklist and a structured questionnaire. A multi-stage random sampling procedure was used to select maize growing farmers from Guto-wayu, Sibu-Sire, Bako-Tibe and Cheliya districts. Major agro-ecological zones (Highlands, Mid-altitudes and Lowlands) were purposively considered while selecting the Peasant Associatons (PA) to be included in the sample. An informal survey was carried out to obtain qualitative information about farmers' socio-economic circumstances and soil fertility management. Finally, based on the information collected, a structured questionnaire was developed and 31 to 34 farmers were selected from each agro-ecology. In total, 97 farmers were interviewed from April to May 2000 using a single visit approach.

Socio-economic characteristics in western Oromiya

Socio-economic characteristics of the sample farmers are shown in Table 1. Farmers in mid-altitude had more farming experience (30 years) than lowland and highland farmers (22 years). Mean family size was about six for the lowlands and highlands and nine for farmers residing in the mid-altitude areas. This shows that larger human populations were found in the highlands and lowlands as compared to mid-altitude areas. However, mid-altitude farmers have a larger number of active family labourers (4) compared to the lowlands and highlands (3). Sampled farmers with elementary education were 40% in mid-altitude but only 30% from the lowlands. More than one-half of the farmers residing in highlands and mid-altitude areas had at least elementary education compared to only one-third from the lowlands.

Farmers in highlands had a larger farm size (2.62 ha) compared to farmers in mid-altitude and lowlands (2 ha). However, highland and lowland farmers allocated only about one-fourth (25-30%) of their cultivated land for maize production while farmers in mid-altitude areas allocated more than one-half (56.7%). This implies the proportion of the cultivated land allocated for maize production in mid-altitude areas is quite substantial and it signifies that maize production is important in the area. On average, highland farmers had more livestock (8.4 livestock units [lu]) than mid-altitude (6.7 lu) and lowland (3 lu) farmers. This shows that a relatively higher livestock population is found in the highlands. This, in turn, implies that manure utilization is relatively higher in the highlands because of the presence of a higher number of livestock.

Table 1. Characteristics and Practices of Sampled Farmers by Agroecology.

	Agro Ecology		
	Highland (N=32)	**Mid-Altitude (N=34)**	**Lowland (N=31)**
Farming Experience			
Farming experience	22.1	30.2	21.6
Before Marriage	5.4	7	6
After Marriage	17	22.6	14.5
Total Family Size(ha)	6.4	8.6	6.1
Active Family Members (17-65)	3.3	4.4	2.8
Over Exploited Family members (14-17)	1.8	1.8	2.1
Dependent Family Members (<14 & >65)	1.5	2.4	1.2
Illiterate (% of farmers in the zone)	25.0	23.5	45.2
Adult education (% farmers who attended)	0.0	20.6	6.5
Elementary school (1-6) (%)	53.1	52.9	32.3
Junior secondary school (7-8) (%)	15.6	0.0	12.9
Secondary school (9-12) (%)	6.3	2.9	3.2
Total Farm Size	2.62	2.0	2.3
Arable land	2.0	1.5	2.1
Maize land	0.45	0.85	0.62
Grazing land	0.62	0.32	0.10
Other crops land	15	0.65	1.50
Livestock (number)	8.36	6.66	3.00
Source of information on fertilizer use			
MoA (% of farmers in the zone)	62.5	61.3	100.0
Other Farmers (%)	6.3	19.4	0.0
Service cooperatives	6.3	0.0	0.0
Soil fertility practices in maize			
Fertilizer use	50	91	23
Manure use	91	71	23
Crop residue use	56	41	39
Crop rotation practice	0	3	0
Fallow use	59	79	61
Multipurpose tree species	25	18	10

SOURCE : Farmer survey (2000)

The main sources of information for improved agricultural technologies in the study area were the Ministry of Agriculture (MoA), farmers and service cooperatives. In all agroecologies surveyed, MoA is the principal source of information for improved technologies (for 70% of farmers), while other farmers are the second most important source. In the lowlands, 100% of sampled farmers responded that MoA is their principal source of information; in the mid-altitude and highlands it was 61% and 62%.

Soil fertility management practices

Farmers in the study area use different soil fertility management strategies. Among these, the most commonly used were chemical fertilizer and manure, but practices differ by zone. Chemical fertilizers are used by half the farmers in the highlands, by most of the farmers in the mid-altitudes (91%), but by few in the lowlands (23%). Manure use clearly decreases with altitude: from most of the farmers in the highlands (91%), a bit less in the mid-altitudes (71%), to few in the lowlands (23%). Other soil fertility practices are also common. About two thirds of farmers in all zones use fallow. More than half the farmers in the highlands use manure, and slightly less than half in the other zones. However, very few farmers use rotation, and few grow multi-purpose trees.

Factors affecting the adoption of chemical and manure use

Feder et al. (1995) showed that many models used in adoption studies fail to meet the statistical assumptions necessary to validate the conclusion based on the hypothesis tested and they advocate the use of qualitative response models. The two models used in adoption studies are the logit and probit. Usually a choice has to be made between logit and probit but, as Amemiya (1981) has observed, the statistical similarities between the logit and probit models make such a choice difficult. The logit model is selected here because the dependent variable is dichotomous and the model is computationally easier for analyzing factors influencing the farmers' decision to adopt different soil fertility management practices. Following Gurajaratti (1988) the model is specified as:

Table 2: Parameter estimates of the logistic regression model for the determinants of Chemical fertilizer and Manure use.

Explanatory variable	Chemical fertilizer use			Manure Use		
	Estimated coefficient	Standard error		Estimated coefficient	Standar d error	
Farming experience (years)	0.02	0.02		0.04	0.03	
Active family members	0.03	0.16		-0.26	0.17	
Highland zone (binary)	-0.45	0.62		2.42	0.77	**
Crop rotation (binary)	-0.83	0.61		-0.90	0.67	
District (binary)	-1.23	1.40		-0.21	1.53	
Literacy (binary)	2.45	0.71	***	1.32	0.69	*
Maize area (ha)	3.29	0.99		0.16	0.91	
Oxen (number)	0.56	0.20		1.08	0.35	**
Constant	-4.29	1.19		-1.93	1.05	
Model Chi-square	38.5		***	43.6		***
-2 Log likelihood	95			83		
Nagelkerke R Square	44			50		
% correctly predicted	72			79		

$$\mathbf{Ln\ (P_i/\ (1\text{-}P_i)\ )=\ \beta_o+\ \beta_1\ X_1+\text{-----}+\ \beta_8\ \ X_8+e}$$

where P_i = probability of adoption, β_i = coefficients, Xi = independent variables, and e = error term.

The dependent variable is the natural log of the probability of adopting manure or fertilizer (Pi) divided by the probability of not adopting (1-Pi). The model was estimated using the maximum likelihood method of SPSS version 10 software. Formation of the model was influenced by a number of working hypotheses. It was hypothesized that a farmer's decision to adopt or reject at any time is influenced by the combined effect of a number of factors related to farmers' objectives and constraints (CIMMYT, 1993). the following independent variables were hypothesized to influence the adoption positively (+), negatively (-), or have either a negative or positive effect (+/-):

- X1 = Farming experience of household head (+);
- X2 = Active Family Labour (+);
- X3 = Highlands (+/-) (1=Yes, farmer is from the highlands; 0=no);
- X4 = Crop Rotation (-) (1=Yes if a farmer practices; 0=Otherwise);
- X5 = District (+/-) (1=If a farmer lives in Bako-Tibe and Sibu-Sire districts; 0=Otherwise);
- X6 = Literacy of the household head; (+) (1=Read and write/Literate; 0=Otherwise);
- X7 = Maize area in hectare (+/-);
- X8 = Oxen (Number of oxen owned) (+).

RESULTS AND DISCUSSION

For the adoption of chemical fertilizer in maize, the logistic model explained 72% of the adoption (Table 2). The chi-square statistic indicates that the parameters included in the model were significantly different from zero at the 1% level of significance. Regression results showed that literacy, maize area, and the number of oxen owned were factors that significantly influenced the use of chemical fertilizer. The estimated coefficients represent a change in odds, or the ratio of the probability of accepting over the probability of not accepting The odds in favor of adoption decrease by a factor 2.45 for illiterate farmers, possibly because illiterate farmers have less access to information. Alternatively, the coefficients can be divided by 4 to obtain an approximation of the percentage change in probability of adoption (Maddala, 1983, p. 23). Therefore, literate farmers can be expected to be 61% more likely to adopt chemical fertilizer.

The odds in favour of adoption increase by a factor 3.29 for farmers allocating a relatively larger area for maize, with the probability of adopting increasing by 82% for each extra ha in maize. The odds in favour of adoption increase by a factor 2.11 for farmers having greater oxen number, with the probability of adopting increasing by 14% for each extra ox.

For the use of manure in maize production, the logistic model correctly predicts 79% of the adoption (Table 2). The chi-square statistic indicates that the parameters included in the model were significantly different from zero at the 1% level of significance. Out of the variables, which were expected to influence the use of manure, the agro-ecological zone, literacy and the number of oxen owned were factors that significantly influenced the decision of manure use. The odds in favour of adoption of manure decreased by a factor 2.42 for farmers in the highlands (probability increase of 60%). The odds of adopting manure increased by a factor 1.32 for literate farmers (probability increase of 33%). The odds in favour of adoption of manure use increased by a factor of 1.08 for farmers having more oxen (probability increase of adoption of 27% for each extra ox.

CONCLUSIONS AND IMPLICATIONS

The results show that both fertilizer and manure use increase with literacy and number of oxen. Moreover, fertilizer use also increases with maize area planted, while manure use increases in the highlands.

Generally, land productivity should be emphasized in western Ethiopia because of increasing population pressure, and this can be achieved through the use of manure and chemical fertilizer. The results of this study show that farmers in the mid-altitudes use more chemical fertilizer than farmers in the highlands and lowlands. Farmers in the highlands allocate a small portion of their land for maize production as compared to the other two agro-ecologies. This indicates farm size is an important determinant of technology adoption especially, fertilizer. There are a greater number of farmers in the mid-altitude zone using improved maize technologies than in the lowland zone. Thus, more extension efforts should be directed towards the lowland and highland zones in order to improve the adoption of improved maize technologies in these agro-ecologies. Use of crop residues, crop rotation, and fallowing are poorly practiced in all agro-ecologies in western Oromiya implying that the use of chemical fertilizer is very important. However, increasing fertilizer prices force the farmer to apply low doses of fertilizer and/or manure. Hence, extension advice on the use organic manure to supplement chemical fertilizer should be strengthened. Additionally, more research efforts should be directed to studying soil fertility mining, supplementation of chemical fertilizers with different sources of organic manure, crop residue management and soil conservation measures to reduce the volume and cost of chemical fertilizer. Other soil fertility research should also be relevant as the use of chemical fertilizer is likely to remain low in the future due to its increasing price.

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FARMERS VOICES ON MOTHER/BABY TRIALS (2000/2001).

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ABSTRACT

Very few Malawians have been able to select a maize variety in the field before buying it in the market. Mother/baby trials are sets of experiments conducted by farming communities whose objective is to evaluate released and pre-released cultivars under farmer-managed conditions and get feedback from farmers who will select cultivars of their choice. For each Mother trial, there are as many as 6-12 corresponding Baby trials within walking or bicycling distance. The mother trial designed by researchers, evaluates a set of promising maize cultivars under optimal and farmer-representative management conditions. It is located in the center of a farming community, often at a secondary school/college or a progressive farmer or at research stations. A local counterpart (a teacher of agriculture, an extension officer or a staff member of a non-governmental organization) manages the mother trial. All baby trials contain a subset of the cultivars in the mother (no more than four) and are planted and managed exclusively by the local farmers that host them. Malawian farmers have made their choices.

The common factor has shown that the best maize varieties do well and farmers choose them. Concern Universal and World Vision International (NGOs) participated in conducting the trials. Sites were as follows:- Chitedze-2 mother + 6 babies, Makoka - 1 mother + 6 babies, Bvumbwe - 1 mother + 6 babies; Kabwato – 1 mother + 6 babies, Linthipe - 1 mother + 6 babies and the rest had run mother trials only:- Bembeke, Ngabu, Mbawa, Chitala, Baka, Lupembe, Bolero, Bunda, Nsipe, Mponela and Kapiri. The field days conducted on these trials (on-farm) last season were an eye-opener to the Ministry of Agriculture since the voice of the Malawian farmers has now been heard. Farmers were taken to visit the trials at milky stage and at harvest for them to identify a variety of their choice. Farmers chose the following varieties:- ZM 521, Masika, Lat A x Lat B, 297 syn gls (A) -f2#, synthetic DRT- SR # (CIMMYT-Ken), ZM 621, ZM 621 flint. These varieties were chosen for the following reasons:- high yielding, flintiness, early maturing and resistance to diseases. Most of all, the trial will enable both the Malawian farmers and the seed multipliers to flourish in the market with the right material at the right time to the right area. Varieties reach the farmers through the formal seed sector though there is a big problem to convince a seed company to multiply an Open Pollinated Variety (OPV) unless there is a ready market for it. Seed companies in Malawi hate the fact that an open pollinated variety is bound to be recycled. The seed companies of Malawi chose to multiply hybrids since farmers are going to buy the seed every year.

INTRODUCTION

The Mother-Baby trials are a last stage of variety testing. They constitute part of the variety development conducted by participation in on-farm verification of promising varieties, which are recently released and are available on the market, while some are experimental cultivars. It is believed that every variety in this trial is suitable for resource-poor farmers' conditions. Some of the treatments (cultivars) are from CIMMYT and have been selected for drought- and N stress-tolerance in the frame of the Southern Africa Drought and Low Soil Fertility Project (SADLSF). Promising results with the SADLSF materials have been obtained in Regional trials conducted by researchers throughout eastern and southern Africa. In this mother-baby approach varieties are evaluated under the following conditions:-

a) Researcher-managed, recommended fertilizer practices
b) Researcher-managed, farmers' fertilizer practices
c) Farmer-managed, farmers' fertilizer practices

The approach is considered robust and conclusive in that the mother-baby trials themselves will evaluate the variety at several sites across the possible fertility management options and ecological zones. Therefore the data from this exercise would form a solid basis for release of any outstanding entry. Thus, apart from the fact that most of the entries are already released, partners would contribute directly to the release of the best varieties.

MATERIALS AND METHODS

Twelve Open Pollinated Varieties and hybrids were tested at Baka and Chitala at low altitude areas and the original populations were Matindiri, Sundwe and Kafula used as checks. This was under researcher and recommended fertilizer applications see Table 1. Twelve open pollinated varieties and hybrids were tested under yellow researcher-managed, farmers' fertilizer practices at Chitedze, Bvumbwe and Makoka and the released populations were Masika and Kakhomera used as checks see Table 4. Twelve open pollinated varieties and hybrids were tested under mid-altitude areas grown at Chitedze, Bvumbwe, Kabwato, Mbawa, Bunda, Linthipe, Kabwazi, Makoka with ZM 621 flint, ZM 621 Dent and AC 969A on position 1, 2 and 3, respectively see Table 2.

Plot Sizes and Planting Pattern

Plot size was 2 rows x 5.1 meters long arranged in an alpha lattice design with 3 replications, spacing was 0.9 meters between rows and 0.3m between plants in the row, planting 2 seeds/station. Maize plants were thinned to 1 plant per station at 2 weeks after emergence. At this spacing the expected plant population was 37,000 plants/ha. Border rows were planted at both ends of the trial to provide equal competition for the plants.

Table 1. Grain yield (t/ha) and agronomic traits of maize varieties in the Low Altitude Mother Trials under optimal fertilization.

Entries	BAKA	CHITALA	Mean	Rank	DP	DS	PH	EH	MSV
1.ZM 621	6.26	5.32	5.79	1	53	55	202	64	1.8
2.Obatampa	6.57	4.79	5.68	2	53	55	216	98	2
3.Z97EWA/EWB	6.11	4.99	5.55	3	46	48	177	91	0.3
4.Kafula	5.21	5.21	5.21	4	54	56	207	99	2.6
5.ZM 421	5.46	4.5	4.98	5	52	54	199	89	1
6.ZM 521	5.35	4.49	4.92	6	52	54	197	96	2
7.ZM 301	4.97	3.99	4.48	7	48	51	202	92	1.3
8.ZM 303	4.79	3.87	4.33	8	48	50	190	102	1
9.DTP-IW	3.82	4.59	4.21	9	49	50	179	86	4.1
10.Matindiri	3.8	4.66	4.02	10	53	55	160	98	4.3
11.Early-MidKatumani	3.31	3.69	3.5	11	47	49	187	91	1
12.Sundwe	3.69	3.69	3.69	12	49	52	186	97	1.3
Mean	4.91	4.48			50	52	192	92	1.9
CV%	22	11			2.8	2.7	6.5	21	29
Lsd (0.05)	1.91	0.9			2.4	2.4	21.2	32	0.97
Min	3.31	3.69							
Max	6.57	5.32							
F. Value	2.96	4.1			***	***	***	NS	***
P	0.013	0.002							
SED	0.87	0.41							

Table 2. Grain yield (t/ha) of maize varieties in the mid-altitude Mother Trials under optimal fertilization.

Entries	Chitedze	Bvumbwe	Kabwato	Mbawa	Bunda	Linthipe	Kabwazi	Makoka	Mean	Rank
1.ZM 621F	8.38	6.4	7.33	1.54	6.21	6.71	5.9	5.6	5.72	1
2.ZM 621	7.5	6.42	7.32	1.66	5.22	6.96	6.14	5.4	5.59	2
3.AC969A	7.17	6.68	6.79	1.34	6.12	7.12	5.42	5.88	5.44	3
4.ZM521	6.92	5.72	6.97	2.87	5.24	6.38	5.48	4.4	5.25	4
5.TSEQZIM	7.2	6.18	7.73	1.99	4.04	6.22	4.25	4.84	5.18	5
6.Z97SYNGLS	5.85	5.38	8.9	1.81	7.16	6.09	5.31	4.75	5.29	6
7..SYNTHETIC-DRT	6.64	5.95	8.32	2.28	3.75	5.23	4.13	4.75	5.09	7
8.SYNTHETIC-NUE	6.79	6.46	6.62	1.61	4.52	6.02	5.24	4.82	4.98	8
9.LATA X LAT B	6.15	6.22	6.34	2.54	4.86	6.29	5.23	4.01	4.93	9
10.MASIKA	5.96	4.43	6.95	1.66	6.63	5.7	4.46	4.07	4.67	10
11.TASEQ	6.14	5.75	6.58	2.21	2.86	5.04	3.24	4.7	4.41	11
12.KAKHOMERA	4.98	4	5.36	2.28	6.63	3.84	3.18	3.14	3.52	12
MEAN	6.64	5.8	7.1	1.98	4.98	5.97	4.83	4.72	4.95	
Min	4.98	4	5.36	1.134	2.86	3.84	3.18	3.14	3.52	
Max	8.38	6.68	8.9	2.87	7.16	7.112	6.14	5.88	5.72	
Lsd(0.05)	2.25	0.94	3.12	0.61	1.58	1.004	2.01	1.25		
CV%	19	9	4	17	18	10	23	15		
SED	1.02	0.43	1.42	0.28	0.72	0.47	0.91	0.57		
F Value	1.72	8.93	0.093	5.09	6.82	7.92	2.04	3.48		

Fertilizer Application

The green trial was fertilized at recommended fertilizer rates for the area 92:21:0 + 4S). The yellow trial got a representative fertilizer application by farmers in the area. The baby trial plot size was determined by the amount of seed, 280 seeds per cultivar. Farmers were asked to plant the seed using a plot length of 7m (a string 7m long was packed together with seeds) m, but choosing their own planting distance between hills and rows. Plots were hand harvested and grain yield was adjusted to represent the weight at 12.5% moisture for all plots. These traits were subjected to analysis of variance using alpha lattice design (Bansiger, et al. 1997).

Table 3. Agronomic traits of maize varieties in mid-altitude Mother Trials under optimal fertilization.

DISEASE SCORES (Scale 1-5)

Entries	OP	DS	PH	EH	GLS	E.t	Gl
1.ZM621 Flint	69	70	218	116	1.9	3.2	2.8
2.ZM621	69	70	214	112	2.1	3.2	3
3.AC969A	71	71	228	135	1.9	2.8	3
4.ZM 521	66	67	203	100	2.1	3.4	2.1
5.TSEQZIM	67	67	207	105	1.7	3.2	3.3
6.Z97SYNGLS	71	72	215	113	1.9	3.1	2.4
7.SYNTHETIC-DRT	69	69	205	108	2.9	2.9	2.5
8.SYNTHETIC-NUE	73	74	204	119	2.5	3.1	2.5
9.LAT A/LAT B(A)	67	67	220	115	2	3.4	3.2
10.MASIKA	71	72	203	101	2.1	3.2	3.2
TASEQ	73	72	244	119	2.6	3.3	2.6
KAKHOMERA	74	75	194	99	2.1	3.6	3.4
MEAN	70	70	211	112	2.1	3.2	2.8
Lsd (0.05)	1.8	2.1	20.6	19	0.37	0.51	0.92
CV%	1.5	1.8	5.75	10	9.98	9.44	19
P	**	**	0.069	0.03	0	0.19	0.14

DP=days to 50% pollen shed
DS= days to 50% silking
PH= plant height in cm
EH= Ear height in cm
GLS= grey leaf spot
GLS= grey leaf spot
GLS= grey leaf spot
GLS= grey leaf spot
GI= Grain index 1= 100% flint; 5 = 100% dent

Table 4. Grain yield (t/ha) of maize varieties in the mid-altitude Mother Trials under farmers' conditions.

Entries	Chitedze	Bvumbwe	Makoka	Mean	Rank
1.Synthetic-DRT	2.6	7.54	4.84	4.99	1
2.ZM 621 FLINT	3.64	6.61	4.59	4.95	2
3.ZM 621	3.92	5.63	5.25	4.93	3
4.TSEQZIM	3.91	6.5	4.1	4.83	4
5.ZM521	4	6.44	3.36	4.6	5
6. AC969A	2.39	7.37	3.6	4.45	6
7.Z97SYNGLS	3.09	6.08	3.57	4.25	7
8.Synthetic-NUE	2.89	6.33	3.5	4.25	8
9.LAT A/LAT B (A)	3.71	6.42	2.47	4.2	9
10. TASEQ	2.65	5.87	3.47	3.99	10
11. MASIKA	2.75	4.79	3.95	3.83	11
12.KAKHOMERA	2.05	4.45	2.35	2.95	12
				4.35	
Mean	3.13	6.17	3.75		
CV%	16	12	27		
Lsd (0.05)	0.9	1.28	1.8		
MIN	2.05	4.45	2.35		
MAX	4	7.54	5.25		
P	0	0.001	0.045		
SED	0.41	0.58	0.82		
F. VALUE	5.97	4.88	2.27		

RESULTS AND DISCUSSION

Results are presented in Tables 1, 2, 3, and 4 for yield and agronomic traits. The highest yields were obtained from Chitedze, Kabwato and Linthipe for mid-altitude, while Baka had the highest yields for Lowland. Mbawa had the lowest yields due to late planting.

There were significant yield differences between varieties at all sites. On the overall means pooled across sites in mid-altitude, ZM621F, ZM621 dent and AC969A were the highest yielding varieties with 5.72, 5.59 and 5.44 tonnes/ha, respectively. ZM621, Obatampa and 297 EWA/EWB were the highest yielding varieties for lowland (Baka and Chitala) with 5.79, 5.68 and 5.55 tonnes/ha, respectively. The checks were all clearly outyielded across all sites. This has prompted and accelerated the release of the experimental open pollinated varieties ZM621, ZM521 and ZM421 since they do well under low N and drought.

CONCLUSION

Farmers, NGOs and staff from both Extension and Research have liked the objectives of the trial. It is hoped that seed multiplication of open pollinated varieties will not be a big problem forever. A few individuals and NGOs have collected smaller quantities of OPV seed for multiplication.

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COMMUNITY-BASED MAIZE SEED PRODUCTION IN COASTAL LOWLAND KENYA.

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ABSTRACT

Farmers at the Kenyan coast lack a supply of affordable and timely maize seed. They often use unimproved and non-recommended seed, leading to poor yields. Since private companies have switched to hybrid maize varieties, the popular improved open pollinated variety, Coast Composite, is no longer offered in the market. To make this seed again available to the farmers, a seed production project was launched at the Coast. Pre-basic and basic seed of Coast Composite and two local varieties (Mungindo and Mengawa) was produced on-station, on 0.25 ha per variety and seed type, in total 1.5 ha. Commercial seed was produced by 4 community groups and 2 farmers in 5 sites, between 0.25 and 1.5 ha per site (4 ha in total). Isolation of plots from other maize farms at pollination was by time and space, and the seed plots were naturally random pollinated. Selection was done based on desirability of plant and ear characteristics before and after pollen shed. Emasculation before pollen shed and plant cutting above the ear was the roguing technique used. Total seed production was 2.8 tons. Seed was sold at harvest, on the spot and in bulk, at Ksh.100 per kilogram compared to the current price for improved seed of Ksh.140 per kilogram. The demand for locally produced improved seed is large, but the costs of the project are high. Future activities should emphasize an increased production as well as a higher recovery of costs, in particular inputs such as basic seed, fertilizer and insecticide. Finally, the requirements for certified seed are prohibitively expensive for small-scale farmers and the market is too small for large-scale producers. Therefore, alternative delivery systems for improved maize seed as well as a new classification need to be explored.

Keywords: maize breeding, maize seed, lowlands, community-based seed production, open pollinated varieties.

INTRODUCTION

Maize in the coastal lowlands of Kenya

Kenya's coastal province has a long history of economic activity, with a distinct differentiation by ethnic group. Swahili traders have been occupying the coastal towns for several centuries, while the nomadic pastoralists roamed the semi-arid hinterland. In between those two groups, the agriculturalists of the Mijikenda tribe settled in a band along the coast about 400 years ago (Waaijenberg, 1994). Until the 19th century, they lived in nine *makaya* or fortified villages on top of wooded hilltops, growing sorghum, millets, and cowpea. During the 19th century, they left the *makaya* to settle on the uplands and plateaus, and adopted maize, rice, and cassava as staple foods. At the end of the 20th century, the Mijikenda were still the most important group within the agriculturalists. Although agriculture is still their main economic activity, it has changed drastically: maize has become the dominant staple while sorghum and millets have basically disappeared from the area (Waaijenberg, 1994).

Maize was probably introduced into East Africa by Portuguese slave traders (Dowswell et al. 1996, p. 18). The first varieties were flints from the carribean, and white dent varieties were only introduced much later. The main agrocecological zone where maize is currently grown is the lowland tropics (Hassan, 1998), a band of about 80 km along the coast. At present, the province produces more than 50,000 tons of maize on slightly less than 50,000 ha, or an average yield of 1.06 tons/ha (Ministry of Agriculture, unpublished data from 1998, 1999 and 2000). More than 90% of the production is in the first season. The region faces a large deficit: while maize is the major staple food, the maize production for its 2.5 million inhabitants (Central Bureau of Statistics, 2001) amounts to only 20 kg/person. The average maize food consumption per person for Kenya is estimated at 94 kg/person (Pingali, 2001).

Maize improvement work started in 1952, but was not very successful in the early years (Wekesa et al., 2003b). In 1974, the broad-based Coast Composite was released, developed from introduced tropical material with tolerance/resistance to maize rust. In 1989, the first hybrid for the lowlands was released: Pwani hybrid 1(PH1), a variety with short maturity (105 days) and higher yield potential than Coast Composite (Table 2). A second hybrid with a higher yield potential, Pwani hybrid 4 (PH4), followed in 1995. Despite these releases, average maize yields did not increase much and are substantially lower than the national average of 1.5 kg/ha.

Adoption of the improved varieties at the coast has been low. A farmer survey from 1998 revealed that 70% of farmers still grew the local varieties, while 22% planted Coast Composite and 21% PH1 (Wekesa et al., 2003b). During Participatory Rural Appraisals (PRA), farmers indicated that the local varieties are hardier and they store well. The improved varieties don't store as well, while the seed is expensive and often of poor quality. The major constraints farmers perceive in maize production are ranked as field pests, cash constraints, wildlife, and storage pests (Wekesa et al., 2003a).

Liberalizing the Kenyan maize seed system.

Up until the early 90s, Kenya followed the classical African seed model, dominated by parastatals. New varieties were developed by public research institutes, now based at

Table 1. Description of coast maize varieties used in community seed project.

	Mungindo	**Mengawa**	**Coast Composite**
Tassels	Tassels: 70% green, 30% purple, Branches: open, others erect, Anthers: yellow. *pollen shed:* 53 days from germination.	Tassels are 70% purple and 30% green. Branches are open and others erect. Anthers: purple. *pollen shed* : 53 days from germination	Tassels 90% green, 10% purple. Branches: open, others erect. Anthers: yellow. *pollen shed* : 54 days from germination.
Leaves	Leaves: green color, fairly wide. A few plants are purple and have purple purple veins. Resistant to foliar diseases like GLS, Maydis blight, Polysosora rust and MSV.	Leaves: green color, fairly wide. A few plants are purple and have purple purple veins. Resistant to foliar diseases like GLS, Maydis blight, Polysosora rust and MSV	Leaves: green color, fairly wide. A few plants are purple and have purple purple veins. Resistant to foliar diseases like GLS, Maydis blight, Polysosora rust and MSV
Stem	Stems: cylindrical and predominantly green, others purple. Plant height: about 220cm.	Stems: cylindrical and predominantly purple, others green. Plant height: about 210cm.	Stems: cylindrical and predominantly green, others purple. Plant height: about 230cm.
Ears	Ear placement: about 120cm. Silking: 55 days from germination. Ears: cylindrical with 12 – 16 rows, predominantly straight.	Ear placement: about 110cm. Silking: 55 days from germination. Ears: cylindrical with 12 – 16 rows, predominantly straight.	Ear placement: about 130cm. Silking: in 55 days from germination. Ears: cylindrical and conical with 12-18 rows, predominantly straight.
Grain	Kernels: white a light yellow background, some purple kernels, shiny flint	Kernels: white, shiny flint	Kernels: white a light yellow background, shiny flint.
Maturity	110 days	110 days	140 days

Table 2. Results of the Community Seed Production project

Site	Area (ha)	Seed production (tons)	Yield (tons/ha)	Variety	Remarks
Mwanamwinga (Mtsengo)	1.5	2	1.33	CC	
Mwamamwinga (Kinarani)	0.5	0.4	0.8	CC	
Mtepeni	0.5	0.4	0.8	CC	
Ribe, farm 1	0.25	0.15	0.6	Mungindo	Because of rodents, replanting was done with these local varieties
Ribe, farm 2	0.25	0.15	0.6	Mengawa	
Kikoneni	1	0.9	0.9	CC	Due to high temperature, rainfall, and humidity, maize rust and maize blight, there was poor germination
Total	4	4	1.0		

the Kenya Agriculture Research Institute (KARI), while seed production was handled by the Kenya Seed Company (KSC), a privately structured company with a majority share owned by the government. Quality control was performed by a seed unit within KARI, extension of new technologies was in the hands of the Ministry of Agriculture, and seed was distributed through the retail network of the Kenyan Farmers Association (KFA). At the coast, the system released the three varieties described above, with mixed success. During the 1990s, however, the donor community (driven by the World Bank) saw the heavy state involvement as an impediment to the development of efficient input and output markets for agriculture, and raising productivity. Markets were liberalized in many countries, increasing efficiency and availability of technology to farmers (Gisselquist and Grether, 2000; Pray et al., 2001).

In the evolution of maize seed industries around the world a life-cycle can be recognized with several stylized stages (Morris et al., 1998). In the pre-industrial stage, farmers select and grow their own seed, which consist only of local OPVs. Individual farmers are the dominant players, although some exchanges between neighbors and family members occur. In the emerging stage, the advantages of specialized institutions such as research organizations is recognized, but the market is still too limited for commercial seed companies. Therefore, the state dominates in this phase, and the varieties produced are mostly OPVs. In the expansion stage, the private sector, i.e. the seed companies, gradually take over seed production and dissemination, thereby switching to the more lucrative hybrid varieties. Finally, in the maturity stage, seed companies also take on research and development of their own varieties. Part of this development, however, depends on hybrid seed sales to cover research costs.

It is more and more accepted that agricultural input markets, in particular the maize seed market, need to be liberalized to allow the private sector to play its role and help move the industry swiftly through the different stages. However, liberalization is a necessary, but not a sufficient condition. For the private sector to operate, it also needs a welcoming and enabling environment (Tripp, 2003). The supply side needs a proper legal framework and regulatory environment. For efficient distribution, proper systems need to be in place, as well as transport infrastructure to decrease the transaction costs (Tripp and Rohrbach, 2001). From the demand side, farmers will use improved seed if it is sold at a fair price, at the appropriate time, at a convenient place, in the quantities needed and in manageable units (Douglas, 1980).

In Kenya, the high potential zones, in particular mid-altitudes, transitional zone and highlands, are very interesting to the seed industry: the large majority of maize is produced here and a large proportion of farmers have adopted new varieties. The liberalization led to the opening of seed markets, with international entries such as Pioneer (US) and Pannar (South Africa) who successfully introduced their materials for the mid-altitudes and transitional zones. In the highlands, however, KSC remained its quasi-monopoly, largely because its competitors lack good late maturing germplasm (Nambiro et al., 2003). Following the live cycle model, KSC has grown more independent from KARI, and developed its own late maturing varieties.

Although agricultural policies are necessarily the same for the whole country, the development of the seed markets is not necessarily homogenous and a country can be at different stages in different areas. Agroecological conditions, market conditions, infrastructure and other aspects can vary tremendously, and influence the stage. As can be expected, new companies were not immediately interested in bringing in new materials for the low potential zones, in particular the semi-arid and lowland tropics. For the semi-arid tropics, KSC produces two open pollinated varieties developed by KARI, but is sells them at the same price of hybrid seed, citing higher transport costs. Some local companies are also producing the same OPVs. Liberalization has increased the number of stockiest in the area, but due to low yield and high costs, seed sales have stagnated. Many NGOs and projects have also started activities in seed production and dissemination, although these activities are not sustainable and depend on external funding (Muhammad et al., 2003). The lowlands, however, have not benefited from these developments. On the contrary, KSC stopped producing its only lowland OPV, Coast Composite, to focus solely on its two hybrids, and no new companies operating here.

Developing alternative seed systems for the low land areas.

The lowland tropic grows about 50,000 ha of maize a year, which is considered just at the limit to justify a breeding program. It is much smaller than any of the other agroecological zones of Kenya, and also at a substantial distance from these other zones. Because of its proximity to the Indian Ocean with its busy trading routes it had, on the other hand, much more access to a wide range of varieties imported by traders. Farmers had many opportunities to try out and adapt these varieties, leading to a range of locally adapted varieties, very popular with farmers. Most farmers select their own seed, but there is also an informal seed market for local varieties, which has not gone through the formal certification process. There is also a market for recycled OPV seed. Some farmers sell their surplus seed to neighboring farmers (revealed during PRAs, Wekesa et al., 2003a), and many stockists sell seed from local varieties (stockist survey of 2000, unpublished data).

Although the private sector stopped providing OPVs for the region, their production is a fairly straightforward process. Moreover, they can be reproduced by farmers and distributed farmer-to-farmer for several cycles without substantial loss of yield potential or good agronomic characteristics. If this seed is produced in the farmers' environment in collaboration with the farmer, and made available to them at a reasonable cost, farmers are likely to buy and grow those varieties. Under these circumstances, and using cheap packaging methods, the cost of seed will be generally lower than the current commercial seed prices. Since farmers are willing to adopt new cultivars when they offer tangible benefits and seed is reasonably priced (Dowswell *et al.,* 1996), this would allow them to substantially increase their production. Seed availability at the right time and cost has been a hindrance to the adoption of improved varieties in the region.

OBJECTIVES

Therefore, a seed production activity was started on an experimental basis in the coastal region of Kenya, to bring affordable maize seed within easy reach of the farmers, as an alternative to commercial seed production. This activity was carried out using a group approach more than individual, where farmers were involved from land preparation up to packaging and seed distribution. Three preferred open pollinated varieties were included in the project plan and planted according to where demand was expected to be highest.

This pilot project analyzed the potential of community seed production. It aims to study how improved seed of preferred open pollinated varieties can be availed in the region at a fair price, appropriate time and convenient place in the quantities needed and in manageable units. It also studies the transfer of recommended management package of the maize crop from planting to storage of harvested produce, and introduction of maize seed production in the area as an enterprise.

MATERIALS AND METHODS

The project's initial goal was to produce only Coast Composite, the popular OPV whose production was discontinued by KSC. The Intellectual Property Rights (IPR) of this variety belong to KARI, who developed it in the early 1970s. The project followed a two-stage approach: first pre-basic and basic seed was produced on-station, followed by mass production by farmers.

In the first stage (long rains of 2000), the pre-basic and basic seed of Coast Composites were produced on plots of 0.25 hectares each on-station during the long rains. The selection pressure was higher for the basic seed production than during the commercial seed production. The purpose of producing pre-basic seed is mainly to rejuvenate, increase the quantity of seed and store it for later use. Its selection criteria or higher than for the other types. In the pre-basic seed plot, 500 ears were selected according to the selection criteria mentioned below. These were then harvested and preserved separately. Basic seed (American terminology adopted by Kenya, corresponds to the British term "foundation seed") is used to produce certified or commercial seed (Government of Kenya, 1999, p. 63), and is subject to less selection pressure. The ears from the basic seed plot were threshed and seed was bulked. This was to be used by the following seasons' commercial seed producers. All activities in the first stage were executed by KARI's scientific and technical staff in Mtwapa.

In the second stage (long rains of 2001), basic seed was used to produce commercial seed in five different sites: four in Kilifi district and one in Kwale district (Table 2). Farmer selection, characterization, adoption and impact monitoring was carried out by the socio-economist, using PRA techniques. The selected farmers were already selling seed of advanced generations of the commercial PH1, PH4, Coast Composite and the local varieties in the area. For this project, a total of 4 ha was planted. This was more than initially planned, due to the great interest in the activity as expressed during the PRAs. However, in one farm at Ribe (Kilifi), the planted seed was eaten by rodents and replaced by local varieties Mengawa and Mungindo. These varieties had been subjected to some genetic improvement on-station, and sufficient seed is stored and maintained in the KARI station of Mtwapa. The fieldwork was done by farmers, with technical support and backstopping by KARI scientific staff and local extension agents.

In total, three varieties were planted on 4 ha on 6 farms: 3.5 ha in Coast Composite, 0.25 ha to Mungindo and 0.25 to Mengawa. The production, management and selection criteria were the same in all the activities only that selection pressure was low.

Coast Composite is the most popular open pollinated improved variety at the coast. It is of medium maturity (140 days), white and flint (Table 3). Mungindo and Mengawa are popular local varieties, also flint. Both are white but Mengawa has a purple cob, husk and tassle, and has some deep purple grains on most cobs. These local varieties are early to medium maturing (110 days), they are more resistant to field and storage pests, relatively more resistant to MSV, tropical rust, and blights. The three varieties, when roasted, taste sweeter than commercial hybrids.

On the station, and in Ribe and Mtepeni, land was prepared using tractor drawn implements, consisting of a disc harrow followed by a disc plough. Animal traction was used on the other sites. Planting was done by hand at all sites, with a spacing of 75 cm between rows and 25 cm between hills. Two seeds were planted but were thinned back to one plant with compensation, to generate a plant density of 65,000 plants/ha. Soil pest control was done using Furadan 3G at the rate of 2.5g per hill.

Two types of fertilizer were used: diammonium phosphate (DAP) was applied one week after germination at the rate of 100 kg/ha, and calcium ammonium nitrate (CAN) was applied in 2 doses of 150kg/ha: at three weeks and at seven weeks after germination (after the first and second weeding). Thinning was done three weeks after germination, allowing two plants per hill in the event of complete failure of a hill. Stem borers were controlled using Bulldock 0.5% G (Beta cyfluthrin 0.5%g/kg), applying a pinch or a brief shake into each maize whorl (12-16 kg/ha) twice: at three and seven weeks after germination. Weeding was done three times in each site: using animal traction in Mtsengo and Kikoneni, by hand at all other sites.

Harvesting was done by hand, carefully picking the selected ears according to the selection criteria mentioned below. The plants to be harvested for seed had been left with their tassels on, while the rejected plants had been cut above the ear. Five hundred ears were selected to form foundation seed for each location. Threshing was done by hand. The 500 seed ears per site were preserved separately while the commercial seed ears were threshed in bulk in both cases leaving about 2 cm to the top and bottom of the ear. These materials were sun dried to moisture content of 13-15 % on average. All seed was treated using Actellic Super against storage pests. It was viewed necessary to use non-toxic drugs to human beings at this level of seed production.

Selection criteria used included maturity, vigor, plant and ear height, diseases, husk cover, lodging rot, and seed texture. Plants that flowered 55-60 days after germination were selected for seed production. Very early and late plants were cut above the ears and rejected. Vigorous plants were favored in the selection process, and plants with heights of 2.8 to 3.2m with medium ear placement were selected. Very tall and short plants with high ear placement were rejected. Plants were also selected for resistance to MSV, the disease of major concern in the region. Other diseases like *Puccinia polysora* rust and *Descheria maydis* affect the crop at an advanced stage and can be controlled with fungicides. All ears that had bare tips or poor husk cover were selected against, and tight husks and droopy ears were favored. Plants with broken stalks, lodged roots, and rotten ears were discarded. Rotten ears were equally discarded. Finally, ears with very dent texture were rejected.

Initially, the project intended to pack seed in 1 kg paper bags for distribution and sale. However, once farmers were aware seed was being produced, they came to buy in bulk on the spot. Since marketing and sales were not a problem, packaging was not necessary.

RESULTS

At the KARI station in Mtwapa, pre-basic and basic seed of coast composite was produced that had been improved on-station. For pre-basic seed 500 ears of each variety were selected, harvested and preserved. Three other plots for basic seed of the three varieties were harvested and 50 kg of basic seed was preserved. The materials selected were mainly flint.

On farm, 2.8 tons of seed were produced on 4 ha. Apart from this commercial seed, 500 plants in each site were selected for pre-basic seed, and stored at the Mtwapa KARI station. Moreover, grain from the rejected plants was consumed as food. Only the commercial seed was sold, at 100 KSh/kg. This was substantially cheaper than the going price of hybrids at 140 Ksh/kg, which created a large demand. All seed was sold on the spot, immediately after harvest, in bulk. Demand was larger than supply, and farmers expressed an interest in continuing this activity. The profits from the sales went to the seed producers. Inputs such as fertilizer and pesticides were provided by the project.

No detailed records on inputs and outputs were kept, preventing a thorough economic analysis. Still, the available cost and revenue data provide some useful insights. The total

Table 3. Economic analysis of community seed production

	Outputs and production factors	Units	Value[a] (Coast, 2001)	Value[b] (Drylands, 1998)
Revenue	Seed production	kg	4,000	
	Area used	ha	4	
	Yield obtained	kg/ha	1000	1,513
	Sales price for seed	KSh/kg	100	36.5
	Total revenue of project	Ksh	400,000	
	Revenue/ha	Ksh/ha	100,000	55,253
Costs	Fertilizer: Diammonium phosphate (DAP) and Calcium Ammonium Nitrate (CAN)	Ksh/ha	5,900	4,375
	Pestides (only Bulldock at the coast)	Ksh/ha	1,120	2,298
	Weeding	Ksh/ha	300	
	Land preparation	Ksh/ha	1,500	
	Labor	Ksh/ha		914
	Total production costs per ha	Ksh/ha	8,820	8,867
	Total production cost/kg of seed	Ksh/ha	12.6	5.9
	Treatment for storage (0.55 g/actellic/kg)	Ksh/kg	0.32	
	Grain price (Mombassa, average 2001 price)	Ksh/kg	13	
Cost	Total project cost	Ksh	260,000	

a Estimation based on observations during the project
b Muhammad et al., 2003., adjusted for an estimated 11% inflation, as calculated from the Consumer Price Index, (Central Bureau of Statistics, 2002)

external financing of the project was 260,000 Ksh, mostly for agricultural inputs and travel allowances. The project did not provide for salaries of project collaborators or labor for the farmers. In total, 2800 kg of seed was produced, and it was sold at 100 Ksh/kg, a total of 280,000 Ksh. Therefore, if the real costs of labor and salaries would be included in the analysis, total costs would clearly be larger than the revenues.

At the farmer's level, total costs of the seed production amount to 8,820 KSh/. This is very similar to the seed production cost for OPV in a project in the drylands, estimated at 8,867 (Muhammad et al., 2003). Seed production yields at the coast, however, were only 700 kg/ha so the production cost amounts to 12.6 Ksh/kg, versus only 5.9 in the drylands. With a price of 100 KSh/kg at the coast (as compared to 13 KSh/kg for grain), the activity is economically feasible. In the drylands, the sales price of improved maize seed was only 36.5 KSh/kg, but because of the higher yield the activity was still economically feasible.

DISCUSSION AND CONCLUSIONS

The project succeeded in its goal, the production of improved maize seed at the community level, even producing more than the planned 3 ha. The three objectives were also met despite the rodent problem at Ribe. Improved maize seed of preferred open pollinated varieties in the area were availed at a fair price, appropriate time and convenient place in the quantities needed and in manageable units. The improved versions of the preferred maize seed in the area were produced within the farmers' environment, and collaboratively with the farmers, and then made available to them at a reasonable price. In the next season, it can be expected that the farmers will plant an increased amount of land to varieties with a good yield potential and hence increase their production. Farmers were willing to adopt new cultivars when they were offered tangible benefits and reasonably priced seed. This exercise of working collaboratively with farmers introduced maize seed production in the area as an enterprise. The seed produced from varieties within the target ecology will provide locally adapted improved varieties at an acceptable price.

