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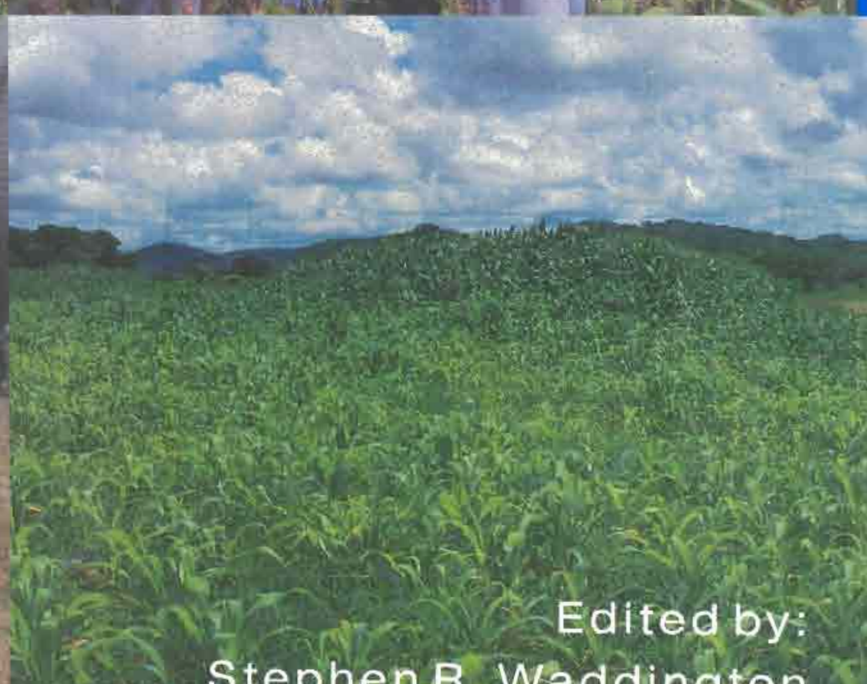
Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe



Edited by:
Stephen R. Waddington
Herbert K. Murwira
John D.T. Kumwenda
Danisile Hikwa
Fanuel Tagwira

SOIL FERTILITY RESEARCH FOR MAIZE-BASED FARMING SYSTEMS IN MALAWI AND ZIMBABWE

Proceedings of the Soil Fertility Network Results and Planning Workshop

Held from 7 to 11 July 1997 at Africa University
Mutare, Zimbabwe

Edited by

Stephen R. Waddington
Maize Programme and Natural Resources Group
CIMMYT-Zimbabwe

Herbert K. Murwira
Tropical Soil Biology and Fertility Programme and
African Centre for Fertilizer Development, Zimbabwe

John D.T. Kumwenda
Department of Agricultural Research and Technical Services
Ministry of Agriculture, Government of Malawi

Danisile Hikwa
Department of Research and Specialist Services,
Ministry of Agriculture, Government of Zimbabwe

Fanuel Tagwira
Faculty of Agriculture and Natural Resources
Africa University, Zimbabwe

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Preface

These proceedings of the Soil Fertility Research Network (Soil Fert Net) Results and Planning Workshop bring together forty papers on soil fertility research for maize-based farming systems in Malawi, Zimbabwe and beyond. They represent over four years of work by members of Soil Fert Net and their associated institutions, and include results from our first Network Trials.

The presentations generated much debate and this is recorded in discussion sessions. A panel of advisors produced an assessment of our work. We end the proceedings with reports from four planning sessions that helped to update and tighten the work priorities of our network for the future.

Stephen Waddington
Herbert Murwira
John Kumwenda
Danisile Hikwa
and Fanuel Tagwira

Harare, Lilongwe and Mutare, June 1998

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OFFICIAL OPENING OF THE SOIL FERTILITY NETWORK WORKSHOP

Cde KENNETH MANYONDA

Resident Minister and Governor of Manicaland

I feel honoured this morning to officiate at this Soil Fertility Network Workshop. Firstly, I would like to extend my warm welcome to all of you, particularly those who have come from outside Zimbabwe. I hope you will have a pleasant stay in Zimbabwe.

I have been told that this workshop is an activity of the Soil Fertility Network for Maize-Based Farming Systems. The goal of this Network, I am told, is to help smallholder farmers in Malawi and Zimbabwe produce higher, more sustainable and profitable yields from their maize and other related crops through improved management of soil fertility. I am also informed that most of the Network members are Researchers from Government Research Institutions and Universities in the two countries who are funded by the Rockefeller Foundation. I would like in this regard to thank the Rockefeller Foundation, for the support that they give to our institutions to enhance their capacity to carry out agricultural research.

Human population pressure has a major impact on land utilization and land degradation. Population pressure leads to the exhaustion of fertile agricultural lands and the progressive utilization of environmentally fragile marginal areas. In the Zimbabwean context, environmental degradation as a result of deforestation, overgrazing and cultivation of marginal lands is already a serious problem closely associated with population growth. As we try to meet the food needs of the growing population in our countries one of the major challenges we have will be to increase food production on the land already under cultivation without bringing marginal land into production. Among other things, such a challenge will require us to make sure the soil is able to adequately provide the nutrients required to sustain the increased crop yields. Current agricultural practices in the region are extractive in nature, taking out more than we are putting into the soil. We are mining the soils. In the long run, we will learn that we cannot defy the laws of nature: "What we sow is what we shall reap". Apart from what we are mining out, we are also losing some of our fertility through soil erosion.

How can our smallholder (Communal) farmers maintain the fertility of their lands? For the Communal farmer, the use of fertilizers to improve soil fertility, despite its great advantages, has major financial implications. This is particularly true in drier regions and in drought years when the return on fertilizer investment is minimal. There is need for you researchers to search for alternative systems of maintaining and even improving soil fertility. As you search for these solutions, I hope you will realize that the farmer also has his own story to tell and he needs to be heard. You must involve her or him at the beginning of the research and incorporate her or his views in the development of your research programs. After all, he is the user of the technology you are trying to develop. For a long time scientists have ignored traditional knowledge systems. There is need for us to evaluate the traditional methods of soil fertility maintenance and address the questions of whether these methods are still adequate to meet the needs of the present and future generations. I happily note from the list of papers to be presented here that the use of animal manure and manures supplemented with fertilizers as well as rotations, as means of improving soil fertility, will be discussed during the course of this workshop. Manuring and rotations are some of the practices our farmers have been using for a long time. It is our hope that whatever technologies come out of your research will not just end up documented in journals which our farmers and extension workers have no access to or cannot read, but will be documented and disseminated to those who it can benefit most.

As most of you may be aware, the Government of Zimbabwe initiated a resettlement program, which has been going on for some years. As Government works hard to help these previously disadvantaged communities we need a strong partnership with research and extension agencies in the country to make sure that these resettled farmers use methods of farming which do not harm the soil environment.

The essence of my message to you today is that as you carry out your work and as you deliberate at this workshop:

- never lose sight of the needs of those who are to be beneficiaries of your services.
- recognize the urgency of this period in our history and the fact that our nations expect relevant and practical solutions to come out of your research.

- appreciate the need to balance increased food production and protection of the environment for the benefit of future generations.
- and remember that the governments and peoples of this region will not measure the success of your research based on the number of papers you publish but on the impact of your research on agricultural productivity.

We all know agricultural research is very important but at the same time very expensive. It is with this in mind that I see your Network being very important as it will help increase awareness of what each one is doing and therefore avoid duplication of effort. As Government we are aware of how under-funded some of our research centres are. This is due to circumstances beyond our control. We view the efforts of organizations that fund agricultural research as complementing or augmenting the efforts of Government. In this regard, I would like to thank again the Rockefeller Foundation for funding agricultural research carried out by some of our Government Institutions. I would also like to thank CIMMYT, the co-ordinator of the Soil Fertility Network for Maize-Based Cropping Systems and organizer of this workshop. As you deliberate and look for solutions for sustainable crop production in the small scale farming sectors in the next few days, I would like to let you know that our government fully supports your efforts.