In the next cycle of seed production, KEPHIS will be involved in the inspection of seed to certify seed quality at the community level. Certified basic seed of the three varieties will be sold to any interested seed producer in the region to be able to make the process sustainable. With the realization that seed is being sold whether certified or not among farmers, there is a need to train local seed producers on issues of seed production and storage to ensure seed quality. Future seed producers should consist of progressive, innovative and capable producers whose farm location provides good isolation to ensure seed purity.

At its current level of benefits and costs, the project is not cost efficient. The purpose of public research is to produce technologies that are public goods for use by farmers and consumers. The public sector should focus on those activities, which are not interesting to the private sector, especially those that are imperfect private goods. OPV seed falls in this category: once sold, the farmer can reproduce the seed and pass it on to other farmers. The seed company cannot prevent recycling of this seed in future years or by other farmers. Still, research funds should be allocated where the return is the highest. The experience of this project shows that farmers are able and willing to produce improved OPV seed locally at 100 KSh/kg. To make such a project more cost effective, costs need to be cut and more seed need to be produced to reach more farmers. Given the large demand for improved OPV seed, the project should also be able to recover more costs by charging for the basic seed as well as the agricultural inputs.

On the policy side, alternative seed production systems need to be explored that respond more to the needs and current practices of farmers. Currently, requirements for the production of certified seed are prohibitively expensive for the small-scale producer, and the market is too small for a large-scale producer. Consequently, improved OPV maize seed is no longer produced at the coast, contrary to popular demand. Responding to this market failure, farmers do produce and sell seed through informal channels. It should therefore be analyzed how these informal channels connected to formal research, using improved material owned by the regional maize program (such as Coast Composite) or by improving local varieties as in this project. The establishment of a new seed category, below the requirements of certified seed, but using germplasm and technical support from the regional maize research program, seems promising. In order to develop a proper category, the benefits and costs of alternative regimes need to be analyzed. In particular, the cost of production of community and individual seed production needs to be understood better, as well as the demand for seed of improved varieties.

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TRADE-OFFS BETWEEN INVESTMENTS IN NITROGEN AND WEEDING: ON-FARM EXPERIMENTATION AND SIMULATION ANALYSIS IN MALAWI AND ZIMBABWE.

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ABSTRACT

When household resources to invest in fertilizer and labour (for weeding) are limited, the important question for a farmer is which of these alternative investments offers the best return. Information and insights pertaining to this question are generally not well known by researchers, extension agents or farmers. This paper reports maize response in farmer trials in Malawi and Zimbabwe and complementary results of a simulation analysis that examines the trade-offs between N and weeding investments taking seasonal variations into account. Participatory farmer trials provided inconclusive results where biophysical and management variations between farms made interpretation of results difficult. Simulation analysis provided a more straightforward result, and showed that a single weeding can provide roughly the equivalent grain returns as a bag of ammonium nitrate. However, the experimental and simulation analysis show that actual return is highly variable depending on a range of factors, including seasonal rainfall, soil fertility, weed pressure and overall farm management.

Keywords: Modelling, mother-baby trials, N fertilizer, participatory research, , simulation, weeding.

INTRODUCTION

It is somewhat axiomatic that weed competition is a major constraint for crop production in smallholder farming systems where chronic shortages of capital, labour and draught power lead to inadequate weed control in crop lands (Ellis-Jones and Mudhara, 1995, Shumba 1984). However, the need to control weeds is well understood by smallholder farmers in sub-Saharan Africa and is widely practised using manual and mechanical methods (Chatizwa *et al*. 1999). The increasing numbers of poorly weeded crops post-flowering is indicative of a growing labour shortage within these farming systems (Ryan and Spencer, 2000) and already a sizable body of research exists on identifying mechanical and chemical methods for more effective and timely weed control (Mabasa *et al* 1999, Twomlow *et al* 1999, Chivinge, 1984).

The benefits of applying N fertilizer to improve crop yield is also well known by farmers, although rarely practised at recommended rates, if at all, mainly because of capital constraints (Ahmed *et al* 1997). However, when household resources to invest in fertilizer and labour (for weeding) are limited, the important question for a farmer is which of these alternative investments offers the best return. Information and insights pertaining to this question are generally not well known by researchers, extension agents or farmers.

Scenario analysis using simulation modelling has shown that investment in weeding could be equivalent to investing in 1 bag of N fertilizer (ammonium nitrate), by removing competition by weeds for soil water and native soil N (Keating *et. al*., 2000, Dimes 2000). Using the results of this analysis, ICRISAT in collaboration with NARES partners in Malawi and Zimbabwe conducted a series of on-farm, participatory trials to test low rates of N fertilizer applied to maize and interaction with weeding frequency. This paper reports maize response in farmer trials in Malawi and Zimbabwe and complementary results of a simulation analysis that examines the trade-offs between N and weeding investments taking seasonal variations into account.

MATERIALS AND METHODS

Since 1997, ICRISAT and NARES partners in Zimbabwe and Malawi have been using the participatory Mother/Baby Trial approach to evaluate 'Best Bet' options for soil fertility management (Snapp, 1999). The experimental data reported for this study are from a sub-set of baby trials to evaluate N x weeding interactions at low rates of N fertilizer (Muza, 2000). Monitoring of soil, crop growth, weed growth and climate was more intensive for the 10 baby trials reported here. The 'farmer' managed baby trials were monitored in each country during the 1999/2000 cropping season – 5 in Zimuto district, Zimbabwe, and 5 in Mangochi district, Malawi. The climate at each location is semi-arid tropical, with a uni-modal rainfall season from November to March. Long-term annual rainfall is approximately 620mm at Zimuto and 650mm at Mangochi.

Design:

At each location, baby trials consisted of 4 un-replicated plots. Treatments were maize at low rates of N fertilizer (N0, N18, N35) with 'normal' weeding frequency, and N18 with one extra weeding. For the purpose of the trials, 'normal' weeding frequency was assumed to be once in Zimbabwe, and twice in Malawi. The area specific fertilizer recommendation in Malawi is a topdress of 69kgN/ha (Twomlow *et al*, 2002), and in Zimbabwe it is 52kgN/ha (Ahmed *et al*, 1997).

Maize seed and fertilizer were supplied to farmers (SC401 and Ammonium Nitrate (AN) in Zimbabwe and MH18 and Calcium Ammonium Nitrate (CAN) in Malawi) and all N was applied post-sowing. In Zimbabwe, the 5 trials were farmer managed with respect to the timing and implementation of sowing, fertilizer application and weeding operations.

Table 1. Crop management and soil analysis data for farmer managed 'baby' trials in Zimbabwe and Malawi.

		Farm #1	Farm #2	Farm #3	Farm #4	Farm #5
Zimbabwe						
	Sowing	07-Dec	29-Nov	24-Nov	03-Dec	29-Nov
	Plants / m^2	2.3	2.3	2.2	1.8	2.7
	1st weeding (das)	17	62	29	37	45
	Fert. Appl (das)	39	77	51	49	47
	%OC (0-10 cm)	0.22	0.24	0.38	0.21	0.23
	pH(0-60 cm)	4.5	-	5.0	-	-
Malawi						
	Sowing	16-Dec	17-Dec	17-Dec	16-Dec	15-Dec
	Plants / m^2	3.4	3.4	3.1	2.9	3.4
	2nd weeding (das)	-	32	42	47	42
	Fert. Appl (das)	-	36	36	36	36
	%OC (0-10 cm)	0.83	0.93	0.93	0.95	0.92

das –days after sowing

Researchers applied the extra weeding treatment around silking, but otherwise only monitored the experiment. In Malawi, field staff assisted farmers with weeding operations and more than likely influenced the timing of sowing and fertilizer operations (see Table 1).

In Zimbabwe, trial areas were located in top-land fields some distance from the homestead, and treatment plots were 10m x 20m. Internal replication was achieved by sampling plots as 10m x10m subplots. In Malawi, trials were located close to homesteads and treatment plots consisted of 8 ridges with 8 planting stations (7.2 x 7.2m). There was insufficient crop stands for sampling replication.

Measurements:

Soil was sampled pre-sowing (Nov 1999) to rooting depth (60-150cm), post-sowing (Dec 1999), and at harvest (May 2000). Soil was analysed for $N0_3$-N (all dates) and %OC (pre-sowing). In Zimbabwe, weed biomass and weed cover (weed intercepts per 10 points on 1 m string within quadrats) were sampled just prior to weeding operations using two 1m x 0.5 m quadrats/subplot (i.e. 4 estimates per treatment). In Malawi, only weed cover (5 locations /plot) was sampled prior to weeding. Final maize biomass and grain yield was sampled using two 12m^2 areas bulked per subplot in Zimbabwe, and the middle 2 rows x 6 stations /treatment plot in Malawi.

At one farm in Zimbabwe and 2 farms in Malawi, the farmer's maize next to the experiments that received no fertilizer or manure was sampled for maize grain yield and weed biomass. In Zimbabwe, 2 areas (total 21m^2 each) were sampled pre-maturity – one where the farmer failed to weed, and another where one weeding had taken place. In Malawi, the farmer's maize had been weeded once and was sampled (13 or 19 m^2 total area) at maturity.

Not all trials were harvested. In Zimbabwe, Farm #4 trial was located alongside a bush land, and cobs were lost to vermin, while for #5, the farmer inadvertently harvested the trial. In Malawi, Farm #1 trial was lost to termite damage.

Statistics:

For Zimbabwe, data are presented as the mean and standard deviation of treatment responses in sampling subplots for the 3 individual farms harvested. For Malawi, treatment response and yield levels were similar across the 4 farms harvested and yield data are presented as mean and standard deviation across farms.

Simulation:

To put the seasonal response to weeding and N into a longer timeframe, the APSIM cropping systems model (McCown *et al* 1996) was used to simulate maize response to weeding frequency at 2 N levels (0 and 18N/ha). The analysis used climate records (1951-1998) for Masvingo (25km from Zimuto), Zimbabwe. The soil parameters used in the simulation corresponded to a shallow sandy soil with a PAWC of 60mm to depth 1 m and OC% of 0.8% in the 0-15cm soil layer. A moderate weed pressure (grass, 4 plt/m^2) was used for the simulated scenario. Planting date for maize varied with on-set of rainfall each season, and it was assumed that the first weed crop was sown and emerged with the maize. Following a weeding event (35 das weeds), subsequent weed germination was responsive to rainfall (5mm in 2 days).

RESULTS

Seasonal rainfall (Nov 1 – Apr 30) at the Malawi site was above average (821mm) and it was excessive at the Zimbabwe site (1,090mm). Table 1 summarizes crop management and soil analysis data for the 'farmer' managed baby trials. While Table 1 shows there is considerable variation in trial management by the farmers in Zimbabwe, the data suggest that field staff influenced management in Malawi, where interaction with farmers and field staff by scientists was less intensive and irregular. Grain yield response to experimental treatments for 3 farms in Zimbabwe is shown in Figure 1. There are observable responses to increasing fertilizer N inputs, but little response to the extra weeding applied at the lower N rate. Large differences between farms are evident in Figure 1 and are at least partly explained by the data in Table 1. For example, the low yields and little N response on Farm #1 reflect the low soil pH and stunted maize growth at this farm. The strong N response on farm #3 is consistent with the early sowing and weeding and low organic carbon levels on this farm, whereas the smaller N response on farm # 2 reflects its very late weeding and N application.

In Figure 1, the farmer's maize alongside the trial that

Figure 1. Maize grain yield response to nitrogen inputs and weeding frequency for 3 farms in Zimuto, Zimbabwe.

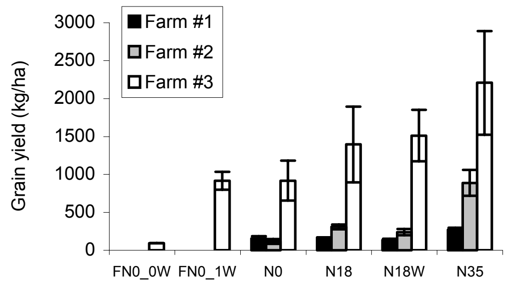
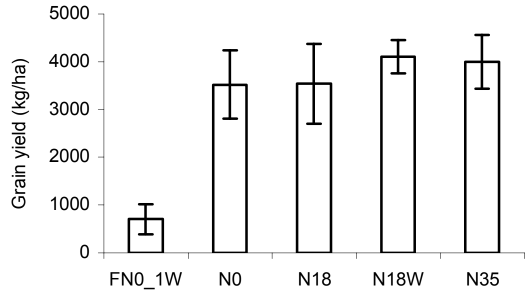


Figure 2. Mean (and std. dev.) of maize grain yield response to nitrogen inputs and weeding frequency on 4 farms in Mangochi, Malawi.



received 1 weeding (FNO_1W) has equivalent management to the control treatment (N0) in the experiment, and these show yields that are similar (Fig 1). By comparison, the farmer's maize receiving no weeding (FN0_0W) has drastically reduced grain yield, and for the weed pressure conditions of the field, the value of the 1st weeding is approximately 800kg of grain /ha. This is almost as much as the extra grain from the 35 units of N fertilizer applied in the experiment. It is also worth noting, that at least 30% of this farmer's field (approx 1 ha) received no weeding.

Mean grain yield response to treatments for the 4 farms in Malawi are shown in Figure 2. No N response is evident in the Malawi result, and grain yields are much higher than those in Zimbabwe. This is partially explained by the higher %OC levels (and presumably, labile nature of associated organic N) of the homestead fields used in Malawi (Table 1), the absence of waterlogging effects as was observed in Zimbabwe, and the higher plant populations. However, another contributing factor is possibly overzealous weed control by farmers and field staff. Field visits in late December and early March saw completely weed free conditions across all treatment plots.

At Farm #3 and #4, this was particularly obvious at the March visit when very high weed pressure was evident in farmer's maize alongside the trial. Having sampled the farmer's maize on these 2 farms, the value of an extra weeding (or was it more than 1?) is shown to be a staggering 2,300kg grain /ha. In the experiment, the value of the 3rd weeding applied to the N18 treatment is shown to be approximately 600kg grain/ha over the control, assuming no N response.

The simulated maize grain yield response to weeding frequency and N levels for a shallow sandy soil at Masvingo, Zimbabwe is shown in Figure 3. The results show a definite N x weeding interaction, with the response to a low input of N equivalent to 400kg grain/ha with no weeding, increasing to 750 kg grain/ha with one weeding. Averaged across N rates, the response to the 1st weeding is 500 kg grain /ha, which is comparable to the average response to 18 units of N/ha for the first 2 weeding regimes.

Interestingly, the simulated average response for the second weeding at both N levels is negligible. However, the standard deviations of simulated means are very large, reflecting the strong influence of rainfall variability on expected response. The maximum simulated benefit for the first weeding at zero N is 700 kg grain /ha, and with N applied it is 1,600 kg grain/ha. These are of a similar range to the estimates derived from the varying conditions of the field experiments (800 – 2,300 kg/ha).

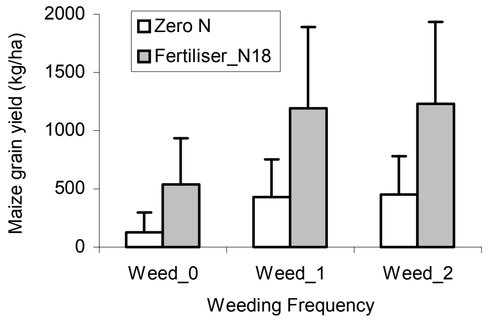
DISCUSSION

Through a combination of participatory field experimentation and simulation analysis, this study has provided estimates on the production returns to investment in weeding and small amounts of N fertilizer for smallholder farmers. In general, on a hectare basis, a single weeding can provide roughly the equivalent grain returns as a bag of ammonium nitrate, but the actual return is highly variable depending on a range of factors, including seasonal rainfall, soil fertility and weed pressure. While an economic analysis that includes the cost of labour and fertiliser inputs is yet to be done, for farm households where chronic labour shortages exist, this type of information could help farmers make decisions on allocating scarce capital resources between purchase of labour and fertilizer (Ahmed *et al*. 1997, Rohrbach, 1998). While the existence of so many poorly weeded crops adjacent to the trial sites is supportive of the general thrust of this current research, it is worth reflecting on possible reasons why the un-weeded fields exist.

One of these is the return on available labour from alternative options. For example, in the case of farmer #4 in Malawi, a cotton crop in the same field as the maize had also been neglected for purposes of weeding. While this farmer was healthy and active when visited, it was notable that he had livestock, and this was where he seemingly preferred to invest his time. Another reason is whole farm management to achieve the farmer's goals on food security. Generally, farmers prefer to plant all of their available land each year, as part of their risk management strategy to deal with unreliable rainfall patterns. Hence, some fields are planted by a farmer each year knowing that there will be insufficient labour to weed, but which may become a priority if the rainfall patterns and crop growth dictates. In other words, the research findings presented here may or may not be valuable to a farmer with weedy fields, depending on the circumstances. As with most research technologies, the real challenge is identifying the farmers and having the information available to those for whom it is relevant.

Simulated yields showed negligible benefits for the second weeding and this was also evident in the experimental results from Zimbabwe. This is at odds with recent weed research in Zimbabwe which found that a single weeding 4 to 6 weeks after emergence gave maize yields 40% lower compared to a crop receiving a weeding at 2 to 3 weeks, followed by a second weeding at 6 weeks after emergence

Figure 3. Simulated maize grain yield response to weeding frequency (zero, 1 and 2 weedings at 35 days after weed sowing) for 2 levels on N input for shallow soil at Masvingo, Zimbabwe.



(Twomlow pers. comm. ICRISAT/World Vision workshop, Nov 2000). However, these results are likely related to timing of the first weeding rather than the frequency of weeding, as Rao *et al*. (1989) reported data for a range of crops that showed lack of effective weed control during the first 20-30 days caused maximum yield losses in crops with a 100 day cycle.

Productivity payoff to alternative investments is not the only worthwhile result to be drawn from this study. Of equal significance are the methods used in the study, in particular the role that simulation played. In the first instance, trial design was changed based on simulation output. Initially the Mother/Baby trials were designed to examine low versus recommended N rates, but this was changed to a N x weeding design following a simulation analysis on the allocation of limited capital to alternative technologies and its effects on whole farm productivity and risk (Dimes, 2000(a and b)). Secondly, the participatory baby trial results were difficult to interpret and were inconclusive in quantifying the pay-offs to investment in weeding as opposed to N fertilizer. In fact, if the farmer's maize had not been sampled, only 2 of the ten trials provided any output that was in any way consistent with the objectives of the study. While a factor here was the limited number of farms sampled at each site, simulation analysis was able to provide a clear analysis of the trade-offs using climate, plant, soil and management data relevant to the experiments. The task ahead is to simulate the range of measured weed and plant growth responses for the on-farm trials themselves, so as to add further credibility for the simulation analysis and encourage similar applications that enhance the efficiency of soil fertility research in southern Africa and elsewhere.

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MAIZE LEAVES AS FODDER: THE POTENTIALS FOR ENHANCING FEED AVAILABILITY ON SMALLHOLDER FARMS IN KENYA.

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ABSTRACT

Dairy farming has been, and still is, highly rated by farmers on smallholder mixed crop-livestock farms as a major source of farm income and manure. The latter is a valuable input that is used to replenish the declining soil fertility status following continuous cropping. A participatory rural appraisal (PRA) of the coffee land-use system of Embu District in eastern Kenya identified that available feeds, including the residual stover after maize harvest do not meet all the needs of the genetically superior cattle breeds kept by farmers in the area leading to low milk production and consequently diminished income base. Farmer participatory constraints and gender analyses done during the PRA identified the use of maize leaves as an alternative and viable option for enhancing feed availability on smallholder farms where maize is traditionally grown as the main staple crop. The potential for exploiting the maize leaves from the local hybrids currently grown maize hybrids was initially tested through farmer managed on-farm research between 1996 and 1999 in which a total of 34 males and 22 females from within 34 households in Embu District participated. This was followed by an on-centre study in 2000 to further validate the nutritional contribution of maize leaves to dairy cattle. The broad objectives of the aforementioned research were: a) to determine the practicality of removing the leaves (defoliation), b) to determine the forage yield from the maize crop and c) to assess the effects of feeding the maize leaf-based diets on milk yield by dairy cattle. The results are discussed in this paper in relation to socio-economic and gender implications, and impact of maize fodder technology to dairy development in Kenya.

INTRODUCTION

The dairy cattle enterprise is important in the livelihood base of smallholder farmers principally due to its cash income generation. However, the current levels of production are lower than the expected potential of most breeds kept by farmers largely due to nutritional problems in terms of quantity and quality of feed (Abate *et al.*, 1987). As a result of increasing human population, cash and food crops occupy the bulk of the farms leaving little land for forage cultivation. For instance, in the coffee/tea land-use systems of Embu District, Napier grass, the main fodder, occupies only 20% of the cropped land (Franzel *et al*., 1996); it does not, therefore, meet the dry-matter requirements of the animals. The quantity and quality of manure is also affected. The inevitable result is that overall farm productivity drops. The development of appropriate interventions that in areas that allow for more efficient use of the maize crop as a source of fodder is considered as one viable option for increasing feed supply at the smallholder farms where maize forms the main staple cereal. Preliminary researcher-managed trials carried out in Embu District had shown that systematic removal of maize leaves (defoliation) at physiological maturity was a valuable source of fodder (Kayongo and Abate, 1982). However, the results from the previous studies were not exhaustive and did not fully take cognisance of farmer circumstances including aspects on socio-economic and gender implications of the maize defoliation technology. There was need to validate further these results under conditions that would allow farmers to be fully involved in testing the technology. It was on the basis of this that on-farm farmer participatory research was initiated within the coffee-dairy land-use system of Embu District.

Study area description

The project targeted farmers within the coffee/dairy cattle land-use production system of Embu District. The area generally has closely clustered farm homesteads with land holdings ranging in size from 0.4 to 4 ha, with an average of 1.5 ha (NAFRP, 1993). The population density is high ranging from 230 to 730 persons with an average of 450 persons per km^2 and bimodal rainfall is totalling approximately 1,200 mm p.a. The farming system of the area is predominantly mixed crop-dairy cattle farming. Although coffee is the main cash crop, over 85% of the farmers grow other crops mainly for subsistence use, the most important being maize which occupies ¾ of the area under food crops (Kiruiro and Muriuki, 1996). Over 98% of the farmers keep exotic or improved cattle breeds, mainly under the stall feeding (zero grazing) system. The predominant forage species planted is Napier grass, which is usually planted on the terraces or the edges of cultivated crop fields.

Study objectives

The broad objective of the study was to develop integrated and sustainable feeding systems based on the use of maize leaves for smallholder dairy farmers. More specifically, the study was to: 1) Assess the practicability of removing maize leaves from the maize crop, 2) Determine the forage contribution from the maize crop and grain yield, and 3) Assess the nutritive value of maize leaves through dairy cattle feeding experiments.

MATERIALS AND METHODS

Research approach

A participatory research approach was applied in implementing the project with farmers being actively involved in all stages of the research process right from problem identification and setting of the research agenda to dissemination of proven technologies. The following were the key steps to the research:

Validation of production constraints from a participatory rural appraisal (PRA).

A focused participatory rural appraisal (PRA), attended by 35 male and 25 female members from 35 households was carried out within the target area. The major objectives of the PRA were to identify:

1. constraints to dairy production and opportunities to overcome these ;
2. prioritise areas of interventions to alleviate these constraints;
3. socio-cultural factors that could affect the proposed research especially gender aspects.

It was recognized from the PRA that, among other factors, feed shortage remained a main limitation to milk production. Intervention measures aimed at optimising the use of the maize crop, the main staple crop in the study area, were suggested to offer the best options for increasing the feed supply. Thus, the maize would be a source of fodder while still providing the grain for human consumption. Farmers indicated that they generally used maize crop stover after crop harvest, but little use is made of the maize leaves while intact on the plant as the maize matures. The leaves fall off and decay as the plant senesces and are therefore wasted.

Farmer selection

For all on-farm research activities, farmers were selected on the basis of their interest to participate and their appreciation of the role the maize crop plays in providing extra feed to dairy cattle. Special efforts were made to include women's involvement by having both spouses (husband and wife) from all the households participating. A total of 34 households were selected represented by 34 male and 22 female farmers. Out of these, 16 households with 16 males and 12 female farmers participating were involved in the collection of detailed data on forage and grain yields from maize. A further 6 households (6 males; 6 females) were finally involved in a feeding experiment to determine the effects upon milk production from feeding the dried maize leaves.

Determination of forage and grain yields

The farmers selected had planted the common varieties under merely standard cultural practices (i.e. spacing of 75 x 25 cm between and within rows with two plants per hole). Designated areas of the cropped land were then demarcated measuring 8 m wide and 10 m long within which 4 rows of maize were used for data collection. The main maize varieties planted were H614, H625 and H511. Removal of leaves is started when the crop approaches physiological maturity (in practice, when the silk of the cobs turn dark brown) and entailed systematic removal of 2 leaves for the 500 variety and 1 leaf for the 600 varieties per plant every week starting with the lower leaves and progressing upwards. This represented about 70% removal of leaves from the plant. The yields of the maize leaves were determined by recording both the weight of the fresh leaves and later the dry weights after air-drying the leaves for 3-5 days on polythene sheet under shade. Samples of the fresh and air dried leaves were taken for Dry Matter (DM) determination. Dried samples of the leaves were sub-sampled for the determination of the chemical composition (DM, CP, NDF, ADF). Grain yields were measured by actual threshing of the grain. Samples of the grains were taken for drying in the oven at 150 ^{o}C for 48 hrs to determine the grain DM yield. Similarly, yields were recorded for the maize stover, and samples were taken for drying (60 ^{o}C for 72 hrs) to determine DM yields.

The research and extension personnel were mainly involved in taking the records of the yields of maize leaves and grain yields from the experimental plots. The farmers measured the same from the rest of the area planted with maize using spring balances so that the overall forage and grain yields on the farm could be quantified. They were also involved in giving feedback information on the practicability of removing the leaves and drying and implications on labour use. However, at least one weekly visit was made by both the research and extension staff to discuss with farmers the extent of implementation of the research.

Feeding experiments

On-farm: The experiment involved 3 lactating grade cows from three different farms. Thus, a 3 x 3 Latin-square design with a diet change-over arrangement. The cows selected were at their 4th-5th month of lactation. The rationale was to compare the standard feed (mainly comprising of Napier grass and banana residues) with diets in which dried maize leaves were offered with dairy meal or with additional forage from calliandra *(Calliandra calothyrsus).* The diet layout was as follows:

Diet A: Farmers standard feed
Diet B: Farmers standard feed + 5 kg.d^{-1} maize leaf meal (MLM) + l kg.d^{-1} dairy meal
Diet C: Farmers standard feed + 5 kg.d^{-1} MLM + 3 kg.d^{-1} fresh calliandra leaves

Each of the prescribed diets in the experiment was offered for a period of 12 days before changing over to the other diet with 5 days being the adjustment period and 7 days collection of data on milk yields. Farmers took the leading role in the management of the on-farm feeding experiment, which included taking daily measurements on the milk yield and amount of calliandra leaves on offer as per experimental design. A simple experimental design was used but the rationale was to allow the farmers to make a rational comparison between their standard practices with the new technologies under their circumstances using, in all cases, simplified procedures including statistical designs well discussed with farmers prior to the start of the experiment. The rest of the farmers not participating also made records on the milk production following the feeding of maize leaves.

On-centre experiment

A complementary feeding experiment was carried out later at the Regional Research Centre, Embu following the on-farm experiment. The objective was to further evaluate the effects of replacing the commonly used commercial supplement (dairy meal) with mixtures of diets containing varying amounts of dried maize leaves, maize germ, fish meal and commercial minerals, on milk yields of 3 lactating cattle grazing on Rhodes grass pastures. A 3 x 3 Latin-square design was adopted as for the on-farm experiment. The composition of the diets is given in Table 1.

Table 1. The physical composition of diets (%, on "as is" basis) in experiment 2.

Diet D	Diet E	Diet F
I00 Dairy meal 2 Minerals	50 Dairy meal 30 Maize leaf meal[a] 10 Maize germ 10 Fishmea 2 Minerals	25 Dairy meal 53 Maize leaf meal[a] 12 Maize germ 10 Fishmeal 2 Minerals
CP = 162 g.kg^{-1} DM	CP = 153 g.kg^{-1} DM	CP = 152 g.kg^{-1} DM

[a] dry leaves were ground using local maize milling plant.

Each diet was prepared in batches of 25 kg every time by thoroughly mixing on a concrete floor. A sample of each diet was collected after every batch for chemical analysis. A sample of the pasture was also collected each period. The diets were offered twice per day just before milking (6:30 a.m. and 3 p.m.) in two equal proportions. Each diet was offered for a period of 10 days; 5 days for adjustment followed by 5 days of data collection. Animals were grazed on Rhodes grass pasture between 8:00 a.m. and 3:00 p.m. every day. They were drenched before the start of the experiment. Milk records were kept for each milking.

Statistical analysis

Data on milk yield from the two experiments was subjected to statistical analysis according to the General Linear Model procedures of SAS (1996).

RESULTS AND DISCUSSION

Forage contribution of maize leaves

Based on farmer participatory evaluation involving male and female farmers, it was noted that the aspects involving removal of maize leaves and subsequent air-drying of the leaves were both found to be practical and gender friendly. The activities did not impinge much on labour or conflict with other activities at the farm during defoliation but formed part of the regular labour.

These aspects were therefore compatible with farmer circumstances. One important aspect for which farmers put a lot of concern was the impact of the defoliation technology in terms of forage contribution. From the data collected on-farm the contribution of maize leaves and resultant effects on grain yield were determined. The results are summarised in Table 2.

The two hybrid maize varieties, H614 and H625, had higher yield of forage than H512 due to their physiological advantage that results in more leaves that are heavy. However, to realise the amount of forage derived from the different maize hybrids the recommended practices for planting maize should be adopted. These include proper

Table 2. Mean yields of maize leaves, maize stover and grain (kg DM/ha or as stated)[1]

Maize type	Defoliated maize leaves		Maize stover		Maize grain	
	Fresh	Air-dried	Control[2]	Defoliated	Control	Defoliated
H614	4940	1500	2760	2320	3780	3580
H625	5330	1730	4340	3380	4050	3780
H511	4820	1315	4680	4500	2560	2490
Mean	5030	1510	3920	3400	3460	3280

[1]Mean adjusted yield determined from 16 farms (16M;12F) and 6 farms (6M;6F), respectively. Variety fresh weights for maize H614, H625 and H511 ranged from 5075-5200; 5410-5560; 4510-4950, respectively.
[1]Represents the yields from the non-defoliated maize

Table 3. Qualitative characteristics of maize leaves relative to other common feed-stuffs

Chemical composition:				
Maize leaves[a]				
Crude protein (CP), g.kg-1 DM	112	110[b]	104	- Current study
NDF, g.kg-1 DM	-	(103)[c]	680	
ADF, g.kg-1 DM	-	-	294	
Maize leaves:		-		
CP, g.kg^{-1} DM			120	Kayongo and Abate (1982)
In-vitro digestibility of organic matter), g.kg.$^{-1}$ DM	-	-	530	
Calcium (%)	-	-	0.46	
Phosphorus (%)	-	-	0.23	
Maize leaves:				
Intact on stalk at normal harvest time,				
CP, g.kg^{-1} DM			52	-Current study
Maize stover:				
At normal harvest time,- CP, g.kg^{-1} DM			43	- Current study
Dairy meal- CP, g.kg^{-1} DM			162	Current study
Napier grass (mature)				
CP, g.kg-1 DM			65	Mwendia *et al* (1997)
In-vitro digestibility of organic matter), g.kg.$^{-1}$ DM			550	
Calcium (%)			0.19	
Phosphorus (%)			0.18	

[a]Derived from pooled sample of H614 and H625 maize varieties.
[b,c] Values for leaves after 5 days air-drying and air-dried leaves stored for 1 year under shelter, respectively.

spacing and more importantly application of fertilizer as done by farmers in this study to ensure healthy growth of the crop and therefore bigger and heavier leaves. The daily dry-matter (DM) requirements for a cow weighing 350 kg is about 10-12 kg (Kiruiro *et al*., 1996). Assuming that the leaves contribute about 5 kg or 1/3 of the daily DM requirements of the cow with the rest from Napier grass, then the total amount of air-dried leaves of 1,510 kg per ha (Table 2) could be used to feed a cow for 130 days (about 4 months). If such leaves were not removed, they would normally go to waste as they senesce and drop off later to decay in the soil. Maize leaves can therefore make a significant contribution to the feed budget of the farm thereby safeguarding the farmers against feed shortages. Despite the forage advantage, defoliation was found to lead to about 5% loss in grain yield per ha. Farmers found the system very attractive because the loss of income from the 180 kg grain lost was far less than the cost of procuring other feed-stuffs from outside the farms during the dry season. The overall farm productivity was therefore enhanced (see economic data).

Nutritional attributes of maize leaves

Chemical composition: One major limiting nutrient to milk production at farm level is the crude protein (CP). Most of the available forages offered fall short of the required CP level and it is now widely acknowledged as the main factor leading to low milk yield. The relative amount of CP and other nutrients for maize compared to other feed-stuffs is shown in Table 3.

It is also observed that maize leaves are relatively high in CP and digestibility. Similarly the levels of calcium and phosphorus. Apparently, air-drying and subsequent storage of dried leaves for over one year under shelter had little effect on CP content of the leaves (Table 2) suggesting that leaves can be stored for use during adverse feed shortage periods. A CP content of 70-85 $g.kg^{-1}$ DM is considered as the least necessary to maximize rumen microbial activity and therefore digestibility of fibre-rich diets (Smith *et al*., 1980). Removal of leaves for direct feeding or drying confers a nutritional advantage compared to leaving leaves intact until harvest time. The quality of the leaves is adversely affected if left intact on the maize plant; a loss of about 50% in CP can occur (Table 3). Defoliation therefore offsets the loss of a valuable feed resource which would otherwise be lost since most leaves senesce and drop off to be later composted into the soil.

Milk production potential of maize leaves: Milk is an important product from the dairy enterprise and ultimately determines the family income levels. One significant attribute of a feed is its ability to promote increased milk yields. Maize leaf-based diets in the current study were generally found to promote better performance than the normal diets offered by farmers. The results of the two feeding experiments are shown in Tables 4 and 5.

It is shown for instance that Diets B and C in the on-farm study containing similar amounts of maize leaves and additional dairy meal or fresh calliandra leaves gave 36 and 18 percent more milk than the normal diet (Diet A), respectively ($P<0.05$). The superiority of diets containing maize leaves was similarly noted in Experiment 2 in which Diet D consisting of dairy meal was not significantly ($P>0.05$) different from Diet E containing 50 percent substitution of dairy meal with maize leaves (Table 5). The results suggested that dairy meal could be substituted up to 50 percent with locally formulated diets containing ground maize leaves without affecting milk yield. A quantitative and qualitative shortage of feeds has been a major impediment to improving dairy production in Embu District and indeed the whole of Kenya. The increased feed on offer coupled with a relatively high protein content and digestibility of diets containing maize leaves could possibly be responsible for the improved milk yields. In addition, the relatively high Ca and P levels of the leaves (Table 3) contribute since the two minerals are important dietary requirements for lactating cattle (ARC, 1980).

Table 4. The mean milk yield ($kg.d^{-1}$) for the on-farm cows fed different diets based on maize leaves (Experiment 1).

Farmer	Diets		
	A	B	C
Farmer 1	13.8	17.1	16.3
Farmer 2	8.2	15.9	10.1
Farmer 3	11.9	13.4	13.8
Mean[+]	11.3^a	15.5^c	13.3^b
SE= 0.5471	CV= 8.57%		

[+]Means represent data collected for 7 days following an adjustment period of 5 days.
[a]Means with different letters differ significantly ($p< 0.05$).

Socio-economic benefits from the maize defoliation system

A partial budget analysis was carried out in order to quantify the economic benefits of the interventions based on maize leaves feeding. The important elements considered were the main costs including the opportunity costs due to loss in maize grain following defoliation, yields of maize leaves and milk, and returns from sale of outputs (milk).

The opportunity cost of labour was ignored in the analysis since both male and female farmers indicated that the labour demand for defoliation was generally low and did not significantly conflict with other activities at the time of defoliation. The economic benefits from two systems where dried maize leaves are incorporated in dairy cattle diets,based on results of Experiment 1 above, are presented in Table 6. However, a 15% field loss in the forage yield from leaves given in Table 2 has been assumed in the calculation of economic benefits.

Table 5. The mean milk yield ($kg.d^{-1}$) for the on-centre pasture-grazed cows fed on different feed supplements (Experiment 2).

Farmer	Diets		
	D	E	F
Cow 1	7.3	7.4	6.0
Cow 2	9.3	9.9	7.8
Cow 3	11.4	10.6	10.8
Mean[+]	9.3^a	9.3^a	8.2^b
SE= 0.1020	CV= 4.42%		

[+]Means represent data collected for 5 days following an adjustment period of 5 days.
[a]Means with different superscript differ significantly ($P< 0.05$).

Table 6. The comparative net benefits from two feeding systems involving use of maize leaf meal with dairy meal (Dm) or calliandra[a].

Variable	Defoliated system	
	MLM + Dm	MLM + Calliandra
Mean yield of leaves per acre (air-dried) (kg)	520	520
Feed days from 520 kg dried maize leaves at 5 kg per day (days)	104	104
Cost of defoliating 520 kg @ kshs 15 per 5 kg leaves[b]	1560	1560
Mean grain loss per acre (kg)	110	110
Cost of lost grain (prevailing cost @ kshs 9 per kg) ***	990	990
Cost of extra dairy meal for 1 kg/day x 104 days @ kshs 14 per kg	1456	-
Cost of harvesting 3kg calliandra/day for 104 days @ kshs 0.50 per kg[c]	-	195
Extra milk (kg) produced in 104 days from daily offer of 5 kg maize leaves per cow (kg)[d]	437	208
Extra returns from milk @ kshs 18 per kg	7862	3744
Total cost (kshs)	4006	2706
Net benefits (returns less costs) (kshs)	3856	1038
Return to extra labour (kshs/hr)	52	167

[a]Unless specified differently, all estimates were determined from data in Table 2 and are based on a mean plot size of 1 acre per farm.
[b]This covers costs on harvesting-2 adults take 1 hr to prepare 10 kg air-dried leaves @ a cost of kshs 30 (determined from on-farm studies).
[c]Harvesting 1 kg calliandra costs kshs. 0.50 according to Kiruiro *et al*. (1996).
[d]Based on mean yields obtained from Experiment 1.

The use of maize leaves in either of the two systems confer extra returns although the returns to capital (income per cow) and labour (income per hour spent) could be higher for the system involving dairy meal. However, considering that dairy meal is costly and the cost of producing calliandra is generally low (Kiruiro *et al*., 1996), then the option involving calliandra fodder tree with maize leaves appears more sustainable. Availability of feed within reach will particularly benefit women whose involvement in dairy cattle management includes fetching feed sometimes from far areas. The component technology on maize defoliation could offer even higher returns to the dairy enterprise through savings made by reducing purchases of other feeds such as maize stover occasionally done during the dry season. In addition, the extra manure produced, presumably of better quality due to incorporation of leguminous fodder trees, could be used to improve crop production and ultimately overall farm productivity.

Considering that land devoted to other fodder crops is unlikely to be expanded, intensive use of available feed resources including maize leaves offer economically viable and sustainable options for enhancing dairy production. Rigorous efforts are being made to encourage farmers to adopt the maize defoliation technology. A critical feed shortage, ready availability of family labour and low household resource endowment in terms of access to alternative feed options is expected to create impetus for adopting maize leaves fodder technology.

CONCLUSION

The on-farm research project has demonstrated that under farmer circumstances, at least within the study area, it is practically feasible to improve feed availability on smallholder farms by utilising the leaves from the maize crop without adversely affecting grain yield. Thus maize, the most commonly grown staple cereal, can make a significant contribution towards meeting part of the dairy cattle nutrient requirements. This is significant considering the fact that feed shortage remains the major production constraint. Results have demonstrated that maize leaf technology can impact positively on the entire household members from the increased milk for sale to earn extra income or for domestic consumption. However, women are likely to benefit more as they are increasingly being involved in managing the dairy sub-enterprise. Based on the household impacts, the technology on the use of maize leaves as fodder is likely to have significant contribution to the development of the dairy sector, which in Kenya plays a major role in the livelihood of the smallholder farmers. The developed technology holds great promise, particularly for those areas where maize is extensively grown especially in Central, Western and Rift Valley Provinces.

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TRANSACTION COSTS AND SMALLHOLDER PARTICIPATION IN THE MAIZE MARKET IN THE NORTHERN PROVINCE OF SOUTH AFRICA

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ABSTRACT

Smallholder maize farming is characterised by low levels of market participation. The objective of the paper is to determine the role of transaction costs in participation of smallholder farmers in maize markets. Transaction costs differ among households due to asymmetries in access to assets, market information, extension services and remunerative markets. The selectivity procedure is applied to determine the factors (related to fixed and variable transaction costs) influencing the decision and level of participation in maize markets by a sample of 157 smallholder farmers in the Northern Province of South Africa. The results support previous studies that existence of transaction costs constrains households from selling. The results suggest that an increase in the arable land by a hectare will lead to an increase in maize sales by R52. However, the sales would decrease by about R77 for every additional household member in the household. The results also suggest that an increase in livestock value by R100 leads to an increase in maize sales by about R1.56. The other positive factors include pension earnings, average education, ownership of a tractor or vehicle, proximity to markets, conditions of the road and contacts with extension officers. The non-farm income, the gender and age of the household head, as well as the combined effect of proximity to town and road conditions were negative but not significant in terms of influencing participation in maize markets. The study recommends the need for policy and institutions to support access to productive assets (such as land) and markets.

INTRODUCTION

Several studies (Van Rooyen, Vink and Christodoulou, 1987; Kirsten *et al*, 1993; and Kirsten, 1994) have in the past referred to the need for structural reform if participation of black farmers in the commercial agricultural sector is to be enhanced. Commercialisation of subsistence agriculture implies an improved ability to participate in output markets. In the developing areas of South Africa, like in other developing countries, smallholder farmers find it difficult to participate in markets because of a range of constraints and barriers reducing the incentives for participation. These may be reflected in hidden costs that make access to markets and productive assets difficult. They also include lack of assets, market information and training. An added factor is that farmers are located far away from the market and have poor access to infrastructure.

Transaction costs, that is, observable and non-observable costs associated with exchange, are the embodiment of access barriers to market participation by resource poor smallholders (Coase, 1960; Delgado, 1999; Holloway *et al*, 2000). These include the costs of searching for a trading partner with whom to exchange, the costs of screening partners, of bargaining, monitoring, enforcement and, eventually, transferring the product to its destination (Jaffee and Morton, 1995; Hobbs, 1997). Transaction costs, however, do not only include the costs of the exchange itself, but also encompass costs associated with the reorganisation of household labour and other resources in order to produce enough for the market.

The main objective of this paper is to investigate the extent to which transaction costs affect participation in maize markets by smallholder farmers in the Northern Province of South Africa. The identification of these transaction cost factors could assist in identifying policy interventions and/or institutional innovations to alleviate constraints and improve the ability of small-scale farmers to be part of the commercial agricultural economy. Transaction costs differ between various households due to asymmetries in access to assets, information, services and remunerative markets (Delgado, 1999). The specific objectives are to identify factors that influence the decision of smallholder farmers to participate in maize markets, to identify factors that could contribute to increased participation in agricultural output markets, and to make recommendations to support policy.

The main hypothesis of the study is that farmers facing lower transaction costs will participate more in the agricultural markets than those farmers facing high transaction costs (Coetz, 1992; Omamo, 1998; Staal, Delgado & Nocholson, 1997; Key *et al*, 2000). These transaction costs reflect the character of the market, but are mainly embedded in household characteristics and their economic environment. As a consequence farmers respond to market barriers by opting for alternative market institutions (Gabre-Madhin, 1999; Holloway *et al*, 2000).

MATERIALS AND METHODS

The study employs selectivity models to identify factors of market participation. The selectivity models involve two-step estimation similar to the Heckman's two-stage procedure. Firstly, probit models are estimated to determine the factors affecting the decision to participate. Then, heckits (OLS accounting for selectivity bias) are estimated in the second stage to estimate the significant factors contributing to the level of participation. The two-step selectivity procedure is similar to the tobit model decomposing the probability to participate and the level of participation.

The analysis is based on the information collected in

Table 1. Distribution of research sites and respondents

Region	No of sites	No. of respondents	No of group discussions
Northern	6	24	4
Lowveld	3	18	2
Central	4	29	4
Southern	6	57	2
Western/ Bushveld	3	29	3
Total	22	157	15

the Northern Province of South Africa in 1997. The Province has a diverse agricultural production. A majority of households (almost 70%) produce field crops, dominated by maize. A typical sample household would plant 1.56 ha of maize, which covers 50% of the arable area. Only 26% of the households produce maize under irrigation in some parts of Southern Region, as well as to Mapela in the Western region. Maize in the Central Region, the Lowveld Region and the Northern Region is grown under dryland conditions. These areas tend to have reasonable level of rainfall. However, relatively less maize is sold and only 20% of respondents sold their maize.

The data for the study were obtained from the randomly selected households following a stratification of five regions in the Province, and random selection of districts and extension ward (consisting of villages). Sampling of households involved obtaining a sample frame of farmers from the extension office. Households were then randomly selected. Where the list was not available before visiting the research site, farmers were convened, matched with the extension officer's register and randomly selected for interview. The face-to-face interviews were conducted with 157 randomly selected farmers. All respondents were requested to answer a set of structured questions. The respondents were given the opportunity to consult with other household members. The responses from the face-to-face interviews were reviewed, and based on this pertinent issues were identified and then presented and discussed during a follow-up group discussion to elaborate on the issues. They were convened through extension officers. Table 1 shows the distribution of sites and the respondents by regions.

The instrument was designed to collect a range of information, which entailed information about household structure, consumption of food and non-food items, factors of production (land, labour, capital, human resource, natural resources, infrastructure, and management), and production. For the purpose of the study the following information was utilised: 1) amounts of maize production sold at the market, 2) characteristics of the households regarding gender and age of the household head, as well as the size of the household, 3) access to income and assets such as non-farm income, pensions, arable land, and livestock as well as transport equipment, and 4) access to market information was also collected in terms of average household education, contact with extension service and proximity to the nearest town where the markets are. The conditions of the roads to the markets were also determined.

For empirical analysis, the three constructs of information, assets and household structure are included in the analysis procedure. To reflect the existence of fixed transaction costs, these constructs were included in the model determining the decision to participate in the market – thereby testing the hypothesis of fixed transaction costs. Similarly, to reflect the existence of variable transaction costs, these constructs were included in the models of the level of participation – thereby testing the hypothesis of variable transaction costs. Table 2 shows the hypothesised relationship between the explanatory variables and market participation.

The first procedure identifies factors that influence a household in its decision to sell maize, as opposed to not selling. The hypothesis is that fixed transaction cost factors

Table 2. Hypothesised relationship with market participation

Variable Description	Variable	Participation decision	Participation level
Market participation			
1 if selling maize	MAIZMKT		
Value of maize sold	MAIZVAL		
Household Endowment (Assets)			
Size of arable land (ha)	ARABLE LAND	+	+
Value of livestock (in R100)	LIVST100	+	+
Pensions earned (R)	PENSION	-	?
Non-farm earnings (R)	NON-FARM	+	+
1 if owning a tractor or vehicle	TRACVECD	+	+
Information Access			
Farming was learned through extension visits	SKOLVIST	+	+
Average household education (yrs)	AVER-EDU	+	+
Distance to nearest town	DISTNTNG	-	-
Road conditions to nearest town are good	RCTNT	+	+
Household Characteristics			
Household head is female	HHGENDA	-	-
Age of household head (years)	HHAGE	+	+/-
Household size in AE	AEHHSIZE	-	-
Interaction Factors			
Interaction of proximity and road conditions to nearest town	DISTNRCT	-/+	-/+
Interaction between education and salary/wage earnings	EDUSLRW	+	+

will be responsible for the decision to participate in the market. The profit procedure was used to determine the marginal effects, that is, the change in the probability of selling as a result of the unit change in the explanatory variable. The positive sign implies that a unit increase in the explanatory variables leads to an increase in the probability of selling maize. On the other hand, a negative sign means that a unit increase in the explanatory variable will lead to a decrease in the probability of selling. The next procedure identifies factors that influence the level of maize sold. It is conjectured that the variable transaction costs factors will influence the level of participation. These models are estimated using the second stage of selectivity (Heckman) model and involves inclusion of a variable to absorb selectivity bias (ECI, 1999). The model results present the partial effects of E[Y] = Xb + c*L with respect to the vector of characteristics. The effects are computed at the means of the Xs. The Xb indicates the direct effects in the regression. Means for direct effects are for selected observations. The c*L indicates the indirect effects in LAMDA or inverse mills ratio. Means for indirect effects are the full sample used for the probit. The direct effects estimates determine the change in the value of sales resulting from the unit change in the explanatory variables for those households who sell. The total effects determine the change in the value of sales resulting from the unit change in the explanatory variable for the entire sample. The positive sign implies that the unit change in the variable leads to positive change in the value of sales.

RESULTS

The LIMDEP econometric software was used to run the procedures (ECI, 1999). The results of the selectivity model are presented and two procedures are discussed.

Decision to sell maize

The model of decision making to sell maize identifies factors distinguishing maize sellers from those who do not. The model is specified as:

Pr(MAIZMKT) = f(ARABLE LAND, LIVST100, PENSION, NFARM100, SKOLVIST, AVER-EDU, RCTNT, DISTING, HHGENDA, HHAGE, AEHHSIZE, DISTNRCT, EDUNFARM)

That is, the probability of selling maize depends on the set of fixed transaction costs factors as indicated. The results of the model are presented in Table 3. The model correctly predicted 82% of the observations, with a significant chi-square of 29.61. Only two of the 14 variables had coefficients significantly different from zero. The size of arable land was positively associated with the probability of selling maize. This could be associated with the fact that a larger area of arable land provides a greater opportunity for surplus production. Generally households decide to sell, when they cannot consume all they have produced. That is, a decision to sell is preceded by a decision to consume. This is in line with the fact that an increase in household size significantly decreases the possibilities for selling maize. The more members the household has, the more likely that most of the produce will be consumed. It follows that the level of sales will mainly depend on the offsetting effects between arable land and household size. As it is, the household size has a greater negative marginal effect than the positive marginal effect of arable land.

Other variables that increased the possibilities of selling maize were the value of livestock, the age of the head of the household, and the ownership of a tractor or vehicle.

The proximity to town, the road conditions, contacts with extension services, being close to town with accessible roads as well as being educated and earning non-farm income

Table 3. Factors influencing decision to sell maize: profit results.

Variable Description	Coefficient		Marginal Effects	
Constant	-0.1978	(1.1338)	-0.0505	(0.2900)
Household Endowment				
Size of arable land (ha)	0.0815**	(0.0347)	0.0208**	(0.0091)
Value of livestock (in R100)	0.0007	(0.0011)	0.0002	(0.0003)
Pensions earned (R)	-0.0000	(0.0005)	-0.0000	(0.0000)
Non-farm earnings (R)	-0.0038	(0.0034)	-0.0010	(0.0009)
Owning a tractor or vehicle	0.3546	(0.3876)	0.9064	(0.0995)
Access to Information				
Farming was learned through extension visits	0.0204	(0.3118)	0.0052	(0.0797)
Average household education (yrs)	-0.0312	(0.0759)	-0.0080	(0.0194)
Distance to nearest town	0.0044	(0.0159)	0.0011	(0.0041)
Road conditions to nearest town are good	0.5028	(0.6936)	0.1285	(0.1776)
Household Characteristics				
Household head is female	-0.0836	(0.3429)	-0.0214	(0.8770)
Age of household head (years)	0.0073	(0.0158)	0.0019	(0.0041)
Household size AE	-0.2595***	(0.0922)	-0.0663***	(0.0224)
Interaction Factors				
Interaction of proximity and road conditions to nearest town	0.0019	(0.0253)	0.0049	(0.0065)
Interaction between education and salary/wage earnings	0.0004	(0.0003)	0.0010	(0.0008)
% Correctly predicted	82			
CHI-SQ	29.61***			
N = 138				
N Selling = 30				

* = 10% sign level, ** = 5% sign level, *** = 1% sign level (Std errors in brackets)

Table 4. Factors of the level of maize sales: heckit results.

Factors	Direct		Indirect		Total	
Constant	594.79	(504.77)	112.59	(2.6245)		
Household Endowment						
Size of arable land (ha)	51.513***	(18.982)	-46.395	(1.0228)	5.1183	(19.009)
Value of livestock (in R100)	1.5625***	(0.5703)	-0.3859	(0.0086)	1.1766**	(0.5704)
Pensions earned (R)	0.0146	(0.0218)	0.0038	(0.0001)	0.0184	(0.0218)
Non-farm earnings (R)	-1.0794	(1.2665)	2.1791	(0.0482)	1.0997	(1.2675)
Owning a tractor or vehicle	216.97	(188.23)	-201.99	(4.4715)	14.982	(188.29)
Access to Information						
Farming was learned through extension visits	147.01	(148.79)	-11.622	(0.3573)	135.39	(148.79)
Average household education (yrs)	9.6355	(35.049)	17.775	(0.3972)	27.411	(35.051)
Distance to nearest town	2.2424	(6.6985)	-2.5056	(0.0569)	-0.2632	(6.6987)
Road conditions to nearest town are good	167.94	(313.39)	-286.40	(6.3443)	-118.46	(313.45)
Household Characteristics						
Household head is female	-152.20	(151.76)	47.619	(1.0912)	-104.58	(151.76)
Age of household head (years)	-6.349	(7.6545)	-4.1295	(0.0919)	-10.478	(7.6551)
Household size AE	-76.947**	(34.465)	147.82	(3.2768)	70.869**	(34.620)
Interaction Factors						
Interaction of proximity and road conditions to nearest town	4.2296	(11.438)	-1.0835	(0.0303)	3.1461	(11.438)
Interaction between education and salary/wage earnings	0.1027	(0.1171)	-0.219	(0.0048)	-0.1163	(0.1172)
LAMBDA	717.23***	(56.426)				
R-SQ	0.54					
ADJ R-RQ	0.48					
F-TEST	9.54***					
N	30				138	

* = 10% sign level, ** = 5% sign level, *** = 1% sign level (Std errors in brackets)

were also positively associated with the probability of selling maize. The insignificant and negatively associated variables included pensions, non-farm income, the gender of the head of the household, and average education.

The level of maize sales

The model identifies factors influencing households to sell more maize. The model is specified as:

MAIZVAL = f(ARABLE LAND, LIVST100, PENSION, NFARM100, SKOLVIST, AVER-EDU, RCTNT, DISTING, HHGENDA, HHAGE, AEHHSIZE, DISTNRCT, EDUNFARM, LAMDA)

That is, the value of maize sales depends on the set of variable transaction costs factors as indicated. The second stage of the selectivity model (OLS accounting for selectivity bias) is estimated to determine significant factors influencing the level of maize sales. The results are shown in Table 4. The model R-Square and adjusted R-square are respectively, 54 and 48% with a significant overall fit. The inverse mills ratio has a coefficient significantly different from zero. This indicates that the selectivity bias would have resulted had the maize sales been estimated without consideration of the decision to sell maize. Only three variables had coefficients significantly different from zero.

The results suggest that an increase in the arable land by a hectare will lead to an increase in maize sales by R52 among those households who have elected to sell maize. However, the sales in this same group will decrease by about R77 for every additional household member in the participating household. When the entire sample is considered an increase in household size by one additional member would lead to a total increase in maize sales by about R71. This implies that the indirect effect (of non-selling households) tends to offset the negative effect of household size. The results also suggest that an increase in the value of livestock owned by R100 leads to an increase in maize sale by about R1.56.

The other positive variables included pension earnings, average education, ownership of a tractor or vehicle, the direct effect of proximity to town, conditions of the road, contacts with extension officers, and the interaction factors. The non-farm income, the gender and age of the head of the household, the combined effect of proximity to town and road conditions, as well as the interaction between education and non-farm income were negative but not significant in terms of influencing the level of the maize sales.

DISCUSSION AND CONCLUSIONS

The pattern of participation in the maize market appears clear. There are two major factors driving entry into maize markets. Firstly, an increased size of the household tended to discourage selling of maize since there is a need to meet the consumption requirements of the household. Secondly, an increased area of the arable land stimulates participation in the market as it allows for an increased production extending beyond the consumption requirements of the household. In other words, participation in the maize market depends on production and consumption factors. However, ownership of livestock positively increased the level of maize sales. It seems that owning livestock neutralises risk of loss of food security when selling maize.

On the other hand the fact that maize is a consumption (or food security) commodity makes identification of pertinent transaction cost factors a bit difficult. As it is, an increase in the likelihood of selling maize, which is related to a decrease in fixed transaction costs, merely requires the provision of land in order to offset the consumption requirement by the members of household. Similarly, the model predicts that only assets such as arable land and livestock owned would ameliorate the variable transaction costs related to maize selling. Because both of these factors are based on access to land, it does make the findings relevant to the situation in South Africa where small-scale farmers have limited access to land. The impression is that for other factors to become significant in maize selling, the land issue needs to be addressed first. At present the land available for maize production doesn't even meet the average household requirements.

Those households selling maize are normally viewed as not commercially oriented as a food crop. The primary policy objective is to use it for food security strategy. Therefore, the farmers' decision to participate in the market is normally driven by the availability of surplus produce. Policy efforts should enhance the production capacity through the provision of land. Finally, for market participation it should be possible for maize to be stored until better market conditions prevail. In other words, the development of storage and/or processing infrastructure would make a difference in the economics of the marketing behaviour of these farmers. Such developments could further provide opportunities for private sector development in the rural areas.

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PARTICIPATORY ON-FARM TRIALS ON WEED CONTROL IN SMALLHOLDER FARMS IN MAIZE-BASED CROPPING SYSTEMS.

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ABSTRACT

Maize and beans are the major food crops in the Central and Eastern Highlands of Kenya. Smallholder farmers either grow maize and beans as intercrops or as sole crops while intercropping is more prevalent. However, the gradual shift from sole crop maize to intercropping maize and beans has generated considerable demand on farm labour.

Use of mechanized or semi-mechanized production methods such as oxen drawn plough is limited due to small farm size and uneven land terrain and is rarely practised in the main maize growing zones. Herbicide use in maize production systems in the Eastern and Central Highlands is therefore an alternative technology for resolving the labour problem. To test the hypothesis and scale up the herbicide use technology, experiments comparing hand weeding versus herbicide use in sole crop maize and intercrop maize and beans were carried out in two districts (Kiambu and Embu) involving farmers within randomly selected villages in maize growing areas. Each farmer was to compare the performance of the crop, control of the weeds, time taken for each operation (spraying, weeding, planting, etc.), grain yield (maize and beans), costs of inputs, and price of maize and bean under each weed management method. Size of plots were 500 m^2. Lasso/Atrazine at 5.0 lt ha^1 was used for sole maize and Lasso + Linuron (3 lt ha^1 + 1.75 kg ha^1 products) were used for the intercrop. Hand weeding was done 2-3 times in the conventional plot. Weed assessment was done by counting the number of weeds per m^2 and the fresh weight of the weeds (separated by species and then totaled up). The data were then subjected to statistical analysis. Results showed that herbicides controlled weeds better than hand-weeding, the maize crop was more vigorous in growth, matured earlier, had higher grain yield (for both maize and beans), required less labour, and had higher net benefits than the hand-weeded plots. The major drawbacks to uptake of herbicide technologies among smallholder farmers included lack of knowledge on the use of herbicides, unavailability of the herbicides at the local markets and high cost of herbicides. In most cases the herbicides were only available in large containers suitable for large-scale farmers and not appropriate for the smallholder sector.

INTRODUCTION

Maize is the most important food crop in East Africa and a major staple food crop for Kenya. (Chui *et al*., 1997). Maize production in Kenya is by both large commercial farmers and small-scale farmers. Production in Central and Eastern Highlands of Kenya is by small-scale farmers.

Production by small-scale farmers is not mechanized. Large-scale farmers have the option to mechanize. The small-scale farmers use simple hand tools in nearly all operations plowing, planting, weeding, harvesting and threshing. These operations are laborious, time-consuming and very inefficient compared to mechanized production. The mitigating factors that influence the non-use of machines include small farm sizes, steep slopes and general land conformation. Farmers are also not exposed to other options available that would ease the maize production drudgery.

The agricultural extension recommendations for all crops, including maize, were based on pure stands and therefore those recommendations were suitable for large-scale farming. Until the 1970s, intercropping, which was practised by small-scale farmers was regarded as a poor agricultural practice and agricultural extension personnel discouraged it. The philosophy of the "Farming System Approach to Research, Extension, and Training," was catalysed by CIMMYT and deliberate efforts were made by the government to evolve it, (Matata and Abedin, 1995). The small-scale farmer derives more benefits from intercropping maize and beans than from sole crop maize and sole crop beans in terms of efficiency of production per unit area as measured by land equivalent ratio (LER), and income equivalent ratio (Edje. Personal comm.). This explains why the small-scale farmers have stuck to intercropping with total disregard to the extension advocacy for sole or pure cropping. Though there are benefits associated with intercropping and that maize bean intercropping is presently a recommended practice, some farmers still think that it is an unacceptable agricultural practice. Field operations such as weeding are fairly cumbersome in intercrops compared to sole crops.

Weed management in maize cropping systems has been studied in both sole cropping and mixed cropping. Physical methods and chemical (herbicide) technologies, and cultural (cover crops and inter-cropping) have been tried and were found successful (Mwangi, 1999). However, these trials were done at isolated individual farms. The results formed the basis for recommendations. Since the scientists had control of the experiments and had access to all required inputs, the participating farmers could not continue to have access to herbicides or sprayers, etc. and therefore, the technologies were not adopted. There was no mechanism to disseminate the technology once the research process was over. This scenario led to the non-adoption of the herbicide technologies in the small-scale farms although analyses showed that the herbicide technologies were cost effective and yielded higher returns than conventional methods (Muthamia, 1995).

Labour constraint has been reported severally as being a block to farm productivity. Competition for labour during the peak period affects maize production more because labour is used for higher income generating activities like picking coffee and ripe fruits. Essential community activities may also effectively compete for labour by withdrawing it from the farm. These activities include funerals, weddings, attending administrative meetings, etc. Diseases were also reported to be a competitor for labour in that sickly people are not productive and further consume the already created household wealth (Murithi *et al*., 2000). Thus, malaria is a common denominator in the project area. HIV/AIDS is also bound to have its own share of affecting farm labour. With this unfolding scenario in mind, the Weed Management Project made deliberate efforts to involve the local communities in planning, evaluation, adaptation, dissemination, and benefit from labour-saving technologies in weed management. The objective of the project was to sensitize the communities on the use of herbicides and to disseminate and perpetuate the technologies that were labour-saving since labour availability would diminish with time.

MATERIALS AND METHODS

Selection of treatments

Farmers grow maize as either a sole crop or as an intercrop with beans as gathered from the PRA. Therefore, strategies that would benefit both cropping systems were formulated. The herbicides selected for use by participating farmers were Alachlor/Atrazine for sole crop maize and Alachlor/Linuron for intercropped maize and beans. These herbicides were already in use in the country. The selected herbicides were pre-emergence soil applied. The conventional method was to hand-weed.

Selection of the participating farmers

The participating farmers were selected during a meeting after giving them the requirements for the trial as:

1. The minimum plot size should be 1,000 sq. meters,
2. The participating farmers must keep records of activities undertaken.
3. The participating farmers should be willing to share information with the other farmers.

The farmers were also informed that three farmers would grow intercrop maize and beans and three would grow sole maize. The villagers set up criteria for selecting the participating farmers:

1. Willingness to follow instructions
2. Should inform other farmers what he/she was doing
3. The participating farmers should be spread evenly in the village so that each villager has a participating farmer close by.
4. Some villages divided the village into two and then selected the farmers through secret ballots.
5. Some villages selected the participating farmers through the group agreeing on those selected.

The selected farmer had to have interest in growing the crop according to cropping pattern.
In each village three farmers participated in sole crop maize, three in intercrop maize and beans.

Plot size: The participating farmers were requested to plant the crop and the experiment was superimposed on the farmer's planted area. A plot for either hand weeding or herbicide treatment was 500 m^2 thus giving a total of 1,000 m^2 per farmer.

Treatment application: The farmers had been shown on how to spray the herbicides and each farmer was given the amount of herbicide to cover the 500 m^2. The farmers were requested to spray when the rains fell and the soil was moist. The application rate was 250 ml. of Alachlor/Atrazine in 10 lt of water to cover 500 m^2 and 87.5 g of Linuron/+150 ml of Alachlor E.C. in 10 lt of water to cover 500 m^2. Hand-weeding was done in the unsprayed plot when the farmer normally does the operation. The farmer recorded the time taken to spray and to do the hand-weeding.

Field Evaluation: The farmers recorded all operations carried out in the experimental plots and the farm in general in a notebook and a form.

Weed evaluation: General visual weed assessment to determine the various weed species was done using quadrats (Susumi, 1984, Terry and Michieka, Sutherland *et al*. 1996) and their intensities at first hand-weeding and second hand-weeding. Comparison between the herbicide treatment and the hand-weeded treatments. A 0.3 m^2 quadrat thrown at random in 10 locations each in herbicide and in conventional treatments was used to select the sampling points in the field. The following information about weeds was recorded:

1. Weed count of all the weeds.
2. Weed count of each weed species
3. The above-ground fresh weight of each weed species
4. Statistical analysis of weeds data was carried out.

Farmer assessment of on-farm trials: Field days were organized in the respective villages when maize was physiologically mature. Time and venue was communicated and attendees converged on the farms selected as the venue. Two farms were selected in each village to represent pure-stand maize crop and intercrop of maize and beans. During the field days, farmers were given a demonstration on how to spray herbicides. The host farmer was given the opportunity to explain to other farmers how he/she carried out the trial.

Table 1. Selected herbicides and their application dosages for different cropping systems/tillage methods.

Cropping system	Herbicide(s)	Dosage
Sole crop maize	Alachlor/atrazine	5.0 lt product/ha.
Intercrop maize and beans	Linuron/alachlor	1.75 kg product + 3.0lt/ha.

Yield assessment

The farmers recorded the yields from the experimental plots separated from the main field yields. The sole crop farmers kept the yield of sole crop maize from the conventional hand-weeded plot and from the herbicide treated plot. The farmers with intercrop maize and beans kept the records of maize and bean grain yields from conventional plots and also from the

Table 2. Farmers' experience regarding the use of chemicals for the control of weeds

Do's	Don'ts
Spray when the soil is moist	Don't spray when the soil is dry
Spray when tilth is fine	Don't spray on clods
Herbicide should cover the soil well	Do not leave unsprayed spots
For pre-emergence herbicides neither the crop nor the weed should have germinated when spraying.	Do not spray pre-emergence herbicides when crop and weeds have emerged.
Spray Round up when vegetation is growing	Do not spray Round up when vegetation is dry.

herbicide treated plot.

Statistical analysis was performed on the data thus assembled. Economic analysis was also carried out.

RESULTS AND DISCUSSION

Evaluation

Farmer assessment of on-farm trials: The farmers exchanged experiences gained during the course of experimentation. The participating farmers had the opportunity to share with the other participating farmers and the non-participating farmers. The non-participating farmers were curious to learn from the participating farmers as well as from the researchers and the extension staff. Based on the observations from the field days it was evident that the herbicides were effective in managing the weeds and the crop looked well than the crop that was hand-weeded. The herbicide treated plots had a uniform crop, the crop matured earlier and also the crop appeared to carry more potential yield.

The farmers had an opportunity to have another demonstration on herbicide application. The portions missed by herbicide spray provided a chance to show the effects of poor or improper application of herbicides. The farmers came up with the "dos and don'ts" in chemical weeding deriving the experiences gained by the participating farmers.

Do's and Don'ts of chemical weeding – Farmers' Experience

The farmers that discussed these were all in favour of herbicide use and they said:

a) Chemical weed control was less tedious
b) Chemical weed control saves labour(30 mins for 500 m^2 vs 3 days for 500 m^2)
c) The saved labour is used in some other farm activities - coffee, livestock etc
d) Chemical weed control results in higher yields of both maize and beans compared to hand-weeding
e) Sometimes there is no casual labour available for employment
f) The cost of employment of casual labour is KSh. 80.00 and must be supplied with tea and lunch.
g) Some weeds such as nut grass, *oxalis latifolia*, *Euphorbia hirta* were not affected by herbicides.
h) Farmers were keen to continue using herbicides

Stakeholders workshops: The purpose of the workshops were:

1. To share the results of the previous season's experiments with the stakeholders.
2. To get the farmers response from the discussions
3. Spell out the roles of the participants/stakeholders
4. Plan for the future activities

Attendees included farmers, extension staff, researchers, and local farm input stockists.

Weed analysis

Statistical analysis of weeds: Lasso/Atrazine (Alachlor/Atrazine) was found to be more effective in controlling annual grassy weeds than Linuron. Weeds that propagate by vegetative means were not controlled by hand-weeding. Some weeds like pig weed, double thorn and gallant soldier were controlled well by both herbicides.

Weeds controlled by Lasso/Atrazine were: *Oxalis spp., Amaranthus spp., Galinsoga parviflora, Nicandra physalodes, Commelina spp., Datura, goat weed, Digitaria velutina,* and purslane. All the other weeds were suppressed by the herbicide.

Weeds controlled by Lasso + Linuron were: *Cyperus spp. Nicandra physalodes, Galinsoga parviflora, Richardia spp., Digitaria velutina, purslane, and Lionotis spp*. All other weeds were suppressed by the herbicide except field bindweed.

Cropping system: Intercropping maize and beans reduced the incidence/numbers of the major weeds compared to the sole crop of maize. The weeds affected included *Cyperus spp., Amaranthus spp., Eleusine indica, Commelina spp., Ageratum, D. velutina, R. Raphanastrum, and Lionotis spp.* Intercropping favoured the growth of certain weed species compared to sole cropping maize. Weeds favoured by intercropping were bindweed*, Oxygonum sinuatum and Datura stramonium*

Yield assessment

Maize: Use of herbicides resulted in significantly higher maize grain yields than hand-weeding in both sole crop maize and intercrop maize The increase in yields of 25 to 50% with a mean of 33% over hand-weeding in sole crops while in intercrop the increase was 20 to 50% with a mean of 33% over three seasons. Introduction of beans as an intercrop resulted in a slight reduction of maize yield by 10 to 25% and a mean of 15% compared to sole crop maize.

Beans: All bean plots were under the intercropping system and observations were for comparison of yields under hand-weeding and herbicide weed management methods. Herbicide use resulted in higher bean grain yield. An average

Table 3. The influence of weed management strategies on weed control during SR.2000/2001

Weed	Sole crop maize weed wt.			Intercrop maize and beans weed wt.		
	Herbicide (Lasso / Atrazine)	Hand-weeding	Probability	Herbicide (Lasso +Linuron)	Hand-weeding	Probability
Cyperus spp.	156.0	193.0	0.62	34.0	282.0	0.008
Oxalis spp.	2.4	29.1	0.06	8.7	12.1	0.60
Tagetes minuta	0.0	12.4	0.22	2.6	5.4	0.50
Oxygonium sinuatum		4.3	0.43	5.1	25.8	0.34
Amaranthus spp.	0.0	176.0	0.03	0.02	55.4	0.11
Nicandra Physalodes	0.0	677.0	0.01	4.2	581.0	0.01
Eleusine indica	0.0	120.0	0.33	0.0	14.0	0.22
Galinsoga parviflora	0.0	123.0	0.01	0.02	243.0	0.02
Bind weed	1.1	2.6	0.39	5.0	5.0	0.90
Richardia spp.	0.0	4.7	0.15	0.0	5.9	0.05
Commelina spp.	0.0	141.0	0.04	81.0	179.0	0.14
Bidens pilosa	0.0	4.1	0.35	0.4	0.0	0.35
Datura stramonium	0.0	50.0	0.06	9.0	102.0	0.20
Setaria verticilata	0.0	93.0	0.13	0.2	106.0	0.10
Ageratum spp.(Goat weed)	0.0	18.0	0.00	7.2	11.5	0.58
Digitaria velutina	0.0	38.0	0.01	0.0	21.0	0.08
Purslane	0.0	22.4	0.06	0.02	13.0	0.08
Lionotis spp.	0.0	11.8	0.35	0.0	8.3	0.03
Raphanus raphanistrum	0.0	7.5	0.15	0.0	3.3	0.36
Eragrostis tenuifolia	0.0	14.2	0.25	0.0	0.0	-
S. alba	0.0	0.8	0.35	0.0	0.1	0.20

Table 4. Result of both number and weight of fresh weed analysis of sole crop maize and intercrop maize and beans using herbicides and hand weeding management practices during second count.

Type of analysis	Mean of the number of weed and weight per plot, per weeding system during second count.					
	Weeding System				Mean	Cv
	Intercrop herbicide	Intercrop hand-weeding	Sole herbicide	Sole hand-weeding		
Population	6.0	57.0	6.0	55.0	**30.0**	62.0
Weight	12.5	139.4	27.0	129.9	**77.2**	31.0

Table 5. Effectiveness of Lasso/Atrazine and Lasso + Linuron on weed species.

Weed	Lasso/atrazine	Lasso+Linuron	Remarks
D velutina	good control	good control	
Wild fingermillet	good control	good control	
Sow thistle	fair	fair	Weed not well distributed
Double thorn	fair	fair	
Nut grass	fair	fair	
Galant soldier	good	good	
Black Jack	fair	fair	
Wandering Jew	fair	poor	
Itch grass	fair	poor	
Setaria pumila	good	good	
Starburr	fair	fair	
purslane	fair	fair	Not distributed
Euphorbia hirta	poor	poor	
Sida alba	good	poor	
Couch grass	poor	poor	
Spindle pod	fair	fair	
Bindweed	good	fair	
Goat weed	good	good	
Richardia	good	poor	
Amaranthus	good	good	

Table 6. Grain yields of sole crop maize and intercrop maize and beans during S.R. 1999/2000 season.

Cropping system	Weed control method	Maize grain yield (t/ha)	SE	Bean grain yield (t/ha)	SE
Sole crop maize	Herbicide	1.7	0.2		
	Hand-weeding	1.24	0.2		
Inter-crop maize and beans	Herbicide	1.49	0.3	0.6	0.07
	Hand-weeding	1.0	0.3	0.38	0.07

Table 7. Mean grain yields of sole crop maize and intercrop maize and beans from S.R. 1999-LR 2001 season (Embu).

Cropping system	Weed control method	Maize grain yield (t/ha)	SED	Bean grain yield (t/ha)
Sole crop maize	Herbicide	2.4	0.16	
	Hand-weeding	1.8	0.16	
Inter-crop maize and beans	Herbicide	2.0	0.17	0.49
	Hand-weeding	1.5	0.17	0.36

Figure 1. Yields of maize under herbicide and hand-weeded methods during 1999/2000.

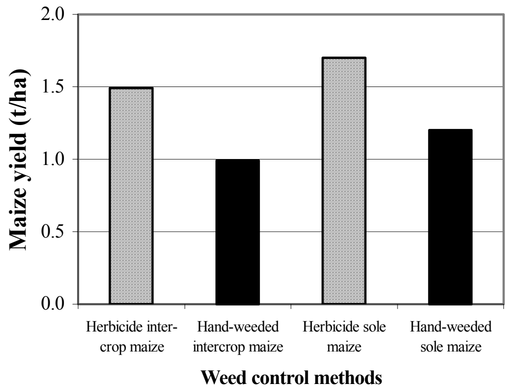
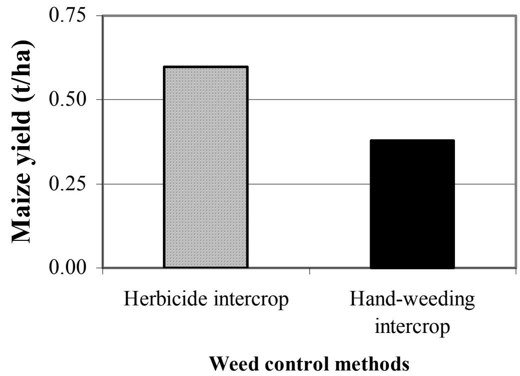


Figure 2. On-farm yield of beans (ton/ha) in an intercrop as influenced by weed control method during SR. 2000/2001.

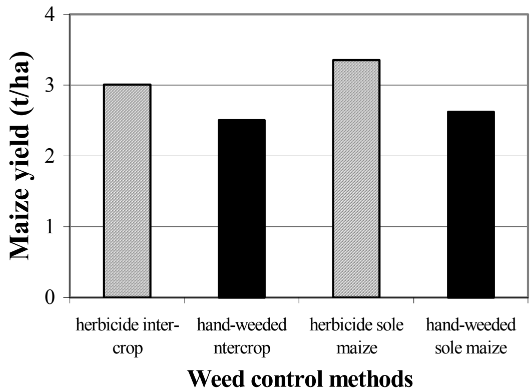


increase of 36% over hand-weeding with seasonal range of 20 to 57 %.

Economics of Weed Management: The results of economic analysis for pure maize and maize/bean intercrop are summarised in tables below. Maize and bean yields, input data-cost of labour for weeding, cost of herbicide and cost of labour for herbicide application were collected.

Partial budget analysis: The results show that the use of herbicides in weed control gave higher net benefits than hand weeding alone in both pure maize and maize/bean intercrop. An increase of 33% in net benefits was realized by applying herbicides and some minimal hand weeding. in maize pure and 29% to 34% in maize/bean intercrop.

Figure 3. Yield of maize under weed control methods.



DISCUSSION AND CONCLUSIONS

The results from the on-farm trials show a marked increase in maize and bean yields by 33% and 36 % respectively, and economic benefits of 33% from the use of herbicides weed management vis-a-vis hand-weeding in smallholder farms.

The increased yields (sole and intercrop) are probably due to better weed control from crop establishment to maturity. There is also a likelihood of better moisture conservation where herbicides are used.

Though the introduction of beans in the intercrops slightly reduced the yield of maize, bean yields offset the losses and resulted in additional yields from beans.

Additional grain yield was shown to be a clear advantage of the herbicides vs conventional hand weeding. The additional yield of beans resulting from an intercrop over sole crop maize showed why the farmers had tenaciously held on to the practice.

Though intercropping was found to cause a reduction of maize yields, the use of herbicides under intercropping resulted in higher maize yields than the sole cropped maize under hand-weeding. Herbicides reduced labour requirement by 32 times compared to hand-weeding. This saving in man-days is used in carrying out other farm activities and leisure.

Table 8. Net Benefits analysis for Short rains(Oct 2000-March 2001). Maize Monocrop (Kiambu)

Benefits & Costs (Ksh/ha)	Hand weeding	Herbicide weeding
Maize yield (t/ha)	***4.35***	***5.39***
Total benefits	76125	94345
Cost of herbicide	-	3910
Cost of herbicide application	-	149
Cost of hand weeding	11308	4337
Total costs that vary	11308	8396
Net benefits	64816	85950

Table 9. Net Benefits analysis for short rains (Oct 2000-Mar 2001) – Maize/bean intercrop (Kiambu)

Benefits & Costs (Ksh/ha)	Hand weeding	Herbicide weeding
Maize yield (t/ha)	***4.09***	***5.01***
Bean yield (t/ha)	***0.5***	***0.5***
Total benefits	93625	110625
Cost of herbicide	-	4640
Cost of herbicide application	-	154
Cost of hand weeding	11308	-
Total costs that vary	11308	4794
Net benefits	82316	105830

Table 10. Net Benefits analysis for the three seasons means of sole maize (Embu) 1999-2001.

Benefits & Costs (Ksh/ha)	Hand weeding	Herbicide weeding
Maize yield (t/ha)	***1.8***	***2.4***
Total benefits	31500	42000
Cost of herbicide		3850
Cost of herbicide application		144
Cost of hand weeding	2726	96
Total costs that vary	2726	4090
Net benefits	28774	37910

Table 11. Net Benefits analysis for the three seasons means of Maize/bean intercrop (Embu)1999-2001.

Benefits & Costs (Ksh/ha)	Hand weeding	Herbicide weeding
Maize yield (t/ha)	***1.53***	***2.00***
Bean yield (t/ha)	***0.4***	***0.5***
Total benefits	42975	57050
Cost of herbicide	-	4640
Cost of herbicide application	-	133
Cost of hand weeding	4120	208
Total costs that vary	4120	4981
Net benefits	38855	52069

Economic analysis shows the advantage of intercropping despite the slight reduction in maize yields. The use of herbicides in intercropped maize and beans produced higher net benefits than in hand-weeded plots.

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MARKET STRUCTURE AND CONDUCT OF THE HYBRID MAIZE SEED INDUSTRY, A CASE STUDY OF THE TRANS NZOIA DISTRICT IN WESTERN KENYA

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ABSTRACT

To understand the organization of the market and assess the degree of competition in maize hybrid seed production and retailing, the structure and conduct of the market was analyzed in Trans Nzoia District, a major maize producing area in Western Kenya. The structure of the market was analyzed in four aspects, namely: market concentration, product differentiation, market integration and conditions for entry in the hybrid maize seed business. The market conduct considered behaviour and activities of the participants, in particular concerning pricing and promotion. Primary data were obtained randomly from a random sample of 30 traders, out of a total of 46 who sell hybrid maize seed within the district, and 30 farmers within the district. Data were collected at the peak of the planting season in the months of February to April 2000. Results show that there is some impact of the liberalization of the seed industry on the distribution side, but it is minimal on the production side. The major impact in the district is that the previous Kenya Farmers' Association's monopoly of seed distribution has been reduced and that now there are many seed traders in retail. Analysis of the market structure reveals that several factors favour imperfect competition in the hybrid maize seed marketing at the retail level, including include unequally distributed shares of transactions among traders, product differentiation, and barriers to entry. The distribution, with a Gini Coefficient of 0.6 in the district, is categorized as oligopolistic, with 61.67% of the market share going to the 4 largest firms. Interviews with traders indicate that conditions for competition were lacking mainly due to barriers to entry such as institutional restrictions and high initial capital. However, traders did not collude among themselves to decide on prices or control sales volume. On the production side, Kenya Seed Company still provides 96.7% of the hybrid maize seed sold in Trans Nzoia District, with Pioneer Company providing the remaining 3.3% of the market share, a clear monopolistic seed production. Farmers showed their preference for the variety H614. They also complained about KSC's perceived inefficiency, and lack of purity of their seed. Unfortunately, they have few alternatives since only KSC offers the late maturing varieties recommended for the moist transitional and highland zones, while the Pioneer variety available (PHB3253) is of intermediate maturity. Recommendations for the seed industry include improved inspection to improve the seed quality, increased access to credit for traders to increase entry, and increased competition in the seed production through encouraging the development of new late maturing varieties, reducing the requirement to release new varieties, and reducing the import tax on seed.

Keywords: Hybrid maize seed industry, seed companies, liberalization of seed marketing, monopolistic, oligopolistic.

INTRODUCTION

The maize industry in Africa is undergoing rapid changes. After independence, most governments continued the policies of tight market control that were put in place by colonial governments, in order to protect the farmers and stabilize prices. Over the years, it became clear that the exclusion of market forces and reliance on bureaucracies was not an efficient way to harmonize supply and demand, and the system became increasingly inefficient. Under pressure from the donor community, many countries liberalized the food crop marketing as well as the fertilizer market (Byerlee and Heisey, 1997). Pressure for liberalization in the seed industry also led to reforms in this sector. Across countries, the maize seed industry development seems to follow a common path (Morris, Rusike and Smale. 1998). In the early stages of the seed industry, only the public sector can make the necessary heavy investment for research, development, and marketing of seed. However, when the sector expands and develops, seed production and distribution becomes increasingly interesting for the private sector. In the final stages, the private sector can take over increasing parts of the research too.

Kenya shows signs of following this general trend. The seed industry is subject to the "Seeds and Plant Varieties Act" of 1991. Unfortunately, a clearly stated seed policy is still missing (Ochuodho *et al.,* 1999). Formerly, research, production and distribution was a government monopoly, dominated by public enterprises such as the Kenya Agriculture Research Institute (KARI), Kenya Seed Company (KSC), and the Agricultural Development Corporation (ADC). In 1996, liberalization of the seed industry was implemented, to improve efficiency in the industry and increase seed purity, among other objectives. Experience from other countries has shown that deregulating the trade of inputs can lead to significant increases in the range and quality of inputs available to farmers, which in turn raises productivity and income (Gisselquist and Grether, 2000).

The growing size and increased commercialization of the global maize economy have been accompanied by an expansion in the industries that provide inputs used in maize production especially improved seed, chemical fertilizers, pesticides and machinery.

Over time as the global maize seed industry has matured, it has undergone a series of restructuring and organizational changes. The nature and pace of these changes have varied among countries, reflecting differences in stages of development and the structure of production from one country to the next, as well as differences in the economic, political and institutional climates. The net result has been a global maize seed industry comprising a conglomerate of different types of national seed industries that vary widely in their organization and performance (Morris, 1998 ;CIMMYT 1994).

In most industrialized countries, the maize seed industry is now largely in the hands of the private sector. The roles of the public institutions like the universities, research institutes, and extension organizations, which once dominated maize research and technology transfer activities, have diminished as private companies have steadily expanded their sphere of influence to take advantage of profit opportunities offered by an increasingly commercialized and input-dependent maize economy (Morris, Rusike and Smale, 1998). Public organizations continue to play an important role in the technology development and transfer process, but they do so within an increasingly narrow and specialized realm. For instance, the focus of publicly funded research has shifted towards more basic research. Very few publicly funded maize researchers now operate towards the applied end of the research spectrum, for example developing and testing finished hybrids because private companies have assumed these functions. Many technology transfer activities have also been carried out by the private sector. For instance, today a maize farmer in Europe or the United States is likely to look first to their input dealer rather than the local government extension agent for technical advice on how to manage their crop.

If the steadily growing world maize economy has provided the impetus for the private sector seed industry to expand, economies of scale in research and seed production have contributed to its increasing concentration. The 1980s and 1990s have witnessed an unprecedented wave of mergers and consolidations during which a large group of independent seed companies have been bought out by, or merged with, larger competitors. In the United States, for example, although the 7 largest companies currently control about 70% of the market for maize seed, 300 other companies also produce and sell maize seed. (Norskog, 1995).

In developing countries, the maize seed industry is more variable in organization and performance (Tripp, 2000). In countries where maize is produced mainly by small-scale, subsistence–oriented farmers using low levels of purchased inputs, private firms have demonstrated an understandable reluctance to enter the market. In these countries, maize research, seed production and seed distribution are generally carried out by public organizations. (Morris, Rusike and Smale, 1998).

Ndambuki (1998) indicated in his case study that in seed marketing three closely associated aspects have to be considered and they were products, customers and the competitors in the seed industry. He failed to elaborate further on the market structure and conduct of the three aspects mentioned above. This gap leads to this study, which analyzes the market structure and conduct thus clarifying the elaborate relationships of the three aspects named above.

The present paper aims to analyze if the deregulation of the Kenyan seed industry had the desired effect. We want to test the hypothesis that liberalization resulted in increased competitiveness in hybrid maize seed market, by studying the market structure and conduct. We will test that by studying if new companies have entered the market, if farmers' access to hybrid maize seed has improved, and if their price has decreased. The study was limited to the Trans-Nzoia district, the district with the highest maize production in the country.

MATERIALS AND METHODS

2.1. Selection of the sample and data collection

The sampling frame was a list of all 46 hybrid maize seed retailers from the licensing department of Trans Nzoia district (Figure 1). Of this group, a random sample of 30 retailers was chosen. Primary data were collected through use of a structured questionnaire, by single visit personal interviews. The data included sales volumes for February–April 2000, by variety. A group of 30 farmers were randomly selected from a list of farmers in the district; available at the district agricultural office, Ministry of Agriculture. Data were collected through use of a structured questionnaire, by single visit personal interviews in April 2000. The data were collected between February and April because this is the peak planting season.

Secondary data were obtained from various seed companies, published and unpublished reports, public libraries, KARI and any past studies carried out were used as sources of secondary information

To detect product differentiation in the market, the packages offered for sale were listed. In addition, traders were interviewed to reveal different after sales services they receive from wholesalers. The services traders provided to farmers were also recorded. The types of maize seed sold in terms of kg per packet were examined for retailers. The retailers were asked if the farmers asked for specific kg/packet of maize seed or if they asked for a specific variety of maize seed. The above questions were aimed at finding out the farmers' awareness of the differentiated products in the market.

Market conduct explains the behavioral characteristics in the market place. Price and promotions are the two variables which were used to determine the market conduct. Traders were asked whether they set prices of hybrid maize seed individually or by colluding with each other, and also if they jointly restricted the amount of seed for sale to raise the market price. Traders were also asked the type of promotions they carried out to advertise the hybrid maize seed. The degree of integration also shows the power of participants in making price decisions. Thus vertical integration may eliminate price as a coordinator between market levels, especially when the market is informal or weak. Integration in the hybrid maize seed market is examined by determining if there are contracts on quantity of seed delivered by seed companies to wholesalers or by wholesalers to retailers. Other forms of integration such as extension of credit between traders were assessed.

Barriers to entry were determined by establishing the threshold capital required for starting business. At the same time, sources of the funds and the current operational costs were analyzed to determine both the diversity and ease of access to credit to facilitate entry. The role of Government in licensing, checking quality standards and creating bureaucratic laws were analyzed as part of possible barriers to entry.

Interviews with 30 farmers were conducted to determine the popular maize varieties and the problems farmers encounter when using hybrid seed

ANALYSIS

The perfect competition market model is often used in economics as a standard by which structure and conduct of markets can be compared and evaluated. Large numbers of buyers and sellers, low barrier to entry, product homogeneity and complete knowledge of alternative choices on the part of producer and consumer characterize the competitive market model.

Structure influences market performance and conduct. Knowledge regarding structure can give indications about competitiveness. The variables used to explain market structure are the degree of market concentration, vertical and horizontal integration, and condition of entry in the market and magnitude of product differentiation. A market concentration ratio is a measure of the percentage share of the market controlled by a specified percentage of firms ranked in order of market share from the largest to smallest (Karugia, 1990). High concentration and inequality indicate oligopolistic tendencies, while conversely, low concentration suggests tendencies towards competition provided there are no serious barriers to entry into the market (Bain, 1951, 1968).

To measure market share, the monthly turnover (in kg of maize seed) of each of the 30 retailers was recorded. The retailers were divided into 5 classes. From the stratification it was found which class controls the highest percentage of transactions. From the above turnover, the Lorenz curves were constructed. Also, to assess retailer concentration the average monthly seed sales of retailers were recorded during the survey and sales shares of the first 4 and 8 largest retailers in the sample calculated. The Gini Coefficient is a comparative measure of inequality in share distribution that is the most commonly used in income distribution studies. It has the range 0 to 1 and oligopolistic behaviour increases as the coefficient approaches 1 while the market becomes most competitive as the Gini Coefficient tends to 0 (Scheid and Sutenan, 1979; Andic and Peacock, 1961). If all traders are divided into k classes by decreasing volumes of seed sales, the Gini Coefficient R can be expressed as: $R = \Sigma^{i}_{k=2} (P_{k-1}\, q_k - P_k q_{k-1}) * 1/10{,}000$ where: P = the cumulative percentage of traders by class k; k = the order of class of traders; and q = the cumulative percentage of volume or values of commodity sold by each group of traders.