With these few remarks, I would like to declare this workshop officially open.

Thank you.

RESEARCH ON SOIL FERTILITY IN SOUTHERN AFRICA: TEN AWKWARD QUESTIONS

LARRY HARRINGTON and PETER GRACE

CIMMYT Natural Resources Group, Lisboa 27, Apdo. Postal 6-641, 06600 México, D.F., México

INTRODUCTION

Success in agricultural research calls for a unique blend of unconstrained creativity and painstaking discipline — creativity in designing technical options intended to be attractive to farm families, tempered by discipline in assessing their performance and attractiveness. Research on soil fertility management is especially difficult, in part because of:

- The many combinations of technical options available (inorganic fertilizers, crop residues, numerous species of green manures, animal manures, intercrops, rotations, agroforestry systems, improved germplasm, etc.).
- The variability in performance of these technical options under different soil and weather conditions.
- The complex ways in which technical options can impinge on existing farming practices.
- The possible importance of their long-term and off-site consequences.
- The complexity of identifying potential areas for extrapolation of research results.
- The importance of policies and institutional arrangements in shaping the farm-level cost-benefit equation that drives adoption.

Research on soil fertility management in maize systems may be difficult, but it is also supremely important for sustainable food security, particularly in sub-Saharan Africa. Adoption of improved maize germplasm has accounted for a little over half of the 1% annual growth in maize yields in sub-Saharan Africa since 1970; improved productivity and sustainability in maize systems must come increasingly from improved soil management practices that fit the infrastructural and institutional circumstances of many African farming systems: low population densities, seasonal labour bottlenecks, poor infrastructure (which increases the cost of external inputs), and price instability (Byerlee *et al.* 1994).

Given the complexity of research on soil fertility management, many researchers concentrate their efforts on a small subset of the important questions, but neglect the more awkward ones. Specific examples include issues relating to problem definition, spatial and temporal extrapolation, farmer participation, factors governing adoption, links with policies, and longer-term and off-site consequences of change.

This paper raises several of these awkward questions without trying to provide any definitive answers. By raising them, however, we hope to stimulate discussion among researchers about themes which may have been ignored and new ones that contribute to understanding and solving important soil fertility problems in Southern African maize systems.

Question 1 - Are soil fertility problems in maize systems well defined?

New soil fertility management practices should aim to solve important problems. But how well defined are the problems? Soil fertility problems normally entail multiple dimensions (Harrington 1996), including:

- The biophysical processes that underpin soil fertility problems in maize systems.
- The direct causes of the problems (which result from the above processes).
- Problem incidence.
- The consequences of problems.
- The pace of change with which these consequences are felt.

Given the exemplary work of the International Fertilizer Development Center (IFDC), the Tropical Soil Biology and Fertility Program (TSBF), the International Center for Research in Agroforestry (ICRAF), national agricultural research systems, and other research organizations (Woomer and Swift 1994), one might assume that the *biophysical processes* associated with soil degradation and low soil fertility in Southern African maize systems were well understood, especially relative to soil fertility depletion (Smaling and Braun 1996) and the requirements for recapitalizing soil fertility, particularly for phosphate (Sanchez 1996). In addition, there has been considerable work aimed at understanding water and nutrient cycling and improving synchrony — the capacity of soils to provide nutrients to plants at the time when they are most needed. Despite the work to date, however, we cannot presume to have a total or even satisfactory grasp of the many biophysical processes that underlie soil fertility problems in maize based agriculture in Southern Africa. Even in Asia, where considerably more research resources have gone into elucidating the processes that drive soil degradation and yield stagnation in intensive rice systems (Cassman *et al.* 1994), those processes have only recently been satisfactorily described, and the underlying causes of declining yields in rice-wheat systems in the Indo-Gangetic Plains remain poorly understood, despite intense study (Hobbs and Morris 1996).

As we ask about important unknowns regarding soil biophysical processes in maize systems in Southern Africa, it may be useful to subdivide process issues into two types:

- Degradation; for example, the on-going loss of organic matter and nutrients in lands with relatively high proportions of clay.
- Management of low fertility soils; for instance, farming on shallow, granitic sands where there may simply be *no degradation processes* at work.

Problem incidence refers to the simple questions, "Which biophysical problems are found on which soils, and where are these soils located?" Simple though they may be, these queries have important implications for technology targeting, the selection of representative sites, site characterization, the georeferencing of experimental locations, the pooling of data across sites, and priority-setting in technology design. Have the questions of problem incidence been answered to everyone's satisfaction? Is it generally known which problems are concentrated on which soils? Are trials georeferenced? Are data pooled across sites in a way that draws on suitable soils characteristics?

Consequences of soil-related problems may be found not only on-site (near-term productivity or longer-term resource quality and system sustainability; e.g., the build-up of *Striga*), but off-site as well (downstream or off-site economic, environmental or ecological effects of land degradation). Off-site consequences of land degradation can be more important than on-site consequences (Anderson and Thampapillai 1990). For example, erosion on sloping hillsides in Indonesia often does not affect the productivity of hillside maize systems, but the resulting siltation can ruin downstream irrigation infrastructure. What are the major off-site economic, environmental or ecological consequences of land degradation in maize systems in Southern Africa?

Pace of change is also important — problems may be more significant if they unfold swiftly. What is the pace of change for major problems of soil degradation in maize systems in Southern Africa?

Finally, it is important to understand the underlying, *non-biophysical causes* of problems to develop viable solutions (Tripp and Woolley 1989). In sub-Saharan Africa, soil fertility problems have been traced to increasing land scarcity, shortened fallow periods, periodic labour shortages, and low use of inorganic fertilizers. The latter factor in turn derives from unfavourable grain/ fertilizer price ratios, driven by poor infrastructure, unsuitable input and product pricing policies, and uneven performance of private sector companies (Mwangi, 1997). Have the important cause and effect relationships been fully worked out for soil fertility problems in Southern Africa? Do they change over sub-regions? Farmers are particularly skilled at helping unravel cause and effect relationships among complex system interactions (Lightfoot *et al.* 1989). Has their experience been tapped?

Question 2 - Does the current "menu" of technical options include promising farmer-developed practices?

There is a tendency in on-farm research for scientists to choose (often rather casually) a small number of technical practices which they subsequently assess in considerable detail. It can be awkward to ask whether the right practices were chosen to begin with. Sometimes, important farmer-developed options are overlooked. There is a fair literature on multiple sources of innovation (e.g., Bebbington 1989) which teaches us that farmers frequently can contribute innovative new practices to the pool of technical options being assessed. The numerous examples include:

- Farmer-developed methods for inserting *mucuna* in maize systems in Southern Veracruz, Mexico (Buckles 1993).
- Farmer-developed surface-seeding practices for establishing wheat after rice in Bangladesh (Hobbs and Morris 1996) and Thailand (Connell 1992).
- Farmer-developed methods of transplanting maize to enable a conversion of a two-crop per year to a three-crop per year system in the Red River Delta of Northern Vietnam (Tinh *et al.* 1992).
- Farmer-developed land management systems for flood-prone areas of the lower Indo-Gangetic Plains (John *et al.* 1993).
- Farmer-developed methods of dealing with erosion in Central Kenya (Tiffen *et al.* 1994).

In Southern Africa, it would be unusual indeed if farmers had no insights into soil management nor options for regenerating soils that have lost their fertility. What are farmers' strategies for regenerating soils? What conditions govern the success of these strategies? Have these approaches been considered in a research program? For soils that may not necessarily be undergoing degradation but that are of low inherent fertility, what are farmers' management practices? Is the Soil Fertility Network research agenda adequately "rich" in options for and developed by farmers?