RESULTS

History of the seed industry in Kenya

In the seed industry, formal and informal sub-sectors can be distinguished. The informal sub-sector deals mostly in farmers' own local seed, which is either saved from own production, bought from the local market, or obtained seed from neighbours. In the formal seed sub-sector, on the other hand, there is an established and legal process for the movement of seed from research, over seed producer, to the farmer. The informal seed sector is important in the low potential areas at the coast (Wekesa et al., 2003), around Lake Victoria (Saylasya et al., 1998) and the dry zones (Muhammad, 2003). The formal seed sector dominates in the high potential areas such as the moist transitional (Ouma et al., 2002) and the highlands (Hassan et al., 1998). Improved seed from the formal sector in the low potential areas is dominated by Open Pollinated Varieties (OPV), while maize seed in the high potential areas, including Trans Nzoia, is almost uniquely hybrid seed.

Much of the seed of improved crop varieties has reached farmers through the formal sub-sector, which was until recently a government monopoly. Research, production and distribution was dominated by public enterprises such as the Kenya Agriculture Research Institute (KARI), Kenya Seed Company (KSC), the Agricultural Development Corporation (ADC) and the Kenyan Farmers' Association (KFA). Although the Kenya Seed Company has the structure of a private company, at the time of the study the majority of shares in the company (52%) were still owned by the government, the rest by KFA and private individuals. After liberalization, new companies entered the hybrid seed market, in particular the Oil Crop Development Company (OCD), Monsanto, Pioneer, and Western Seed Company.

Seed quality control was previously in the hands of KARI, but with the liberalization a regulatory agency, the Kenya Plant Health Inspectorate Service (KEPHIS), was established. KEPHIS is responsible for the National Performance Trials (NPT), in which varieties need to show good results before they can be released. After release, KEPHIS inspects seed farms and production plants, and certifies the seed if the required standards are met. Certification of seed is a legal requirement in Kenya.

MARKET STRUCTURE

Trans-Nzoia produced 232,560 tons of maize in 1998, more than any other district in Kenya. It also has the highest yield, 3.6 t/ha (estimates of the Ministry of Agriculture). The 1999 census counted 575,000 people in Trans-Nzoia district, with a population growth of 2.9 %/year. Extrapolating for 1998, the maize production was 416 kg/person, also the highest in the country.

In the district, 46 traders are licensed to sell seed. A sample of 30 was selected for the survey. Hybrid maize seed is only a small part of their commercial activities. Most stores are first of all hardware stores or they sell agricultural inorganic inputs. Average monthly hybrid seed sales for the study period, February to April 2000, ranged from Kshs. 11,200 (100 kg) to Kshs. 12,096,000 (108 tons). Older firms were generally firms with high turnover, had been in existence for a long time and had earned consumer loyalty

Table 1. Average monthly value of hybrid maize seed transacted by sample retail traders (February-April 2000), (organised in six classes according to sales volume)

Average value of seed sales (Million Kshs per month)[a]	Number of retailers	Class Relative frequency	Total monthly value of seed sales (Million Kshs)	Class % of total sales.
<0.5	11	36.6	1.92	4.0
0.5-1.0	7	23.3	4.50	9.4
1.0-1.5	5	16.6	5.82	12.1
1.5-2.0	2	6.6	3.90	8.1
2.0-2.5	1	3.3	2.24	4.7
> 2.5	4	13.3	29.57	61.7
Total	30	100.0	47.95	100.0

[a] Average retail price of 1 kg of hybrid maize seed = 114 KSh, $US 1 = Ksh 74.

Figure 2: Lorenz curve for the traders of hybrid maize seed in Trans Nzoia

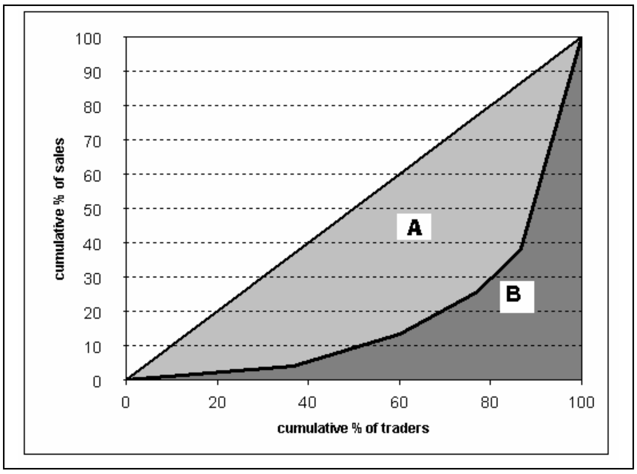

Table 2. Prices of maize seed in Trans-Nzoia, per package and per kg

	price/package				price/kg			
Package size	2	5	10	25	2	5	10	25
KSC seed	225	560	1120	2800	113	112	112	112
Pioneer seed	335	750	1599		168	150	160	

loyalty over time.

To study market concentration, the retail traders were divided into 6 groups (see Table 1 for specifications), by segments of 500,000 Ksh (1 $US = Ksh 74, at the time of the study, February-March 2000). The retail traders have also been classified into small, medium and large-scale with arbitrary cut-off levels of hybrid maize seed values.

Traders with sales of less or equal to Ksh. one million per month comprise 60% of the total number of traders sampled, but only have a small market share (13% of the total sales). The medium size traders (between 1 and 3 million Ksh per month) comprised 27% of the total traders and had a market share of only 24.67% of the total sales. The group of large traders (> 3 million Ksh/month) comprised only 13.3% of the total traders but had more than 61% of the total market.

Following Bain's classification (Bain 1951), based on distribution of sales over the different groups, the Trans Nzoia hybrid maize seed retailing system was judged as being moderately to highly concentrated.

An alternative way of studying the degree of market concentration is by drawing the Lorenz curve, which depicts the cumulative distribution of sales against cumulative distribution of traders (Figure 2. The surface of the area between the Lorenz curve and the diagonal of the graph (A), divided by the area under the diagonal (A+B) represents the Gini coefficient, an indicator of inequality in distribution ranging from 0 to 1 (0 = absolute equality, 1 = complete inequality). The Gini coefficient for inequality in market shares was found to be 0.63. A Gini Coefficient higher than 0.4 can be considered as oligopolistic (Parker and Connor, 1979) so the retail market for hybrid maize seed in Trans Nzoia exhibits clear oligopolistic tendencies. The Lorenz curve shows, for example, that the smallest 50% of traders control only 10% of sales volume, while the largest 15% lof traders control 60%.

PRODUCT DIFFERENTIATION

Nine hybrid maize seed varieties are currently being sold in Trans Nzoia District. Six are varieties of KSC's late maturity 600 series (H614, H622, H625, H626, H627, H628), two represent KSC's medium maturity series (H511, H512), and one variety is from Pioneer namely PHB3253. The KSC seed is bought straight from the producer, who is based in Kitale, center of Trans-Nzoia, while Freshco Company, a marketing agent of Pioneer seed, distributes PHB3253. The survey showed that 96.7% of the retailers sold seed from the Kenya Seed Company while only 3.3% sold seed from Pioneer Company. KSC does not allow their distributors to sell seed from other companies.

The packaging of Kenya Seed Company varieties was in packets of 2kg, 5kg, 10kg, and 25kg. The KSC could occasionally package 50kg on order from an individual consumer. Within a variety the different sizes of packets are rightly regarded as differentiated product lines. The traders revealed that 100% of their customers were aware of the various variety types in the market, the size and rang, and buyers often based their choices on these factors. KSC has, however, a strict constant price policy: retailers are required to sell all seed at the same price, regardless of package, type (hybrid or open pollinated), or place (centre of the city or rural market).

Occasionally some traders provide different after sales services to the farmers. Transport services to the nearest bus station were provided by 36.7% of the traders while 3.3% of the traders provide extension services to the customers. The moment product differentiation sets in homogeneity decreases and so does market competition

BARRIERS TO ENTRY

The retailers frequently mentioned two barriers to entry in the hybrid maize seed market retailing system: institutional restrictions and initial capital requirements. The initial capital requirement was at least Kshs. 50,000, relatively high compared to the wage rates in the country. 0f the traders interviewed, 60% said that it was difficult to obtain the initial capital. Only 6.7% obtained a loan from the bank, 10% received funding from the cooperatives, and one trader obtained initial capital from Pioneer Seed Company. So 80% of the traders relied on savings only for their initial capital. Due to the fairly high initial capital requirement, entry for seed sellers is difficult and provides protection to those already established.

The Kenya Seed Company requires retailers to be recommended by the divisional agricultural officer. Most seed sellers expressed disgust at the nightmares they had to go through before getting a letter of recommendation from the divisional agricultural officers in the Ministry of Agriculture. KSC then provides the retailer with a licence card to sell the seed. Unfortunately, the issue of this card can take months, sometimes years.

The regulatory framework requires a traders' license from the government, but this is generally issued without any problems. The license is issued annually by the municipal councilman, and amounts in practice to a tax by the local government. The cost of the license depends on the total sales volume of the trader, including maize seed. In most cases traders start their business without a license, which the municipal council will eventually issue after assessing the sales volume realized. None of the traders limited themselves to seed, as they indicated that seed retailing was a seasonal business and not a reliable source of income during the rest of the year.

INTEGRATION AND CONTRACTUAL AGREEMENTS

The survey revealed that there is some horizontal integration: four of the hybrid maize seed retailers interviewed owned two shops and one had three shops. It would be difficult to accept the notion that retailers acquired more than one seed shop so as to improve their efficiency. Since KSC determines the prices, the integrated shops can only achieve to increase their turnover and hence the profits. Vertical integration was depicted by KSC, which acted as a manufacturer, wholesaler and retailer as it contained a seed shop, which sold seed to consumers at retail price. Again, this integration is not expected to increase efficiency but only to increase the sales volume of the company.

MARKET CONDUCT

Farmers can buy their maize seed directly from KSC, or from agents, subagents and retailers. The prices differ at the various marketing channel levels, but are all set by KSC. The KSC prices are uniform all over the country and do not consider transportation costs. Pricing in any one given year or season is fixed but is reviewed periodically and determined by seed producing companies. Traders on the outskirts of Kitale town made minimal profits as transportation costs were incurred, further reducing the profit margins. Due to lack of incentives by the traders outside town to sell seed, farmers were forced to travel to Kitale to purchase seed. The effect was that some farmers purchased enough seed for two seasons so as to lower costs of going back to Kitale to search for seed.

The survey also revealed that since Pioneer 's introduction in Trans Nzoia, it has hardly been able to penetrate the market, with a share of only 3.3% of sales. Pioneer' seed is more expensive (Table 2), but its major problem is that the variety offered (PHB3253), is of intermediate maturity, while KSC offers late maturing varieties in their 600 series, which are recommended for the area.

Seed promotions are mainly undertaken by Kenya Seed Company at places such as the Agriculture Society of Kenya and Harambee shows, and through the mass media.

Farmers' view of the hybrid maize seed industry and the seed performance.

H614 variety was ranked first by almost all the farmers followed by H625 and H628. The farmers gave the advantages of H614 mainly as being: high yielding, disease and insect resistant, less rotting in fields and during storage, less lodging and finally good tasting. The farmers complained about the impurity of the seed from Kenya Seed Company, as it was a mixture of different varieties. They indicated that they buy seed under one varietal name but when the crop starts tasseling in the field they observe that, it was a mixture of different varieties of seed. The farmer is well aware of the tasseling characteristics of different varieties and can easily identify the different varieties in the mixed seed. Ninety-six point seven percent of the farmers admitted that they did not use the new PHB3253 seed because it was low yielding and easily rots in storage. The two main reasons as to why the PHB3253 seed is unable to penetrate the market is that it is a seed for mid-altitude zones and so cannot yield highly in highlands like the H600 series produced by the Kenya Seed Company and farmers are aware of that. Also due to the high import duty imposed on it, it further reflects on the high buying prices and so becomes more expensive than the locally produced seed of the Kenya Seed Company thus raising production costs.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of market structure reveals that there are factors that favour imperfect competition in Trans Nzoia hybrid maize seed marketing at the retail level. These include unequally distributed shares of transactions among traders, the existence of product differentiation and barriers to entry. However, based on the Gini Coefficient of 0.6 the market is categorized as oligopolistic. The impact of liberalization intended for the seed industry has so far had minimal impact on the production side in the seed industry, but some impact on the distribution side. The only impact in the District is that the monopoly of distribution of the seed initially done by KFA has been reduced and now there are many traders in seed retailing. In spite of the fact that the government allowed other companies in the seed industry, KSC still has 96.7% of the market share in the District indicating that there is still a monopoly of seed produced.

Some recommendations for the seed industry include improved inspection, increased access to credit, and increased competition. First, KEPHIS should introduce stern punishment for the seed companies who give adulterated seed to unsuspecting farmers and ensure that farmers get pure seed. Second, the government should facilitate easier access to credit so more traders can enter the business. One way is to encourage micro-finance organizations to offer credit to traders so that they can expand their businesses. Third, competition in the seed production sector should be encouraged. Finally, The Kenya Agricultural Research Institute should develop more late maturing varieties and offer them to different seed companies. Barriers to entry for importers could be relaxed, in particular the costly mandatory three year National Performance Trials. Finally, Government should consider lowering the import tax on seed, as it did for fertilizer, to make agricultural inputs cheaper to farmers.

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BIOPHYSICAL OR ECONOMIC PERFORMANCE – WHICH REFLECTS FARMER CHOICE OF LEGUME 'BEST BETS' IN MALAWI?

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ABSTRACT

The ICRISAT Mother-Baby (MB) trial model has been used to test Malawi's 'Best-Bet' legume-based soil fertility management technologies since 1997. The purpose of the MB approach is to enhance farmer participation in conventional on-farm research and facilitate their evaluation of technologies. This paper reviews the agronomic and economic performance of the technologies under test and compares them with farmer assessments. Three seasons results show that the legume-intensified 'Best-Bet' systems performed as expected, increasing yields from as little as 0 kg ha^{-1} in the 1997/98 season, to in excess of 3,000 kg ha^{-1} in 1999/2000 when compared to the unfertilized maize. Yet, farmers still expressed concerns about the marginal loss of maize production and labour implication. Farmers weighed the benefits of weed suppression and potential cash earnings, against input costs, problems of seed and fertiliser access, and problems of grain market delivery. Marginal rate of returns analysis identified mucuna-maize rotation, maize-pigeon pea intercrop, pigeon pea + groundnut intercrop-maize rotation, and maize + tephrosia as the technologies that offer substantial benefits and a competitive rate of return to farmers' investments. The identification in Baby trials matched the technologies farmers identified best fit their circumstances and are likely to be selected first for adoption.

Keywords: Agronomic-led technology path, best-bet legume-based soil fertility management technologies, marginal rate of returns analysis, mother-baby trials.

INTRODUCTION

From a household livelihoods perspective the poorest and most food-insecure farmers in sub-Saharan Africa are located in the semi-arid areas, where the natural resource base is both fragile and infertile. Surveys in these areas have consistently shown that smallholder farmers fail to achieve the yields obtained by researchers in trials conducted on research stations and farmers' fields (Ahmed *et al.,*1997; Rohrbach,1998; Freeman, 2001). The yield gap continues to persist despite widespread adoption of improved open-pollinated varieties and hybrids. Much of the yield gap is explained by non-adoption of complementary agronomic management practices needed for farmers to fully exploit the increased potential of the new cultivars (Blackie, 1994). Most crop management recommendations currently diffused to smallholders through extension are not useful to farmers because they are made without considering their severe resource constraints, high riskiness and uncertainty of crop and animal production and risk-aversion. A major challenge facing sub-Saharan Africa is to find an agronomic-led technology path for farmers in marginal areas, which expands investments in soil fertility improvement in order to remove the binding constraints of poor soils, unreliable rainfall and drought (Blackie and Jones, 1993).

Even though there has been a concerted effort throughout sub-Saharan Africa to move to on-farm experimentation, with a much greater degree of farmer participation, many researchers and development specialists fail to understand or take account of farmers' real priorities (Kanyama-Phiri, *et al.,* 2000). Research programmes still assume that rural household production goals focus on maximizing yields or financial returns, while in reality they may be concentrating on getting the most return from the available household labour pool, or from a very small cash investment, or securing and maximizing household food security (Ahmed, *et al.,* 1997; Rohrbach, 1998). For many households the cash requirement needed to buy inorganic fertilizer far exceeds their total annual cash income. The lack of cash or access to credit dominates decision-making at the household level and is central to adoptable technologies, as is the availability of household labour. The organization of labour within rural areas of sub-Saharan Africa is a complex topic, as many households are forced to sell their labour in return for food or cash which, in turn, compromises their agricultural efforts (Kumwenda, *et al.,* 1997; Rohrbach, 1998). For this expanding group more emphasis on organic sources of nutrients, especially legumes, that capitalize on the freely available nitrogen in the atmosphere, is one potential strategy for increased soil fertility (Kumwenda, *et al.,* 1997.).

To address this situation in Malawi, soil scientists and agronomists from the National Agricultural Research and Extension Services (NARES) met in 1996, to synthesize information, published information and the results of years of on-farm research. 'Best-bet' technology options identified (Table 1) for further on-farm assessment aimed to intensify farming systems through incorporation of legumes and would require minimal cash and labour inputs (Kanyama-Phiri *et al.,* 2000).

The ICRISAT Mother-Baby (MB) trial model (Figure 1: Snapp, 1999) has been used to test Malawi's 'Best-Bet' legume-based soil fertility management technologies since 1997. The purpose of the MB approach is to enhance farmer participation in conventional on-farm research and facilitate their evaluation of technologies. This paper reviews performance of the technologies under test and compares agronomic and economic evaluations with farmer perceptions

Table 1. Plant population density, cropping system pattern and description of 'best bet' legume/maize technologies. Biological and farming system traits for each technology are listed. G'nut = groundnut, PP= pigeonpea.

	Technology	Population density (X1000)	Biological characteristics (Variety and planting arrangement and cropping system pattern)	Farming system characteristics
1.	Maize sole cropped *	Maize: 37	Maize hybrid cultivar MH18, three maize plants per planting stations, 0.9m X 0.9 m intervals between ridges. Occasional low density intercrop planted by farmers, at less than one per 3 maize plants, so considered "sole cropped".	Current farmer practice throughout Malawi, produces staple maize crop with minimal labour
2.	Maize + pigeonpea (PP) intercrop*	Maize: 37 PP: 37	Temporal compatibility. PP cultivar ICP 9145 planted at the same time as maize, 3 plants per planting station spaced halfway between each maize station. PP grows slowly, which reduces competition.	Low cost, low risk strategy: PP is a bonus crop; in a low density intercrop system that prioritizes maize yields.
3A.	G'nut + PP intercrop year 1, rotation with maize year 2	G'nut: 74 PP: 37	Groundnut cultivar JL 24 or CG 7 was grown as a single row, 15 cm spacing on ridges spaced at 0.9 m intervals. To enhance residue biomass quantity and quality, a 'bonus' PP crop intercropped with a short duration grain legume.	A higher cost system that prioritizes grain legumes as well as maize. G'nut seed is minimized to lower costs, and use farmer-adoptable seeding rates. PP is a bonus crop.
3B.	Soya bean + PP intercrop, rotation with maize year 2	Soya bean: 222 PP: 37	Same as G'nut + PP, except a double row of 15 cm spaced soybeans planted along each ridge. Indeterminate variety Magoye, does not require inoculum (nodulates with indigenous Rhizobium) to maximize performance on-farm.	Higher density of seed is possible given that seeds are smaller and cost is cheaper than groundnuts. PP is a bonus crop.
4.	Maize + Tephrosia vogelii relay intercrop	Tephrosia vogelii 20 kg seed broadcast /ha Maize: 37	Temporal compatibility, enhanced by planting Tephrosia with maize at 1st weeding. Green manure screening studies indicated widespread adaptability of Tephrosia.	Planting designed to minimize labour, seed is broadcast along ridge and incorporated by weeding operation.
5.	Mucuna puriens rotation	Mucuna:74	Mucuna has widespread adaptability as a green manure or grain legume, it produces about 5 t/ha residue biomass and 1.8 t/ha seed yield for most agroecosystems of Malawi.	Farmers eat or sell mucuna seed in some parts of Malawi. Weed suppression may be a major benefit of *Mucuna puriens*

* either planted with area specific fertilizer recommendations (69 kg Nitrogen/ha, 20 kg Phosphorus/ha) or without any fertilizer.

This paper reviews performance of the technologies under test and compares agronomic and economic evaluations with farmer perceptions from three seasons of trials for the Central Plain and the Lake Shore of Malawi (Figure 1).

MATERIALS AND METHODS

ICRISATs approach to on-farm experimentation uses the mother and baby trial design. Mother trials are researcher-managed and completely randomized with four replications per site. Mother trials are designed to present farmers with as many options as possible and enable them to choose technologies that best fit into their farming system (see Table 1 for details). Mother trials enable farmers to make direct comparisons of different best bet technologies in the same field and the same year and over several years. Baby trials are located around mother trials, and consist of a sub-set of treatments chosen from the mother trial (see Table 2). Baby trials are researcher- or farmer-managed and are not replicated. Baby trials allow farmers to see for themselves the performance of treatments in different trial sites, and increase testing across space under different management conditions. Although the number of baby trials varies by site and year, about 20 new trials were initiated per mother trial each year. Maize and grain legume yields were measured at

Figure 1. Mother-Baby Trials and their loaction in Malawi.

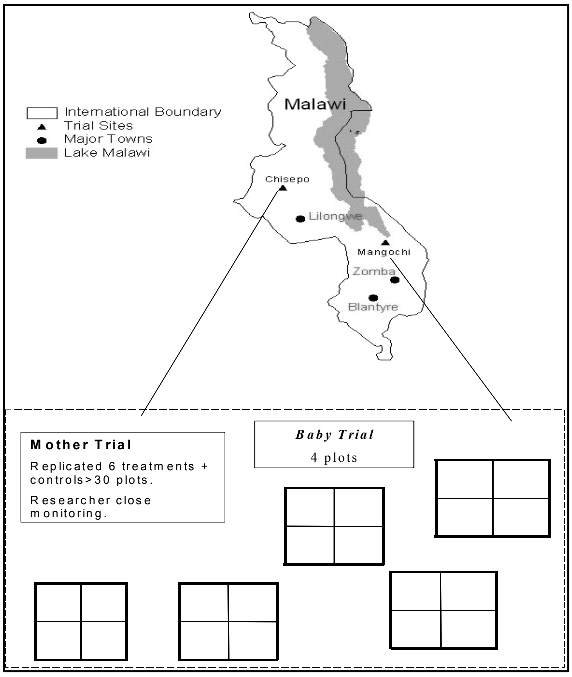


Table 2. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) baby trial plot design

Year 1		Year 2	
Maize-pigeon pea intercrop	Maize-*Tephrosia* intercrop	Maize-pigeon pea intercrop	Maize-*Tephrosia* intercrop
Groundnut-pigeon pea intercrop	Maize (control)	Maize	Maize (control)

harvest each season for the mother and baby trials at each location. In addition to baby trials, farmer experimentation trials were set up to enable farmers to conduct experiments of their own choice of options. Farmer trials allow them to develop their own methods to experiment, modify treatments to better fit into their whole-farm system, and share experimental results with other farmers.

To fully understand the household labour implications of the 'Best-Bet' technologies, field days were held on a seasonal basis and farmers' perceptions of each technology were solicited through matrix ranking exercises. These field days were followed up by a series of focus group discussions in March, 2001, with farmer groups in the Chisepo and Mangochi areas (Rusike and Twomlow, unpublished field notes). At each of these meetings the farmers were asked to describe their cropping calendar, the labour resources used for each task, local input and output prices (see Table 3), the 'Best-Bet' technologies they had been evaluating, and what, if anything they had adopted or adapted.

Table 3. Nominal Prices of Inputs and Commodities in the Study Areas, 1997/98-1999/2000.

Prices and Costs (Malawi Kwacha/kg)	Year		
	1997/ 1998	1998/ 1999	1999/ 2000
Nominal Market Prices of products			
Maize	5.00	6.25	3.00
Groundnut	18.00	20.00	20.00
Pigeonpea	15.00	19.00	20.00
Bean	8.00	10.00	10.00
Mucuna	5.00	10.00	15.00
Transport cost farm-market	0.20	0.23	0.30
Harvesting and processing costs per kg			
Maize	1.43	1.60	2.02
Groundnut	12.68	14.59	19.03
Pigeonpea	4.19	4.79	6.17
Bean	4.19	4.79	6.17
Mucuna	4.19	4.79	6.17
Field prices of product			
Maize	3.51	4.51	0.68
Groundnut	5.25	5.27	0.67
Pigeonpea	10.74	14.08	13.53
Bean	3.74	5.08	3.53
Mucuna	0.74	5.08	8.53
Market level prices of inputs			
Family labour opportunity cost per hour	3.33	3.83	5.00
Calcium Ammonium Nitrate per kg (26%N)	5.92	11.60	13.00
20:20:0+4S per kg	7.44	14.80	17.20
Urea per kg	7.62	14.00	15.60
MH18 Maize seed per kg	22.00	70.00	63.90
JL24 or CG7 Groundnut seed	30.00	40.00	35.00
ICP145 Pigeonpea seed	25.00	30.00	60.00
Bean seed	40.00	50.00	60.00
Tephrosia seed	10.00	10.00	10.00
Mucuna seed	25.00	20.00	15.00

This information was combined with grain and input prices from annual records of market prices and then used to calculate partial budgets for each 'Best-Bet'. Partial budgets were used to calculate the present value of net benefits for each option. Marginal rate of returns analysis was used to determine what financial benefits might accrue for a rural household and the potential risks. Price data were included for the three years for which there are agronomic trials' data and deflated to 1999 constant prices.

RESULTS AND DISCUSSION

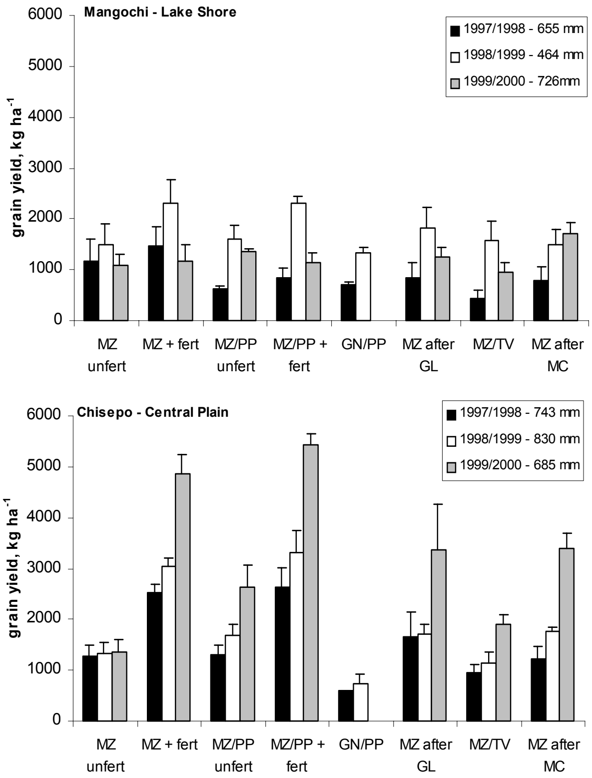
Grain yield responses

Three seasons results from the two mother trials show that the legume intensified 'Best-Bet' systems performed as the technocrats expected, increasing yields from as little as 0 kg ha^{-1} in the 1997/1998 season, to in excess of 3,000 kg ha^{-1} in 1999/2000 when compared to the unfertilized maize (Figure 2).

The yield data in Figure 2 show that:

1. Fertilizer applied at the recommended rate of 69 kg N/ha + 20 kg P/ha at the central plain site doubled or even trebled maize yields, as was the case in the 1999/2000 season.
2. Yield response was more variable at the drier, riskier lakeshore site, particularly in the 1998/1999 season (note the standard deviations). The marked lack of response in 1999/2000 is attributed to the host farmer being ill and eventually dying.
3. Sole maize yield was markedly more variable than maize + pigeonpea intercrop yield. This supports other research findings that have shown reduced risk with intercrop systems.
4. Fertilizer can be applied to either a sole maize crop or a maize + pigeonpea intercrop – the yield response is similar in both cases, particularly in the less risky central plain regions.
5. Legume intensified systems (without fertilizer) at the central plain site consistently increased grain yields over the three seasons, from as little as 0 kg/ha in the 1997/1998 season, to in excess of 2,000 kg per ha in 1999/2000. Despite these impressive increases, the overall productivity of the system was only about half as effective as fertilizer applied at the recommended rate of 69 kg N/ha + 20 kg P/ha, where fertilizer increased yields by 1,200 to 3,500 kg per ha.
6. Yield response of all technologies was more variable at the drier, riskier lakeshore site (note the standard deviations), the exception was pigeonpea intercrop systems which produced relatively stable and increased yields in the 1998/1999 and 1999/2000seasons.
7. Yields of the maize/grain legume systems were the same, or slightly higher, than continuous, sole cropped maize. Legume grain generally has a much higher market value, and calorie content, compared to maize grain. Farmer assessment of system performance will vary, depending on farmer perception of legume value, and labor requirement to grow the legume.
8. Maize yield was the only product of the maize/*Tephrosia vogelii* relay intercrop green manure system within the mother trials. We expected this yield to increase over time by the addition of nitrogen-rich residues from the T.vogelii. For the lake shore site there was no significant increase in yield after three years of implementing the

Figure 2. Grain yield response of sole cropped maize to area specific fertilizer recommendations (69 kg N + P ha-1) compared to yield of maize/legume intensification 'Best Bet' systems.



system. It was disappointing to note that maize yield enhancement occurred only in the third year of trial implementation for the central plain site, with a yield increase of 550 kg/ha over the unfertilized maize crop.

9. As with 8) above, maize grain yield is the only product of the Maize/Mucuna puriens rotation within the mother trials, yields that were expected to increase over time by the addition of the nitrogen-rich residues from the Mucuna puriens. Although the maize yields from the initial cycles of the rotation were disappointing, significant yield benefits at both locations occurred in the third season, 1999/2000, when maize yields increased by 600 to 2,000 kg/ha. The grain from M. puriens is also being used as a food in times of shortage, although it is not readily marketable due to its low value.

The results from the baby trials reflect how the sub-set of 'Best-Bets' performed under a range of farmer management environments (Table 4). For treatments tested in baby trials the maize/*T. vogelii* treatment produced the highest maize yields summed over the three years, followed by maize + pigeon pea, and unfertilized maize control. The pigeon pea + groundnut intercrop-maize rotation gave the lowest maize grain yields. As in mother trials different treatments have different trade-offs between maize grain and legume grain, labour requirements, timeliness in weed control and fuelwood uses.

Farmer Perceptions

Farmer assessment of the technologies (negative and positive traits listed in response to open-ended questions) is presented in Table 5, by male and female household heads. Farmers participating in the trials expressed strong interest in the technologies. However, a number of constraints to technology adoption and trade-offs underlying technology

Table 4. Grain yields of maize and legumes from on-farm trials carried out with 33 farmers, located in three agro-ecozones (Chisepo and Mangochi). The data present three years of production for best bet technologies: Sole maize = sole cropped, continuous maize, Maize/PP = maize/pigeonpea intercrop, Leg/PP = maize rotation after a legume/pigeonpea intercrop and Maize/Tv = maize/*Tephrosia vogelii* relay intercrop (technologies described in Table 1).

	Chisepo		Mangochi	
	Maize	Legume	Maize	Legume
1998	N=23		N=25	
Sole Maize	1152	NA	1993	NA
Maize/PP	963	155	1702	372
**Leg/PP* & Maize rotation	NA	1442	NA	1186
Maize/Tv	1016	NA	1880	NA
1999	N=19		N=39	
Sole Maize	1350	NA	1323	NA
Maize/PP	1514	224	1643	280
Leg/PP & **Maize* rotation	2056	NA	2284	NA
Maize/Tv	1704	NA	1874	NA
2000	N=39		N=32	
Sole Maize	1521		1640	NA
Maize/PP	2321	ND	1910	ND
Leg/PP & **Maize* rotation	NA	2715	NA	1903
Maize/Tv	4109		2227	NA
Total (3 year)				
Sole Maize	4023	NA	4956	NA
Maize/PP	4797	379	5255	653
**Leg/PP* & Maize rotation	2056	4157	2284	3089
Maize/Tv	6829	NA	5981	NA

**Italics* = phase of the rotation implemented this year, grain yields reported are from this phase.
NA – not applicable ND – no data available for grain legume

Table 5. Malawi preference data summary. Presented as percentage of farmers that noted a trait (positive or negative) in an open-ended question regarding traits farmers associated with the maize and maize-legume technologies included in the trials. PP = pigeonpea, Legume = groundnut or soya bean, Tephrosia = Tephrosia vogelii

Technologies (see Table 1)	#1 Maize	#2 Maize + PP	#3 Legume + PP / Maize rotation	#4 Maize + Tephrosia
Positive Traits:				
Less labour per 2 crops		25.0	25.0	0.0
Easier to weed required		25.0	41.7	19.4
Less land per 2 crops		16.7	25.0	0.0
Less weeds and other pests		8.3	5.6	0.0
Early harvest	30.6	16.7	25.0	0.0
Increased food security	16.7	58.3	69.4	25.0
Fuelwood produced		16.7	2.8	13.9
Early emergence	19.4			
Low labour requirement	22.2	2.8	11.1	
Soil fertility improved		38.9	36.1	36.1
Cash sales potential		30.6	33.3	16.7
Negative traits:				
Weed control problems	25.0			36.1
Pest problems	11.1	16.7	5.6	8.3
Seed availability	5.6	19.4	41.7	22.2
No affordable fertilizer	11.1	0.0	0.0	16.7
Reduced food security	58.3	13.9	8.3	61.1
Soil fertility decline	11.1			
Low grain legume price		8.3	30.6	
Late harvest or slow growth		16.7	33.3	
Livestock damage		27.8	19.4	
Limited market access		11.1	19.4	5.6

were elicited through on-going discussions with farmers and surveys documenting farmer perceptions (Tables 5 and 6).This information on farmer evaluation and decision-making would not normally be considered during the course of on-farm trials designed simply to test technology performance. Subsequent focus group discussions with host farmers in the two locations (Rusike and Twomlow, unpublished field notes, March 2001), highlighted that the more innovative farmers at both sites had begun their own experiments with the maize/*T.vogelii* treatment and *Mucuna puriens*. Households at both sites are;

- coppicing the *T.vogelii* and harvesting the wood from their plots and
- planting *Mucuna puriens* as a relay intercrop with their maize, a practice not uncommon in other parts of Malawi.

The impact of these farmer innovations requires further investigation to assess the tradeoffs households are willing to make in terms of overall household requirements and soil fertility.

Economic Performance

Yet, farmers still expressed concerns about the marginal loss of maize production and labour implications. Farmers weighed the benefits of weed suppression and potential cash earnings, against input costs, problems of seed and fertiliser access, and problems of grain market delivery. Ultimately, adoption of these technologies appears more likely to depend on the market returns to legume production and underlying opportunity costs of labour, capital and land, rather than on the contributions of these crops to soil fertility. Marginal rates of return analysis of Mother trials identified mucuna-maize rotation, maize-pigeon pea intercrop-maize rotation, and maize-pigeon pea plus fertilizer treatments as the best technologies that offer substantial benefits and a competitive rate of return to farmers' investments (Table 7). Marginal rate of returns analysis of Baby trials identified maize-pigeon pea intercrop, groundnut-pigeon pea intercrop-maize rotation, and maize-tephrosia as being attractive for adoption by farmers (Table 8).

Table 6. Constraints cited to expanding legume area, survey data presented as a percent of response for male headed households (MHH) and female headed households (FHH).

Constraints:	Chisepo		Mangochi	
	MHH (n=100)	FHH (n=19)	MHH (n=87)	FHH (n=33)
Lack of seed or cash to buy seed (%)	62	57	53	49
Lack of labour (%)	22	33	8	14
Low yields (%)	3	3	30	32
Land shortage (%)	5	4	7	3
Limited market (%)	5	4	2	3
Other (%)	3	0	0	0

Table 7. Marginal returns analysis of undominated treatments tested in mother trials, 1997/1998-1999/2000

Chisepo		Mangochi		Dedza	
Treatment	Return (%)	Treatment	Return (%)	Treatment	Return (%)
Unfertilized maize	n.a.	Unfertilized maize	n.a.	Unfertilized maize	n.a.
Mucuna-maize	1562	Mucuna-maize	675	Mucuna-maize	135
Maize-Tephrosia	Dominated	Maize-Tephrosia	Dominated	Legume-maize	1743a
Maize+pigeon pea	Dominated	Maize+pp unfertilized	Dominated	Maize/Tephrosia	101b
Groundnut+pp	Dominated	Groundnut + pp	44	Maize+legume unfertilized	Dominated
Maize+fertilizer	60[a]	Maize+fertilizer	Dominated	Maize+fertilizer	Dominated
Maize+pp+ fertilizer	152[a]	Maize+pp+ fertilizer	Dominated	Maize+legume+ fertilizer	Dominated

a. If rule out mucuna-maize system
b. If rule out mucuna-maize and bean-maize systems

CONCLUSIONS

Tables 9 and 10 compare the agronomic, economic and farmers' preference of the different treatments tested. For Mother trials the ranking based on agronomic criteria is different from that based on economic criteria because of different resource requirements, and input and output prices of maize and legumes. The rankings based on economic criteria and farmers' preferences are the same for mucuna-maize rotation and maize-pigeon pea treatments but different for other treatments because the marginal rate of return analysis does not consider resource constraints, access to input and output markets, risk and food security. For Baby trials, there is a high correspondence between rankings based on economic criteria and farmers' preferences. This shows that baby trials achieve a better targeting of technologies that best fit farmers' circumstances and which are likely to be selected first for adoption.

The diversity of opinions and knowledge solicited through formal surveys, focus group discussions and one-on-one interview with farmers throughout southern Africa in recent years only seeks to highlight that farmers are currently following an integrated nutrient management approach using a diversity of soil fertility amendment practices in a complicated manner that best fit individual household resources (Ahmed, *et al.,* 1997; Coote *et al.,* 1998; Kumwenda *et al.,* 1997; Rusike and Twomlow unpublished field notes, 2001).

Unfortunately, at the same time many research and extension programmes focus on single interventions, and rarely take account of farmers' perceptions of on-farm research and the adaptations they make, that could be included in future research initiatives.

Overall our findings indicate the value of linking participatory, on-farm assessment of individual technologies with broader analysis of technology adoption constraints and competing technology choices (Tables 8 and 9). We suggest that future research should pursue market–seed linkages and integrated nutrient management strategies, with a strong focus on farmer innovations that have arisen out of this current work.

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Table 8: Marginal returns analysis of undominated treatments tested in baby trials, 1997/1998-1999/2000

Treatment	Chisepo	Mangochi	Dedza
	Return (%)	Return (%)	Return (%)
Unfertilized maize	n.a.	n.a.	n.a.
Maize Tephrosia	49	39	Dominated
Maize + Pigeon pea	239	649	331
Groundnut + Pigeon pea	220	184	Dominated

Table 9. Technology choice of options tested in mother trials, 1997/1998-1999/2000.

Option	Agronomic	Economic	Farmer Acceptability
Unfertilized maize	5	6	5
Maize + area specific fertilizer	2	4	7
Maize + pigeon pea	3	2	2
Maize + pigeonpea +area specific fertilizer	1	3	6
Groundnut+pigeon pea	6	5	3
Maize + tephrosia	4	7	4
Mucuna-maize rotation	7	1	1

Table 10. Technology choice of options tested in baby trials, 1997/98-1999/2000.

Option	Agronomic	Economic	Farmer Acceptability
Unfertilized maize	3	4	4
Maize + pigeon pea	2	1	1
Groundnut + pigeon pea	4	2	2
Maize + tephrosia	1	3	3

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EFFECT OF GROWING ANNUAL FORAGE LEGUMES WITH MAIZE AND MAIZE LEAF DEFOLIATION ON GRAIN AND STOVER YIELD COMPONENTS AND UNDERSOWN FORAGE PRODUCTION

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ABSTRACT

Two experiments were conducted to assess the effect of forage legumes grown with maize and maize leaf defoliation on grain and stover yield and forage production and to select compatible forage legumes to be grown with improved maize. Three annual forage legumes were grown with maize in 1996 and 1997. Various proportions (rates) of maize leaf defoliation were also carried out when forage legumes were grown in association with maize in plots arranged in a split plot design. Maize leaf defoliation treatments (0, 25, 50, 75 and 100%) were assigned to sub-plots and growth stages of maize at the time of defoliation (tasseling, silking and milk stages) as main-plot treatments. The forage legumes were established when undersown with maize at about knee height growth stage without reducing the grain and stover yield but the forage yield was low compared to sole forage production. Grain yield of maize was significantly affected by rate of leaf defoliation, growth stages and their interaction. There was also a significant effect on the yield of stem, cob and defoliated leaf due to rate of leaf defoliation. However, the yield of husk, leaves, tassel and the undersown forage legumes were affected by rate of leaf defoliation only. The results revealed that the critical rate of maize leaf defoliation that does not affect the grain and stover yield components as well as the yield of undersown forage crops lies below 50%.

Keywords: Annual forage legume, defoliation, grain and dry matter yield, growth stages, maize, stover yield components,

INTRODUCTION

One of the bottlenecks of livestock production in Ethiopia is feed shortage. Due to this problem, animals hardly meet their nutritional requirements and livestock productivity, in terms of meat and milk, is very low, draft power from oxen is minimal which thereby affects food crop production under smallholder crop/livestock farming systems.

Integration of food and forage crops is a useful practice in areas where both crop and livestock farming are simultaneously practised (Lulseged *et al*., 1987). Multiple cropping systems can actually give more efficient total resource exploitation and greater overall production than sole crops (Habtamu *et al*., 1996). As an alternative approach, integration of forage legumes with cereals that can be easily adopted by the farmers has been tested in the highlands of Ethiopia (Minale *et al*., 1997). Forage legumes enhance soil fertility, improve yields and nutritive values of crop residues, sustain feed production during the dry seasons, suppress weeds and combat erosion (Tothil, 1986; Nnadi and Haque, 1986; Lal, 1984; Humphreys, 1994; Thung and Cock, 1979). In terms of the technical feasibility of this approach, results in Ethiopia show that forage legumes such as lablab, clover and vetch are capable of leaving 30-60 kg N per hectare in the soil to be used by the next crop. The residual N of several legumes in Ethiopia increased the yield of maize, sorghum and wheat between 112-190, 138-174 and 105-124 percent, respectively, compared to growing them after oats (Nnadi and Haque, 1986).

The yield of forage legumes grown with tall and high yielding maize varieties is found to be low compared to sole grown forage legumes due to competition for growth promoting factors like moisture, temperature, light and so on (Tessema and Halima, 1998). On the other hand, feeding of different maize parts by defoliation during the wet season for livestock by smallholder farmers is a common practice in most parts of Ethiopia. Fekadu (1999) reported that the tassel, plant parts above the ear and other maize stover are among the common animal feed types from maize source. These feed types are obtained during different times according to the stage of the crop's growth. Maize at an early stage of maturity provides animal feed starting from the time of first weeding, where there is no other feed source. Presently there is no information about the grain and stover yield components of improved maize varieties under leaf defoliation at various growth stages when forage legumes are grown in association with maize. Therefore, the objectives of this study were to select compatible forage legumes that could establish under maize and to assess the effect of maize leaf defoliation at various growth stages on grain and stover yield components of maize and forage production when maize is grown with annual forage legumes.

MATERIALS AND METHODS

The study was conducted at Adet Agricultural Research Centre (AARC), Northwestern Ethiopia, 445 km from Addis Ababa. The area is located at 11°17' N latitude and 37° 43' E longitude at an elevation of 2,240 m above sea level. The centre is characterised by alluvial soil and to some extent by red and black soils. The experiments were conducted on red soil representing one of the typical soil types of the region. The annual rainfall of the area is 1,285 mm with a range from 860 to 1,771 mm and 109 rainy days per year (average of 14 years, 1986-99). There is one main rainy season extending from May to October.

The average annual minimum and maximum air temperatures are 8.8 and 25.4 °C, respectively (AARC, 1999).

Three annual forage legumes (*Vicia dasycarpa, Vicia villosa and Vicia atropurpurea*) with maize and the control

Table 1. Mean maize grain, stover components and forage yield for the undersowing experiment at Adet , 1996-97.

Treatments	Grain Yield (t/ha)	Stover Yield Components (t/ha)				Forage yield (DM t/ha)
		Husk, leaves and tassel	Stem	Cob	Total	
Vicia Villosa	9.28	7.10	9.81	2.21	19.12	0.99
Vicia dasycarpa	10.60	7.79	10.65	2.54	20.98	0.68
Vicia atropurpurea	10.24	7.55	11.58	2.44	21.57	0.58
Sole maize (control)	10.49	7.76	10.99	2.44	21.19	-
Mean	10.15	7.55	10.76	2.41	20.72	0.75
SE (±)	0.54	0.21	0.58	0.13	0.76	0.09
LSD (0.05)	NS	NS	NS	NS	NS	0.06
CV(%)	15.00	7.67	15.00	14.99	10.32	27.27

(maize only) were grown during 1996 and 1997 using a randomized complete block design with three replications. The forage legumes were broadcast at the knee high stage of maize growth. The effect of maize leaf defoliation when grown with forage legumes was carried out using a split plot design in 1999 and 2000, where the rate of leaf defoliation (0, 25, 50, 75 and 100%) as sub-plot and different growth stages of maize (tasseling, silking and milk stages) as main-plot treatments, respectively. Leaf defoliation was done starting from the bottom leaves depending upon the rate of defoliation in each growth stage. The sub-plot size was 5.1 by 3 m. The spacing between replications and plots were 2 and 1 m, respectively, while spacing between individual plants within rows and between rows was 0.3 and 0.75 m, respectively.