Question 3 - What have been farmers' experiences in using new practices suggested?
Not only can farmers help provide new technical prototypes and options; they are frequently good sources of insights on technical options already under study. Often farmers will have previous experience with a technology and thus possess a reasonable understanding of its performance under different circumstances.

In the Soil Fertility Network agenda, the following technical interventions are among those emphasized in research: legume green manures to foster regeneration of exhausted soils; groundnut cropping patterns in long-term trials; crop sequences involving legumes, maize, and sunflower; soybean-maize rotations; cattle manure x inorganic N; overcoming limiting nutrients on the Kalahari sands; and many, many more. Local farmers must surely have some knowledge of these practices. Have systematic efforts been made to tap farmers' past experiences with the "new" practices being developed within the Network? How has such information been incorporated into Network findings?

Question 4 - Which new soil fertility management practices are best suited to which soil types?
In our first question, the issue of *problem* incidence was raised: "Which biophysical problems are found on which soils, and where are these soils located?" A similar question can be asked regarding the targeting of *solutions* to these problems: "Which soil management practices are best suited to which soils, and where are these soils located?" Clearly, for example, research to identify the nutrients that limit maize productivity in Kalahari sands is most relevant to those soils. Are there differential responses by soil type for other aspects of fertility management in maize based production systems? As suggested earlier, how does this affect site selection, data analysis, and synthesis of results? Which data can sensibly be shared over which sites? What are the potential extrapolation areas for different technologies? Are test sites georeferenced? Are they and their soils characterized? Are the results of soil analyses used in answering some of the above questions? Should the Soil Fertility Network organize a database on soil fertility management practices by soil type?

Question 5 - How can new practices be adapted most efficiently to the conditions of different systems?
Soil variability is only one factor that affects the cross-site synthesis of research results and the adaptation of prototype practices to farmers' circumstances. Indeed, adapting prototype practices to defined farming systems is a classic area for farmer participation in research. Much of the literature on participatory experimentation — farmer involvement in technology adaptation — deals with crop improvement. Examples include farmer participation in selecting advanced lines of common bean in Colombia (Ashby *et al.* 1987) and Rwanda (Sperling and Scheidegger 1995), and farmer participation in selecting rice varieties in Nepal (Sthapit *et al.* 1996). However, farmers and researchers have also worked together to tailor crop and system prototype technologies. Here we can cite the use of vining legumes to rehabilitate *Imperata* infested lands in the Philippines (Lightfoot *et al.* 1988) or the use of grassy strips with farmer-selected trees for erosion control in hillside maize systems in Southern Philippines (Fujisaka 1989). In fact, a whole new literature has grown up around participatory adaptive experimentation (e.g., ILEIA 1989).

Have researchers in the Soil Fertility Network worked with farmers to tailor prototype technologies studied by the Network to the needs and circumstances of different farming systems? This would require, of course, a characterization of the major farming systems in the target area. Is there a need to strengthen the capacity of Network members to engage in participatory experimentation for technology adaptation? Is there a need to re-examine the balance between researcher-managed strategic research vs. participatory adaptive research?

Question 6 - How do the new practices perform under drought?
The attractiveness of new soil management practices to farmers will, in part, depend on how these practices perform under drought conditions; Southern Africa is, after all, a region noted for rainfall variability and weather-related risk. Other things being equal, soil management practices that perform poorly under drought conditions are likely to be less attractive to farmers. First, however, what is meant by the term "drought"? To be useful, the concept itself must be described more precisely. For instance, does it refer to:

- Late onset of rains?
- Early end of rains?
- Erratic dry spells during the rainy season?
- Concentration of rains in fewer events?
- Reduced average seasonal rainfall?

Most importantly, what climatic scenarios are of most concern to farmers?

Maize itself is especially susceptible to drought-occasioned yield losses during flowering and grain filling, crop development phases which occur from mid-season to late in the season (Westgate 1997). Unreliable rainfall during seedling establishment early in the season has also been cited as a major cause of yield reductions and even crop losses in maize (Bänziger *et al.* 1997). In the absence of a rich dataset (one that features multiple long-term experiments that extend over a large number of years, and that suitably reflect variation in weather patterns), stability of performance of soil management practices best can be assessed through modelling. An example of modelling to assess the riskiness of a given technology option is offered in the following section. Note, however, that fruitful simulations from validated models also require an input — data from trials accompanied by a minimum dataset (Table 1) (though these need not come from long-term trials).

Simulation models and risk management - an example -- To demonstrate the use of simulation models in assessing yield variability under different weather conditions, an example is maize response to fertilizer at Chitedze, Malawi. Crop production practices are those as described by Thornton *et al.* (1995) in their evaluation of the CERES-maize model in Malawi. The CERES-Maize and SOYGRO models are used — these are available in the whole system decision support package known as DSSAT (v3.1). One simulation experiment involving a single-season maize crop with an array of urea applications (0, 60, 120, 180 kg N/ha) was performed. The fertilizer applications in this simulation were in multiples of 30 kg N/ha, at approximately weekly intervals. The initial application was two weeks after planting. Historical weather records (1984-91) from Chitedze Research Station were used in seasonal analysis, with the crop being grown under identical soil conditions for each of seven seasons. This eight year weather set was used to generate a theoretical weather dataset for a twenty-year analysis. In the simulation, the mineral N content of the top 50 cm of sandy-loam soil at the time of planting each year was 44 kg/ha (assuming a bulk density of 1.3 g/cm^3) with a volumetric water content of 0.11 cm^3/cm^3). A 500 kg/ha residue cover with an N content of 0.53% was also incorporated at that time. This analysis produces a range of yields for each fertilizer treatment solely dependent on the different weather conditions for each season. In all simulations a plant population of 37,000 plants/ha was used, planted on 20 November each year. The maize cultivar was a local traditional variety. The model does not take into account the impact of weed populations and pest damage on yield. It also assumes that phosphorus is non-limiting.

Table 1. The minimum dataset for simulation of cropping systems.

Measurement	Depth increment (cm)	Timing
Maximumtemperature	Surface	Daily
Minimum temperature	Surface	Daily
Solar radiation or Sun hours	Surface	Daily
Rainfall	Surface	Daily
Organic C	0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+	Sowing
Organic N	0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+	Sowing
Ammonium/Nitrate-N	0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+	Sowing, harvest
Ammonium/Nitrate-N	0-5, 5-10, 10-20	Tasseling,anthesis and harvest.
Total P	0-5, 5-10, 10-20, 20-40	Sowing
Extractable P	0-5, 5-10, 10-20, 20-40	Sowing
pH	0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+	Harvest
Crop residues	Surface, 0-5, 5-10, 10-20	Sowing, harvest
Total aboveground biomass		Tasseling, anthesis and harvest
Tillage	Record depth and type	Record date
Irrigation	Record method	Record date
Fertilizer	Record depth and type	Record date
Germination (50% of plants)		Record date
Anthesis (50% of plants)		Record date
Maturity (50% of plants)		Record date
Grain yield		Record
Grain N		Record
Grain number @ harvest		Record

Annual simulated maize yields for the single season nil fertilizer treatment are depicted in Figure 1. Seasonal rainfall varied from 588 mm in 1990-91 to 1052 mm in 1986-87, with an average of 878 mm. Simulated yields varied from 1.5 t/ha in 1989-90 to 2.6 t/ha in 1988-89, with an average of 1.9 t/ha.

There was no significant relationship between total *seasonal* rainfall and yield for any treatment. This is not surprising — simplistic empirical models which attempt to predict yield from total growing season rainfall without accounting for distribution are rarely accurate. This is illustrated in Figure 2, where above-ground dry matter accumulation is compared for two seasons (1987-88 and 1989-90) with similar total seasonal rainfall (808 mm). In 1989-90 there was substantial early season rainfall, leading to waterlogging and lower yields (1.5 t/ha). In contrast, rainfall was more evenly distributed in 1987-88 leading to higher yields (2.1 t/ha).

One way to quickly assess the relative performance of each treatment in response to the same weather conditions is through a cumulative probability function plot. The output for each treatment (in this case yield for each year) is ordered from lowest to highest and plotted against equal increments of cumulative probability. It is evident from Figure 3 that the local maize cultivar with no fertilizer is unlikely to attain a grain yield greater than 2.6 t/ha under the specified range of climatic and management conditions. Under these conditions, this cultivar has a 50% probability of yielding at or below 1.9 t/ha.

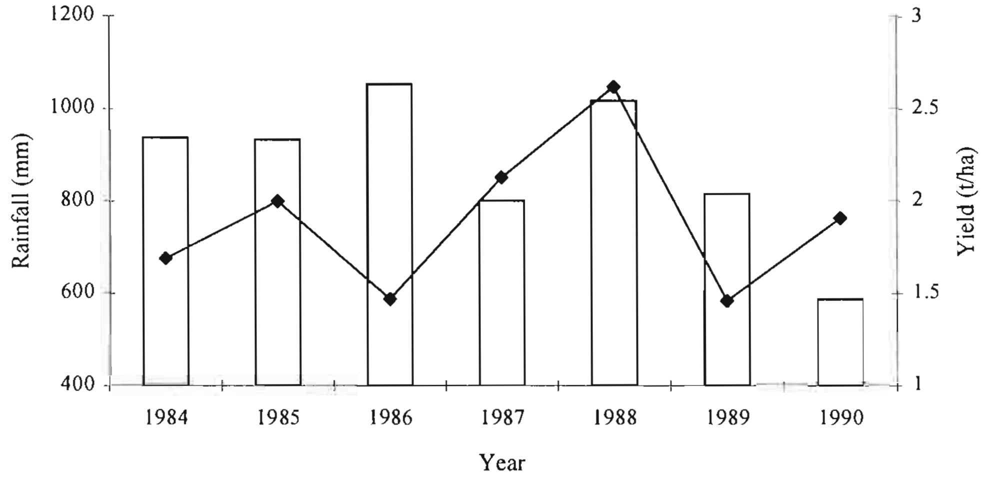

Figure 1. Seasonal rainfall (bars) and simulated maize grain yield (points) for a local cultivar grown at Chitedze, Malawi (nil fertilizer), using the CERES-Maize model.

Note that the above results are based on a climate dataset of relatively short duration. When we ran the same nil fertilizer treatment with a theoretical twenty-year weather dataset, the simulation output included two years of complete crop failure. When we plotted each of the four treatments as cumulative probabilities (Figure 4), the maximum attainable yield with the local cultivar using the actual recorded weather at Chitedze for 1984-1991 was 3.2 t/ha. When we used the full twenty-year dataset we obtained a similar yield.

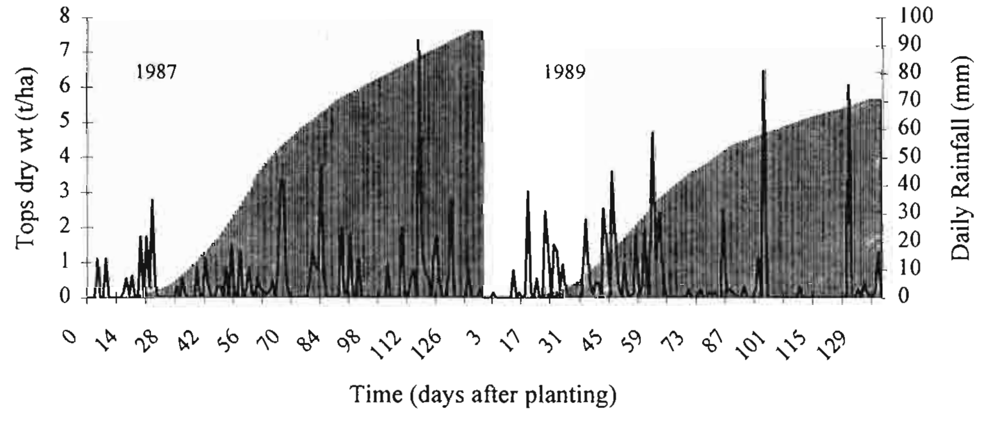

Figure 2. Daily rainfall (lines) and simulated accumulation of aboveground maize biomass (shaded) for a local cultivar grown at Chitedze, Malawi (nil fertilizer), in 1987-88 and 1989-90.

Modelling can also be used to simulate and thereby forecast likely longer-term effects on crop yields and soil quality indicators associated with the introduction of new rotations or the use of green manure cover crops or manures.

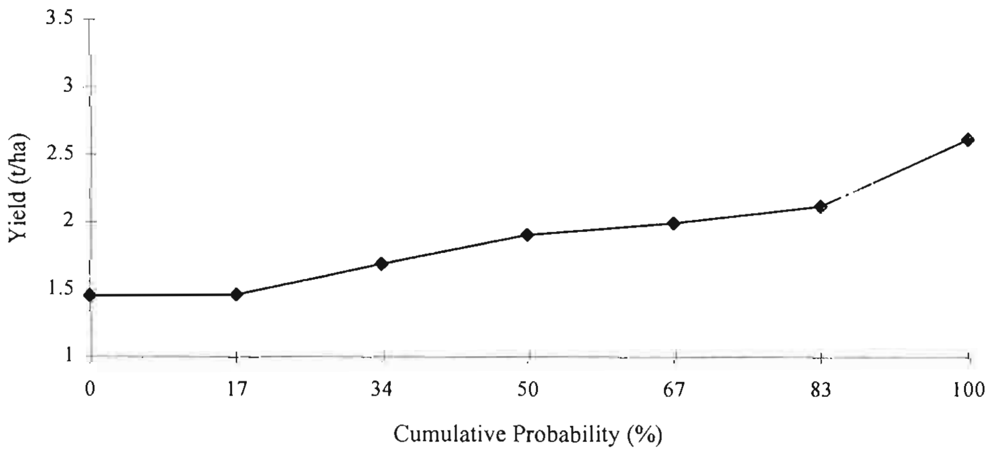

Figure 3. Distribution of simulated maize yields for a local cultivar grown at Chitedze, Malawi, for seven single seasons (1984-85 to 1990-91) under identical initial conditions.

Question 7 - How do the new practices mesh with farmers' risk management strategies?