Released maize variety (HB-660) was planted in the 1st week of June in the experimental periods on well prepared moist red soil. Fertiliser at a rate of 100/100 kgha^{-1} N/P_2O_5 was applied using broadcasting method on the plots. Diammonium Phosphate was applied at planting while half of the nitrogen fertiliser in the form of urea was applied at planting and after establishment when maize reached the knee high stage. One adaptable annual forage legume species (Vicia villosa) previously tested during the undersowing experiment in 1996 and 1997 crop seasons at AARC was selected and planted when maize reached the knee high stage for the defoliation study. The seed rates were 25 and 15 kg ha^{-1} for maize and forage legume, respectively. Weeding was done systematically by selecting broad leaved and other critically damaging weeds manually after undersowing annual forage legumes. Uniform samples that represent the whole plant in each treatment were taken randomly and sun-dried by leaving in the sun until the moisture lost for partial dry matter analysis of the maize stover components and annual forage legumes.

Maize and forage legumes were harvested from all the treatments excluding guard rows from all the plots at full maturity and at 10-50% flowering stage, respectively. Grain yield was determined at 12.5% moisture content of maize and individual samples of the maize stover components and undersown forage legume were taken for DM analysis, which was determined by oven drying at 65 ^{o}C for 72 h until constant weight was obtained. Analyses of variance were carried out using SAS (1998) by the general linear model procedure for grain yield and dry matter yield of the stover components and forage legumes. Mean separation was carried out using the least significant difference. Mean differences for grain and dry matter yield of the maize stover components and undersown forage legumes were considered significant at P<0.05.

RESULTS AND DISCUSSION

Growing of forage legumes in association with maize

Maize grain, stover yield components and DM forage yield are presented in Table 1. Forage crops grown under maize did not reduce maize grain and stover yield components compared to sole maize production. The system relatively increased total fodder yield (stover yield components plus forage). All annual forage legumes were established when undersown in maize at knee high growth stage. Results indicated that there were highly significant (P < 0.05) yield differences among the undersown forage legumes.

Mean maize grain yield obtained in combination with forage legumes and the sole maize crop were 10.04 and 10.49 t/ha, respectively. Total crop residue yield (forage plus stover yield components) in the two years from the undersown plot was 20.31 t/ha. The highest grain yield and total stover yield component when maize was grown with *Vicia dasycarpa and Vicia atropurpurea* were 10.60 and 21.57 t/ha, respectively. The overall mean grain and total stover yield components were 10.15 and 20.72 t/ha, respectively (Table 1). The growth and yield of the undersown forage legumes were lower in contrast to sole forage planting. This could be attributed possibly to light competition during the main rainy season when the maize crop was at vegetative stage. Growth of forage legumes showed gradual increase as the amount of rain declines at the last periods of the rainy season (end of August). *Vicia villosa* was the highest yielding forage legume species compared to others when undersown in maize. Different forage crops were established under maize without reducing the grain and stover yield components in Ethiopia (Alemu *et al.*, 1987; Lulseged *et al.*, 1987; Tessema and Halima, 1998; Tessema, 2001). However, the forage yield varies depending on the nature (annual/perennial) of the forage crops grown with maize, climatic and soil condition of the area and the type of maize varieties used for undersowing purpose.

Effect of maize leaf defoliation at various growth stages

Grain yield of maize was significantly (P<0.05) affected both by the rate of leaf defoliation and growth stages of maize and their interaction (Table 2). The highest maize grain yield of 8.82 t ha^{-1} was obtained from 25% maize leaf defoliation at milk growth stage. Silking and milk growth stages of maize gave the same grain yield of 6.65 and 7.15

Table 2. Grain yield (t ha^{-1}) of maize as affected by rate of leaf defoliation at various growth stages

Growth stages	Rate of leaf defoliation (%)					
	0	25	50	75	100	Mean
Tasseling	9.07^{a}	7.98^{abc}	7.10^{bc}	4.50^{e}	1.07^{g}	5.94^{b}
Silking	8.78^{a}	8.47^{ab}	7.70^{abc}	5.35^{de}	2.93^{f}	6.65^{a}
Milk	8.68^{a}	8.82^{a}	6.78^{cd}	6.63^{cd}	4.85^{e}	7.15^{a}
Mean	8.84^{a}	8.42^{a}	7.19^{b}	5.49^{c}	2.95^{d}	6.58

SE (±) for comparing growth stage means = 0.23
SE (±) for comparing rate of defoliation means = 0.30

Within rows and columns, means followed by the same letters are not significantly different at P < 0.05

Table 3. Dry matter yield (t ha-1) of the stem component of maize as affected by rate of leaf defoliation at various growth stages

Growth stages	Rate of leaf defoliation (%)					
	0	25	50	75	100	Mean
Tasseling	7.84	6.04	6.72	5.02	8.12	6.75^{a}
Silking	7.10	6.95	5.52	5.01	4.82	5.88^{b}
Milk	6.92	7.15	4.91	4.50	5.00	5.70^{b}
Mean	7.28^{a}	6.71^{ab}	5.72^{cd}	4.85^{d}	5.98^{bc}	6.12

SE (±) for comparing growth stage means = 0.24
SE (±) for comparing rate of defoliation means = 0.31

Within rows and columns, means followed by the same letters are not significantly different at P < 0.05

Table 4. Dry matter yield (t ha-1) of the cob component of maize as affected by rate of leaf defoliation at various growth stages.

Growth stages	Rate of leaf defoliation (%)					
	0	25	50	75	100	Mean
Tasseling	2.00	1.77	1.43	0.98	0.28	1.29^{c}
Silking	2.03	1.93	1.77	1.15	0.82	1.54^{b}
Milk	1.98	2.00	1.60	1.73	1.47	1.76^{a}
Mean	2.01^{a}	1.90^{a}	1.60^{b}	1.29^{c}	0.86^{d}	1.53

SE (±) for comparing growth stage means = 0.06
SE (±) for comparing rate of defoliation means = 0.08

Within rows and columns, means followed by the same letters are not significantly different at P < 0.05

Table 5. Dry matter yield (t ha-1) of husk, leaves and tassel components of maize as affected by rate of leaf defoliation at various growth stages

Growth stages	Rate of leaf defoliation (%)					
	0	25	50	75	100	Mean
Tasseling	7.71	6.87	4.95	3.89	2.84	5.25
Silking	8.09	6.31	6.19	4.00	2.93	5.50
Milk	7.80	6.61	5.38	4.78	3.29	5.57
Mean	7.86^{a}	6.59^{b}	5.51^{c}	4.23^{d}	3.02^{e}	5.44

SE (±) for comparing growth stage means = 0.21
SE (±) for comparing rate of defoliation means = 0.27

Within rows, means followed by the same letters are not significantly different at P < 0.05

Table 6. Dry matter yield (t ha-1) of the defoliated leaf components of maize as affected by rate of leaf defoliation at various growth stages

Growth stages	Rate of leaf defoliation (%)					
	0	25	50	75	100	Mean
Tasseling	-	0.25	0.91	1.35	2.09	0.92^{b}
Silking	-	0.35	1.02	1.86	2.31	1.11^{a}
Milk	-	0.49	1.06	1.90	2.72	1.24^{a}
Mean	-	0.36^{d}	0.99^{c}	1.71^{b}	2.37^{a}	1.09

SE (±) for comparing growth stage means = 0.06
SE (±) for comparing rate of defoliation means = 0.08

Within rows and columns, means followed by the same letters are not significantly different at P < 0.05

Table 7. Dry matter yield (t ha-1) of the undersown forage legumes as affected by rate of leaf defoliation at various growth stages

Growth stages	Rate of leaf defoliation (%)					
	0	25	50	75	100	Mean
Tasseling	1.01	2.11	1.49	1.68	2.80	1.82
Silking	1.39	1.74	1.71	2.26	2.49	1.92
Milk	1.36	1.58	1.61	2.03	1.54	1.62
Mean	1.25^{d}	1.81^{bc}	1.60^{cd}	1.99^{ab}	2.27^{a}	1.79

SE (±) for comparing growth stage means = 0.11
SE (±) for comparing rate of defoliation means = 0.14

Within rows and columns, means followed by the same letters are not significantly different at P < 0.05

ha^{-1}, respectively, while tasseling stage of maize had low grain yield of maize (5.94 t ha^{-1}) during the study. Similarly, the control (without defoliation) and 25% leaf defoliation provided higher but not significantly different grain yield of maize (8.84 and 8.42 t ha^{-1}, respectively).

There was a significant (P<0.05) effect on dry matter yield of the stem and cob components of maize due to rate of leaf defoliation and various growth stages separately (Tables 3 and 4). However, dry matter yield of the husk, leaves and tassel components of maize were significantly affected by rate of leaf defoliation only (Table 5). Both rate of maize leaf defoliation and growth stages showed a significant (P<0.05) effect on the DM yield of the defoliated maize leaves (Table 6). Rate of maize leaf defoliation had a significant effect on the yield of undersown forage legumes (Table 7). Mutetikka and Kyarisiima (1997) reported that by systematic defoliation, quality forage could be obtained from maize without significantly decreasing grain yield of the crop and up to 0.4 t/ha DM can be obtained by harvesting the leaves below the ear leaf.

CONCLUSION

Grain and stover yield components of maize reduced as the rate of maize leaf defoliation increased from 0 to 100% but the reverse holds true for the yield of the defoliated maize leaf and undersown forage legumes. The result revealed that the critical rate of maize leaf defoliation that does not affect the grain and stover yield components as well as the yield of undersown forage crops lies below 50%.

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ECONOMICS OF INTEGRATED TILLAGE AND WEED CONTROL PRACTICES ON MAIZE-BASED SYSTEMS IN THE SMALLHOLDER FARMING SECTOR OF ZIMBABWE.

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ABSTRACT

Smallholder farmers in Zimbabwe rely heavily on draught animal power and ox-drawn mouldboard ploughs for primary tillage and crop establishment. Reduced tillage studies in the past have proved that it is a viable option, which ensures early planting and has less draught animal power demand. Work conducted in two communal areas of Zimbabwe (Chihota, and Tsholotsho) showed that labour can be significantly reduced by the use of half the recommended rates of atrazine (herbicide used in maize) either banded (applying herbicide close to the maize) or full cover. The objective of this paper is to analyse the profitability of tillage and weed control practices in smallholder farms. Using two seasons' data, gross margin analysis showed there were higher returns to cash expenditure ranging from 1.08 to about 2.65 per dollar invested for the reduced tillage and banded atrazine treatments in the three sites. In Tsholotsho, which is a drier area, reduced tillage and either mechanical or use of atrazine banded was more profitable with returns to cash expenditure of Z$2.79 and Z$ 2.65 per Z$ invested, respectively. In Chihota, a relatively wetter area, reduced tillage and banding atrazine in combination with mechanical weeding was more profitable with returns of Z$ 2.05 and Z$ 1.97, respectively. It might be worthwhile for farmers in the two areas to use reduced tillage with mechanical, atrazine or manual weeding depending on their resources.

Keywords: Atrazine, hand weeding, integrated weed control practices,, reduced tillage.

INTRODUCTION

The major constraints to increased maize production in the smallholder sector are low soil fertility, poor access to draught animal power and labour bottlenecks at the start of the planting season. Smallholder farmers in Zimbabwe rely heavily on draught animal power and ox-drawn mouldboard ploughs for primary tillage and crop establishment. It has been recognised that even if the draught power is available, the ploughing operation itself is time consuming and can delay planting of crops. Various work on reduced tillage (Shumba *et al*., 1989, Twomlow *et al.*, 1998) have shown that reduced tillage using a ripper tine to open planting furrows has not only addressed the draught animal power problem, but also ensured early planting.

Herbicide use as a form of weed control has not been adopted in the smallholder sector mainly because of the high cost in purchasing the input. However, due to the associated high costs, various studies have been conducted to reduce the dosage rates of the herbicides on maize especially atrazine. Solonen, 1992 showed that even if the dosage is reduced by a third or half, the corresponding maize yield levels are similar to those obtained under maximum weed management levels; although the weed control efficiency is reduced. In addition, herbicide usage has been done in the intra-row space before removing the inter-row weeds through mechanical cultivation weeding or hand hoeing. Applying herbicides on a 22 cm band reduced herbicide costs by 50% (Chivinge and Schwappenhauser, 1994).

Reduced tillage studies have proved that it is a viable option, which ensures early planting and has less draught animal power demand (Twomlow *et al.*, 1998, Mabasa *et al.,* 1997). The agronomic and weed control effects of both reduced tillage and herbicide use have been documented. However, no economic analysis of an integrated weed control system has been conducted using data from on-farm experiments within DR & SS. In analysing the socio-economic implications of tillage and weeding studies, it is necessary to consider farmer resource levels. These resources include cash availability to purchase inputs, DAP availability, labour availability and implement availability. Adoption practices will depend on likely productivity levels based on the availability of these resources as well as rainfall and soil fertility factors. Alternative systems are likely to be adopted by differently resourced farmers.

The objective of this paper is to assess the financial feasibility of using various tillage and weed control methods in two contrasting communal areas taking into consideration farmer resource levels.

MATERIALS AND METHODS

The paper uses data from past on-farm research trials conducted by the Weeds Research Team of the Agronomy Research Institute in the 1995/1996 season and 1996/1997 season conducted in two contrasting communal areas of Zimbabwe. Two tillage practices and seven weed management systems were evaluated in the farmers' fields at sites in Chihota (NR 2, average annual rainfall = 750 to 1,000mm), Nharira (NR 3, average annual rainfall = 650-800mm) and Tsholotsho (NR 4, annual average rainfall = 450-650 mm) communal areas. Due to discrepancies in the data in Nharira, only the Chihota and Tsholotsho data sets are used in this paper. The tillage treatments were conventional tillage and reduced tillage. Conventional tillage (CT) used an animal drawn mouldboard plough and involved winter-ploughing and spring- ploughing at Chihota, winter ploughing at Nharira and Spring ploughing at Tsholotsho. The conventional tillage practices described above are the current farmers'practices for those areas. Reduced tillage

Table 1. Areas and treatments

NR	Chihota	Nharira	Tsholotsho
	II	III	IV
Average rainfall	750-1000	650-800	450-650
1995/1996 rainfall	664	463	967
Tillage treatments			
Conventional tillage			
Winter plough	x	x	
Spring plough	x		x
Reduced tillage			
Planting furrows	x	x	x
Weeding treatments			
Hand weed at 4 and 6 weeks	x	x	x
Ox cultivation and hand weed at 4 and 6 weeks	x	x	x
Banded atrazine and ox cultivation at 2 and 4 weeks	x	x	x
Full atrazine and ox cultivation at 2 and 4 weeks	x	x	x
Ox plough and hand weed at 4 and 6 weeks	x	x	x
Banded atrazine and ox plough at 6 weeks	x	x	x
Ox cultivation and hand weed at 2 and 6 weeks	x	x	x

(RT) involved opening of the planting furrows using the mouldboard plough. The weeding treatments are reported in Table 1.

Atrazine (herbicide used in maize systems) was applied using a knapsack sprayer calibrated to deliver 223 l/ha of liquid. In each communal area, four farmers with fields within the same location were chosen to participate in the experiments. All farmers were allocated to seven weed management treatments. The treatments were replicated twice per farmer. The blanket fertiliser recommendation used by the public extension system (Agritex) level of 300 kg/ha Compound D and 250 kg/ha ammonium nitrate was used. In addition, detailed labour data collection was done for all the treatments focussing mainly on weeding activities. Labour data for the tillage activities were obtained from the farm management handbook of Agritex. For additional agronomic information about the trials refer to Mabasa *et al* ., 1998.

The study uses a simple input-output budgeting technique (gross margin analysis) to evaluate the economic benefits of the various treatments included in the trials. Gross margin analysis technique has been used in the analysis of various agronomic trials. The choice of using the gross margin analysis was reached after noting that real farmer practices of the area were not included as one of the treatments. According to Table 1, the treatment of hand hoeing after 2 and 4 weeks was the only one near to the real farmer practices but the inclusion of 300 kg Compound D and 250 kg of Ammonium Nitrate meant that the treatment could not be used as a farmers' practice. Gross margin analysis is a farm management technique that is used to compare the gross benefits of a technology and the variable costs associated with adoption of the technology.

Although gross margin analysis is useful in assessing the returns to limited resources, it has many limitations. One of the biggest limitations of gross margin analysis is that it is static. Most of the budgets normally look at what happens over a season or using prices for one season. In trying to remove some of the static effects, we used data, which were pooled over two seasons and from two different sites across Zimbabwe and also conducted some sensitivity tests to assess how changes in prices and yield might affect the returns to limited resources.

Various indicators can be obtained from the gross margin results, which can be used to assess returns to limiting resources. The following indicators were used to assess the returns to limiting resources: returns to land, returns to labour, returns to draft animal power and returns to cash investment. In trying to assess uncertainty, sensitivity analysis was conducted by varying the yield levels obtained as well as varying the prices of the output.

RESULTS AND DISCUSSION

Labour input for weed management

Detailed labour data collection was conducted for the weeding operations in all the trials conducted. As shown in Tables 2 and 3, weeding treatments that involve hand weeding took more hours compared to mechanical and herbicide weeding. Herbicide use reduced weeding hours considerably in all areas. It is important to note that for total labour hours, treatments such as banded atrazine and full cover atrazine had the least hand weeding hours in all sites. For example, treatment with atrazine used as full cover and either reduced or conventional tillage results in an average of about 10 hours required for weed control. However, for some of the treatments that involve ox-cultivation, there was an increase in the draught animal hours for example reduced banded atrazine and cultivation weeding at 2 and 4 weeks. Treatments that involve the usual farmer practice of hand hoeing twice results in increased labour requirements which an average of about 117 hours for the two areas. However, there are differences in the weed species in the two sites as reported by Mabasa et al., 1998.

Economics of tillage and weed control practices

Conservation tillage: Tables 4 and 5 show gross margin analysis results of conventional and reduced tillage systems in Chihota. Conventional tillage and all the weed control methods tested gave negative gross margins/ha in Chihota. Ploughing twice in areas like Chihota is very costly as there are very few farmers with adequate draught animal power. The costs for ploughing in Chihota is about Z$2,000 per hectare. This is also coupled with the fact that yields in Chihota are generally low due to soil infertility (Bellon *et al.*, 1998). It is also important to note that on average, the yields for most treatments are below 2 t/ha). As mentioned earlier in this paper, using the Agritex recommended levels of fertiliser in all the treatments biases a lot of the results, as there is no real farmer practice. In Tsholotsho, mainly as a result of the increased yields experienced (over 3 t/ha in most treatments), all the treatments had a positive gross margin/ha (Tables 6 and 7). In general, a combination of conventional tillage and Agritex fertiliser recommended levels is not beneficial in terms of returns to land.

Returns to cash expenditure are also very low with treatment 4 (atrazine applied at full cover and ox-cultivator weeding at 6 weeks) having the highest of only $1,21 which is not attractive at all given what most farmers would want from a new technology (at least 50% cited in most studies). All the returns to labour in the conventional tillage treatments are lower than the rural wage rate as well as the returns to DAP.

Table 2. Labour requirements for various weeding treatments in Chihota.

Treatments	Ox-cultivator (hrs)	Hand hoe (hrs)
Reduced H @ 4 and 6 wks	0	105
Reduced CH @ 4 and 6 wks	17	79
Reduced BA+C@ 2 and 4wks	13	0
Reduced FA+C@ 6wks	9	0
Reduced PH@ 4and 8wks	27	59
Reduced BA+P@ 6wks	16	0
Reduced CH@ 2 and 6wks	18	71
Conventional H @ 4 and 6 wks	0	171
Conventional CH @ 4 and 6 wks	19	117
Conventional BA+C@ 2 and 4wks	16	0
Conventional FA+C@ 6wks	10	0
Conventional PH@ 4and 8wks	33	111
Conventional BA+P@ 6wks	21	0
Conventional CH@ 2 and 6wks	18	109

Table 3. Labour requirements for various weeding treatments in Tsholotsho

Treatments	Ox-cultivator hrs	Hand hoe hrs
Reduced H @ 4 and 6 wks	0	79
Reduced CH @ 4 and 6 wks	21	40
Reduced BA+C@ 2 and 4wks	19	0
Reduced FA+C@ 6wks	8	0
Reduced PH@ 4and 8wks	35	66
Reduced BA+P@ 6wks	16	0
Reduced CH@ 2 and 6wks	16	35
Conventional H @ 4 and 6 wks	0	113
Conventional CH @ 4 and 6 wks	20	88
Conventional BA+C@ 2 and 4wks	20	0
Conventional FA+C@ 6wks	9	0
Conventional PH@ 4and 8wks	50	66
Conventional BA+P@ 6wks	18	0
Conventional CH@ 2 and 6wks	16	45

Table 4. Gross margin analysis for conventional tillage and weed management in Chihota

Treatment	Hand hoe @ 4 and 6 weeks	OC @ 4 and 6 weeks	BA + C @ 2 and 4 weeks	FA + C @ 6 weeks	PH @ 4 and 8 weeks	BA +P @ 6 weeks	CH @ 2 and 6 weeks
Yield (kg/ha)	**1293**	**1429**	**1555**	**1725**	**953**	**1632**	**981**
Gross margin	-6455	-5629	-3644	-2352	-9251	-3291	-8541
Gross margin exc labour and DAP	-765	208	1053	2213	-3197	1604	-2997
Labour hours	338	308	193	194	297	201	281
DAP hours	50	69	68	60	83	71	68
Returns to cash expenditure ($ per $)	0.93	1.02	1.10	1.21	0.69	1.15	0.71
Returns to labour ($ per hour)	-2.26	0.68	5.45	11.41	-10.76	7.97	-10.66
Returns to DAP ($ per hour)	-15.30	3.02	15.49	36.89	-38.52	22.59	-44.07

Table 5. Gross margin analysis for reduced tillage and weed management in Chihota

Treatment	Hand hoe @ 4 and 6 weeks	OC @ 4 and 6 weeks	BA + C @ 2 and 4 weeks	FA + C @ 6 weeks	PH @ 4 and 8 weeks	BA +P @ 6 weeks	CH @ 2 and 6 weeks
Yield (kg/ha)	**2011**	**2053**	**2352**	**1836**	**1906**	**2465**	**1919**
Gross margin	2782	2971	5728	2271	1970	6429	2126
Gross margin exc labour and DAP	6286	6587	8670	4922	553	9478	5628
Labour hours	270	263	192	167	247	200	251
DAP hours	20	37	33	29	47	36	38
Returns to cash expenditure ($ per $)	1.71	1.75	1.97	1.56	1.63	2.05	1.64
Returns to labour ($ per hour)	23.24	25.03	45.13	29.40	22.39	47.48	22.44
Returns to DAP ($ per hour)	314.31	178.02	262.71	169.74	117.77	263.27	148.11

Table 6. Gross margin analysis for conventional tillage and weed management in Tsholotsho

Treatment	Hand hoe @ 4 and 6 weeks	OC @ 4 and 6 weeks	BA + C @ 2 and 4 weeks	FA + C @ 6 weeks	PH @ 4 and 8 weeks	BA +P @ 6 weeks	CH @ 2 and 6 weeks
Yield (kg/ha)	**2923**	**3510**	**5110**	**3138**	**3557**	**2848**	**3664**
Gross margin	6196	9868	21647	8418	9801	6391	11567
Gross margin exc labour and DAP	1139	15594	26983	12841	15950	10823	16716
Labour hours	340	364	329	245	374	239	318
DAP hours	45	71	60	54	101	60	61
Returns to cash expenditure ($ per $)	2.08	2.45	3.38	2.20	2.49	*2.03*	2.55
Returns to labour ($ per hour)	33.52	42.79	81.92	52.52	42.62	*45.30*	52.64
Returns to DAP ($ per hour)	253.22	219.63	44.72	237.80	157.92	*180.38*	274.03

Table 7. Gross margin analysis for reduced tillage and weed management in Tsholotsho.

Treatment	Hand hoe @ 4 and 6 weeks	OC @ 4 and 6 weeks	BA + C @ 2 and 4 weeks	FA + C @ 6 weeks	PH @ 4 and 8 weeks	BA +P @ 6 weeks	CH @ 2 and 6 weeks
Yield (kg/ha)	**3441**	**3433**	**3851**	**3365**	**2996**	**3372**	**4048**
Gross margin	11284	11078	14394	11201	7262	11180	15510
Gross margin exc labour and DAP	15100	15043	17977	14465	11937	14571	19462
Labour hours	302	288	254	229	327	235	298
DAP hours	20	46	35	29	76	35	36
Returns to cash expenditure ($ per $)	2.41	2.41	2.65	2.34	2.13	2.36	2.79
Returns to labour ($ per hour)	50.06	52.18	70.77	63.28	36.52	62.04	65.33
Returns to DAP ($ per hour)	755.02	327.03	513.64	498.79	157.07	416.31	540.62

Reduced tillage: Results for the reduced tillage treatments in both areas show positive returns to land, labour and draught animal power. In Chihota, treatments 6 (banded atrazine and ox-plough weeding at 6 weeks after emergence), 3 (banded atrazine and ox-cultivator weeding at 2 and 4 weeks after emergence) and 2 (ox-cultivator and hand-hoe weeding at 4 and 6 weeks after crop emergence) had the highest returns to the factors of production. Treatment 6 in particular had the highest returns to cash and labour compared to all other treatments. In Tsholotsho, treatment 3 (banded atrazine and ox-cultivation at 2 and 4 weeks) came second in terms of profitability to treatment 7 (ox-cultivation and hand hoe -weeding at 2 and 6 weeks). It is also important to note that treatment 1 (hand hoe weeding at 2 and 4 weeks) which is close to the true farmer practice also showed a higher gross margin per ha in Tsholotsho mainly as a result of the low weed pressure experienced in the area compared to Chihota (Mabasa *et al* 1998). Reduced tillage generally results in earlier planting and this is also coupled with a drastic reduction in the costs associated with ploughing.

DISCUSSION AND CONCLUSIONS

It is quite evident from the results that reduced tillage and the application of banded atrazine as a weed control method is more profitable than mechanical or hand weeding. Conservation tillage in Chihota gave negative returns to investment mainly as a result of the increased costs of ploughing twice and the general low yields that are experienced in Chihota. Based on the results, one can observe that farmers in Chihota might be better off trying reduced tillage in combination with either banded atrazine or mechanical weeding with a plough depending on their resources. Those with cash resources might opt for the atrazine as weed control whilst those with ploughs might use them for mechanical weeding. On the other hand, the results for Tsholotsho, a drier area, showed that there are positive returns to investment in both conservation and reduced tillage combined with any weeding method. However, the returns are more for reduced tillage compared to conservation tillage. It would thus be beneficial for farmers to invest in reduced tillage and any type of weeding method that suits their labour and or cash resources.

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ON-FARM LEGUME EXPERIMENTATION TO IMPROVE SOIL FERTILITY IN ZIMUTO COMMUNAL AREA, ZIMBABWE: FARMER PERCEPTIONS AND FEEDBACK

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ABSTRACT

A study was conducted in 2000-01 in the semi-arid Zimuto Communal Area in Zimbabwe to compare mineral fertilizer application methods with farmers. Three fertilizer application methods, the flexible Fertilizer Management Package (FMP), the AGRITEX extension method and the FARMER method were compared in 10 farmers' fields. The FMP is a flexible package where N is applied in relation to rainfall and crop growth. Compound D (8:14:7 NPK) was broadcast when the maize was planted. Ammonium Nitrate (AN) was applied at 10 days after crop emergence, and at 30 days and 60 days in relation to rainfall and crop growth. The AGRITEX package provided Compound D at planting and AN was applied once when the crop reached knee high. In the FARMER practice, fertilizer management was done following the farmers' planned concepts of fertilizer management, and this generally involved little fertilizer and combination with cattle manure. Farmers managed the fields. Results showed high observed Nitrogen Use Efficiency (NUE) values of 80 kg grain per kg N applied at rates below 20 kg N/ha but very low NUEs (- 5 kg of grain per kg of N) with fertilizer rates above 90 kg. The NUEs declined as more N was applied. The FARMER practice was lowest and the FMP being highest. The homestead fields gave highest maize yields. There were no differences between the FMP and Agritex packages on maize yields. Farmer management of the fertilizer packages revealed that extension information on fertilizer management was limited. Farmers tended to modify the packages towards their fertilizer management concepts. Feedback from farmers suggested that the farmers best liked the FMP package, but suggested they will need support to access the N fertilizer it needs. Farmers suggested promoting a simplified FMP package with a maximum of two timings/doses of topdress N fertilizer.

INTRODUCTION

Low soil fertility has been identified as a fundamental biophysical constraint to agricultural production in Southern Africa (World Bank, 1989; Sanchez, *et al.,* 1997). In Zimbabwe, the problem has been made worse by the legacy of colonial land policies. Smallholder farmers were concentrated into communal lands to grow maize on sandy soils with few soil fertility inputs. The soils in these areas are generally derived from granite and gneiss, producing coarse-grained sands (with less than 15% clay) that are inherently infertile (Grant, 1981) and have low nitrogen and phosphorus contents (Mashiringwani, 1983). Successful production of food in such soils depends on the use of N fertilizer (Grant, 1970; Waddington *et al.,* 1991). Because of the increasing costs of inorganic fertilizers, farmers have complemented them with traditional fertilizers such as animal manure to supply the much-needed nitrogen in the soil. However, manure quantities and quality are declining, producing poor and very variable responses (Mugwira and Murwira, 1997). Food production in smallholder agriculture therefore remains low (FAO, 1999; Low and Waddington, 1991).

Demand for food is increasing as the human population increases. This trend results in a continuing challenge to produce enough food to feed families (McCalla, 2000). Without proper interventions through modification of current practices or the identification of new options to smallholder agriculture, food production will continue to decline per capita and per unit area. Reeves (1998) pointed out that no single method of farming in any region remains sustainable without change. In support, a review of recent literature (Loehman *et al.,* 1994; Low and Waddington, 1991) indicate similar thoughts that methods for soil fertility improvement need to be dynamic to meet the changing forces in farmer societies. Present production methods in smallholder agriculture need to be modified to come up with options that can sustainably replenish soil fertility and increase maize yields. Farmers are also looking for change as indicated by the support they give to on-farm research in Zimbabwe. Legume-based technologies are being developed with farmers in Zimuto, southern Zimbabwe. The legumes improve soil fertility (Sakala *et al.,* 2001) and add diversity to the food options for farmers (Gilbert, 1999; Kumwenda and Gilbert 1998). In Zimuto, farmers in the focused discussions ranked the issue of soil fertility number one and legumes were chosen for their potential to provide a wide range of uses.

This research was conducted to identify and evaluate legume technology options for soil fertility improvement within the context of farmers' livelihood and risk management strategies in Zimuto, Zimbabwe. Specific objectives were to (1) assess legume performance by land types, (2) identify legumes that best replenish soil fertility, and (3) assess legume suitability in intercropping systems under smallholder conditions.

MATERIALS AND METHODS

Site selection and group formation

Zimuto is a dry area of south-central Zimbabwe in Zimbabwe Natural Region IV, with a unimodal rainfall season from October to March. Rainfall occurs in sporadic convectional storms with a 30% chance of a mid-season drought in January or February (Hagmann, 1995). The average rainfall is 631 mm with a range of 200 – 1,000 mm. Agriculture in the area is rain-fed with little wetland irrigation. The soils are predominantly sandy, formed from granite with low moisture holding capacity, little organic matter or nitrogen and low pH. The soils are characterized by their position in the catena. The dry topland granitic soils of the upland ridges and valley slopes comprise well drained moderately shallow coarse to medium grained dark yellow or brown sands and sandy loams. The vleis have shallow to moderately drained dark brown coarse-grained sands, loam sands to clay loams while the vlei margins have moderately deep imperfectly drained dark brown coarse sands with mottling below 0.5 m. The differences in the soil catena influence the type of management and resource use. For example, about 60% of the manure is applied in the vlei. Other crops growing in the vlei are groundnut, rice, and bean. Wetland crop production (wheat and vegetables during the cool dry season) is done in the vleis. In addition to maize, the topland fields grow cowpea, bambara, groundnut, millet, sweet potatoes and other minor crops largely for home consumption.

The farmer groups were formed from the communities that work with CARE International on the conservation of dam catchment areas. Through discussions with farmers around the dams to identify agricultural problems, soil fertility was mentioned to be the most important constraint to agricultural production. Discussions were then focussed on identifying cheap and sustainable ways to improve soil fertility. A small group of 14 farmers was then formed in Chikato to conduct on-farm legume trials in the fields. However using the Country Almanac (1998), Zimuto conditions are similar to 40% of the total country area hence the results of the studies could be used elsewhere.

Context and trial design

The project started in the 1999/2000 growing season with fourteen farmers. Nine legumes were tried on-farm using the mother-baby approach developed for farmer assessment of legumes in Malawi (Kamanga *et al.,* 2000). Four of the legumes (*Mucuna pruriens* (velvet bean), *Crotalaria grahamiana*, pigeon pea and sunnhemp) were introduced to the area by the project while five others (Cowpea spreading, cowpea bunch, bambara, groundnut and soyabean) were traditional legumes. Four mother trials were implemented, each managed by three or four farmers. A mother trial had 18 plots, each measuring 10 x 20 m, set in a simple way to compare an intercrop and a sole crop of each legume. Two of the mother trials were set on homestead fields and two on the topland fields to compare the performance of legumes across these two important land types. Baby trials were subsets of the mother trials. Farmers chose four legumes to plant in their fields as a baby trial. Details of farmer choices of legumes are shown in Table 1. Table 2 shows the simple comparison layout of the legumes in a mother trial. On one side, all legumes were planted as sole crops and on the other side they were inter-cropped with maize. All legumes except mucuna in the intercrop were planted at the same time with maize. Mucuna was planted six weeks after maize was planted in the intercrop, because previous research had shown it climbs up maize plants and pulls them down if planted too early (Gilbert, 1998).

The planting of legumes followed agronomic specifications developed from previous work by Soil Fert Net members (Waddington *et al.,* 1998) as shown in Table 3. To reduce competition, the spacing of some legumes (soyabean, bambara, groundnut, mucuna, and *C. grahamiana*) was changed. Due to poor germination of grahamiana and sunnhemp in the first year, farmers changed their depth of planting from 5 cm to near the soil surface. Other legumes were planted as in the first year when they were drilled and covered with soil. Because of poor soils, Single Superphosphate was applied to all legume soils to supply phosphorus to stimulate root development and growth.

Agronomic field data sheets

With the help of enumerators, farmers were given field data sheets to record activities and observations they made in the season. The sheets indicated the name of farmer, plot layout, treatment assignment, rainfall received, dates of operations, plant count, yields, soil sampling and farmer

Table 1. Farmer Legume Options x Field Type

Farmer's name	Legume Variety										
	Pigeon-peas	Soya-beans	Bambara	Ground-nuts	Mucuna	*C. juncea*	*C. grahamiana*	Cowpeas (spreading)	Cowpeas (bunch)	Comp. D	AN
M. Dowa		H	VM	VM/H	VM	VM	VM	VM	H		
Z. Zvokuenda											
R. Nyenyai		T	T/V	T/V	T	T	T	T/H	T		
A. Paringira	G	T	T	T	T	T	T	T/H	T		
N. Chitima			T	T	T				H		
J. Zireva	VM	T	T	T	T				VM		
D. Matsvange		T	T/VM	T	VM			T	T		
S. Mupunza		T	T	T	T						
D. Madhoro		T	T	T	VM						
J. Chiramba					H/VM	H/VM	H/VM				
K. Chigiya			T	T	T	VM		T/VM	T		
M. Chishere		T			H/VM				T		
N. Mudakuenda			T	VM	T				T		
F. Nguvo			T	H	T				H		

V = Vlei (wetland), VM = Vlei margin, H = homestead and T = Topland.

Table 2. Mother trial plot layout and legume assignment, Zimuto, Zimbabwe, 2000/2001

Mucuna	Sun hemp	Grahamiana	Pigeon peas	Cowpeas	Cowpeas	Soy-beans	Groundnuts	Bambara
Maize-Mucuna	Maize-sun hemp	Maize-grahamiana	Maize-pigeon peas	Maize-cowpeas	Maize-cowpeas	Maize - soybeans	Maize-groundnuts	Maize-Bambara

Table 3. Planting pattern and seed rates of legumes in mother trials

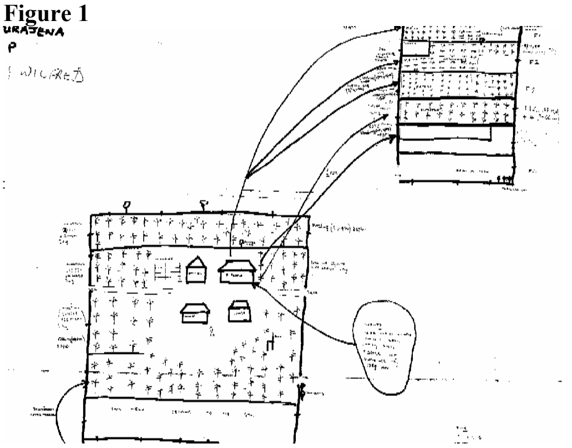
Legume	Sole system	Intercrop system	Seed rate ($20x10m^2$)
	(cm x cm)	(cm x cm)	(kg)
Pigeon pea	90 x 30	90 x 30	3
Soybean	20 x 5	20 x 5	4
Bambara	40 x 20	40 x 30	8
Groundnut	30 x 20	40 x 20	8
Mucuna	50 x 25	90 x 25	20
Sunnhemp	40 x 10	90 x 5	3
Grahamiana	40 x 10	90 x 5	8
Cowpea spread	90 x 30	90 x 30	5
Cowpea bunch	40 x 20	40 x 20	10

comments over the year. There was also a checklist of what the enumerator had to do. The enumerator assisted farmers to measure yields from the crops in the plots. The yields shown in this paper were averages from the four mother trials.

Resource allocation maps (RAM)

These are useful management tools for farmers and were used to collect information from farmers about their farming. With the help of the enumerator, each farmer drew up the maps of their fields initially in 1999 and indicated how resources were allocated to different field types. The RAMs indicated household members, amounts and routes for resources, dates of operations, labour use and harvested crops and were updated several times in 1999 through 2001. They form a good platform for group discussions and decision-making on resource allocation by farmers. Figure 1 shows one of the maps developed by farmers in the area.

Figure 1



Group discussions

These were used to elicit perceptions about the trials. Apart from the field data sheets, farmers used the group discussions to outline their perceptions and feedback on the performance of the trials. Subsequent sections in this paper detail farmers' perceptions. In the ranking exercise, farmers identified several criteria for evaluating the performance of the technologies. The criteria were:

Yield level: Farmers said that this research focused on improving the yield of crops, especially maize, through use of legumes. The legumes that would be incorporated in the systems should increase maize yields in association or in subsequent years. The impact of legumes on soil fertility restoration depends largely on the volume of biomass the legume produced (Gilbert, 1998; ICRISAT/MAI 2001). Good biomass production in some farmers' fields in the first year encouraged other farmers to view it as an important aspect for identifying the legumes that would perform and help the poorer soils.

Tolerance to drought: Because of the drought that often occurs mid season in the area, some legumes were affected from moisture stress. Farmers found that such legumes may not suit the dry conditions that frequently occur. In evaluating the legumes, tolerance to drought was included in the criteria. Those legumes that tolerate harsh conditions were observed to be suitable for the environment in the area.

Food and feed value: Farmers first concern was how to produce enough food from the degraded soils. Use of legumes for soil fertility improvements provides a good option. However, adoption of legumes for soil fertility would be high if the legumes also provide additional food to the farmers. In addition to that, farmers said that legumes should also provide feed to animals so that they could improve on the milking potential of the cows.

Labour: Labour is one of the factors that affect the incorporation of legumes into smallholder farming systems. Farmers said that legumes should be compared for their labour requirements so that those that need less labour could be identified.

Suitability in intercrop: Maize as a staple food crop is intercropped with many other crops. Farmers said that in their systems, very few crops were planted as sole crops. To suit the system, new crops should be evaluated for intercropping.

Figure 2. Rainfall for Chikato area for 2000/2001 season.

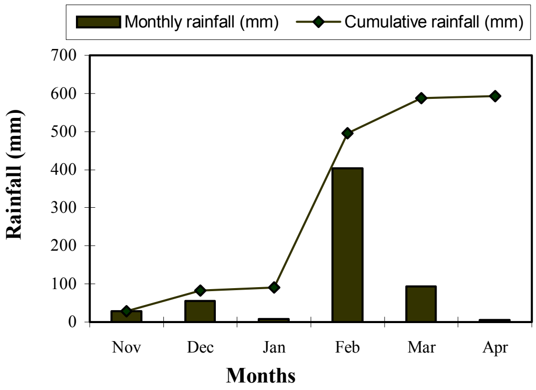
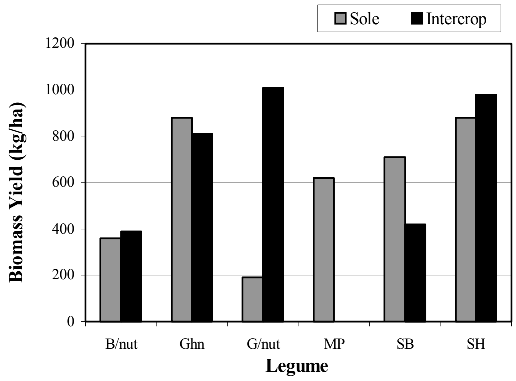


Figure 3. Biomass yield by legume in Zimuto, Zimbabwe.



RESULTS

First year (1999/2000): Farmers' capacity to experiment

The value of land and the importance of maize made most farmers avoid risks through planting legumes on their poorer fields. Sixty percent of the farmers used poor lands (such as previously fallowed topland) and germination and growth were low, resulting in little biomass and seed. The remainder of the farmers planted the legumes on fields that had received animal manure. The response of legumes on manured fields also varied because some fields had received fresh manure that affected germination and growth. Farmers attributed the reduced germination to heat produced from decomposing manure.

Almost no legumes planted in the vleis grew well. Mucuna was affected by waterlogging. Also the legumes did not do well in heavily depleted topland sands. However, those planted on better lands in the upland showed some potential to improve soil fertility. In these fields, farmers observed that mucuna plants twine up maize plants on the border with it. This led to farmers doubting whether to intercrop mucuna with maize planted at the same time. However, through group discussions on the first year of legume performance, farmers chose to intercrop the legume with maize, but as a relay crop planted 6 weeks after planting maize.

Noting poor germination and growth for grahamiana, sunnhemp and other small seeded legumes in the first year, farmers reduced the planting depth from greater than 5 cm to near the soil surface. In the second year, all farmers that used manure for the legumes applied well-decomposed manure that improved germination and growth. Broadcasting some of the legumes also affected germination, hence farmers changed to hole and drill planting methods. However, farmers noted that hole or drill planting requires more labour than broadcasting the seed. In general in the first year, all crops had better germination when planted as sole crops than when intercropped.

In the evaluation by farmers, the potential of legumes to improve soil fertility was observed to be high. More farmers are requesting to join the group or to obtain seed. The project has started a programme to bulk the seed supply of legumes through collaboration with CARE International in the 2001-02 cropping season. However, the demand for the legumes has become so large that there is need to further increase seed production through participating farmers.

Second year (2000/2001): Implementation of changes

After implementing the changes from year 1, the germination of legumes improved, with those planted on homestead fields being the best. This was especially true where well-decomposed manure had been applied in such fields. Table 1 gives details of the types of the fields used for the baby trials in 2000-2001.

Rainfall in 2000/2001 season

Figure 2 shows rainfall records from the farms for the 2000/2001 crop season. Total rainfall received in the area was 593mm that year, about 50 mm below the average rainfall in the area. The rainfall started in November and was followed by a long mid season dry spell that lasted for eight weeks through January. This period was crucial to the farmers for timely application of top dressing fertilizer, the planting of legumes in intercropping plots and for weeding. The dry spell in January reduced the growth of legumes through moisture deficit, aphid attack and delayed planting of legumes in the intercrop. Farmers found that sunnhemp, groundnut and cowpea were greatly affected by moisture stress. In addition to moisture stress, aphid attack destroyed bunch type cowpea, groundnut and bambara nut. Over 500 mm of rainfall was received in February and March. However, by this time damage had already been caused to crops. The maize was flowering and some crops died from moisture stress. The early planted maize that matured around this time started to rot in the fields; especially ears of SC501 that has poor husk cover.

Biological performance of legume systems

Poorly distributed rainfall affected timely operations by farmers, crop growth and yield performance in the season. Farmers evaluated the performance of the legumes to identify legumes that withstand harsh conditions and still yield something for farmers.

Two parallel measurements were made from solecrop and intercrop plots. The results (Figure 3) show that some legumes suit the intercropping systems while others do better

Figure 4. Grain yield for legumes in Zimuto, Zimbabwe.

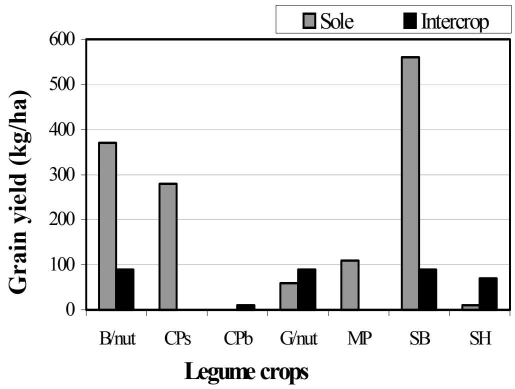
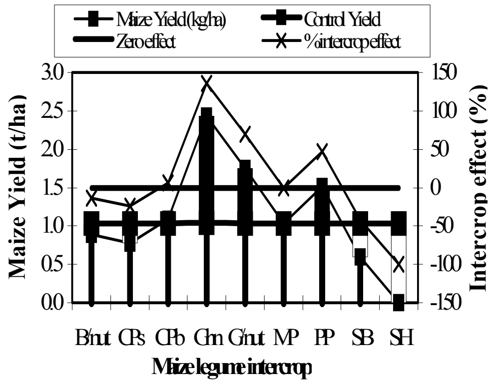


Figure 5. Maize Yield (kg/ha) and % intercrop effect on grain yield.



when grown as sole crops. There were no differences in biomass yields between sole and intercrop with bambara (360 vs 390 kg/ha) and with grahamiana (880 vs 890 kg/ha). Groundnut biomass yield (1,010 kg/ha) was higher when intercropped than when grown as a solecrop (190 kg/ha). Soyabean did better in a solecrop than when intercropped. Cowpea and pigeon pea biomass was not recorded from all of the farmers. The bunch type cowpea matured early and it was not possible to record the amount of biomass, while pigeon pea had fresh pods and farmers did not want to destroy them. Groundnut biomass yield from the intercrop was surprisingly high since it does not usually intercrop well. The high biomass with intercropped groundnut could have resulted from less moisture loss from the maize during the long mid season dry spell.