Farm families that survive or even thrive in a

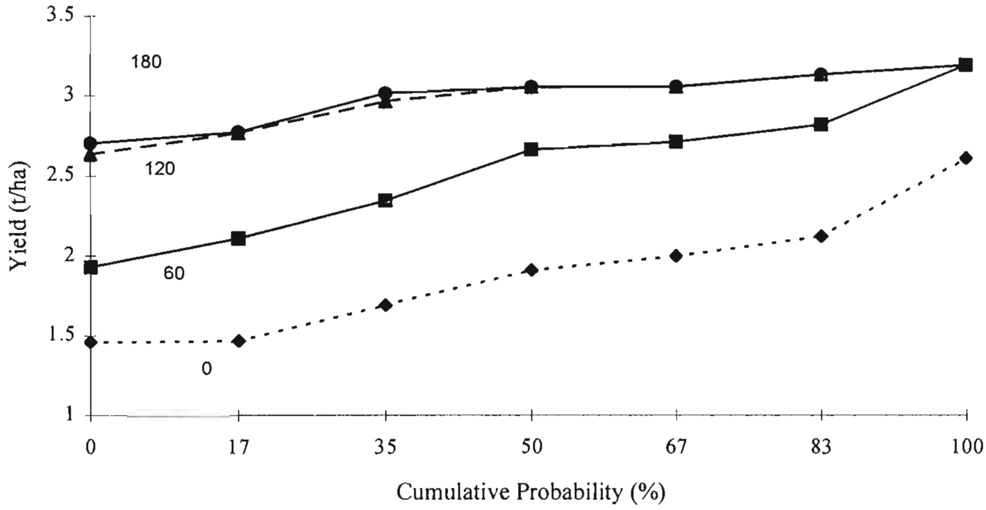

Figure 4. Distributions of simulated maize yields for a local cultivar grown at Chitedze, Malawi, for seven single seasons (1984-85 to 1990-91) under identical initial conditions and fertilizer N addition of 0, 60, 120 and 180 kg N/ha in the form of urea.

drought-prone, risky environment understandably have developed strategies to deal with climatic variation. For Southern African families who rely on maize systems for income and employment, risk management strategies might feature (Scoones *et al.* 1996):

- Staggered maize planting.
- Early maturing maize varieties.
- Maize seed soaking.
- Crop diversification.
- Crop sequences or rotations that foster moisture conservation.
- Landscape management (e.g., varying the relative intensity of use of low-lying lands vs. hillsides).
- Use of cattle husbandry or off-farm or non-agricultural employment as alternative sources of income, etc.

To these options may soon be added another important one — drought- and low-N tolerant maize varieties (Edmeades *et al.* 1997).

How well do new soil management practices mesh with these risk management strategies? Might recommended intercrops or undersown legumes rob moisture from maize during a drought, further reducing grain production badly needed for subsistence? Are the high labour inputs needed for green manure management feasible if farm family survival during drought periods depends on livestock management or off-farm employment? How can researchers and farmers work together to answer these questions?

Note that new maize technology (modern varieties and fertilizer) can sometimes be risk efficient (Ames *et al.* 1993; Smale *et al.* 1994). Can organic-based technologies do as well?

Question 8 - How well understood are the factors governing adoption of new soil management practices?

Good performance under drought conditions and a good fit with farmers' risk management strategies are crucial in determining the attractiveness of new technology to farm families. But other factors — particular those that influence the near- and longer-term costs and benefits of adoption — may be equally important.

Information on factors governing adoption can be generated during farmer participatory adaptive experimentation (see Question 5, above). At times, however, dedicated adoption studies are needed (see CIMMYT Economics Program 1993 for a summary of methods useful in conducting adoption research). In addition, there is no substitute for a sound economic analysis — and a sound farmer assessment — of practices being proposed for widespread dissemination. Whatever the source or type, information on factors governing adoption can be exceedingly useful, as the following examples show.

- Farmers in Western Kenya began using improved fallows that feature direct seeding of *Sesbania* in place of maize on their least productive maize lands, even though the yield increase in the following maize crop was only about 25%. Farmers quickly realized that the savings in crop labour offset foregone maize yields and used the practice to reclaim depleted land. Understandably, adopting households were those with access to off-farm income or with low labour to land ratios (Swinkels *et al.* 1996), and an awareness of this helped in targeting the technology.
- In West Africa, researchers have found that adoption of *Mucuna* in maize systems has been greatest where soil fertility is declining and inorganic fertilizers are not subsidized, where noxious weeds (like *Imperata*) severely affect maize production, and where farmers have good contact with development organizations that facilitate access to *Mucuna* seed (Vissoh *et al.* 1997). Knowledge of these factors has guided subsequent dissemination efforts involving *Mucuna*.

What is known about factors that govern the adoption of soil management practices for Southern Africa? What is the cost-benefit equation for the major technical options — both near-term and longer-term? Are inorganic fertilizer, lime, or other soil amendments really profitable to farmers when realistic transport costs, interest rates and product prices are included in the analysis? See Perrin and Anderson 1979 - or updated versions - for methods of partial budget economic analysis of agronomic experiments. What are the hidden costs of adoption?

For example, is it possible that open grazing by livestock during the dry season constrains green manure growth or use of crop residues as a source of organic matter? Is the fencing of land a hidden cost of adopting these practices? Should farmers plough immediately after harvest to incorporate green manure biomass and so avoid it being eaten by roaming cattle? Is it feasible for most farmers to plough in such a manner? Participatory research with farmers, economic analysis of trials, and adoption studies can help answer these important questions.

Question 9 - What mechanisms are in place to accelerate and improve the quality of adoption by informing the policy debate?

Policymakers typically have multiple objectives, only one of which may be to improve the productivity and sustainability of maize systems. Policy decisions *will* be made, whether or not the information base to support these decisions is complete. Decisions, once taken, can have unexpected or unintended consequences for agricultural production in general, and maize system productivity in particular.

Agricultural scientists and research managers may not necessarily be the best people to determine or influence policy, but they have a very important role in helping inform the policy debate. What mechanisms are in place for agricultural scientists or research managers to provide essential information to policymakers?

The adoption of improved technologies that depend on the use of purchased inputs, such as seed and fertilizer, is strongly conditioned by the policy environment with respect to input supply and prices. To foster adoption, the following are said to be needed:

- A cost-effective mix of price policy, credit, input supply, and extension, (with special attention to the economics of fertilizer use, the availability of fertilizer, price policies and credit, pricing environment and distribution costs, the privatization of supply, and infrastructure development) (Mwangi 1997).
- Mechanisms for ensuring that such programs are sustainable over the long term, given the short-term nature of most maize production campaigns (Byerlee *et al.* 1994).

The adoption of improved soil management technologies that depend on organic as well as inorganic inputs will be conditioned by other dimensions of the policy environment; these include participatory extension to foster farmer learning of knowledge intensive technologies, access to green manure seeds of good quality, improved markets for grain legumes, and policies that encourage use of crop residues and green manures as soil amendments or mulch (for example, support for fencing off land).

Information on factors governing adoption of productivity enhancing, resource conserving practices needs to be packaged and made available to local, regional and national level policymakers. Are there mechanisms in place to do so?

Question 10 - Will adoption of improved soil management practices materially contribute to the regeneration of the soil resource base? Over what time frame? With what other longer-term or off-site effects?

The Soil Fertility Network has several objectives, among them: to help rehabilitate exhausted soils and to foster improved productivity of maize systems through improved soil fertility. Rehabilitation of exhausted soils and improvement of soil fertility does not happen overnight. Some might assert that the objectives of soil rehabilitation and substantial improvement of soil fertility are inherently unattainable, even if farmers were to fully adopt the best recommended soil fertility management practices.

Several types of studies can help elicit information relative to this issue, including long-term experiments, farmer monitoring, or chronosequence studies (Triomphe 1996). Does the Soil Fertility Network manage such research?

Rather than wait years or decades for this information to emerge, models can be used to simulate the long-term consequences for soil fertility of the introduction of different soil management practices. Several (APSIM, CENTURY, SOCRATES) serve the purpose. Have modelling approaches been used to explore the longer-term consequences of adoption for the productivity and sustainability of maize systems? Are data gathered in trials that can be used to validate these models? Should the Soil Fertility Network strengthen its skills in this area? Note, again, that fruitful simulations from validated models require an input in the form of data from trials accompanied by a minimum dataset (Table 1).

Finally, as noted in an earlier section (see Question 1), off-site consequences of land degradation are important worldwide. These off-site consequences often relate to water quantity or quality for downstream users (e.g., siltation of irrigation infrastructure or pollution of water for urban consumers from erosion in the uplands). What are possible off-site consequences of the introduction of new soil fertility management practices and, if there are any, how should they be assessed?

CONCLUSION

We began this paper by pointing out that agricultural research is complex and that success in research calls for a unique blend of creativity and discipline. The participants in the Soil Fertility Network are to be complimented on both counts. We recognize that much excellent work has been done and, by asking the above questions, hope to strengthen this excellence.

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STRATEGIES TO REPLENISH SOIL FERTILITY IN AFRICAN SMALLHOLDER AGRICULTURE

ROLAND J. BURESH and KEN E. GILLER

International Centre for Research in Agroforestry (ICRAF), P.O. Box 30677, Nairobi, Kenya; Department of Biological Sciences, Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK.

SUMMARY

Nutrient outputs exceed nutrient inputs in many smallholder farming systems in sub-Saharan Africa (hereafter referred to as Africa). This mining of soil nutrients has lead to depletion of soil fertility, which can only be overcome through increased input of nutrients from biological N_2 fixation, organic materials and commercial fertilizers. The quantities of organic materials and commercial fertilizers available to smallholders, however, are often limited. The stark realization of continuing soil fertility depletion in many smallholder farming systems in Africa has lead to a call for an alternative approach to nutrient management in which the replenishment of soil fertility is viewed as an investment in natural resource capital. Replenishment of soil fertility with a large, one-time addition of nutrients is (i) more suited to P than N and (ii) suited to external interventions by governments or agencies to invest in soil fertility. The quantity of added nutrient, however, must not exceed the storage capacity of the soil. Nutrient application rates required to replenish soil fertility will be less on sandy than clayey soils. When the supply of organic materials and fertilizers is limited, seasonal application of small to moderate amounts of nutrients to an agricultural area normally results in greater aggregate production for the area than large application of nutrients to only a portion of the area. The challenge is to selectively target applications of commercial fertilizers and organic materials to ensure that limited financial resources and limited amounts of fertilizer and organic resources are effectively used to both optimize crop responses and restore productivity of depleted lands.

INTRODUCTION

Traditional shifting cultivation with long-duration fallow periods previously sustained low but relatively stable production of food crops in Africa. Shifting cultivation, however, has disappeared as increasing population density and pressures for land use led to intensive, sedentary agriculture on small-scale land holdings and expansion of agriculture into marginal areas. The intensification of agriculture in small landholdings in Africa has typically not been accompanied by sufficient inputs of nutrients through biological N_2 fixation, organic materials and commercial fertilizers to match the outputs of nutrients through harvested products and losses. The result has been widespread mining of soil nutrients and depletion of soil fertility in smallholder agriculture in Africa (Smaling *et al.*, 1997).

High nutrient stocks in soils can buffer negative nutrient balances before nutrient availability reaches a critical threshold below which a crop yield goal can no longer be obtained. Nutrient depletion, for example, can continue for many years on soils with large stocks of available inorganic P before P limits crop yield, and nutrient depletion can continue for many years on soils with large stocks of K-bearing weatherable minerals before K limits crop yield. On soils with low nutrient stocks, however, the decline in nutrient availability and crops yield will be more immediate.

The reversal of soil fertility depletion in Africa undoubtedly requires inputs of nutrients, although there can be alternative approaches for the addition of nutrients. In this paper, we explore possible ways in which the limited nutrient resources available to smallholder farmers can be used to maintain and enhance crop yields and restore soil fertility.

THE CALL FOR SOIL FERTILITY REPLENISHMENT

One approach to overcoming soil fertility depletion would be to focus on nutrient balances within smallholder agricultural land and thereby advocate addition of sufficient nutrients to ensure positive balances — greater inputs than outputs of nutrients. Such an approach, however, fails to recognize that the addition of a nutrient is only required when the soil stocks of the nutrient have been depleted to a critical threshold below which a desired crop yield can no longer be obtained. Advocating nutrient inputs to ensure positive nutrient balances would result in the unnecessary addition of some nutrients that are not limiting crop growth (Shepherd and Soule, 1998).

Another approach for addressing soil fertility depletion is to simply focus on the application of nutrients for improvement of crop yields. Excellent agronomic responses to fertilizers have been demonstrated for major food crops in Africa (Bekunda *et al.*, 1997; Quiñones *et al.*, 1997), but the inputs of nutrients in organic and mineral forms remain low in smallholder agriculture in Africa. High costs of fertilizer, lack of credit, delays in delivery of fertilizer and poor transport and marketing infrastructure serve as disincentives to fertilizer use by smallholder farmers.

The stark realization that soil fertility depletion continues apace (Smaling *et al.*, 1997) despite years of fertilizer research in Africa (Bekunda *et al.*, 1997) has led to a call for an alternative approach in which the replenishment of soil fertility is viewed as an investment in natural resource capital (Sanchez *et al.*, 1996; 1997; Izac, 1997). This approach highlights that soil fertility has its own "capital" value, whereby soil nutrient capital is defined as the soil stocks of essential elements that become available to plants within 5 to 10 years (Sanchez and Palm, 1996). Soil P capital can be built up rapidly with a large, one-time application of P fertilizer (Buresh *et al.*, 1997b), but N capital can be built only gradually through increases in soil organic matter (SOM) (Giller *et al.*, 1997).

Sanchez *et al.* (1997) and Izac (1997) argue that an investment in soil fertility replenishment, which moves smallholder farmers from unsustainable nutrient-depleting production systems to sustainable production systems, can provide socially and environmentally desirable externalities. They further argue that an equitable mechanism for implementation of soil fertility replenishment would be for the implementation costs to be shared among the groups in society that benefit.

SOURCES OF NUTRIENTS

The main sources of N inputs are biological N_2 fixation, organic resources either recycled within the cropping field or concentrated from a larger area and commercial mineral N fertilizers (Giller *et al.*, 1997). Options available to smallholder farmers for providing soil N include (i) crop sequences and intercrops with grain legumes, green manures and trees, (ii) better integration of crop residues and animal manures into the cropping system and (iii) use of mineral N fertilizers.

Soil P becomes available to plants through weathering of soil minerals, release from soil sorption sites and mineralization of SOM. The main sources of P inputs are organic resources either recycled within the cropping field or concentrated from a larger area and commercial P fertilizers (Buresh *et al.*, 1997b). Phosphorus, unlike N, is not biologically fixed from air, and the P content of plant residues and manures is normally insufficient to meet the requirements for sustained crop production (Palm, 1995).

Many smallholder farmers in Africa have lacked the financial means and appropriate incentives to purchase sufficient fertilizer to balance the outputs of nutrients with harvested plant products. The result has been low yields of staple food crops and food deficits, particularly in densely populated areas. This is in contrast to food production in the United States where the large scale of farms and the relatively low fertilizer prices mean that a large amount of grain is produced on land no longer required for domestic food requirements and is exported at low prices. Despite the large increases in the population of the United States during this century, the harvested cropland used to feed its population has decreased by about 30 million ha as a result of high-input agriculture (Buol and Stokes, 1997).

The price of fertilizer at the farm in the United States is much less than that in most rural areas in Africa (Bumb and Baanante, 1996). During the 1996/7 growing season, for example, it was estimated that 1 kg of N as mineral fertilizer cost the equivalent of 20 kg of maize (*Zea mays* L.) grain in Malawi, whereas a farmer in the United States could purchase 1 kg of N with 3 kg of maize grain (S. Carr, 1997, personal communication). Whether fertilizer use will be economic for smallholder farmers in remote regions in Africa without some form of intervention (e.g., improvements in roads, transport, credit schemes, price regulation or direct subsidies), thus remains a topic of vigorous debate.