Grain yields were compared between sole and intercropped legumes (Figure 4). Bambara nut, spreading cowpea and soybean did well in the sole cropping system. Soybean was the highest yielding with 560 kg/ha of grain, the second was bambara nut (370 kg/ha) and then 280 kg/ha from spreading cowpea. In the intercrop, bambara and soybean gave similar yields of 90 kg/ha, while cowpea gave no grain. Yields of grahamiana and pigeon pea were not measured. Farmers harvested fresh pigeon pea for relish, making it difficult to measure the yields. An unknown larvae pest destroyed the pods of Grahamiana.

Maize yield from the intercrop

A comparison of the effects of legumes on maize intercropped with different legumes is shown in Figure 5. Grain yield of maize was highest in the grahamiana- based system (2,430 kg/ha), with groundnuts being second (1,750 kg/ha) and the pigeon pea based system came third (890 kg/ha). The sunnhemp-based system gave no grain. The maize yield in the mucuna intercrop was used to compare.

Instead of planting mucuna six weeks after planting maize, it was planted late due to the dry spell. At this time the maize was in the early stages of flowering and the mucuna started to spread when the maize had matured, giving very minimal if any interaction effect. The maize yield from the maize + mucuna intercrop was used to compare the intercrop effect on maize yield. The zero effect line was calculated from this yield as a control for comparison. The legume that had maize yield above the line did not adversely affect maize yields. At the same time, all systems with yields below the zero effect line were negatively affected. Grahamiana, pigeon pea and groundnut-based systems positively influenced maize yields. Bambara, spreading cowpea, sunnhemp and soyabean had their yields below the zero effect line, suggesting a negative influence on maize yields. The zero yield from sunnhemp suggest that the legume out-competed the maize crop.

The percentage effect on yield reduction or increment is shown in the same figure. Yields increased by 150% in the grahamiana-based system and by about 70% in the groundnut and 40% in the pigeon pea based systems. The figures suggest that besides little competition, the legumes are beneficial to the soil and crops in the same season. One possible explanation could be a cover mulch effect that conserves moisture especially during the dry spell. On the other hand, there was a 100% maize yield reduction in sunnhemp and about 50% in soyabean and spreading cowpea. The reduction in cowpea depends on the plant population density. Intercropping cowpea with maize is a common practice for most farmers in the area and few yield reductions were mentioned (Shumba, 1990). In farmers' practices, the population of cowpea is very small so that yield reductions on maize yields are negligible. The yield trend agrees with farmer observations that maize in the grahamiana and pigeon pea based systems did not wilt much.

Farmer perceptions on uses of legumes

Farmers planted traditional and introduced legumes in the trials. Traditional legumes were described as those legumes that farmers had been planting and using while those brought by the CIMMYT Risk Project were new and most farmers had not planted or used them before. Some of these crops were planted by forefathers but were abandoned for various reasons.

Within two years of experimentation, farmers identified different household and alternative uses for introduced legumes (Table 4).

Farmers came up with a wide range of uses of legumes. Traditional legumes were mainly grown for food taken in different forms. Cowpea and bean leaves are eaten as vegetable relish while fresh. The leaves are also boiled, dried and preserved for use in the dry season when green vegetables are scarce. Grain is utilized as relish. While green and fresh, groundnut, pigeon pea, cowpea and bambara nut are boiled as a vegetable relish, rich in protein. The fresh green pods are also boiled and eaten as snacks. Grain is also

Table 4. Farmer perceptions on household and alternative uses of legumes by gender .

	Cowpea	G/nut	Bambara	Mucuna	P. pea	Graham	Sunhem	Soybean
Food	All groups	All groups	All groups	All groups	All groups	Not mentioned by any group	Not mentioned by any group	Female group
Soil fertility	Not mentioned by any group	Female and mixed group	Not mentioned by any group	All groups	All groups	All groups	All groups	Male and mixed group
Market	All groups	All groups	All groups	Not mentioned by any group	All groups	Not mentioned by any group	Not mentioned by any group	Male and mixed group
Animal feed	Male and mixed group	Male and mixed group	Not mentioned by any group	Male group	Not mentioned by any group	Not mentioned by any group	Male group	Not mentioned by any group
Weed control	Not mentioned by any group	Not mentioned by any group	Not mentioned by any group	Male and mixed group	Female group	Female and mixed group	Not mentioned by any group	Not mentioned by any group
Firewood	Not mentioned by any group	Not mentioned by any group	Not mentioned by any group	Not mentioned by any group	Female group	Female group	Not mentioned by any group	Not mentioned by any group

Key:
Female group
Male group
Female and mixed group
Male and mixed group
All groups
Not mentioned by any group

cooked as relish when it is dry or ground to make a thick paste (lupiza) that is used as relish as well. Groundnuts can be roasted and salted and taken as a snack or pounded to form traditional peanut butter. Groundnut is pounded to flour used to season leaf vegetable relish, porridge and other relish dishes. In addition to food, legumes provide opportunities for markets locally or are sold to the Grain Marketing Board if produced in abundance. Farmers also noted that apart from food and market the legumes improve soil fertility. It had been from this knowledge that some farmers systematically rotate legumes with maize to capitalise on the residual fertility. However, farmers do not experience a large impact from the legumes on soil fertility because legumes grown do not produce much biomass or fix much N in the soil. The way the residues are managed after harvesting also contributed to this. The legumes are in the first place grown on a smaller scale and the residues are directly fed to livestock.

Mucuna and grahamiana produced higher biomass than other legumes. Farmers ranked these crops high on their potential to improve soil fertility. Besides the soil fertility, farmers wanted to learn about the utilization of some legumes. Special reference was made to mucuna whose grain is bigger than pigeon pea grain. Because of the L-dopa in mucuna, farmers were advised not to cook mucuna until preparation lessons are conducted. Farmers were thinking that mucuna could be used for coffee and suggested to explore this further. There is a variety of the bean that is similar to mucuna and in Malawi is used for coffee extraction.

The farmers who harvested pigeon pea liked the taste and ease to prepare it. For example, Mr Chishere commented, '*Pigeon pea inonaka se beans uye haitri nguva yakawanda pamoto. Inogona kushandiswa se usavi…*", The pigeon pea grain is sweet, just like beans, and it does not take time to cook and if cooked, you enjoy the food. In addition to food, some farmers used pigeon pea stems for firewood. Soybean was used to extract milk from it but that has a lot of difficulties to prepare. Alternatively, farmers noted that legumes such as pigeon pea, soybean and mucuna could be used to feed animals. Male farmers especially, who said that the legumes would be used to feed cows to produce more milk for consumption and sale, took this as an advantage. Goats like pigeon pea, and commercial Brahman cattle ate mucuna. Local cattle breeds did not eat mucuna forage. Farmers observed reduced weed incidences in plots grown to mucuna, grahamiana and sunnhemp. This was another good benefit to the farmers, especially for the control of some weeds including the parasitic *Striga* weed that reduces maize yields.

Gender influence on perceptions on legume uses

Gender plays a role in the values attached to each legume. Different farmer groups had different perceptions on legume uses. All groups ranked the legumes first by the role the legume plays in food availability. Grahamiana and sunnhemp were not mentioned to have food value. If adoption were based on food value, these legumes would have been considered last. Female farmers mentioned soybean to be useful for food and at the same time indicated the constraints associated with its utilization. Introduced legumes were highly valued for soil fertility improvements while the traditional ones were for consumption. Similarly, traditional legumes were mentioned for food and markets. On the other hand, agreements on soil fertility from mucuna, pigeon pea and grahamiana were observed from all groups. Female farmers associated the ranking to uses that were directly linked to the household. For example women mentioned firewood as a benefit from the legumes whereas the male group did not see this as important. The trends given above imply that those legumes that both improve soil fertility and give bonus grain yields have a high probability of being adopted and adapted by farmers.

Farmer ranking of legumes

Figure 6 shows the farmer ranking of legumes based on uses. In general, food and soil fertility were the main reasons from farmers for growing the legumes. This was the same in all groups, although there were differences when individual groups ranked the legumes as shown in appendices 1-3. Different crops have different uses but in these figures, farmers ranked each use relative to the other and importance to the whole welfare of the household. In all the ranking, food, soil fertility and market seem to be high across the crops. Fuelwood was mentioned in two-legume crops and weed control in three crops.

Perception on legume suitability by field type

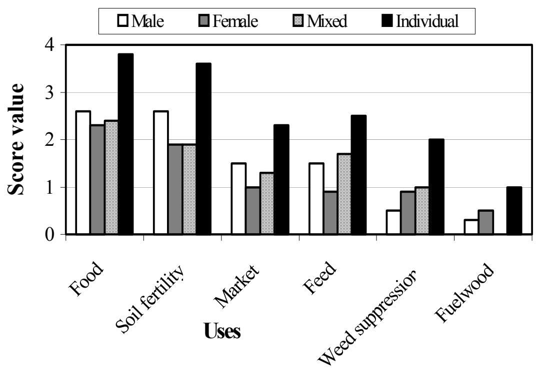
Evaluation by farmers of the legumes in two years summarized how the legumes would suit in the different field types (Table 5). From the four mother trials, the homestead

Table 5. Legume suitability by field type and season as observed by farmers.

Legume	Season	Field type			
		Vlei	Vlei margin	Homestead	Topland
Mucuna	Wet	✘	✘	✔✔	✔✔
	Dry	✘	✔✔	✔	✔
	Avg	✘	✔	✔✔	✔✔
Pigeon pea	Wet	✘	✘	✔	✔
	Dry	✔	✔✔	✔✔	✔
	Avg	✘	✔✔	✔✔	✔
Grahamiana	Wet	✘	✔	✔✔	✔
	Dry	✘	✔	✔	✔
	Avg	✘	✘	✔✔	✔
Sunnhemp	Wet	✘	✘	✔✔	✔✔
	Dry	✘	✔	✔✔	✘
	Avg	✘	✘	✔✔	✔
Cowpea	Wet	✘	✘	✔✔	✔
	Dry	✘	✘	✔✔	✔
	Avg	✘	✘	✔✔	✔
Soybean	Wet	✘	✘	✔✔	✔
	Dry	✔	✔	✔	✔
	Avg	✘	✘	✔✔	✔
Groundnut	Wet	✔	✔	✘	✔✔
	Dry	✔✔	✘	✘	✘
	Avg	✔✔	✘	✔	✔✔
Bambara	Wet	✘	✘	✘	✔✔
	Dry	✘	✘	✘	✔✔
	Avg	✘	✘	✘	✔✔

✔✔ means legume suits best; ✔means legume suits and ✘means legume does not suit

Figure 6. Farmer ranking of legumes by uses in Chkato.



performed better than the topland fields. In abandoned fields, farmers observed that legumes had poor germination. Wild animals damaged the legumes. These pests did not affect mucuna and sunnhemp. Besides these problems, low soil fertility contributed to poor performance of the legumes. The performance in the topland clearly indicates that establishment of legumes in poor lands is difficult and may be expensive. Homestead is the best land for all legumes except bambara nut and groundnut. Farmers said that bambara does well in poor fields and hence it suits the topland best. Groundnut gives a lot of pops in the homesteads that have had more manure. Homesteads suit most legumes because they are relatively fertile from manure and litter from the household wastes used there. Of all the legumes, groundnut and pigeon pea were observed to grow well in the vlei and vlei margins. They are planted in August or September and harvested in December or January. The main constraint to legume production in the vlei is waterlogging. Pigeon pea does not perform well in waterlogged conditions (Nene, 1990). If planted on ridges, the problem is reduced (Kumar Rao, 1998). Mucuna and other legumes germinate but subsequently become yellow and stunted when waterlogged. Growing legumes at the same time with maize would make it difficult to incorporate their biomass in the vlei. However, other options may still work if fast growing legumes such as sunnhemp are used.

Farmers similarly evaluated the legumes on whether growing them in rotation was any better than intercropping. Mucuna, sunnhemp and soybean were found to be highly competitive for resources and may eventually kill the maize or reduce the yields. Grahamiana, pigeon pea and groundnut suit in intercropping systems and as well as sole crop systems.

Farmer perceptions on constraints and opportunities

Main constraints identified by farmers were low soil fertility, diseases and pests, lack of adequate seed, market structure, lack of technical knowledge on management of legumes and no food value. Farmers pointed out that the soils were very poor so that without fertilizers or manure the crops did not grow well. Poor germination and performance in the first year was partly attributed to this. In the discussions, farmers said that growing a good legume would require planting them on the better land or applying manure to them as well. It would be difficult for a farmer to apply manure to legumes and not maize and the same time difficult to locate better land to legumes than to maize. These thoughts by farmers helped them to conclude that those legumes that suit intercropping systems would be more compatible with the farming systems. In doing so, labour would be reduced, legumes would benefit from the manure or fertilizer applied to maize and also planted to prime land. In the second season, all legumes germinated well on soils with manure and single super phosphate fertilizer.

Diseases and pests were mentioned to be the additional common constraint to legume production. Farmers observed that some soil-borne pests destroyed the seed of both legumes and maize before germination. Wild animals that came at night also removed seeds and seedlings. Aphids become a problem to cowpea, groundnut and bambara in the dry spell. The aphid attack was so devastating that in some farmers' fields the bunch cowpea did not yield. "Surf" washing powder was used to try to control it, but it did not help. Boring insects, which laid eggs inside the pods attacked pigeon pea, and the larvae destroyed the fresh grain. This was so common with the second harvest of the pigeon pea. In general, this is a big constraint with cowpea and pigeon pea production. A similar problem was experienced in grahamiana. Farmers did not know what to do to reduce the attack on pigeon pea. Arrangements are underway by the project to involve entomologists and pathologists to look into the disease and pest attacks in the legumes.

Seed availability was widely mentioned as a big problem for adoption. For maximum soil benefits from legumes, biomass has to be incorporated into the soil (Bowen *et al.*, 1988; Ikerra *et al.*, 2000; Singh 1983). Evidence is sometimes conflicting, but Gilbert, (1998), Kumwenda *et al.*, (1996) and Chanika *et al.*, (1999) reported that best responses for maize come when the legumes were incorporated at peak flowering.

Sakala, *et al.,* (2001) observed no differences on yield response from incorporating at flowering and incorporating after seed harvest. The former practice leads to seed availability problems. Farmers wanted seed so that they could expand plantings in the next season and so they did not incorporate the legumes at flowering as required by the project. Sakala's observation would go well with farmers and the idea of sustainability.

Market was another constraint that farmers mentioned especially for legumes such as mucuna. Small production levels of traditional legumes did not worry farmers much for market, but in the case of mucuna, farmers needed to know whether if they produced the seed in bulk it could be sold. If markets were not identified for such legumes, adoption would be affected. Technology development with farmers should therefore go along with market identification. There is need to empower farmers to create markets within their communities. For example in Mangochi in Malawi, the soil fertility project implemented by ICRISAT taught farmers how to prepare mucuna for consumption. In the second season the participating farmers prepared it and started selling it in the local market as a snack. The market for mucuna was created and is still there in the area. For mucuna, knowing how to prepare it for consumption would lead to the creation of markets for local consumption.

Competition for limited resources was another constraint mentioned by some farmers. Legumes that suit the sole systems would not be the best option for those with limited land, manure and labour. The priority in any season was to grow at least a food crop, in this case maize, in prime land with a large share of resources. Legumes that would best perform in sole systems would then suffer in such households.

DISCUSSION

Biological performance of legume systems

The legumes that produced more biomass in intercrop also gave better grain yield. As a general rule of thumb, only legumes producing above 2 t of biomass (about 60 kg N/ha) would be expected to give a better yield response for maize the following year (Gilbert, 1999; ICRISAT, 2000). The biomass shown in the figures indicate that little impact should be observed next season. However, this may not be the case since the yield shown was the average of the four mother fields. Buckles *et al.,* (1998), in their study on mucuna in the hillside of northern Honduras, found that soil fertility improvements from the legumes were relative to biomass accumulation. Performance in individual fields in Zimuto was variable with the crops in the homestead fields performing better than the topland. Response in the homesteads may be better than in the topland fields. The low biomass and grain yields were the result of water deficit stress experienced during the dry spell. An eight-week dry spell caused severe damage to the crops through moisture stress and diseases. Similar effects of a dry spell were observed by Loehman *et al.,* 1994 in a study on measuring yield risk effects of new technologies in Cameroon. Nevertheless, legumes in the homestead fields performed better than in the topland fields, indicating that soil fertility is a key issue to consider in producing good legume crops. Low performance of legumes in abandoned fields means that it is difficult and expensive to establish legumes in poor soils. The topland is less fertile and in some cases the soil is shallow. Because of low soil fertility, germination is poor and growth is minimal. For normal establishment, a farmer would need to apply inorganic fertilizer to boost growth.

The results of maize yield in the intercropping systems showed that different legumes affect maize yield differently. The plots that gave maize yields greater than the control plot showed that the legume and maize were compatible. For example, grahamiana not only gave high biomass yield but also had the highest maize yields. Similarly, pigeon pea and groundnut had better yields than other legumes. Despite good performance from grahamiana, farmers observed that pigeon pea and groundnut-based systems were better because of the grain they harvested from these legumes. On the other hand, the total loss of yield with sunnhemp implies that farmers would not intercrop it for a soil fertility benefit and it likely has few chances of being adopted. Its fast growing characteristics make it cover and shade the maize easily, and the leaf biomass is ready for incorporation when the maize is still green (Gilbert, 1999). The high yield of biomass from sunnhemp suggests that the crop took advantage of the resources that were applied to maize. This system will be of benefit if the following maize in the next season will more than compensate for the yield reduction made this season. On average the yield performance for the maize following the sunnhemp should be more than 2 t/ha to offset the loss made by the competitive effect of sunnhemp on the maize.

The implications from these studies are numerous. First, those legumes will not be adopted purely for soil fertility benefit. There must be other corollary benefits

Table 6. Farmers identified constraints and some opportunities on legumes in Chikato

Legume	Constraints	Opportunities
Cowpea	- Aphid attack - Twine maize	- Use "Surf" but not effective - Intercropping reduces aphids
Bambara	- No intercropping - Prone to striga (*Bise*)	- Rotation with Rapoko
Groundnuts	- Aphid attack - Compete for planting labour with maize	- Intercropping reduces aphid problem - Market available
Mucuna	- Poisonous - Grows faster, kill maize, additional labour as sole - Dried seed difficult to open - No markets - Little knowledge - Seed availability	- Reduces weeds - More biomass - Pest resistant
Pigeon pea	- Seed availability - Pod diseases and pests - Poor soils, no proper growth	- Animal like the crop - Suits intercropping
Grahamiana	- No food value - No market	- Suits intercropping - Weed suppression
Sunnhemp	- Same as grahamiana - Little biomass - No intercropping	- Animals eat
Soybean	- Requires manure	- No markets

perceived by farmers (Gilbert, 1999), which include suitability in intercropping systems (Figure 6), bonus grain yield for food (Low *et al.,* 1991; Figure 4) and weed suppression (Vissoh, *et al.,* 1998). In addition, farmers' perceptions indicated that some legumes could be used for animal feed and fuelwood. Farmers perceived all these as corollary benefits. Second, that legume performance by field type may be a constraint to adoption, especially for resource-poor farmers who cannot afford enough manure. Thirdly, that if well managed the legumes would play an important role in diversifying farmers' cropping systems.

Farmer perceptions on field performance of legumes

Agronomic and biometric evaluations of technologies are no substitutes to farmer evaluation (Mutsaers, *et al.,* 1997). Statistical evaluation indicates relative performance of technologies based on a given set of conditions. It lacks explanations to a diversity of perceptions from farmers on the technologies (Mutsaers, *et al.,* 1997). Farmer evaluation is a key to the success of the technologies and what is perceived as good in their conditions reflects their socio-economic status. Results of a one year interaction with farmers indicate that farmer involvement in the technology development increases the needs for more legumes by farmers. Farmers' ranking of legumes was consistent on other issues. Gender played a role on the uses of the legumes. Immediate needs such as food and fuelwood were highly emphasized by female farmers while male farmers pointed out more about animal feed. Although the trends were similar, individual group rankings (appendices 1-3) vary on the values given to each use for different legumes.

In terms of suitability of legumes for intercropping, grahamiana outperformed all legumes. Farmers ranked mucuna to be high, based on biomass produced in the sole systems while grahamiana was best for intercropping. Results shown in the figures agree with farmers' perceptions that grahamiana and pigeon pea are best for both systems while mucuna performed better as a sole crop. The results imply that planting maize together with either of these legumes could increase farm crop yields from a piece of land.

The wide range of constraints given in Table 6 indicates that farmers had to work hard to establish the legumes. First, labour was mentioned not to be a big problem because draft animal power was used for ploughing. However, it is the timing of activities that would be a problem and result in labour shortage. The implications are that households with no draft power may experience more problems especially in establishing the legumes as sole-crop legumes. The same households may not have the capacity to hire in labour for timely planting and weeding of legumes. Sole legume systems therefore best fit those that have adequate resources such as land, and potential labour. The ranking also implies that decisions about what legume to incorporate in the systems may depend on the influence of the head of the household (Fergusson, 1994; Kolli and Bantilan, (1997).

CONCLUSIONS

The performance of legumes across field types has indicated that most legumes are suitable in homestead fields. Farmers' evaluation of legumes showed a high interest in mucuna for a sole system, and grahamiana or pigeon pea for intercropping systems. The opportunities arising from the evaluation were the identification of legumes by field type, the need to improve planting depth, and new ideas about the utilization of legumes. The challenges were noted to be diseases and pests, especially in pigeon pea and cowpea, and soil fertility to improve legume performance. Labour problems, and improvements in intercropping to reduce yield reduction and legume utilization still need further research. The legumes that provided high yields in the sole and intercrop systems were liked for their potential to improve soil fertility.

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APPENDIX 1. Mixed (Male and Female) group ranking uses.

Legume	Uses	Ranking
Cowpea	Food	3.8
	Markets	2.0
	Animal feed	2.6
Groundnuts	Food	3.7
	Animal feed	3.4
	Market	2.4
	Soil fertility	2.5
Bambara	Food (lupiza), snack, relish	3.6
	Market	2.9
Mucuna	Could be used for food	1.6
	Soil fertility	3.8
	Observed animals eat leaf	1.0
	Reduce weeds	3.8
Grahamiana	Soil fertility	3.8
Sunnhemp	Soil fertility	2.4
	Feed animals	1.6
Pigeon pea	Food	3.2
	Soil fertility	3.0
	Animal feed	3.6
	Market	1.0
Soybean	Food, soybean milk, porridge	3.0
	Market	2.2
	Soil fertility	2.0

APPENDIX 2. Male group perceptions on legume uses

Legume	Uses	Ranking
Cowpea	Food; leaf and grain vegetable, paste,	4.0
	Markets	3.2
	Residues as feed	2.0
Groundnuts	Food; relish, pea nut butter, snack, seasoning	4.0
	Animal feed	3.8
	Markets	2.9
Bambara	Food (lupiza), snack, relish	3.4
	Market	3.0
Mucuna	Could be used for food	1.4
	soil fertility	4.0
	Observed animals eat leaf	1.2
	weed suppression	3.6
Grahamiana	Soil fertility	3.8
	Firewood	1.0
Sunnhemp	soil fertility	1.6
	Animal feed	1.2
Pigeon pea	Food; fresh grain, snack relish	3.8
	Soil fertility	3.4
	Animal feed	3.5
	Market	1.7
	Fuelwood	1.0
Soybean	Food, soybean milk, porridge	3.9
	Market	1.3
	Soil fertility	2.8

APPENDIX 3. Female identified uses of legumes and their importance.

Legume	Uses	Ranking
Cowpea	Leaves as vegetable relish, pods as relish and snack, grain cooked, mixed with maize kernels	3.9
	Selling	2.4
Bambara	Food	3.7
	Sell	3.0
Groundnut	Residues for manure	2.0
	Food	3.6
	Sell	2.4
	Animal feed	2.8
Mucuna	Green manure	3.8
	Animal feed	1.0
	Food	1.2
	Weed suppression	2.9
Grahamiana	Soil fertility	3.6
	Weed suppression	2.4
	Fuelwood	1.4
Sunnhemp	Soil fertility	2.6
Soybean	Food	3.0
Pigeon pea	Food	3.4
	Animal feed	2.8
	Soil fertility	3.0
	Fuelwood	1.6

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VERIFICATION TRIALS AND FARMER-MANAGED DEMONSTRATIONS IN INTEGRATED WEED MANAGEMENT UNDER DIFFERENT TILLAGE SYSTEMS AND FERTILITY LEVELS IN SMALLHOLDER FARMING AREAS OF ZIMBABWE.

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ABSTRACT

Verification trials and farmer-managed demonstrations in integrated weed management under different tillage systems and fertiliser application rates were conducted in Chihota, Nharira, Tsholotsho and Chiweshe smallholder areas of Zimbabwe in the 1998/99 and 1999/2000 seasons.

The effects of tillage system (conventional vs reduced), weed control method (herbicide vs traditional farmer practice) and fertiliser application rate (recommended vs farmer's level) on maize grain yield and weed biomass were compared over two seasons in the four districts. Maize grain yield decreased under reduced tillage (RT) in the second season in Chihota due to the prolonged dry spell after crop emergence (ACE). In Nharira and Tsholotsho the tillage system did not influence yield. There was higher weed biomass accumulation under RT in the second season in Tsholotsho. Band application of Atrazine at 1.8 l/ha did not affect maize yields compared to the farmer's traditional weed control practice across all sites. In Nharira the herbicide treatment had lower weed biomass. Soil fertility management did not affect maize yields in Nharira. Incessant rains in the 1998/1999 growing season experienced in Chihota after topdressing leached the nitrogen fertiliser. This resulted in lower maize yields in the recommended fertiliser treatment. In Tsholotsho applying the recommended fertiliser increased maize yields by 25 and 99 percent in the two seasons. Weed biomass was lower under recommended fertility in Chihota. In farmer-managed weed control demonstrations the use of herbicide technology increased maize yield by 36 and 37 percent in Chihota and Chiweshe, respectively. A plough pan was detected between 20 - 40 cm in six farmer's fields in Chihota, two fields in Nharira and at 20 cm in one field in Tsholotsho in both conventional tillage (CT) and RT systems. This study suggests that there is potential to use herbicide technology under different tillage systems. Farmers in Tsholotsho will benefit by using the recommended fertiliser rates.

INTRODUCTION

Late planting and untimely weeding are some of the constraints in maize production under smallholder farming conditions. Reduced tillage crop production involving the use of a ripper tine to open planting furrows (Shumba, 1989) has not only addressed the draught power problem, but also ensured early planting. Maize yields of 2.5 t/ha can be achieved by early planting in ripped furrows compared to 1.0 t/ha when ploughing was done after the first rains (Grant, 1981). Other studies have also indicated that delays in planting for more than 21 days after the first effective rains reduces maize grain yield by 32 per cent (Shumba, 1989).

The success of RT systems depends on efficient weed control (Elwell, 1989; Smith, 1989). About 30 per cent of the labour input in producing maize is spent on weed control, with an average of two weedings per crop cycle (Shumba, 1985). To avoid yield reduction, the first weeding should be done two weeks after crop emergence (Mabasa and Rambakudzibga, 1993; Shumba, Bernstein and Waddington, 1990). In Chihota, Nharira and Tsholotsho, 76, 85 and 54 per cent of the farmers own ox-drawn cultivators. The majority of the farmers cultivated twice with the first cultivation between three and four weeks after crop emergence, intra-row weeding following immediately after each cultivation (Mabasa *et al*; 1995).

At the beginning of the rain season (October/November), weeding and planting compete for labour. Farmers prefer to go on planting to take advantage of the moisture. This usually results in delayed weeding leading to low grain yields.

Uncontrolled weed growth reduced maize grain yield by between 34.4% and 96.3% in communal areas of Zimbabwe (Mabasa and Nyahunzvi, 1995). The common methods of weed control are hand hoeing, ox-cultivation and ox-plough weeding. These methods are not very efficient under persistent rainfall conditions (Sharman, 1970). Much as the ox-plough and ox-cultivator can be efficient, they need to be in good working condition. On the other hand, it is very difficult to achieve timely weed control using the hoe.

Because weed control in the smallholder sector is being done after the critical time, most of the nutrients are taken by weeds at the expense of the crop. At 6 weeks after crop emergence, top dressing operations and weeding compete for labour. Farmers prefer to finish weeding before they top dress. As a result, the top dressing is done at the wrong time and the crop which has suffered severe weed competition is not likely to respond to fertilizer application.

Herbicides have a potential to be used in communal areas, but they are hardly used by the farmers. The high cost of the technology is one of the reasons why farmers do not adopt use of herbicides. Use of low doses or banded herbicide application provide opportunities for farmers to efficiently control weeds. This study was a follow up to the on-farm trials conducted in these areas from the 1995/1996 to 1997/1998 seasons. The objective of this study was to involve communal area farmers in the evaluation of technologies which ensure timely planting, timely weed control and improved soil fertility in order to maximise maize grain yields.

MATERIALS AND METHODS

A total of 17, 13 and 15 farmers in Chihota, Nharira and Tsholotsho, respectively, participated in the verification trials on tillage, weed management and fertility levels in the 1998/1999 and 1999/2000 seasons. Most of the farmers were retained from the experimentation phase. Additional farmers were chosen with the assistance of extension staff. Uniform stands of 37,037 (0.9 m x 0.3 m) were established in Chihota and Nharira. Farmers in Tsholotsho preferred 24,691 (0.9 m x 0.45 m). Half of the participating farmers in the verification trials used recommended fertiliser rates of 300 kg/ha compound D (8N:14P_2O_5:7K_2O) and 250 kg/ha Ammonium Nitrate (34.5 %N) and the other half used their own fertiliser levels. Top dressing was done at 4 and 8 weeks ACE. These farm sites formed the main plots measuring 30 m x 20 m. Tillage formed the sub-plots measuring 30 m x 10 m. Weed management were the sub-sub plots.

Forty nine (49) farmers participated in the farmer managed demonstrations at Chihota, Nharira and Tsholotsho in the 1998/1999 season and four farmers at Chiweshe in the 1999/2000 season. These were mainly farmers who could purchase the herbicide on their own. The farmers tested the banded Atrazine 1.8 l/ha (0.9 kg a.i./ha) versus their traditional weed control practice. The farmers were supplied with the knapsack sprayers and the herbicide Atrazine. For the farmers who already owned sprayers, the sprayers were calibrated and they were given the herbicide. The farmers band sprayed Atrazine on one half of the contour and followed their traditional weed control practice on the other. Tillage and fertility management was according to the farmer. In both the verification trials and the farmer managed demonstrations, the farmer did the supportive mechanical weed control.

Weed samples for dry matter determination were taken from 0.5 m x 0.45 m quadrates placed at three random positions within the plot, at the crop physiological maturity. At harvesting clean cobs from a nett plot of 4.5 m x 5 m were weighed on a spring balance. Ten cobs were randomly selected and one row of grain was shelled from each cob for moisture determination on a Protimeter digital grainmaster meter. A shelling percentage of 83 was used to determine the field grain weight. Grain yield was corrected at 12.5 % moisture content. In the 1999/2000 growing season, growth patterns in the verification trials particularly at Chihota were associated with tillage treatments, therefore, it was considered necessary to test the soil strength in these plots. A Pilcon Hand Vane Tester was used and measurements were made at 0.05 m intervals to a maximum depth of 0.60 m profile. . Paired t-test comparison of means was used to test differences in maize grain yield and weed dry matter accumulation of the three factors.

RESULTS

Farmers' tillage systems, weeding method and fertiliser rates were those established in a survey (Mabasa *et al*, 1995). Weed species and weed distribution were similar to those identified by Mabasa, Shamudzarira, Makanganise, Bwakaya and Sithole, in their experiments in 1998.

Tillage effects: There was significantly higher maize garin yield under CT than RT at Chihota in the 1999/2000 season (Table 1). Tillage effects were almost significant ($P<0.08$) on grain yield at Nharira in the 1998/1999 season. In Thsholotsho, tillage effects did not influence maize grain yield. Weed dry matter accumulation was not influenced by the tillage treatment in Chihota and Nharira in the two seasons. Reduced tillage produced higher weed weights in the 1999/2000 season in Tsholotsho. These were influenced by the encroachment of *Cynodon dactylon* in the reduced tillage plots.

Weed management: Band spraying Atrazine at 0.9 kg a.i./ha produced similar yields with the farmer`s traditional weed control practices at all sites (Table 2). The highest yields were realised in Nharira in the 1998/1999 and in Tsholotsho in the 1999/2000 growing season. There was significantly ($P<0.01$) more weed biomass accumulation under the farmer weed management than the herbicide treated plots in Nharira in the 1998/1999 season. There was no difference in weed dry matter in Chihota and Tsholotsho.

Fertiliser levels: The depression in maize grain yield in the 1998/1999 season at Chihota was due to the incessant rains experienced after top dressing (Table 3). The farmers withheld fertiliser application until the conditions were conducive. In Nharira there was no yield difference between the recommended and farmers' application levels. Maize grain yields were significantly ($P<0.01$) increased by 25 and 99 per cent in the two seasons in Tsholotsho, by applying the recommended fertilizer rates. This can be explained by the wide gap between the farmers' fertilizer application rates. Farmers in this area are cautious not to put large amounts of fertilizer because of the high incidence of drought. Weed dry matter weights were significantly ($P<0.05$) higher under the farmers' traditional weed control practice than the Atrazine sprayed plots in the 1999/2000 seasons in Nharira. In Chihota and Tsholotsho weed weights were not influenced by the two weeding treatments.

Farmer managed demonstrations: In the 1998/1999 season 49 farmers tried the herbicide technology on their own in Chihota, Nharira and Tsholotsho. Four farmers in Chiweshe used the herbicide in the 1999/2000 season. There was 35.8 and 36.8 per cent maize grain yield increase at Chihota and Chiweshe smallholder areas, respectively, when farmers used Atrazine on their own (Table 4). At Nharira and Tsholotsho there were no yield differences between applying herbicides and the farmer's control practices.

DISCUSSION AND CONCLUSIONS

This study was conducted as an extension and scaling up effort of the promising technologies generated during the experimentation phase. The farmers were left to do most of the implementation work with minimum guidance from the researchers and extensionists. Results of the experiments (Makanganise, *et al*. 1997; Mabasa, *et al*. 1998) were used as reference points.

Tillage effects were only significant on maize grain yields in Chihota over the two seasons. Plant growth was markedly lower in reduced tillage in the 1999/2000 growing season when rainfall was deficient early in the season at Chihota. The prolonged dry spell could have affected fertiliser uptake particularly under reduced tillage. The effects of tillage were least significant on sandier soils at Tsholotsho. Grant, Meikle and Mills, 1979, showed that shallow ploughing has deleterious effects on the crop, which is enhanced in seasons of early drought. This is also emphasised by the shear vane values for resistance to soil strength, which had similar trends at all sites under RT and CT systems (Figure 1, 2 and 3). The profiles of soil hardness were a result of the farmers' tillage practices in the past, before these demonstrations. Weed dry matter weights were higher in reduced tillage in the second season at

Table 1. The effect of tillage system on maize grain yield production and weed biomass in three smallholder farming areas of Zimbabwe.

Treatment	Maize grain yield (kg/ha)					
	Chihota		Nharira		Tsholotsho	
	1998/99	1999/00	1998/99	1999/00	1998/99	1999/00
Conventional tillage	988 ± 189	1392 ± 314	3763 ± 415	1713 ± 216	1953 ± 238	2378 ± 334
Reduced tillage	2415 ± 1679	773 ± 179	3288 ± 486	1919 ± 196	2116 ± 254	2160 ± 250
d.f.	23	21	19	25	31	27
paired t test	ns	*	p = 0.08	ns	ns	ns
	Weed biomass (g/m^2)					
Conventional tillage	23.7 ± 3.5	23.9 ± 3.7	23.2 ± 5.3	27.8 ± 4.4	75.5 ± 7.4	18.9 ± 2.9
Reduced tillage	21.4 ± 4.5	20.4 ± 3.2	30.0 ± 7.1	29.3 ± 3.5	84.1 ± 7.6	28.1 ± 3.8
d.f.	23	21	19	27	29	27
paired t test	ns	ns	ns	ns	ns	*

ns = not significant; *p < 0.05

Table 2. The effect of weed management system on maize grain yield production and weed biomass in three smallholder farming areas of Zimbabwe.

Treatment	Maize grain yield (kg/ha)					
	Chihota		Nharira		Tsholotsho	
	1998/99	1999/00	1998/99	1999/00	1998/99	1999/00
Herbicide	800 ± 144	1187 ± 251	3683 ± 475	1761 ± 214	2185 ± 285	2138 ± 281
Farmer's practice	937 ± 189	979 ± 275	3368 ± 432	1871 ± 195	1884 ±197	2400 ± 311
d.f.	23	21	19	25	31	27
paired t test	ns	ns	ns	ns	ns	ns
	Weed biomass (g/m^2)					
Herbicide	25.90 ± 4.35	22.77 ± 4.12	18.56 ± 4.75	25.75 ±3.72	81.17 ± 8.06	24.11 ± 3.34
Farmer's practice	19.20 ± 3.52	21.50 ± 2.62	34.66 ± 7.06	31.32 ± 4.14	78.47 ± 6.91	22.89 ± 3.64
d.f.	23	21	19	27	29	27
paired t test	ns	ns	**	p<0.076	ns	ns

ns = not significant; **p< 0.01

Table 3. The effect of fertility management on maize grain yield production (kg/ha) and weed biomass (g/m^2) in three smallholder farming areas of Zimbabwe.

Treatment	Maize grain yield (kg/ha)					
	Chihota		Nharira		Tsholotsho	
	1998/99	1999/00	1998/99	1999/00	1998/99	1999/00
Recommended level	618 ± 155	1479 ± 349	3408 ± 515	2031 ± 243	2259 ± 232	3019 ± 344
Farmer's practice	1120 ± 166	822 ± 172	3643 ± 385	1694 ± 176	1810 ± 253	1519 ± 130
d.f.	42	27	35	41	61	34
two sample t test	*	ns	ns	ns	ns	***
	Weed biomass (g/m^2)					
Recommended level	24.80 ± 3.3	15.35 ± 2.2	32.20 ± 7.7	29.80 ± 4.8	78.70 ± 9.3	22.40 ± 3.1
Farmer's practice	20.30 ± 4.6	30.40 ± 4.2	21.00 ± 4.0	26.50 ± 3.4	81.10 ± 3.9	24.60 ± 3.8
d.f.	42	28	28	41	61	51
two sample t test	ns	**	ns	ns	ns	ns

ns = not significant; *p<0.05; **p<0.01; ***p<0.001

Table 4. The effect of weed control method on maize grain yield (kg/ha) in farmer-managed demonstrations conducted in Chihota, Nharira, Tsholotsho and Chiweshe communal area.

Weed control method	Chihota 1998/99	Nharira 1998/99	Tsholotsho 1998/99	Chiweshe 1999/00
Atrazine banded 1.8 l/ha	2206 ± 499	3274 ± 560	2117 ± 818	1800 ± 72
Farmer's weed control	1625 ± 303	2878 ± 614	2046 ± 370	1317 ± 105
d.f.	16	13	6	3
Paired t test	p = 0.099	ns	ns	*

ns = not significant; *p<0.05

Figure 1. Soil resistance (Kpa) in conventional and reduced tillage systems at maize physiological maturity in Chihota communal area in the 1999/00 season.

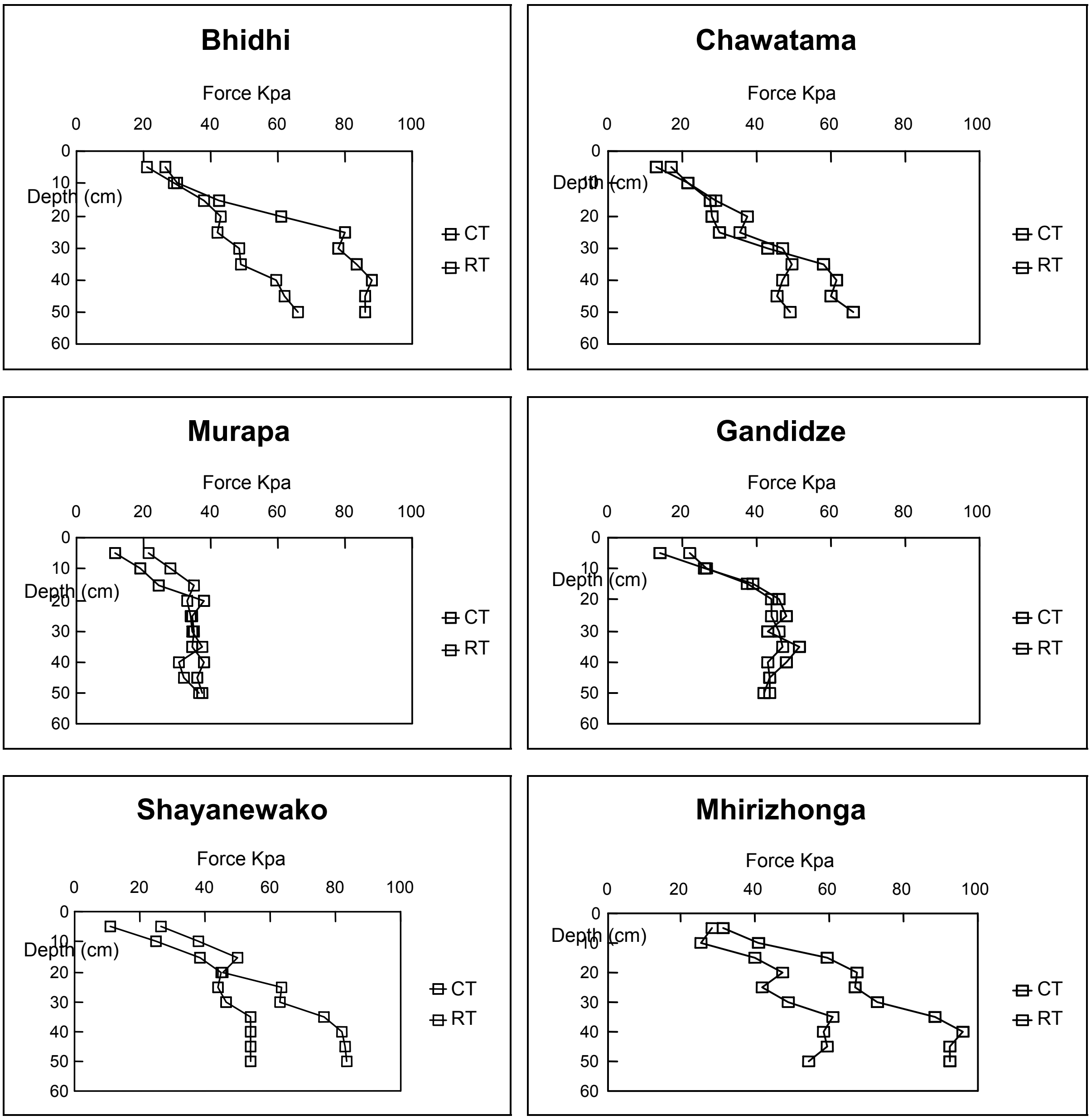


Figure 2. Soil resistance (Kpa) in conventional and reduced tillage systems at maize physiological maturity in Nharira communal area in the 1999/00 season.

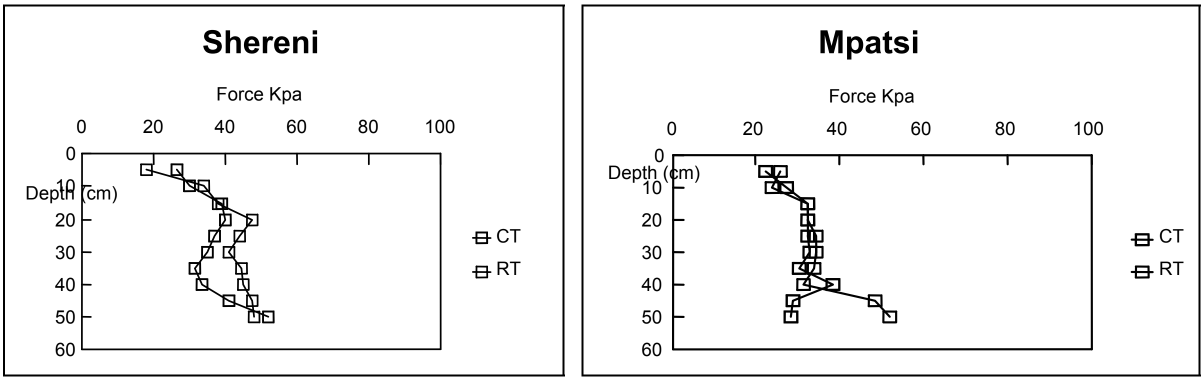
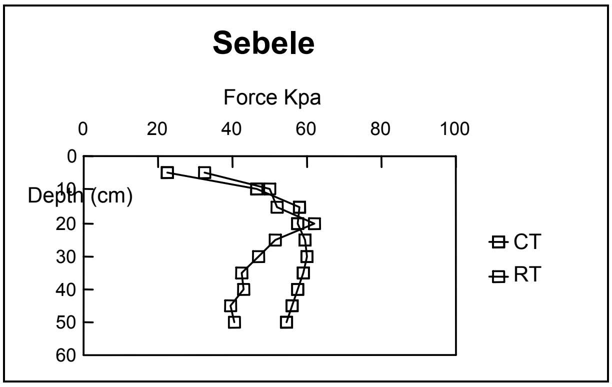


Figure 3. Soil resistance (Kpa) in conventional and reduced tillage systems at maize physiological maturity in Tsholotsho communal area in the 1999/00 season.