Museveni (1997) argues that high value crops should be grown on small pieces of land and low value crops on large pieces of land; a sensible approach which should help to provide the income required to purchase fertilizers and other inputs. Unfortunately the range of high value products that smallholder farmers can cultivate is generally rather limited. Fertilizers used on cash crops such as cotton (*Gossypium hirsutum* L.) or tobacco (*Nicotiana tabacum* L.) can give residual soil fertility benefits for subsequent crops. Perennial crops such as coffee (*Coffea* spp.) are attractive because they can provide regular income and scope for intercropping (especially during establishment), which spreads the cost of fertilizers and allows greater nutrient recycling where erosion and leaching are important.

Organic materials can be a relatively important source of nutrient inputs for many African smallholder farmers that lack the financial resources to purchase sufficient mineral fertilizers (Palm *et al.*, 1997). If mineral fertilizers eventually become readily available and more widely used by smallholder farmers, the extra labour and management requirements for use of organic resources or green manuring may well lead to a decline in their use as in the large-scale commercial farming sector in Zimbabwe

(Giller *et al.*, 1997) and much of Asia (Rosegrant and Roumasset, 1988).

STRATEGIES FOR NUTRIENT MANAGEMENT

All productive agriculture results in removal of nutrients at harvest. Careful management can prevent unnecessary wastage and improve the efficiency of nutrient recycling. Soil nutrient levels must, nonetheless, be maintained above a critical threshold through replacement of the nutrients removed at harvest in order to sustain production. This critical threshold will vary for nutrients, yield goals and soil types.

Nutrients can be concentrated onto small areas to create fertile "hot-spots", as is essentially the case where animal manure is used (Giller *et al.*, 1997). But whether on a national, regional or farm scale, the input of nutrients in mineral or organic forms is essential in the long-term with the notable exception of systems where biological N_2 fixation is sufficient to meet N requirements. The basic challenge is how to best target applications of commercial fertilizers and organic materials to ensure that limited financial resources and limited amounts of fertilizer and organic resources are effectively used to produce staple food crops and restore productivity of depleted lands.

Crops typically respond to small additions of nutrients, and increasing rates of nutrients result in diminishing returns (Figure 1). The economic optimum nutrient rate is where marginal costs equal marginal benefits. Nonetheless, high efficiency of input use (crop production per unit of added nutrient) is obtained with small nutrient additions, and strategic use of limited inputs in mineral and organic forms can be advocated (Sanchez, 1994). Indeed, substantial responses in yields of cereals and legumes are often found to amounts of nutrients as small as 25 kg N ha^{-1} and 10 kg P ha^{-1} (Buresh *et al.*, 1997b; Gladwin *et al.*, 1997). When the supply of nutrient inputs for an agricultural area is less than the economic optimum, small seasonal application of inputs to the entire area will result in greater aggregate production for the area than large application of inputs to only a portion of the area.

There can be a minimum threshold nutrient application rate below which the added costs for inputs and their application exceed the added benefits from production. This threshold nutrient rate will normally be higher for organic inputs than commercial mineral fertilizers due to greater labour cost for the application of a unit of nutrient in organic than mineral form. This is consistent with the observation that smallholder farmers frequently concentrate limited quantities of organic inputs on a portion of their crop production area.

Low rates of nutrient inputs might be inefficient when crop response to small nutrient additions is slight, such as when the response curve is essentially "s-shaped" or sigmoidal (Figure 1) (de Wit, 1994; Van Noordwijk, 1998). Sigmoidal response curves, however, remain largely theoretical. The closest we have come to obtaining a sigmoidal response curve under field conditions is when both the parasitic weed striga [*Striga hermonthica* (Del.) Benth.] and P strongly limit maize yield. At a site in western Kenya without N and K limitations, maize responded strongly to 50 kg P ha^{-1} when striga infestation was low (Figure 2). In the presence of high striga infesta-

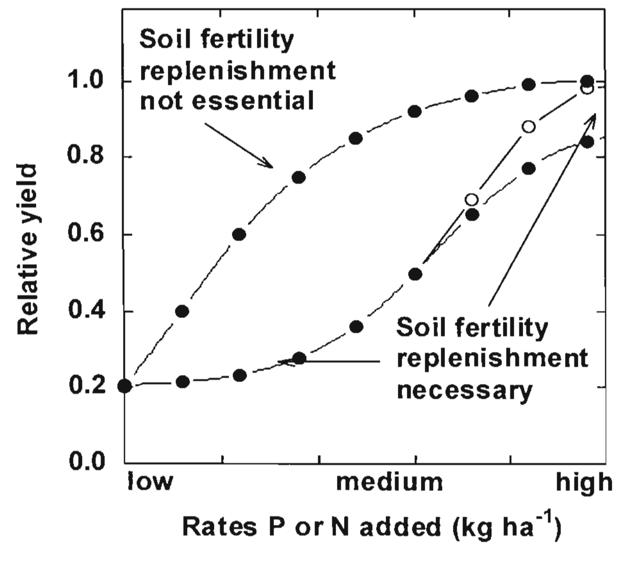

Figure 1. Potential response curves to addition of nutrients as organic manures or mineral fertilizers (adapted from Van Noordwijk, 1998).

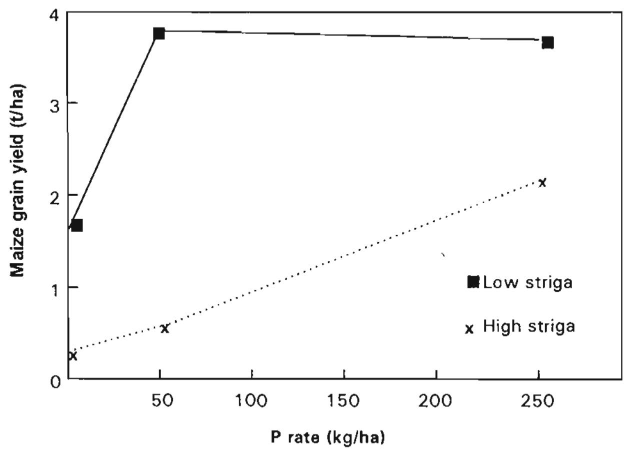

Figure 2. Effects of striga infestation on maize grain yield response to P in an experiment with added N and K in western Kenya (B. Jama *et al.*, unpublished data). Results for low striga are the mean of three replications, and results for high striga are from a fourth replication in the same experiment.

tion, on the other hand, maize response to 50 kg P ha^{-1} was negligible, but then maize yield gradually increased between 50 and 250 kg P ha^{-1}. This apparent sigmoidal response curve indicates that small applications of P would not be effective under conditions of high striga infestation. Either striga control must be combined with P application or very high rates of P application would be required to increase yield.

Although N and P are the nutrients most limiting for production of annual food crops, other nutrients such as K (Anderson, 1974; Smithson *et al.*, 1993) and S (Friesen, 1991) can be required. Some organic resources add significant quantities of several nutrients, in particular N, K, S and Ca. Part of the greater response of maize to tithonia [*Tithonia diversifolia* (Hemsley) A. Gray] green biomass than to urea at equal rates of N reported by Sanchez *et al.* (1997) is due to the addition of P and K with tithonia but not with urea on a soil deficient in P and K. Cations in animal manure (Grant, 1967) can reduce problems of soil acidity and aluminium toxicity.

The amount of available organic resources in smallholder agriculture in Africa, however, is generally insufficient to meet the demand for either N (Giller *et al.*, 1997) or P (Palm *et al.*, 1997). Good crop yields can, nonetheless, be sustained solely by use of mineral fertilizers as long as care is taken to prevent problems of soil acidification, which can occur from prolonged use of N fertilizers. The approach to yield improvement advocated by Sasakawa-Global 2000 relies on large additions of mineral fertilizers, although the need to use organic manures where available is acknowledged (Quiñones *et al.*, 1997).