Tsholotsho. This was due to the encroachment of *Cynodon dactylon*.

This study confirmed earlier findings (Mabasa *et al.* 1998) that maize grain yield between applying half the recommended Atrazine rate and the farmers' weed control practice produced similar results. Soil moisture which is one of the important environmental conditions for the efficacy of the herbicide Atrazine was adequate at spraying at all sites in the two growing seasons. The decision by the farmer to use the herbicide to control weeds depends on cost, availability and know-how. The economics of herbicide technology versus the commonly used weed control practices are discussed here in a separate paper. It was also evident that the use of the herbicide Atrazine in the farmer managed demonstrations increased maize grain yields by 35.8 and 36.8 per cent respectively in Chihota and Chiweshe. The presence of *Eleusine indica* in Nharira resulted in higher weed dry matter weights in the farmer's weed control practice. Rambakudzibga and Mabasa, (1993) showed that *E. indica* has a protracted emergence pattern. The weed continued to emerge well after the farmers have finished their weeding operations. However, it is effectively controlled by the herbicide Atrazine. Another observation is that some fields in Nharira have red clay soils, which are difficult to cultivate and weed under wet conditions. Farmers with these fields cannot efficiently control the weeds using the ox-cultivator or the hand hoe.

Response to fertiliser application rates by maize grain yield was more positive in Tsholotsho, insignificant in Nharira and least consistent in Chihota. The yield increase obtained in Tsholotsho can be explained by the wide gap between the recommended levels and the farmer's application rates at this site (Mabasa *et al*. 1995). Similar yield responses to the recommended fertiliser rates in Tsholotsho were noticed in the experimentation phase (Makanganise *et al*. 1997). In the second season weed weights were higher in the farmer's weed control practice in Chihota. In other studies (Di Tomaso, 1995; Makanganise *et a*l, 1997) showed that higher fertiliser rates increased weed dry matter weights when weeds were poorly controlled. These results imply that weed control was sufficient. There is potential of increasing maize yields in Tsholotsho if farmers increase their fertiliser application rates close to the recommended levels. Retarded crop growth may be experienced under RT if moisture becomes limited during the first few weeks ACE. Using the herbicide Atrazine at half the recommended rate provides a feasible option for the timely control of weeds. However, the extension staff must be trained in the use of herbicides so that they could, in turn, train more farmers in their areas. Farmers who were exposed to the herbicide technology proved that they could successfully utilise it to improve their maize yields.

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DETERMINATION OF NITROGEN AND PHOSPHORUS FERTILIZER LEVELS IN DIFFERENT MAIZE-FABA BEAN INTERCROPPING PATTERNS IN NORTHWESTERN ETHIOPIA.

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ABSTRACT

A field experiment was undertaken for two years (1999 and 2000) at Adet and Mota experimental stations in northwestern Ethiopia with the objective of determining the appropriate planting pattern and optimum rate of N and P fertilizers for maize-faba bean intercropping. A factorial combination of four nitrogen rates (0, 32, 64, and 96 kg N/ha), three phosphorus rates (0, 46 and 69 kg P_2O_5/ha) and two planting patterns (1:1 and 2:1 maize: faba bean alternate row planting) were tested along with two sole crop treatments of maize and faba bean. The experimental design was Randomized Complete Block (RCB) with three replications. The results indicated that there was significant difference in maize grain yield at the two locations due to nitrogen and phosphorus fertilizer levels. Significant difference in faba bean grain yield was observed due to planting pattern. The Land Equivalent Ratio (LER) is more than unity in most of the cases. The highest LERs, 2.0 at Mota and 1.5 at Adet were obtained when a planting pattern of 1:1 maize: faba bean alternate rows were used with the application of 96-46 N- P_2O_5 kg/ha. The economic analysis has also confirmed that the specified treatment gave the best advantage at all the locations.

Keywords: Ethiopia, Faba bean, intercropping, maize, nitrogen, phosphorous, planting pattern.

INTRODUCTION

A survey in the Amhara region, northwestern Ethiopia, indicated that in subsistence economy the farmer uses a combination of crops grown on a piece of land. The combination is in such a way that cereals, pulses, and oil seeds are represented in order to achieve his/her major objective of food self-sufficiency (UNDP, 1996). The most important crop mixtures used by farmers in the area are sorghum-chick pea, sorghum-faba bean, sorghum-barley, sorghum-finger millet, finger millet-rape seed, wheat-barley, pea-horse bean, maize-rape seed, maize-potato, and Maize-faba bean (Aleligne and Regassa, 1992 UNDP, 1996, and personal observation). Most of the farmers who practise intercropping say their reasons are land scarcity and avoidance of risk of crop failure; however, the reasons of some of the farmers are soil erosion and labour scarcity (UNDP, 1996).

Maize/Zea mays/faba bean /Vicia faba/ intercropping is one of the most frequent intercropping systems. In the high lands of east and south Africa, and in Mexico the practice of intercropping of maize with faba bean exists (Altieri *et al*, 1986, and Dowswell *et al*, 1996). In our area no research has been done on intercropping of food legumes and cereals. This study is supposed to fill the information gap about planting patterns and nutrient management for best use of maize-faba bean intercropping. The main objectives of this study are therefore:

- To determine the appropriate planting pattern in maize-faba bean intercropping;
- To know the optimum amount of nutrient combinations required for maize-faba bean intercropping.

MATERIALS AND METHODS

The experiment was carried out at Adet and Mota Experimental stations. The two stations are located in Gojam region, northwestern Ethiopia. The geographical position of Adet is $11^0 17'$ N and $37^0 31'$E, while that of Mota is $11^0$12N and $37^0 88'$E. The altitude of Adet and Mota is 2,240 and 2,470 m.a.s.l, respectively. The average annual rainfall of Adet and Mota areas is 1,293 and 1,296 mm, respectively, of which about 70% are received during the months from June to September. The mean maximum and minimum temperature are 24^0 C and 9^0 C at Adet and 24.3^0 C and 9.6^0 C at Mota.

The experiment consisted of factorial combinations of four nitrogen, three phosphorus rates and two planting patterns. The nitrogen levels are 0, 32, 64, and 96 kg N/ha, while the phosphorus rates are 0, 46 and 69 kg P_2O_5/ha. The two planting patterns are 1 maize row/1 bean row and 2 maize rows/1 bean row alternate planting. In case of 1 maize row/1 bean row planting there were maize rows planted at a row spacing of 75 cm and at the middle of two maize rows there was one bean row. However, for 2 maize rows/1 bean row alternate planting the maize was planted at a row spacing of 75 cm and after two maize rows a faba bean row was planted at the middle of the 75 cm maize spacing. Other than the twenty-four treatment combinations there were two sole crop treatments one for maize and the other for faba bean. The sole maize was planted at a spacing of 75 cm x 30 cm with the application of fertilizer at a rate of 64-46 kg N-P_2O_5/ha. Sole faba bean was planted at 40 cm x 8 cm with the application of fertilizer at a rate of 18-46kg N-P_2O_5/ha. The design was a RCB with three replications.

The CS-20 DK faba bean variety and the BH-540 maize variety were used. In the case of the intercropping treatments maize and faba bean had been planted at the same time. Half of the N fertilizer was applied at planting and the remaining N at knee height of the maize, however, for the sole bean the entire N rate was applied at planting. In all cases the P_2O_5 rates were applied at planting. Each plot of the trial had six rows of maize, 75 cm x 30 cm, with different rows of bean according to the respective planting pattern. The two extreme rows of maize were considered as border rows. The sizes of the gross and net plots were therefore 4.5m x 5.1m and 3m x 5.1m, respectively.

Data were collected on grain yield, 1,000-seed weight and plant height for the two crops, whereas number of cobs/plant was taken for maize. Number of pods/plant and number of seeds/pod had been recorded for faba bean. The data were then subjected to analysis of variance (ANOVA) using MSTATC microcomputer software. Land Equivalent Ratio (LER) had been calculated to assess the productivity of the intercropping systems by the equation (Willey, 1991):

LER = Yab/Ya+Yba/Yb, where
Yab = Yield per unit area of crop a in mixture
Ya = Yield per unit area of sole crop a
Yba = Yield per unit area of crop b in mixture
Yb = Yield per unit area of sole crop b

Mean grain yield were also subjected to economic analysis using partial budget methodology (CIMMYT, 1988). The average price of maize and faba bean grains over three months at the time of harvesting where the price is supposed to be lower had been taken over three consecutive years (1998-2000). The sensitivity analysis has been worked out by assuming that the cost of fertilizer inputs increased by 10% while the price of grain remains unchanged.

Thus the following prices/costs were used:

	Price/cost for normal economic analysis (Birr/kg)	Price/cost for sensitivity analysis (Birr/kg)
Maize	0.84	0.84
Faba bean	1.47	1.47
DAP	2.94	3.23
Urea	2.17	2.38

RESULTS AND DISCUSSION

The two years data analysis indicated that there were significant differences in maize grain yield at Adet and Mota due to differences in Nitrogen and Phosphorus fertilizer levels (Table 1).

Maize grain yield was not affected by planting pattern at both locations. The interaction of any of the factors did not show significant difference in maize grain yield at Adet. While at Mota, interactions of planting pattern and phosphorus fertilizers, nitrogen and phosphorus fertilizers and also interaction of all the factors (planting pattern, nitrogen and phosphorus fertilizers) showed significant differences on maize grain yield (Table 2). Significant differences in faba bean grain yield due to planting pattern were observed in the across years analysis of the two locations (Table 3). Application of different levels of N and P_2O_5 fertilizers to the maize rows did not bring significant difference in faba bean yield at both locations.

The statistical analysis for the parameters other than grain yield indicated that nitrogen fertilizer application significantly influenced maize plant height at Mota and Adet (Table 4). Difference in P_2O_5 fertilizer levels influence maize plant height only at Adet. Statistical difference in maize thousand-kernel weight was observed due to nitrogen and P_2O_5 fertilizers at the two locations (Table 5). Thousand seeds of faba bean showed significant response only to the application of P_2O_5 fertilizers at Adet, while it showed both for nitrogen and P_2O_5 fertilizers at Mota (Table 6). Intercropping pattern, nitrogen, and P_2O_5 fertilizers at Adet significantly influenced faba bean plant height. However, only nitrogen fertilizer causes significant difference on plant height of faba bean at Mota. Number of faba bean seeds/pod and pods per plant were influenced by none of the factors at the two locations.

Land equivalent ratio (LER) analysis was carried out in order to assess the advantage of intercropping over sole cropping (Table 7). The LER is more than unity in most of the cases at the two locations, which shows that intercropping of maize and faba bean is advantageous in many instances rather than planting each of the crops sole. The highest LERs, 2.0 at Mota and 1.5 at Adet, were recorded when a planting pattern of 1 maize: 1 faba bean alternate rows were used with the application of 96-46 N-P_2O_5 kg/ha. The maximum LER values indicate the specific planting pattern and fertilizer level gave a 100% advantage at Mota and a 50% advantage at Adet than planting maize or faba bean independently. The highest LER at Mota, 2.0, indicates that a land size which is double the one used for the intercrops would have been required to get equivalent yield by planting the crops separately (Willey, 1991).

Similarly the maximum LER value at Adet, 1.5, indicate additional 0.5 unit of land would have been needed to get equal yield to planting maize and faba bean in pure stands. Difference in LER results due to difference in fertilizer levels, planting pattern and locations. LER was less than one at Mota when no nitrogen fertilizer was applied in

Table 1. The over all effect of nitrogen and phosphorus fertilizers on grain yield of maize.

N (kg ha^{-1})	Adet Rate of P_2O_5 (kg ha^{-1})				Mota Rate of P_2O_5 (kg ha^{-1})			
	0	46	69	Mean	0	46	69	Mean
0	3169	4044	4345	3853	1091	1331	1389	2840
32	4446	5618	5901	5321	1710	2221	2356	3967
64	5281	6502	6544	6109	2513	2616	2478	4526
96	5069	6788	6295	6050	2790	3691	2741	4702
Mean	4491	5738	5771		2026	2465	2244	
CV (%)	21				23			
	N	**P_2O_5**	**N x P_2O_5**		**N**	**P_2O_5**	**N x P_2O_5**	
LSD (1%)	534	463	NS		238	206	411	
LSD (5%)	708	613	NS		314	272	545	

Table 2. Effect of fertilizer, planting pattern and their interactions on the grain yield of maize.

N/ P_2O_5 (kg ha^{-1})	Adet			Mota		
	Planting Pattern		Mean	Planting Pattern		Mean
	1M: 1Fb*	2M: 1Fb**		1M: 1Fb	2M: 1Fb	
0/ 0	3194	3144	3169	1173	1010	1091
0/ 46	3747	4342	4044	906	1756	1331
0/ 69	4254	4437	4345	1101	1677	1389
32/ 0	4295	4598	4446	1701	1719	1710
32/ 46	6262	4974	5618	2443	2000	2221
32/ 69	6193	5609	5901	2286	2427	2356
40/ 0	5412	5150	5281	2886	2141	2513
64/ 46	6134	6870	6502	2873	2359	2616
64/ 69	6787	6302	6544	2028	2929	2478
96/ 0	5126	5012	5069	2454	3126	2790
96/ 46	7108	6469	6788	4110	3273	3691
96/ 69	5943	6647	6295	2540	2942	2741
Mean	5371	5296		2208	2279	
CV (%)	21			23		
	PP		PP	N x P2O$_5$	PP x P_2O_5	N x PP x P_2O_5
LSD (1%)	NS		NS	411	291	582
LSD (5%)	NS		NS	545	385	770

*1M: 1Fb = Maize: 1 Faba bean alternate row planting
**2M: 1Fb = 2Maize: 2 Faba bean alternate row planting.

Table 3. Effect of fertilizer, planting pattern and their interactions on the grain yield of faba bean.

N/ P_2O_5 (kg ha^{-1})	Adet			Mota		
	Planting Pattern		Mean	Planting Pattern		Mean
	1M: 1Fb*	2M: 1Fb**		1M: 1Fb	2M: 1Fb	
0/ 0	579	248	413	604	275	439
0/ 46	652	238	445	627	449	538
0/ 69	578	259	418	815	283	549
32/ 0	730	192	461	7242	237	480
32/ 46	548	205	276	668	252	461
32/ 69	625	235	430	792	286	539
64/ 0	617	211	414	678	274	476
64/ 46	489	295	392	761	243	502
64/ 69	607	181	394	749	327	538
96/ 0	587	230	408	768	386	577
96/ 46	637	268	452	872	322	597
96/ 69	616	245	430	7094	287	540
Mean	605	233		737	301	
CV (%)	35			25		
	PP	N x P2O5	N x PP x P2O5	PP	N x P2O5	N x PP x P2O5
LSD (1%)	290	NS	NS	314	NS	NS
LSD (5%)	215	NS	NS	233	NS	NS

Table 4. Effect of fertilizer, Planting pattern and their interactions on Plant height of maize.

N/ P_2O_5 (kgha^{-1})	Adet			Mota		
	Planting Pattern		Mean	Planting Pattern		Mean
	1M: 1Fb*	2M: 1Fb**		1M: 1Fb	2M: 1Fb	
0/ 0	165	165	165	158	147	152
0/ 46	180	182	181	153	148	150
0/ 69	189	182	186	159	160	160
32/ 0	195	192	194	159	167	163
32/ 46	208	194	2001	169	155	162
32/ 69	208	199	204	156	178	167
64/ 0	199	202	200	178	168	173
64/ 46	201	216	209	178	176	177
64/ 69	206	211	208	175	187	182
96/ 0	202	194	198	187	182	185
96/ 46	211	210	211	194	190	192
96/ 69	212	209	210	188	197	192
Mean	198	196			171	172
CV (%)	6.2			8.5		
	N	P2O5	N	P2O5; N x P2O5	PP x P2O5	N x PP x P2O5
LSD (1%)	55	48	7	NS	8	NS
LSD (5%)	73	63	9	NS	11	NS

Table 5. Effect of fertilizer, planting pattern and their interactions on thousand kernels weight of maize.

N/P_2O_5 ($kgha^{-1}$)	Adet			Mota		
	Planting Pattern		Mean	Planting Pattern		Mean
	1M: 1Fb*	2M: 1Fb**		1M: 1Fb	2M: 1Fb	
0/ 0	328	343	335	274	272	273
0/ 46	339	355	347	272	280	276
0/ 69	362	351	356	262	293	277
32/ 0	356	356	356	289	304	296
32/ 46	373	342	357	307	293	300
32/ 69	379	372	375	304	311	307
64/ 0	367	356	361	313	302	307
64/ 46	388	391	398	329	322	325
64/ 69	379	369	374	282	324	301
96/ 0	386	362	374	296	306	301
96/ 46	381	375	378	350	329	339
96/ 69	376	371	373	321	326	323
Mean	367	361		299	305	
CV (%)	5.5			10.7		
	N	**P2O5**	**N**	**P2O5; N x**	**PP x P2O5**	**N x PP x P2O5**
LSD (1%)	9	8	15	NS	NS	NS
LSD (5%)	12	11	20	NS	NS	NS

Table 6. Effect of fertilizer, planting pattern and their interactions on thousand seeds weight (g) of faba bean.

N/P_2O_5 ($kgha^{-1}$)	Adet			Mota		
	Planting Pattern		Mean	Planting Pattern		Mean
	1M: 1Fb*	2M: 1Fb**		1M: 1Fb	2M: 1Fb	
0/ 0	434	418	426	451	474	462
0/ 46	439	429	434	489	500	494
0/ 69	442	438	440	482	482	482
32/ 0	420	417	418	489	474	482
32/ 46	442	429	436	468	473	470
32/ 69	460	440	450	490	510	500
64/ 0	432	426	429	468	448	458
64/ 46	434	448	441	474	473	473
64/ 69	447	458	452	493	519	506
96/ 0	435	429	432	471	502	487
96/ 46	447	432	440	472	496	484
96/ 69	440	442	441	501	513	508
Mean	439	434		479	489	
CV (%)	6.0			4.2		
	N	**P2O5**	**N**	**P2O5**	**N x P2O5**	**PP x P2O5; N x PP x P2O5**
LSD (1%)	NS	11	NS	9	23	NS
LSD (5%)	NS	14	NS	13	31	NS

the first planting pattern, 1maize: 1 faba bean row. The result observed at Adet showed that the lower LER values were observed when the lowest nitrogen rates were used in the second planting pattern (2maize: 1 faba bean row intercropping). Variation in LER results due to difference in fertilizer levels, planting pattern and locations. The differences in LER showed that nutrient levels, planting pattern, and locations are determinant for an intercropping system to be advantageous or not.

Similar results had been reported by different authors (Palaniapan, 1985 and Trenbath, 1986, Andrews and Kassam, 1983). The LER analysis for the two locations has also revealed that suitable intercropping pattern for different areas might differ based on factors like the potential of the areas, the adaptability of the varieties, etc., in line with the reports of some writers (Francis, 1986 and Trenbath, 1986, Robinson, 1997).

Economic analysis of the results has also indicated that intercropping of maize and faba bean is more advantageous than sole planting of the crops (Table 8 and Table 9). The highest economic advantage with a net return of Ethiopian Birr 5,536 at Adet and Birr 3,578 at Mota were observed for the treatment which is a combination of a planting pattern of 1 maize: 1 faba bean alternate rows combined with the application of 96-46 N-P_2O_5kg/ha. The monetary advantage gained from the intercropping treatment at Adet is 43.91 % and 112.59% higher over the sole planting of maize and faba bean, respectively. The economic advantage gained from the same intercropping treatment at Mota is 113.54% and 92.80% higher over the sole planting of maize and faba bean, respectively. According to the results of the sensitivity analysis, the best treatment still remains profitable at the two locations even if the price of fertilizer inputs increase by ten percent (Table 10 and Table 11). The LER and economic analysis have confirmed that the intercropping practice of maize and faba bean is superior to and advantageous over sole cropping. Given the nitrogen fixing nature of faba bean, the system is more reliable for sustainable and environmentally safe crop production than the sole production of the cereal, maize (Sanchez, 1975 and Pal and Shehu, 2001). The system also offers the production of not only carbohydrate but also protein for the balanced nourishment of the farmer's family (Francis, 1986).

Table 7. Effect of fertilizer, planting pattern and interactions on Land Equivalent Ratio at Adet and Mota (1999-00)

Planting Pattern	N (kg/ha)	P_2O_5 (kg/ha)	Land Equivalent Ratio (LER)					
			Adet			Mota		
			Maize	Faba b.	Total	Maize	Faba b.	Total
1:1	0	0	0.55	0.26	0.8	0.41	0.37	0.8
1:1	0	46	0.65	0.30	0.9	0.31	0.38	0.7
1:1	0	69	0.74	0.26	1.0	0.38	0.50	0.9
1:1	32	0	0.75	0.24	1.0	0.59	0.44	1.0
1:1	32	46	1.09	0.25	1.3	0.84	0.41	1.3
1:1	32	69	1.07	0.28	1.4	0.79	0.49	1.3
1:1	64	0	0.94	0.28	1.2	1.00	0.42	1.4
1:1	64	46	1.06	0.22	1.3	0.99	0.48	1.5
1:1	64	69	1.18	0.28	1.5	0.70	0.46	1.2
1:1	96	0	0.89	0.27	1.2	0.85	0.47	1.3
1:1	96	46	1.23	0.29	1.5	1.42	0.53	2.0
1:1	96	69	1.03	0.28	1.3	0.88	0.49	1.4
2:1	0	0	0.55	0.11	0.7	0.35	0.17	0.5
2:1	0	46	0.75	0.11	0.9	0.61	0.28	0.9
2:1	0	69	0.77	0.12	0.9	0.58	0.17	0.8
2:1	32	0	0.80	0.09	0.9	0.59	0.15	0.7
2:1	32	46	0.86	0.09	1.0	0.69	0.15	0.8
2:1	32	69	0.97	0.11	1.1	0.84	0.18	1.0
2:1	64	0	0.89	0.10	1.0	0.74	0.17	0.9
2:1	64	46	1.19	0.13	1.3	0.82	0.15	1.0
2:1	64	69	1.09	0.08	1.2	1.01	0.20	1.2
2:1	96	0	0.87	0.10	1.0	1.08	0.24	1.3
2:1	96	46	1.12	0.12	1.2	1.13	0.20	1.3
2:1	96	69	1.15	0.11	1.3	1.02	0.18	1.2

Table 8. Economic analysis of Maize-Faba bean intercropping at Adet

Planting Pattern	N (kg/ha)	P_2O_5 (kg/ha)	Total variable cost (TVC)	Gross benefit (Birr)	Net benefit (Birr)	MRR%
2:1	0	0	8	2704	2696	-
1:1	0	0	16	3177	3161	5813
2:1	32	0	158	3429	3570	286
1:1	32	0	166	3946	3779	2601
2:1	64	0	309	4171	3861	58
1:1	64	0	317	4905	4587	9070
1:1	32	46	376	5456	5080	848
1:1	64	69	631	5931	5299	85
1:1	96	46	677	6213	5536**	509

** The first profitable treatment

Table 9. Economic analysis of Maize-Faba bean intercropping at Mota

Planting Pattern	N (kg/ha)	P_2O_5 (kg/ha)	Total variable cost (TVC)	Gross benefit (Birr)	Net benefit (Birr)	MRR%
2:1	0	0	8	1125	1117	-
1:1	0	0	16	1683	1667	6869
1:1	32	0	167	2239	2072	268
1:1	64	0	317	3076	2758	453
1:1	96	46	678	4256	7578**	227

** The first profitable treatment

Table 10. Sensitivity economic analysis of Maize-Faba bean intercropping at Adet.

Planting Pattern	N (kg/ha)	P_2O_5 (kg/ha)	Total variable cost (TVC)	Gross benefit (Birr)	Net benefit (Birr)	MRR%
2:1	0	0	8	2704	2696	-
1:1	0	0	16	3177	3161	5813
2:1	32	0	174	3729	3555	249
1:1	32	0	182	3946	3763	2601
2:1	64	0	340	4171	3831	42
1:1	64	0	348	4905	4557	9070
1:1	32	46	412	5456	5044	762
2:1	64	46	570	5583	5013	-20
1:1	64	69	693	5931	5237	182
1:1	96	46	744	6213	5469**	454

** The first profitable treatment

Table 11. Sensitivity economic analysis of Maize-Faba bean intercropping at Mota.

Planting Pattern	N (kg/ha)	P_2O_5 (kg/ha)	Total variable cost (TVC)	Gross benefit (Birr)	Net benefit (Birr)	MRR%
2:1	0	0	8	1125	1117	-
1:1	0	0	16	1683	1667	6869
1:1	32	0	182	2239	2057	235
1:1	64	0	348	3075	2727	403
1:1	96	46	744	4256	3512**	198

** the first profitable treatment

CONCLUSION

The results of the experiment have shown that with intercropping it is possible to produce additional yield of faba bean without any decrease of maize yield at both locations. The system offers a chance of profitable production as the LER and economic analysis confirmed it. The combinations of 1 maize:1 faba bean planting pattern with the application of 96-46 kg N- P_2O_5 /ha was found to be the highest profitable treatment. It also gave the farmers the option of producing both carbohydrate and protein at the same time. The intercropping system is more appropriate in terms of sustainability than sole cropping of cereals since the legume component enriches the soil through nitrogen fixation. There was also good ground coverage during intercropping which was important with regard to soil conservation especially at the early stage of the maize crop.

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ON-FARM COMPARISON OF FERTILIZER APPLICATION PRACTICES TO ASSESS NITROGEN-USE EFFICIENCY WITH MAIZE IN ZIMUTO COMMUNAL AREA, ZIMBABWE

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ABSTRACT

A study was conducted in 2000-01 in the semi-arid Zimuto Communal Area in Zimbabwe to compare mineral fertilizer application methods with farmers. Three fertilizer application methods, the flexible Fertilizer Management Package (FMP), the AGRITEX extension method and the FARMER method were compared in 10 farmers' fields. The FMP is a flexible package where N is applied in relation to rainfall and crop growth. Compound D (8:14:7 NPK) was broadcast when the maize was planted. Ammonium Nitrate (AN) was applied at 10 days after crop emergence, and at 30 days and 60 days in relation to rainfall and crop growth. The AGRITEX package provided Compound D at planting and AN was applied once when the crop reached knee high. In the FARMER practice, fertilizer management was done following the farmers' planned concepts of fertilizer management, and this generally involved little fertilizer and combination with cattle manure. Farmers managed the fields. Results showed high observed Nitrogen Use Efficiency (NUE) values of 80 kg grain per kg N applied at rates below 20 kg N/ha but very low NUEs (- 5 kg of grain per kg of N) with fertilizer rates above 90 kg. The NUEs declined as more N was applied. The FARMER practice was lowest and the FMP being highest. The homestead fields gave highest maize yields. There were no differences between the FMP and Agritex packages on maize yields. Farmer management of the fertilizer packages revealed that extension information on fertilizer management was limited. Farmers tended to modify the packages towards their fertilizer management concepts. Feedback from farmers suggested that the farmers best liked the FMP package, but suggested they will need support to access the N fertilizer it needs. Farmers suggested promoting a simplified FMP package with a maximum of two timings/doses of topdress N fertilizer.

INTRODUCTION

This paper focuses on farmer-led participatory on-farm experimentation to compare three methods of mineral fertilizer management on maize in a semiarid area of Masvingo, southeast Zimbabwe. It further explores how the group of 11 smallholder farmers perceive the innovations on how best to use the available fertilizers. The goal was to provide small-scale resource poor farmers with acceptable methods of fertilizer use, which could be readily disseminated, to minimize input costs while increasing maize yields.

Mineral fertilizers have been shown to increase maize yields in southern Africa (e.g., Ingram and Swift 1990; Smale 1991), including under smallholder conditions (Blackie and Jones 1993). Evidence from other studies, however, indicates that fertilizer use-efficiency is often low on smallholder farmers in the region (Barbier 1991; Mushayi et al. 1999; Shamudzarira et. al. 2000). Mushayi et al. (1999) measured agronomic Nitrogen-Use Efficiencies (NUE) (defined as extra kilogram of grain per extra kilogram of N applied) that were often below 10 kg of grain per kilogram of N applied on farmers' maize crops in sub-humid zones of Zimbabwe. In addition, data from on-farm experiments conducted in Malawi indicates that agronomic NUEs obtained on-farm were noticeably less than those achieved on-station (Kumwenda et al. 1996).

Agronomic NUE depends, among other things, on crop and crop variety, climatic factors such as rainfall, soil fertility, weed pressure, method of fertilizer application, time of fertilizer application, rates of application, and labour available to the farm. Time of application is crucial because the crop needs to have sufficient nutrients at the right stages of growth. The crucial stages have to be synchronized with available nutrients in the field (Myers et al. 1997). Greater and more efficient use of chemical fertilizers can substantially increase crop yields under Zimbabwe smallholder conditions (Mushayi et al. 1999). Yet the vast majority of smallholder farmers in semiarid Zimbabwe apply little or no fertilizer at all to their maize crop (Rohrbach 1998).

As part of a comprehensive study of farmer risk management strategies in Zimuto Communal Area, one group of farmers was involved with the development of fertilizer management strategies for maize, the most widely grown crop in the area. Consistently low yields by smallholder farmers have led to several questions about fertilizer management. During focused group discussions with farmers in the Maranda area of Zimuto on mineral fertilizer management in maize, the farmers listed issues and ranked them. The issues raised in order of priority (from highest to lowest) were

- types and amounts of fertilizers used;
- methods and time of application;
- splitting versus one time application;
- decisions on which crops to apply fertilizer to;
- labour requirement and the type of management of the fields before and after fertilizer application;
- which practice is sustainable?;
- are the practices the same for all the field types?; and
- does the use of on-farm resources increase with each fertilizer type and application practice?

The answers to the issues raised by farmers were developed through focussed group discussions to capture farmer perceptions on the practices and modelling of farmer-developed scenarios about fertilizers using the Agricultural Production Systems sIMulator (APSIM) crop simulation model. To provide a focal point for this work with smallholder farmers, we conducted an on-farm experiment with farmers to compare three methods (practices) of using the available nitrogen fertilizer.

Objectives

The main objective of the study was to identify the most economical and sustainable way of increasing fertilizer use efficiency and thereby increasing maize yields per unit area. Through partnership with farmers, the best method of using limited fertilizer input to maximize yields would be identified and adapted to suit local conditions. Specifically, this work was developed to

1. compare the N-use efficiency of fertilizer application methods;
2. assess the suitability of the methods to different land types and farmers types; and
3. compare the practices for yield and resource needs (labour, amount of fertilizer, etc).

MATERIALS AND METHODS

Context of trials, options, and numbers

Ten farmers were involved in conducting the on-farm experiments, each farmer hosting three plots, which measured 20 m by 10 m. The experiments were designed through group discussions and farmers were full partners in the design and management of the trials, including data collection.

Three fertilizer application options were compared in the three plots. The practices were the University of Zimbabwe fertilizer management package (FMP), the AGRITEX practice (AGRITEX), and the farmer's own practice (FARMER). For each of the three plots, the farmer received 3 kg of Compound D (8:14:7 NPK) fertilizer and 5 kg of ammonium nitrate (34.5 % N) fertilizer. The farmers planted a commercial maize hybrid, SC 501, in all plots.

The fertilizer practices

The UZ Fertilizer Management Package (FMP). The University of Zimbabwe Soil Science Department has been working with smallholder farmers from seven smallholder farming areas in Zimbabwe Natural Regions II, III, and IV to develop and test a flexible fertilizer management package (FMP) for use under variable rainfall conditions (Piha 1994; Piha et. al. 1998). The farmer group in Maranda in Zimuto Communal Area was involved with this university project. The approach used in the FMP aims to supply nutrients at rates that are equal to those removed by a crop of maximum yield under "average" rainfall conditions. For nutrients that are fairly immobile (e.g., P, K, and S) a fixed amount is applied annually as a basal fertilizer, which is broadcast and ploughed in just before maize planting, with reductions made for generalized soil contributions. After crop emergence, seed gap filling is done within seven days. Nitrogen fertilizer rates are, however, varied during the season through a series of up to three topdressing applications to match supply to crop requirements and to reduce N losses. The first dose of topdressing N fertilizer is broadcast along the ridges at 10 days after maize emergence. The crop is then weeded after the fertilizer has been broadcast to reduce competition for the fertilizer between maize and weeds. The second and third doses of top dressing N fertilizer are applied at 30 and 60 days after crop emergence, depending on rainfall and crop growth. The rate of N-used at each application is determined based on the expected yield decline that occurs as a result of drought stress. Nitrogen is applied if the crop is not water stressed but withheld if it is. The Risk Management Project has been involved in evaluating the package with farmers for its applicability, economic viability, and sustainability.

All farmers broadcast compound D in the FMP plots immediately before ploughing and planting maize. All farmers applied the first dose of N at 10 days after crop emergence. Due to midseason drought that occurred for about six weeks, 90% of the farmers did not apply N at 30 days after emergence but applied it when the rains had resumed and the maize was near flowering. Table 1 shows the amounts of fertilizer used for each practice by all farmers. Farmers used the fertilizer mainly on homestead fields.

AGRITEX practice. The AGRITEX recommendation is that a basal dressing of Compound D fertilizer should be applied in each planting station when the maize is planted, followed by a topdressing of N when the crop is knee-high, with an application of 250 kg Compound D and 80 kg ammonium nitrate per hectare. After ploughing, farmers applied fertilizer to the planting station and planted their maize. Of the ten farmers, six applied the Compound D at planting, but others modified the practice. One farmer broadcast it after planting and three farmers applied it at the 3-leaf stage. The three farmers that applied after emergence said that they wanted to be sure of crop germination before applying the fertilizer. This widespread practice was a risk averting strategy related to fertilizer use by the farmers. To avoid losing the fertilizer due to a prolonged dry spell, farmers did not apply AN to the crops during the mid-season dry spell, but applied it when the maize was about to tassel. Only two farmers had already applied the fertilizer at the knee-high stage when the dry spell started. The application of N was much delayed and this reduced the NUE. Due to the mid-season dry spell that lasted for about six weeks, most farmers delayed the application of N until the coming of the rains, at which time the maize crop was tasseling.

The farmer practice. In this practice, individual farmers were to manage the "FARMER practice" plots the way they considered best for yield and returns to inputs. There were many variations on what farmers did in this plot. Seventy percent of the farmers applied cattle manure and only four farmers applied Compound D, with just one farmer applying all 3 kg. Nitrogen fertilizer was applied to the maize around the tasseling stage and two farmers retained the fertilizer for next season. For those farmers that applied manure, it was ploughed under before planting. The variations came from whether manure was used. Some farmers did not apply Compound D to the trial plots because they thought it would give higher returns if applied in the vlei (seasonal wetland) than in the trials.

Data collection

Through focussed discussions with farmers on the objectives and expected outputs of the on-farm experimentation, a list was made of the information required to answer the farmers' questions. The data collected

Table 1. Comparative descriptions of the three fertilizer practices used in Maranda, Zimbabwe, 2000-01

Farmer's name	Field type	FMP	AGRITEX practice	FARMER practice
	All	3 kg Comp D 5 kg AN	3 kg Comp D 5 kg AN	3 kg Comp D 5 kg AN
Chareva	HS, sandy soil	1 kg Comp. D 3 kg AN	1 kg Comp D 5 kg AN	1 kg Comp D, manure 5kg AN
Madesha	HS, sandy	.25kg Comp. D 1.5 kg AN	.25kg Comp. D 1.5 kg AN	.25 kg Comp. D 1.5 kg AN
Majoni	HS, sandy soil	3 kg Comp D 0 kg AN	3 kg Comp D 0 kg AN	0, manure 0 kg AN
Mudarikiri	TL, sandy loam	3 kg Comp D 1 kg AN	3 kg Comp D 0 kg AN	0, manure 0 kg AN
Mudyahoto	HS, sandy loam	3 kg Comp D 2 kg AN	3 kg Comp D 2 kg AN	0, manure 2 kg AN
Mugomeri	HS, sandy	3 kg Comp D 1.5 kg AN	3 kg Comp D 4 kg AN	0, manure 0 kg AN
Musasa	HS, sandy loam	3 kg Comp D 2 kg AN	2 kg Comp D 2 kg AN	2, kg Comp D 0 kg AN
Musasa L	TL, sandy loam	3 kg Comp D 0 kg AN	3 kg Comp D 0 kg AN	0, kg AN 0 kg AN
Musindo	HS, sandy loam	3 kg Comp D 1.5 kg AN	3 kg Comp D 1 kg AN	3 kg Comp D 1 kg AN
Nyeve	HS, sandy loam	3 kg Comp D 2 kg AN	3 kg Comp D 2 kg AN	0, manure 1 kg AN

HS = Homestead field, TL = Topland field

Table 2. Advantages and disadvantages of the practices

Practice	Advantages	Disadvantages
FMP (UZ)	Fertilizer benefit other crops in intercrop Green and vigorous crops Highest yield and returns	Wilting is high in dry spell More labour to apply fertilizer Burn crops in dry spell Very expensive Difficult to manage intercropping Not sustainable Think too much salts in stover and may affect livestock
AGRITEX	Resistant to dry spell Less fertilizer than FMP Less labour to apply it Allows intercropping	More labour than farmer has More money than farmer has
FARMER	Very resistant to dry spell Cheaper and less labour Sustainable for resource poor farmers Allows intercropping	High variations and low yield Extensive Need manure

concentrated on issues affecting efficient N-use, e.g., labour, timing, available credit, and farmers' perceptions. The issues included farmers' questions about fertilizer use; farmers' perceptions about splitting N versus a one-time application in relation to rates, availability and climatic variability, and what farmers thought would be the best practice among the three practices for efficient use of fertilizer.

Data was collected through field data sheets that were administered by enumerators and farmer field diaries in which farmers recorded their crop observations, operations done in each plot, and the labour employed. In addition, farmer-developed resource allocation maps (RAMS[1]) (Figure 1) were used to collect whole farm data about resource allocation on different field types. The RAMS are useful tools for collecting information with farmers about their farming systems. Each farmer, with the help of the enumerator, drew up maps of their fields in relation to the homestead. The RAMS indicated household members, amounts of resources, sources of resources, number and type of fields, type of soils in the fields, proportion of resources allocated by field types, dates of operations, labour, and amounts of harvested crops. The RAMS provided a platform for group discussions on issues about farming in the fields, planning by farmers, farmer information exchange, and comparison of resource allocation by fields. However, farmers cited difficulties in constructing the RAMS and recording information as a major disadvantage. This was the major problem for three illiterate farmers in the group of ten.

In addition to map development, focussed group discussions were conducted. The issues included decision-making about resource allocation and operations, perceptions about the performance of the practices, and suitability by farmer and land types. The discussions were important because farmers and researchers co-learnt about the activities of other members of the group, which fostered unity among members, and the discussions served as a good forum for communication between the farmers and researchers. Agronomic data was recorded by enumerators through use of data recording sheets that included history of the fields where the plots were laid, plot layout, treatment assignment, rainfall, dates of operations, plant counts, soil sampling, farmer comments, and grain yields.

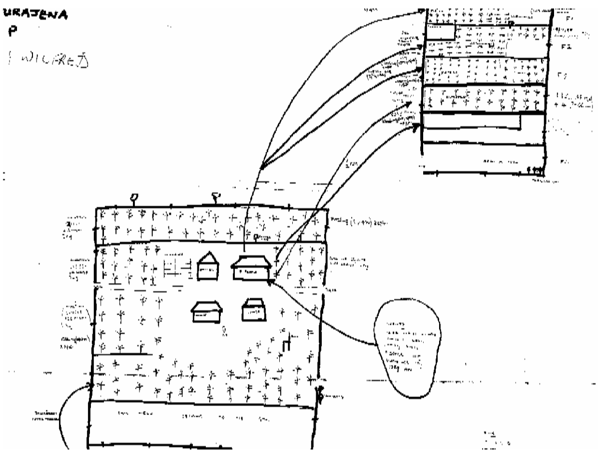
RESULTS AND DISCUSSION

Farmers' knowledge about factors affecting N-use efficiency

Moisture. Farmers were aware of the role moisture plays with crop growth. The moisture status also governs their decisions on fertilizer application to the crops.

[1] RAMS are resource allocation maps drawn by farmers to represent their homesteads and the fields and how resources are allocated.

Figure 1. A resource allocation map for Mr. E. Musasa's farm, Maranda, Zimuto.



According to farmers, fertilizers were applied when they were convinced that soil moisture is sufficient to dissolve the fertilizer in the soil. Farmers determine that soil moisture is sufficient for fertilizer application in a number of ways, including cutting a hole in the soil profile to assess the depth of moisture, visual observation of the field in relation to moisture, and through use of rain gauges. Farmers said that a moisture depth of more than 6cm is good for fertilizer application.

Size of crop and vigour. Recommendations point out that any compound fertilizers have to be applied at planting or within 7 days of planting maize. Farmers in the area do not normally apply compound fertilizer at planting. Compound fertilizer is applied after emergence, and usually a 3-4 leaf stage was reported as the most practical indicator of when to apply the fertilizer. Farmers use this practice to minimize the risk of losing scarce inputs if the crop fails to emerge. Shumba (1989) showed that there is little or no difference in maize yields between applying Compound D at planting versus after emergence, but the latter is far less risky. Additionally, planting without fertilizer speeds up planting, meaning a larger area can be planted before the soil dries. The recommendation for AN is that it be applied within 21 days of planting. In the study area, the application period for AN varied from knee-high plants to the tasseling stage. Farmers said they believed that the maize most needed nutrients at the tasseling stage and that applying it at that time provided the required amounts of nutrients. Such thoughts and practices by farmers reduce the N-use efficiency and need to be improved through on-farm research and discussions with farmers. Crop vigour is one of the factors that influence decisions on whether to spot apply fertilizer. In the discussions, some farmers said that when they have insufficient quantities of fertilizers, they apply it only to the maize plants that are strong and green, indications of high potential for high yields. In such a way, farmers not only increase the fertilizer efficiency, but also reduce the risks of wasting fertilizer through application to plants that would yield little or nothing. Normally, where farmers apply manure, the maize crop is vigorous and AN fertilizer is mostly applied to that maize.

Splitting and one time application. Application of basal and top dressing fertilizers ensures that the crops have enough nutrients throughout their growth. In Zimuto, 30% of the farmers split the fertilizers on their fields, 63% applied AN only, and 7% mixed compound D and AN and applied it once at knee-high to tasseling. Mixing was done when farmers noted that each type of fertilizer separately would be inadequate to cover all of their land. Mixing also reduced the time required to apply the fertilizer, as compared to separate applications, although they realized the use efficiency might be affected.

Field type. Four general land types (vlei, vlei margin, homestead, and topland) were identified during surveys with farmers in Zimuto (Vaughan and Shamudzarira 2000). The vlei (low lying seasonal wetland) is the most important land type for crop production and animal grazing. Manure is used extensively (Nzuma et al. 1998) and a large fraction (70%) of this manure goes to the vlei fields. Maize is the main crop grown in the vlei fields. Ninety-four percent of the acquired fertilizer[2] is applied to maize and about 56% of this fertilizer goes to the vlei fields in the form of top dressing manured fields or by splitting Compound D and AN on fields without manure. The rest of the fertilizer is applied to the homestead and topland fields. The homestead has second priority for fertilizer application. Normally, farmers do not use Compound D in such fields but put it where manure was not applied. Ammonium nitrate fertilizer is applied to all fields as a top dressing and its use efficiency is increased when applied to maize that received enough manure or Compound D.

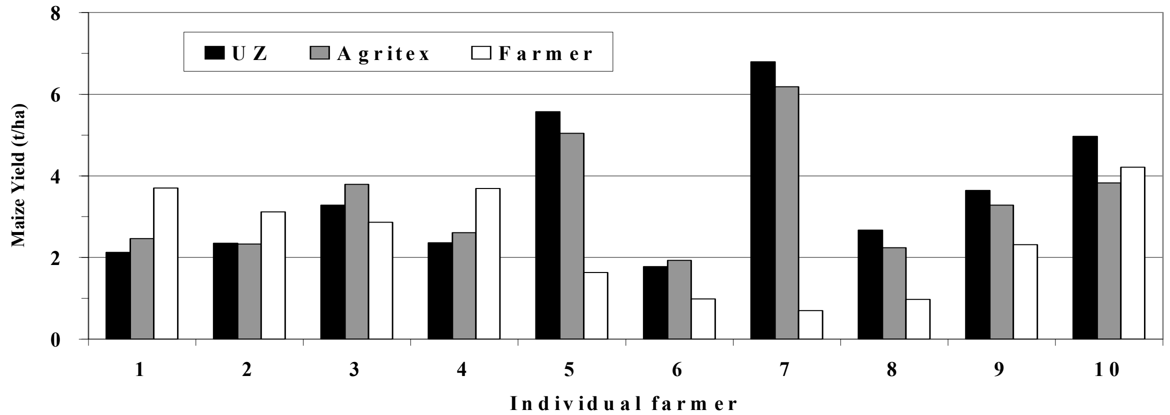
Choice of crops. The main crop in the area is maize (*chibage*). It gets a larger share of the applied fertilizers. In the vlei, rice benefits from the fertilizer applied to maize, while in the homestead, cowpea and pumpkins benefit likewise. Finger millet (*rapoko*) and sweet potatoes are the other crops that receive fertilizer in the homestead and topland. Formerly, rapoko was mixed with other crops like maize, but rarely so today. In a maize-based intercrop, both types of fertilizer are applied to maize as the main crop, but the fertilizer also benefits the associated crops. In maize and groundnut, it is always applied to the planting station to reduce groundnut pops. However, when land and labour are available, farmers grow crops separately to optimize the benefit of the fertilizer on the maize.

Capital. Capital determines the potential for acquisition of fertilizers. Farmers with capital can get enough fertilizer and those with little capital have less ability to do so. Inadequate fertilizer may tempt farmers to spread the input to cover a large area. This may not be a problem in fields that received enough manure because this would increase fertilizer use efficiency. On the other hand, farmers with enough fertilizers may not prioritize but rather apply it to all the crops that need fertilizer. Adequate amounts are applied and high fertilizer use efficiency is achieved (Snapp 1995).

Timing of application. Untimely fertilizer application to crops has been a big problem for extension providers in smallholder agriculture (Kumwenda et al. 1996). In the discussions, farmers pointed out that applying fertilizer late results in low maize yields. For example, farmers noted that

[2] The percentages were based on what farmers used in two years, by field types.

Figure 2. Maize yield (t/ha) from fertilizer practices.



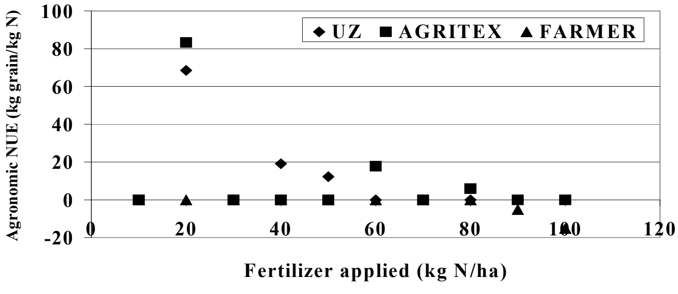
higher maize yields were realized by farmers who top dressed AN fertilizer when the maize was knee-high than those who top dressed when the crop was tasseling. It is well known that fertilizer applied at tasseling is not fully utilized (Kumwenda et al. 1996) and the resulting maize yields are low. This practice may be uneconomical for farmers even when they acquire sufficient fertilizer.

Social problems. Farmers experience diverse and uncontrollable social encumbrances, such as funerals, illnesses (particularly malaria and HIV/AIDS), and other social obligations that may affect their ability to apply fertilizer on time. Illness is a major factor. A household taking care of a sick person may not complete farm operations either on time or well. Hiring labour is often not a viable option for such farm families because of the expense and difficulty of locating good help.

Farmer perceptions about performance of the fertilizer practices

Maize yields. Figure 2 shows yields in t per hectare from the fertilizer practices by farmer. The FMP (UZ) and AGRITEX practices seem to show little difference in yields by both farmer and soil types (see Table 1). Grain yields with the FMP practice ranged from 1.78 t/ha^{-1} (lowest) to 6.79 t/ha^{-1} (highest). For the AGRITEX practice, the lowest yield was 1.93 t/ha^{-1} and the highest 6.18 t/ha^{-1}, while in the FARMER practice the range was from 0.7 to 4.21 t/ha^{-1}. The trend of yields with these practices is that in sandy soils the yields were lower than in the sandy loam soils. The yields increased variably in the sandy loam soils (Figure 2).

Figure 3. Agronomic N use efficiency for the fertilizer practices in Maranda derived by APSIM simulations.



Grain yields from the FARMER practice were the lowest. This was expected given the lower nutrient input from the farmer. High yields in the sandy loam compared with the sandy soils suggest that farmers using small amounts of fertilizers are better off farming sandy loam soils than in sandy soils. A farmer with sandy soils needs to apply a little more fertilizer to achieve similar yields to those on the sandy loam fields. In addition, the yield differences obtained with the practices were probably because increased N-use efficiency was a function of the relative amount of fertilizer applied and timing of application. The FMP practice received more fertilizer through splitting and that improved nutrient uptake by the crops and gave a better yield performance than did the FARMER practice.

One striking aspect observed from the interactions of the farmers' group was the decision on where to allocate the trials. All except two farmers allocated the plots to the homestead fields. Those two farmers had their plots on the topland. Fertilizer is a scarce input to many farmers and they wanted to make sure that they maximized returns to its use. In this case, the decision to assign plots to the homesteads was a way to maximize use of the fertilizer in the more fertile fields. In Figure 2, the similarity in yields from the FMP and AGRITEX practices is not surprising, since the two practices were virtually identical as implemented by farmers. Indeed, one insight drawn from this is that farmers have problems truly understanding the fertilizer practices developed for them.

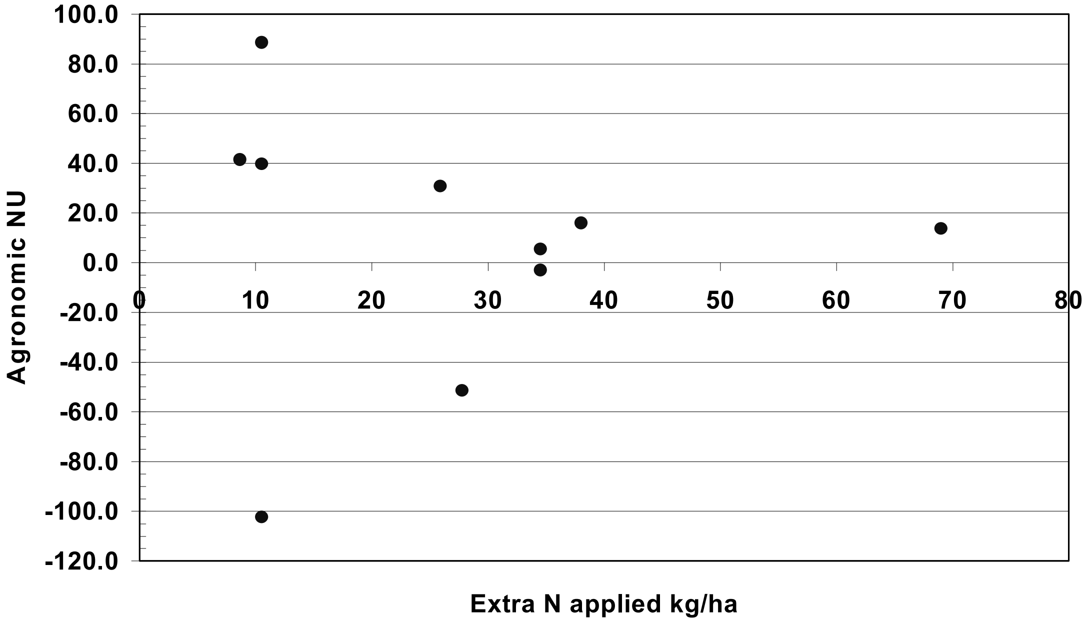
Fertilizer N-use efficiency (NUE). Figure 3 shows the agronomic NUE for the three fertilizer practices as calculated by the APSIM model, while Figure 4 gives NUEs measured from the plots in Zimuto. Measured NUEs (Fig. 4) were variable but generally high (40-85 kg grain/kg N applied) at 10 kg N/ha. Simulated NUEs using the APSIM model showed a similar trend of high initial NUEs and a decline at higher rates of N (Fig.3). The FMP is as high as 83 kg grain/kg N applied while AGRITEX is about 79 kg grain/kg N. The FARMER practice was lowest with 23 kg grain/kg N. Despite little differences between the FMP and AGRITEX practices, the practices showed far better maize response to the N applied than the FARMER practice. The modeled values were unusually high for the on-farm conditions, especially in the homestead fields that are more fertile. The rainfall was also good for use of small amounts of N. Differential management of the fields by farmers, which may

Table 3. Manure and fertilizer combinations by farmers in their maize crops, by field type in Zimuto, Zimbabwe fields (Number out of 10 farmers)

Field type	Manure Only	Manure + AN	Manure + Comp. D	Manure + Comp. D + AN	Comp. D + AN
Vlei	1	6	-	-	2
Vlei margin	-	1	1	-	-
Homestead	1	2	-	1	4
Topland	-	1	-	2	2
Average yield (t/ha)*	0.36	1.08	0.29	1.62	0.41

* Average maize grain yields from farmers' combinations of manure and fertilizers in the fields.

Figure 4. Measured on-farm agronomic NUEs at Maranda, Zimuto during the 2000/01 season.



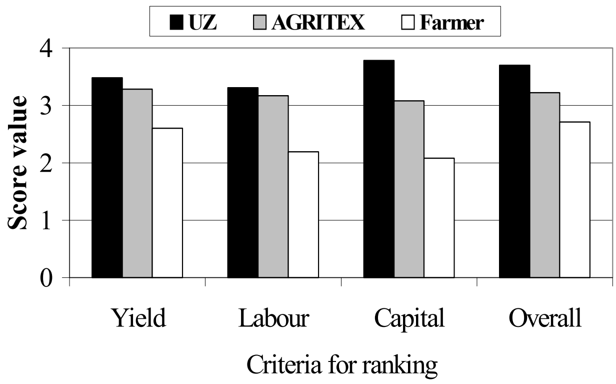
affect the plant fertilizer recovery and internal plant use may explain this.

In other studies on NUE in southern Zimbabwe, Shamudzarira et al. (2000) reported observed maize response values of -15 to 70 kg grain per kg N from N rates of 40 to 160 kg N/ha on station, and simulated response values of 78-10 at similar N rates on different soil types, using APSIM. Similar high NUEs have been measured for small amounts of N (approx 9 kg N/ha) applied to maize crops in many parts of southern Zimbabwe (see ICRISAT-Zimbabwe and SDARMP, 2003). Keating et al. (2000), in their study on the effect of weeds, simulated NUE values of 31–60 and 25–47 kg grain with and without weeds, respectively. The values in Figure 4 fall within the ranges observed in those two studies. The results from Keating et al. (2000) suggest that with good weed management, farmers will get more returns. In addition to proper weed management, adequate rainfall helps the utilization of applied fertilizer by the crop, hence increased maize yields in smallholder farmers' fields.

Labour. Figure 5 shows how farmers ranked the fertilizer applications methods based on yield level, labour, capital required, and overall performance. Farmers observed that the FMP practice requires a lot of labour and/or time to apply the fertilizer. The AGRITEX practice was observed to be intermediate for labour, while the FARMER practice did not need much. The four-time application of fertilizer in the FMP practice indeed does require much labour. Farmers had to broadcast the fertilizer and plough the field before planting. Under the AGRITEX practice, the farmers had to plough, plant, and apply the fertilizer together. Two farmers thought that the FARMER practice needed more labour than the other practices. The farmers said that removing manure from the kraals, taking it to fields, and spreading the manure for incorporation in the fields was more labour demanding than just applying fertilizer. Perhaps what is most important to note is that family labour is used to perform these activities and that most farmers do not attach a value to this source of labour. Wermer (1987) and Leach (1995) made similar observations in different studies in Malawi where farmers apparently did not attach a value to the family labour used in their fields.

Capital. With escalating input prices, farmers find it very expensive to purchase fertilizers. The FMP practice requires up to four separate fertilizer applications, which would be difficult for many farmers to afford. In the study, farmers ranked the FMP practice number one (least liked) based on the amount of fertilizer it requires. Both the FMP and the AGRITEX practices require 150 kg of Compound D (3 bags of 50 kg each) and 250 kg of ammonium nitrate (5 bags) per hectare. The farmer practice that used manure only requires 3 bags of ammonium nitrate. The costs of the FMP and AGRITEX practices are high for an average semiarid

Figure 5. Farmer ranking of fertilizer practices.



(Score value: 1 - 4 was used. 1 = least liked, 2 = less liked, 3 = liked and 4 most liked)

zone smallholder farmer whose purchasing power is often too low to meet the modest household needs for food. The large fertilizer requirements of the non-FARMER practices may explain why access to credit appears to be important for the adoption of the practices on a large scale.

Overall performance. Farmers said that the FMP practice was very encouraging in terms of the yields realized. Farmers were hopeful that those that can afford the fertilizer and have labour to apply it according to the practice would have more returns on their investments.

One farmer (Mr. Musasa) had this to say, '*Chinonetsa ndechekuti hatina mari yakakwana, tahchashandisa nzira yarehwa neve FMP nokuti yakanaka sitereki uye inounza mari yakawanda. Ndichango zama hangu kana kushandisa mfudze kana kuapulaya AN wangu katatu futi muchibage changu'*. 'It is just that we can't find enough money. The FMP practice is very good and profitable. Surely, I will try it in my field this year and if I don't find Compound D, I will use manure and apply my AN three times to the maize'.

His remarks suggest two things: (1) that the farmer found the practice profitable, and (2) that he can adapt it by using manure instead of Compound D. This is already an improvement to the FARMER practice. In addition, the ranking revealed that yield differences farmers *observed* among the three practices at harvest made more of an impression than did the statistical analysis.

Perceived advantages and disadvantages of practices

In the discussions, farmers pointed out advantages and disadvantages of the practices (Table 2). The advantages and disadvantages helped in the final ranking of the practices and whether the farmer believes the practices are adaptable to her/his field. For example, manure would be used as a basal fertilizer to reduce the purchase of Compound D. The farmers said that as long as the yields outweigh the costs of labour and fertilizers, they would devote the resources to implement the practices. This determination by farmers shows that they not only appreciated the practices, but that they are committed to adopting and adapting them to suit their fields.

From the discussions, farmers discovered that the FARMER practice would be sustainable and suitable for a wide range of farmers if it were modified. The changes pointed out by farmers focused on the flexibility of fertilizer application in relation to rainfall, and time and amounts of fertilizer application. Although the FMP and AGRITEX practices were observed to be expensive and not suitable for many resource poor farmers, the practices have components that would improve the FARMER practice. However, the few that could afford fertilizers said they were encouraged and willing to adapt the FMP practice, using up to two topdress applications based on rainfall and crop status. The farmers said that every household used at least some fertilizer in one field or part of a field and that most of them put manure on one field and a little N fertilizer on another to give a bigger overall yield. The researchers observed that the use of integrative approaches would help increase the efficiency of the little fertilizer that farmers use. For example, manure and proper timing and amounts of inorganic fertilizer in homestead and vlei fields would concentrate nutrients onto manageable fields, resulting in a better stand of maize and higher yields.

Farmer perceptions about split versus one-time fertilizer applications

Farmers know that splitting fertilizer applications increases maize yield, meaning that they realize it is an efficient use of this input. However, the splitting depends on whether the farmer has enough fertilizer. Normally, Compound D is applied at planting or within a week after planting while AN is applied at the knee-high stage. In practice, most farmers apply once, either by mixing Compound D and AN or by applying AN only. If AN is applied, it either follows manure, Compound D, or is used alone. When manure is applied in the field, a farmer may apply AN, but rarely Compound D. The total rates of application do not change when split or given as a one-time application, except in cases where the farmer spreads the input over more fields. Splitting gives the crops nutrients at crucial stages of growth in the season. However, best yields come from a combination of manure and AN or Compound D and AN. Table 3 shows proportions of farmers with different combinations of manure, Compound D, and AN by field type.

The numbers are based on farmers' responses about their practices during the previous two years. Manure and AN were used mainly in the vlei and in the homestead fields. Only one farmer indicated applying manure, Compound D, and AN—in one field in the homestead and two in the topland. The values confirm that manure and Compound D are rarely applied in the same portion of a field, but rather are applied to different portions in order to have higher overall yield. This means that if a farmer has manure and Compound D, more area and more crops will be covered. Those farmers who did not have manure used Compound D and AN in the vlei, in the homestead, and on topland fields. Most likely this indicates that many farmers can afford to buy some AN while few can buy Compound D, and very few can afford both. It also shows how farmers prioritize their fertilizer applications by fields. Most farmers favour the vlei for fertilizer use, applying it to maize as the staple crop and rice (another important cereal). However, Compound D in the vlei is applied where manure has not been applied. The homestead fields also get more fertilizer. Farmers pointed out that these fields benefit from the farmyard manure and refuse from the house and the maize does relatively better than other fields with Compound D and little AN. The topland gives good yields if manure or fertilizer is used. Farmers said they apply fertilizers to topland fields if they have sufficient quantities.

Table 4. Fertilizer management in maize by field and season types

If season is	Vlei	Homestead	Topland
Dry	Apply once after manure Fertilizer is well used	Apply once and if severe hold the fertilizer	Not a priority If applied manure apply once
Wet	Plant early, split and apply early If late, apply once	Split and put more fertilizer	Split and put more fertilizer
Average	Apply manure Split if no manure	Split and apply more fertilizer	Split and apply more fertilizer

Splitting fertilizer by type of season. Farmers use several means to forecast growing conditions for the upcoming season. If October is windy, the forecast is that the rains may be delayed and will probably be insufficient. Wild fruit trees (Muula) also help indicate the type of season. If the fruits are abundant, the following season will be a dry one. Based on the forecast, farmers plan their activities following the type of season expected. For example, if farmers predict a dry season, then farmers plan to use early maturing varieties and diversify the crops to be grown in different fields. This planning also dictates where to apply the fertilizer and whether to split it. Table 4 shows what farmers plan to do with the fertilizer based on the predicted season type.

The farmers first priority for fertilizer use is the vlei, secondly the homestead fields, and lastly the topland. However, some farmers have fertile homesteads and apply their fertilizer to the topland, especially where manure has been applied.

Advantages and disadvantages of splitting. Farmers said that they mixed Compound D and AN in the ratio of 1:1 by weight, and applied one teaspoon to each maize plant, once between about knee-high and tasseling. This fertilizer application ratio, rate and time is inadequate to meet the needs of the crop. Split applications of fertilizer would help to increase the use efficiency and increase maize yields. Farmers cited several advantages and disadvantages of splitting fertilizer (Table 5).

Farmers said splitting the fertilizer increases crop yield and is less risky. Farmers split the fertilizer by applying Compound D and AN when available, or manure and AN. However, farmers pointed out that the soils are poor, and just applying manure or AN once would not produce food security for most households. Manure use should continue, but in addition, those with sufficient resources to purchase fertilizers should split the AN in the field twice or more since there are good returns to doing so (Figure 1).

Vlei. The FMP practice is best in the vlei fields when the season is average. It can be used in a low (dry) rainfall season since fertilizer is applied in relation to rainfall. In a very wet season, the splitting would minimize the effects of leaching of nutrients from the rooting zone of the maize crop.

Farmer perceptions about suitability of practices by season and field type

Farmers noted that the various practices fit well with specific conditions. Farmers said that the application of

Table 5. Advantages and disadvantages of splitting fertilizer applications

Application method	Advantages	Disadvantages
Splitting	Avoids risks of loosing fertilizer in bad season Synchronization is good Maize grows better Time to find additional fertilizer	Limited area is covered More labour More fertilizer More money
One time application	Good fertilizer utility Saves labour Efficiency in the uptake of nutrients Cover more area and more crops Less money	Risky in case of drought Risky in case of leaching in wet season

fertilizer close to the maize roots would improve uptake. In the vlei, there is normally a lot of moisture, so that the FMP would not be well suited, especially the later applications since the fields would be waterlogged. The AGRITEX practice would perform well in the vlei in a higher rainfall (wet) season.

Homestead. In the homestead fields, farmers said that the FMP practice was best suited to a wet season. More fertilizer would be available to the crop in this practice. In a low rainfall season, crops would burn because of excess fertilizer.

Topland. In the topland, the FMP practice was seen to perform well in wet and average seasons. The AGRITEX practice performed well on toplands in wet and average seasons. However, for manure, the farmer would need more in all seasons in the topland to produce sufficient yields. The compound fertilizer takes a long time to dissolve and may burn the crop when applied in a low rainfall season, while AN dissolves easily and is best when there is average moisture.

Farmer practice. The FARMER practice is suitable to many conditions, but does not give good yields. In cases of late planting, fertilizer is not used in the vlei, but is used in the homestead or topland, or held for the next season. Farmer emphasis on manure in the FARMER practice means that the farmer without cattle should strive to invest in manure to be used in the fields. Without manure, the FARMER practice may bring about low yields in all land types. Depending on rainfall pattern during the initial half of the season, farmers varied the fertilizer inputs to maize, applying more when they are sure of a farmers do not apply the fertilizer. If the dry spell was so prolonged that fertilizer could not be applied again, or if the crops were not good enough to warrant fertilizer use, farmers hold it and use it on winter crops in the vlei or use it on maize the next season.

Seasonal cropping and labour calendars

Different operations carried out by farmers at different times in the season are shown in Table 7. Generally, agricultural operations form a cyclic pattern with different peak periods based on the crop and activity. For example, maize is planted as early as August or September in the vleis, while at the same time manure has to be applied and spread in the homestead and topland fields. Similarly, in the topland and homestead fields, most crops must be planted between

Table 6. Suitability of practices as defined by farmers

Field type	Season type	FMP	AGRITEX	FARMER
Vlei	Dry	Can be used but apply early	Only when planted early	Suitable
	Wet	Not suitable	Not suitable	Suitable
	Avge	Suitable, plant early	Suitable	If manure is applied
Home-stead	Dry	Crops may burn	Manure added	More manure
	Wet	Suitable	Suitable	More manure
	Avge	Suitable	Suitable	More manure
Topland	Dry	Not suitable	Manure added	More manure
	Wet	Suitable	Suitable	More manure
	Avge	Suitable	Manure added	More manure

October and November, while weeding and fertilizer application require the labour in the vlei. During these months, farmers' time is spread thin as they are occupied with all these different operations, although they clearly plan and prioritize the required work. From August through November, farmers plan to hire labour from households that do not have enough food or from groups of young men who need cash for social group functions. August and September are busy months for planting maize and rice, gap filling, weeding, fertilizing, and stalk borer control in the vlei. In August, farmers that plan to grow groundnut as a sole crop collect leaf litter from forests and apply it to the fields. Leaf litter makes groundnut grow well but does not help maize. In the maize/groundnut intercrop, leaf litter is not applied to avoid negative effects on the maize crop. Similarly, from October to December these activities are at a peak in the homestead and topland fields. Farmers said that in the vlei fields, maize is largely intercropped with rice, groundnut, pumpkin, and bean, but rarely with cowpea, rapoko, or bambara. Where intercropping is done, maize acts as a trap crop for groundnut and rice pests. Rice is broadcast in the maize field while groundnut is planted in rows between maize lines. In such fields, fertilizer is applied directly to the maize crop to reduce the amount absorbed by groundnut.

Farmers also apply Compound D and gypsum to groundnut to supply the crop with phosphorus and sulphur for normal vegetative growth. The leaf litter probably supplies these elements upon decomposition in the fields. In homesteads, maize is intercropped with cowpea, pumpkin, and bean. Groundnut is grown mostly in the topland where leaf litter is used. The homestead fields make groundnut pop because of their elevated fertility. Rapoko and bambara nut are mainly grown as sole crops in the homestead and topland fields. After harvesting, maize crop residues from the vlei are stacked to dry and later taken to the kraal for manure while the rice residues are incorporated at winter ploughing. Groundnut haulms are taken to the kraal to be used as animal feed. Unlike the vlei maize residues, the topland or homestead maize residues are stacked near the kraal to feed the animals during the dry season. In so doing, the residues mix with cow dung and urine to produce an improved manure mixture. The mixture is taken out of the kraal and heaped to further decompose before it is taken to the priority fields.

Table 7. Seasonal cropping calendars and rules of thumb developed by farmers in Maranda (Note: normal type is for vlei and italics is for topland and bold is for both)

Crop	June July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Marc	April	May
Maize	**Remove kraal manure** *Winter ploughing*	Manure, Planting, Comp. D, Gap filling, *Manure,* Weed 1, Stock broker control, Weeding 2, Apply AN, *Incorporate manure, Plant*			*Planting Weed 1 Apply Comp.* D	**Harvest.** *AN Weed 2 Stalkborer*	Harvest	*Planting sweet potatoes*	*Harvesting green maize*	*Harvest topland Staking stover*	*Plough topland if moist/* vlei
G. nuts		Leaf litter Comp. D broadcast planting	Weed 1 Gypsum *Leaf litter*	Weed 2 *leaf litter plant and Comp. D*	*Weeding gypsum applied*	*Weeding*	Harvest Residues taken to kraals		*Harvesting topland*	*Staking residues*	**Winter ploughing fields**
Bambara					*Ploughing, planting in top land, 1st weed*		*Earthing up*		*Harvesting. Residues remain in the field*		
Maize/ G. nuts		Plant G/nut after maize emergence, g/nuts, Weeding		AN to maize only	Weeding			Harvest g/nuts, Harvest maize, Stover in kraal G/nuts residues in kraals			
Maize/ Cowpea		*Apply manure in topland, homestead, Broadcast cowpea. Plough and plant maize*			*Comp. D to maize Weed 1*	*AN and weeding 2*		*Harvest maize, stover staked for manure, Harvest cowpea residues to kraal and some incorporated*			**Winter ploughing topland**
Rapoko		Plough, broadcast fertilizer *Dry planting, Plough and plant* Weeding 1. Comp. D application			Weed 2. *Broadcasting,* Weed 3 *Weed 1. Comp. D, Weed 1 apply AN*			Harvesting *Harvest residue incorporation*			**Winter ploughed topland**
Maize/ Rice		Apply manure, Broadcast rice seed, Plant maize, Gap filling, Comp. D applied late 1st weed, stalk borer control, weeding 2, AN						Harvest maize	Harvest 1 of rice, Harvest 2 of rice Rice residues incorporated, ploughing and harrowing		

Farmers have learned through experience to recycle the resources available to them and to allow the biological processes of their farm animals, and later the decomposition of the manure mixture, to produce a good homemade fertilizer for use in the fields.

CONCLUSION

This project has contributed to our knowledge about fertilizer use in the Maranda farmer group through various comparisons made under farmer management and conditions. Some parts of the FMP and AGRITEX practices may be usefully extracted by the farmers to increase maize production. However, the FMP and AGRITEX practices require more labour and capital than is available to most resource poor farmers in semiarid Zimuto, unless support is given to allow access to these inputs. The study showed that farmers have not been exposed to and generally are not aware of technical information about fertilizer practices. They tended to modify the practices towards their own concepts. It is hoped that the results of this work will help the farmers to better understand the principles of the various practices and how to best apply them to achieve more efficient use of fertilizer under their conditions.

More work, however, is required. We need to look at the effects of varying the rates of fertilizer and its practicality, depending on rainfall pattern during the first crucial half of the rainfall season, the time of application, weeding, legume use, and fertilizer practices. There is a need to run the data through models using long-term rainfall records to test frequencies of productivity gains from the practices. In Phase II, the Risk Management Project will conduct further research in the area to test a simplified FMP practice on the different field types to see where and when a farmer would get best returns. These flexible N inputs will be compared with a fixed very small amount of N fertilizer (approximately 10 kg/ha/year) on the different field types. This practice has been shown to be robust under varying rainfall; it is practicable and economic for maize in many parts of southern Zimbabwe. The project researchers together with farmers will also assess the role of legumes in each fertilizer practice.

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ACCELERATED TECHNOLOGY DEVELOPMENT: THE CASE OF MAIZE VARIETIES IN THE MOIST TRANSITION ZONE OF KENYA

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ABSTRACT

Maize is the most important food crop in Kenya. However, the poor rate of adoption of new varieties has been attributed in part to the poor interaction between breeders and farmers. An on-farm trial design methodology, known as "Mother and Baby Trials", was used to evaluate thirty new elite maize hybrids using farmer participatory methods at three sites located in Embu and Muranga Districts during the long rains of 2001. The varieties were evaluated in a mother trial using criteria generated by farmers during Participatory Rural Appraisals (PRA). There was no particular new maize variety that was consistently identified by farmers as better than the two local checks, PHB3253 and H513, across the three sites. In Makengi, Embu District, two new maize varieties were statistically better than PHB3253 and 11 were better than H513. In Ndunduri and Wangu in Embu and Muranga Districts, respectively, there were notable differences between some new maize varieties and the local checks, although the differences were not statistically significant. Mother and Baby on-farm trials are a novel methodology for obtaining farmer input and feedback on the selection of new varieties that are in advanced stages of development or are ready for release. The identification of superior maize varieties should be linked to a reliable seed supply system to increase the likelihood of adoption.

Keywords: Maize breeding, participatory research, technology transfer

INTRODUCTION

Traditional approaches to developing agricultural technologies have had limited success in adoption by smallholder farm households. This realization has developed into a well argued critique of the technology transfer model and has generated considerable interest in, and research into, alternatives based on participatory approaches (Chambers, 1989; Okali et al., 1994; Maurya et al., 1988). These participatory ideas and the associated rhetoric form a major component of what has been described as the 'new development" paradigm. Currently there is a body of research and documentation of practical field experience that provides considerable support for the concept of farmer participation in technology research and development. Chambers *et al*. (1989) reviewed work on providing farmers with varied genetic material. Maurya et al. (1988) tested advanced rice lines with villagers in Uttrah Pradesh and successfully identified superior material that was preferred by the farmers. In Rwanda, farmers selected 21 varieties from a wide range of bean cultivars grown in the field that were first selected by them in on-station trials (Sperling, 1992). In Kenya, several approaches have been used to identify important germplasm attributes and these attributes have subsequently been used to identify popular germplasm. Ouma *et al*. (1996) used farmers' evaluation of pearl millet in on-station trials in semi-arid areas of Tharaka and Mbeere Districts to identify cultivars that were subsequently chosen, tested by farmers on-farm, and recommended for bulking by the local farmers' site committees.

The common arguments in all these approaches is that end users of the technology need to be involved at critical stages and make real choices in technology development. Conventional approaches have relied too strongly on researchers and technical specialists identifying constraints and possible solutions and then attempting to transfer these to the rural settings. Local skills and knowledge are frequently not recognized, and rarely included in this process which is managed and controlled by outsiders.

This paper focuses on the "Mother and Baby" on-farm trial design as a methodology for obtaining farmers' input and feedback on the selection of new maize varieties that are in advanced stages of development or are ready for release. The Mother and Baby trial design, developed by ICRISAT (Snapp, 1999) and modified for use in farmer participatory varietal evaluation by CIMMYT (Bänziger and De Meyer, 2002), is used to evaluate new varieties at the last stages of the selection process, and can contain 10 to 20 entries. The design combines a researcher-managed central trial, called the 'mother trial', containing all the new varieties, and farmer managed satellite trials, called 'baby trials', each containing a unique subset of 3-4 of the varieties. By combining both designs, the advantages of both can be exploited. The mother trial provides statistical data for the breeders, which are used to select for particular traits, and those data can be used to speed up the variety release process. The baby trials, on the other hand, not only provide yield data under farmers' conditions, but also farmers' evaluation of these varieties according to the farmers' own criteria. Combining these data gives a clear picture of the adaptability of a variety to a given area and the likelihood of its adoption. Subsequently, the decision can be made to proceed with the release process. The present discussion is based on work that was conducted during the long rains of 2001 in a maize producing area, the moist transition zone of eastern Kenya. Although the mother and baby methodology stresses evaluations at mother trial and baby trial, the discussions presented here are based on evaluations done in the mother trial.

MATERIALS AND METHODS

Selection of sites for mother and baby trials

Two major maize producing districts were purposively selected. These were Embu and Muranga Districts. One division each was then randomly selected from the two Districts and subsequently two villages were selected in Embu and one in Muranga. The study site was then determined by the availability of adequate land for a mother trial. The three sites for the mother trials were located at a school, on a farmer's land and at Wangu Farmers Investment, a Non-Governmental Organization focusing on agricultural extension. Around each mother trial there were twelve satellite on-farm trials called baby trials within walking distance of the mother trial site.

Participatory Rural Appraisal (PRA)

Participatory rural appraisals were conducted at two sites in Embu and one site in Muranga. The purposes of the PRAs were twofold – 1) to identify important criteria that farmers use to evaluate maize varieties, and 2) to choose farmers on the basis of willingness to participate in the baby trial design. During the PRA, important attributes considered by farmers in the selection of new germplasm were identified and subsequently used to evaluate maize varieties in the mother trials.

Farmers evaluation of Mother trials

The farmers were first given a tour of the trial and an introduction of its purpose. They were asked to fill in a short questionnaire about their personal characteristics (age, gender, experience in farming, education and so forth) and the characteristics of their farm (size, acreage in maize and so forth), to make links possible between preferences and farm characteristics. Subsequently, they were asked to proceed in small groups and to each give an overall evaluation of each variety (on a scale of 1 to 5 where 1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = very good), as well as an evaluation for each of the criteria they considered important during the PRA. If farmers were unable to write, technicians or volunteers (from organizations such as Ministry of Agriculture) filled in the forms for the farmers. Farmers evaluated at least two replicates planted in two lines (rows) per variety. At some sites, replicates 1 and 2 were evaluated, while in others farmers evaluated replicates 1 and 3. Thirty two varieties were evaluated (Table 1), including two local checks (PHB3253 and H513), at the physiological maturity stage. Data related to farmer, farm and technology attributes were entered in SPSS spreadsheet and analyzed by the same.

RESULTS

Important characteristics in the selection of maize varieties

One of the most important reasons for carrying out farmer evaluations is that farmers are more likely to assess a technology with criteria and objectives that are different from the criteria used by the breeder. A major benefit of farmer evaluation is to ensure that scientists design, test and recommend new technologies in the light of information about farmers' criteria for the usefulness of the innovation (Ashby, 1990). An attempt was made to understand the most important attributes farmers consider in selecting maize varieties to plant before undertaking evaluations in the mother and baby trials. While there were strings of similarities in the attributes used to choose maize varieties, the sets of attributes were unique at each site. Farmers in Embu and specifically Makengi village considered husk cover, maturity period, pest and disease tolerance, and yield as major attributes in the selection of maize varieties. In Muranga District, apart from maturity period, pest and disease tolerance and yield, farmers viewed cob filling, cob size and drought tolerance as critical attributes in their selection of maize varieties. In Ndunduri village, Embu District, good taste for *ugali* making and *githeri* as well as ease of threshing were additional attributes in the selection of maize varieties. However, they are factors to consider when maize has already been harvested.

Table 1. Pedigree of elite maize hybrids evaluated in Mother and Baby trials

Entry No.	Pedigree
1	[[TUXPSEQ]C1F2/P49-SR]F2-45-5-1-2-B/CML202//CML78
2	CML445/CML202//CML78
3	CML388./CML202//CML78
4	DTP2WC4H255-1-2-2-B-B-B/CML202//CML78
5	LPSC3H144-1-2-2-2-2-#-B-B-B/CML202//CML78
6	LPSC3H144-1-2-2-2-4-#-B-B-B/CML202//CML78
7	LPSC4F273-2-2-1-B-B-B/CML202//CML78
8	CML442/CML202//CML78
9	P21MRRSC2-19-1-2-2-2-B-B-B/CML202//CML78
10	CML444/CML202//CML78
11	SPLC7F182-1-2-2-B-B-B/CML202//CML78
12	CML312/CML265//CML78
13	CML373/CML202//CML78
14	CML216/CML202//CML78
15	CML442/CML444//CML78
16	CML444/CML445//CML78
17	CML216/CML254//CML78
18	CML312/CML216//CML78
19	CML312/CML444//CML78
20	CML312/CML384//CML78
21	CML312/CML373//CML78
22	CML312/CML247//CML78
23	CML395/CML247//CML78
24	CML197/CML216//CML78
25	CML197/CML384//CML78
26	CML197/CML247//CML78
27	CML197/CML254//CML78
28	CML216/CML444//CML78
29	CML216/CML373//CML78
30	CML216/CML247//CML78
31	PHB3253
32	H513

Farmer assessment of maize varieties - Mother trial

The new maize varieties were measured against the two local checks, PHB3253 and H513. Recent studies (PRA conducted by IRMA and AMS project) showed that PHB3253 is widely grown by farmers. In Embu and Muranga Districts, 75 % of the farmers indicated that they grew PHB3253. Similarly, H513 was grown by 75 % of the farmers in Embu District. In Makengi, Embu District, two new maize varieties were statistically different from PHB3253 and 11 were better than H513 (Table 2). In Ndunduri, although there were some new maize varieties that were notably good compared to the local

Table 2: Farmers evaluations of mother trial - Makengi

Entry No.	Early maturity	Pests and diseases	Husk cover	Lodging	Yield
5	3.25	3.05	4.15	4.9	3.42
30	3.25	3.1	4.1	4.9	3.33
8	4.00	3.9	4.65	4.75	3.25
27	3.75	3.85	3.85	4.8	3.17
1	3.45	3.25	4.45	4.9	3
26	3.15	3.55	4.25	4.75	3
22	2.75	3.3	4.65	4.9	2.92
32	3.45	3.25	4.15	4.75	2.92
19	3.47	3.37	4.32	4.79	2.91
23	3.65	3.15	4.35	4.9	2.83
11	2.75	3.1	4.5	4.75	2.67
4	3.25	2.95	4.7	4.9	2.58
16	2.75	2.75	4.6	4.9	2.58
7	2.85	2.75	3.45	4.75	2.58
18	2.7	2.75	3.7	4.5	2.58
17	3.65	3.6	4.3	4.85	2.5
14	2.8	3.2	4.3	4.85	2.5
24	2.75	2.55	3.4	4.95	2.5
29	3.53	3.47	4.32	4.89	2.45
28	2.85	2.8	4.45	4.9	2.42
9	2.55	2.4	3.55	4.85	2.42
6	2.6	2.3	3.45	4.9	2.42
21	2.45	2.45	4	4.85	2.33
31	2.9	3.35	4.35	4.8	2.25
15	2.9	3.75	4.3	4.75	2.17
2	3.15	2.75	4.4	4.9	2.17
3	2.85	3.2	4.2	4.75	2.17
12	2.7	2.5	3.55	4.85	2.17
25	3.05	3.3	4.35	4.8	2.08
13	2.3	2.55	4.4	4.75	2.08
10	2.8	2.7	4.4	4.85	2
20	2.45	2.5	3.65	4.9	2
Mean	3.02	3.05	4.16	4.83	2.57
Min	2.30	2.30	3.40	4.50	2.00
Max	4.00	3.90	4.70	4.95	3.42
LSD	0.72	0.75	0.65	0.15	0.68

Table 4: Farmers evaluations of mother trial – Muranga

Entry No.	Early maturity	Pests and diseases	Husk cover	Yield
14	3.31	3.24	4.71	3.62
13	3.41	3.76	4.53	3.47
31	3.03	3.71	3.97	3.38
18	3.09	3.59	4.56	3.35
3	2.88	3.53	4.66	3.13
5	2.75	3.32	4.41	3.09
24	3.09	3.29	4.21	3.09
6	3.06	3.06	4.47	3.06
10	3.06	3.68	4.12	3.06
20	2.88	2.66	4.75	3
32	2.75	2.74	4.5	2.91
22	3.06	3.44	4.35	2.79
9	3.22	3.47	4.5	2.74
21	2.5	3.06	4.47	2.74
1	2.97	3.29	4.47	2.68
15	2.84	3.62	4.5	2.56
16	2.59	3.76	4.76	2.53
25	2.9	2.94	4.06	2.5
8	2.59	3.25	4.19	2.47
27	2.69	3.06	4.12	2.44
7	2.81	3.76	3.88	2.38
12	2.56	3	4.35	2.35
23	2.22	3.03	4.06	2.35
26	2.62	2.65	4.41	2.29
11	2.44	3.18	4.06	2.26
28	2.91	3.56	4.53	2.24
30	2.8	3.38	4.53	2.19
2	2.44	2.71	3.91	1.74
19	2.1	2.84	4.19	1.69
29	2.09	3.03	3.53	1.65
4	2.37	3.35	3.91	1.56
17	1.59	2.88	3.56	1.47
Mean	2.74	3.25	4.29	2.59
Min	1.59	2.65	3.53	1.47
Max	3.41	3.76	4.76	3.62
LSD	0.66	0.58	0.54	0.97

Table 3: Farmers evaluations of mother trial - Ndunduri

Entry No.	Early maturity	Drought	Pest and diseases	Cob size	Husk cover	Cob filling	Grain size	Yield
4	3.83	3.39	3.72	3.44	3.67	3.61	3.56	3.44
2	2.94	3.17	2.94	3.06	3.17	3.28	3.11	3.39
30	3.44	3.06	2.94	2.72	3	3.11	2.94	3.39
6	3.72	3.44	3.17	3.06	3.61	3.44	3.22	3.28
13	3.28	2.89	2.72	2.83	3.11	3.61	3.28	3.22
16	3.61	2.78	2.5	2.56	2.67	3.22	3.17	3.22
26	3.56	3.33	2.78	3.22	2.94	3.67	3.39	3.17
31	3.33	2.89	2.72	2.83	3.22	3.11	3.22	3
28	3.39	2.78	2.83	2.61	2.72	3.11	2.72	2.94
11	3.5	2.44	2.5	2.89	3.11	3.22	3	2.83
21	3.17	2.89	2.78	2.83	2.78	2.72	2.67	2.78
19	3.11	2.89	2.56	2.39	2.83	2.61	2.83	2.78
17	2.89	2.72	2.83	2.56	2.94	2.61	2.67	2.72
24	2.89	2.72	2.56	2.67	2.94	2.89	3.39	2.67
22	2.72	2.56	2.67	2.67	2.83	2.83	2.94	2.67
3	2.78	2.56	2.61	2.33	2.89	2.39	2.78	2.67
10	3.61	2.78	2.5	2.61	2.83	2.39	2.67	2.61
9	2.88	2.59	2.69	2.35	2.53	2.18	2.53	2.59
32	2.78	2.83	2.39	2.44	2.56	2.56	2.78	2.5
12	2.89	2.18	2.39	2.39	2.72	2.72	2.44	2.5
23	2.44	2.61	2.44	2.44	2.61	2.61	2.67	2.5
15	2.53	2.24	2	2.29	2.65	2.65	2.65	2.47

Entry No.	Early maturity	Drought	Pest and diseases	Cob size	Husk cover	Cob filling	Grain size	Yield
1	3.11	2.67	2.39	2.61	2.89	2.89	2.89	2.39
20	3	2.67	2.28	2.67	2.78	2.72	2.94	2.39
18	3.06	2.39	2.56	2.28	2.44	2.61	2.78	2.39
29	2.67	2.5	2.83	2.44	2.39	2.39	2.33	2.39
8	3.11	2.33	2.22	2.61	2.06	2.28	2.61	2.22
25	2.5	2.22	2.44	2.44	2.56	2.39	2.56	2.22
27	2.28	2.28	2.28	1.72	2.33	2.44	2.89	2.22
7	3.5	2	2.39	2.56	2.78	3.28	3.06	2.17
14	2.56	2.06	2.06	2	2.22	2.11	2	1.94
5	2.78	2.33	2.06	2.5	2.17	2.28	2.28	1.72
Mean	3.06	2.66	2.59	2.59	2.78	2.81	2.84	2.67
Min	2.28	2.00	2.00	1.72	2.06	2.11	2.00	1.72
Max	3.83	3.44	3.72	3.44	3.67	3.67	3.56	3.44
LSD	0.69	0.63	0.58	0.57	0.62	0.75	0.59	0.74

checks, the observed differences were not significant (Table 3). Likewise in Muranga District, two new maize varieties and at least 9 varieties were perceived to be superior to H513 and PHB3253. However, the differences were not significant (Table 4).

DISCUSSION AND CONCLUSION

The results of the farmers' evaluations indicate that no particular new maize variety was consistently superior to the local checks across all sites. However, there were a number of new maize varieties that were perceived to be better than the local checks, though at some sites the differences were not significant. The number of farmers participating in the evaluation was low and probably this may explain the results obtained.. During the generation of attributes for maize variety selection, post-harvest attributes were shown to be important. However, they were excluded in the evaluation conducted prior to harvest. Against the above revelation it may be worthwhile to conduct evaluations at important stages of plant growth so as to take into account all the important attributes. Although farmers suggested more than one stage for evaluating maize varieties, this was not taken into consideration and probably affected the results obtained. It may also be worthwhile to increase the number of rows per variety to allow the farmers to more easily make comparisons among varieties based on their attributes.

The results of the evaluations indicated that it is possible to identify promising varieties earlier based on farmer's methods of assessment and thus saving several seasons of on-station testing. Benefits can be realized from varieties getting to farmers earlier.

Bringing farmers on-station to participate in varietal evaluation has the advantage of indicating to the researchers the wide range of criteria farmers use in selecting crop varieties. In standard breeding the choice of varieties may be based on criteria that are less important to farmers with the result that varieties that would have been selected get winnowed out. In the case presented here there were new maize varieties that were considered more superior than the local checks and these could be further evaluated for subsequent recommendation. New varieties that do not measure up to the farmers' attributes should be dropped. Although involving farmers early in variety selection is commendable and allows good varieties to be identified, the seeds should eventually be made accessible to farmers. It is hoped that good varieties identified through mother and baby trial design will eventually be linked to a good seed supply system.

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Best Presentation Awards

In order to encourage oral and poster presentations of high quality from participants in the Conference, the Program Committee offered a cash prize for the best oral presentation and the best poster presentation by a national program scientist from the Eastern and Southern Africa region. Oral and poster presentations were judged by two 4-member panels of distinguished International Scientists according to ten criteria related to presentation (delivery or design; timing or presenter interest), use of visual aids (legibility, simplicity, number/ sequence) and content (introduction, organization, substantiation, summary/ conclusions, significance/ originality). The following scientists were independently and unanimously chosen in each category:

Best oral paper: Ms. Tuaeli Mmbaga, Selian Agricultural Research Institute, Arusha, Tanzania: "Drought Management Options in Maize Production in Northern Tanzania"

Runner-up oral: Dr. Vernon Kabambe, Chitedze Research Station, Malawi: "Relative Roles of Herbicide, Genotype Resistance and Fertilizer in Integrated Management of Striga Asiatica in Maize in Malawi"

Best poster paper: Ms. Elizabeth Nambiro, University of Nairobi, Kenya: "Market Structure and Conduct of the Hybrid Maize Seed Industry, a Case Study of the Trans Nzoia District in Western Kenya"

Runner-up poster: Dr. G. Bigirwa, Namulonge Agriculture & Animal Production Research Institute, Uganda: "Farming Components Responsible For Gray Leaf Spot Disease Severity in Districts of Contrasting Incidence"