BUILD UP OF SOIL NITROGEN FERTILITY

Nitrogen deficiency can be rapidly alleviated through the addition of mineral N fertilizers or readily decomposable, N-rich organic materials; but the application of these N sources does not rapidly replenish soil N stocks — the so-called soil N capital. Soil N capital can not be rapidly replenished with a large, one-time application of N in mineral and organic forms. The key to building soil N capital is increasing the SOM content of soil (Giller *et al.*, 1997). The replenishment of soil N capital, however, is not immediately essential to ensure crop production in many cases.

The addition of N in mineral and organic forms should not exceed the N retention capacity of the soil, which is less for sandy than clayey soils. Otherwise, it is likely that N will be lost, thereby reducing economic efficiency of the N input and possibly resulting in associated problems of pollution of water resources and soil acidification. Large additions of N-rich organic manures can lead to substantial N losses due to rapid N release that exceeds N uptake of the crop. Large additions of N-poor organic resources with substantial available C are likely to lead to short-term problems of N availability due to N immobilization.

The amounts of organic materials available for soil amendment in smallholder agriculture are generally too small to build SOM. Therefore, the potential for building SOM, and concomitant soil N capital, is typically limited unless the land is fallowed (Giller *et al.*, 1997). The storage capacity for SOM in soils depends on the amount of clay and fine, silt-sized particles in the soil (Figure 7-3 in Giller *et al.* 1997). Sandy soils typically have little potential to store additional SOM, and hence they have less potential for increasing soil N capital than more clayey soils. There are also risks in sandy soils of leaching of nutrients in organic forms following large additions of organic materials (Brouwer and Powell, 1995).

The greater productivity associated with mineral fertilizer use provides greater inputs of organic residues that can help to maintain SOM (Buol and Stokes, 1997). Soil organic matter has many benefits for crop growth that result both from improvements in soil structure and by ensuring more constant nutrient supply (de Ridder and van Keulen, 1990).

BUILD UP OF SOIL PHOSPHORUS FERTILITY

External interventions by governments or other agencies that aim to replenish soil fertility with large, one-time additions of nutrients to raise farmers above a "poverty threshold" can be an option with P. The P input can be either soluble P fertilizer, direct application of sufficiently reactive phosphate rock (PR) or the combination of soluble P fertilizer and PR (Buresh *et al.*, 1997b). The rates of P required to overcome P deficiency and build soil P capital increase with increasing P-sorption capacity (Buresh *et al.*, 1997b), which can vary greatly among P-deficient soils (Figure 3). Large applications of P are only appropriate on soils with moderate or high P-sorption capacity and without allophane (Sanchez *et al.*, 1997). On such soils, a one-time large application of P would be a long-term investment because of the residual benefits from the added P.

A large, one-time, corrective application of P followed by periodic maintenance applications of P was an essential component of the successful conversion of acid, infertile soils of the Brazilian Cerrado into productive soils (Lopes and Guilherme, 1994). Large applications of P as PR (1 t ha^{-1}) and a cover crop of mucuna [*Mucuna pruriens* var. *utilis* (L.) DC.] are pro-

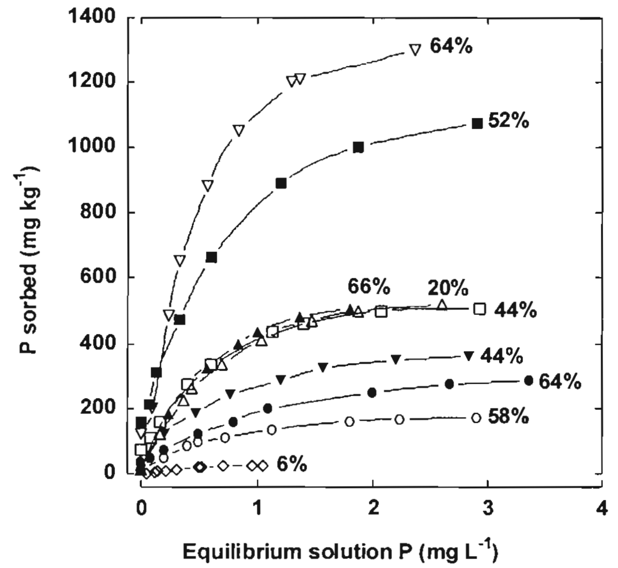

Figure 3. P adsorption isotherms for a range of Kenyan soils (redrawn from Musandu and Giller, 1994). The percentage values refer to the clay content of the soils.

posed for rehabilitation of land in Southeast Asia infested with imperata grass [*Imperata cylindrica* (L.) Räusch.] (von Uexküll and Mutert, 1995). Excessive additions of P undoubtedly risk environmental pollution, but there is emerging evidence that rapid nutrient replenishment of erosion-prone, P-deficient soil can reduce nutrient losses by erosion and runoff. A large, one-time application of P fertilizer to highly P-deficient soil with moderate P-sorption capacity in Kenya reportedly reduced soil erosion and loss of P because of dramatically increased ground cover from vegetation during early crop growth (M.R. Rao, 1997, personal communication cited in Buresh *et al.*, 1997b).

Large, one-time applications of P, however, restrict use of limited quantities of P fertilizers to a relatively small land area in any given season. Small seasonal applications of P fertilizer, on the other hand, enable use of P inputs on a much larger land area at rates on the steep part of the crop response curve. When crops respond to small applications of P rather than follow a sigmoidal response (Figure 1), repeated seasonal applications of P fertilizer can provide greater aggregate yield increase than large one-time applications with the same total quantity of P fertilizer (Buresh *et al.*, 1997b). Assume, for example, that maize yields are 1 t ha^{-1} with no added P, 3 t ha^{-1} with 25 kg P ha^{-1}, and 5 t ha^{-1} with 100 kg P ha^{-1}, but available fertilizer is only 2.5 t P. Then uniform distribution of the P over 100 ha (25 kg P ha^{-1}) will result in a mean yield of 3 t ha^{-1} for the 100 ha, whereas application of all P to only 25 ha (100 kg P ha^{-1}) will result in a mean yield of only 2 t ha^{-1} for the 100 ha.

External interventions with a large, one-time addition of P to replenish P-deficient soils and raise farmers above a "poverty threshold" may be attractive when considering medium-term, macroeconomic policy and ease of implementation. Whether this approach represents the most efficient use of scarce P resources in terms of agronomic efficiency (crop production per unit of added nutrient) can be strongly debatable.

CONCLUSIONS

A recent book on replenishing soil fertility in Africa (Buresh *et al.*, 1997a) has heightened awareness of the problem of soil fertility depletion and demonstrated the existence of substantial knowledge to address the problems of soil fertility in Africa. In the case of N and in many cases with P, the careful targeting of the limited amounts of mineral fertilizers and organic resources to optimize crop responses is probably the most effective way of addressing problems of poor soil fertility for the farmer. However, there are circumstances where large inputs of P and organic matter are an option to restore the productivity of P-deficient lands.

Questions continue to emerge on the need for mineral N fertilizer vis-a-vis biological N_2 fixation and recycled organic resources to increase soil fertility and crop production. A realistic assessment is needed on the proportion of the required N inputs that can be met through biological N_2 fixation and recycled organic resources. Surveys are required to determine the potential to exploit under-utilised niches near cropped fields for production of organic resources. Analyses are merited to determine the potential of crop sequences and intercrops with grain and green manure legumes to supply N via biological N_2 fixation.

The heightened awareness of the need to immediately address soil fertility depletion leads increasing to a debate on the desired balance between policy interventions and investments that "push increased soil fertility" through immediate use of more nutrient inputs and "pull increased soil fertility" through increased markets and processing facilities for a greater diversity of agricultural products. The challenge ahead is to develop carefully targeted nutrient and crop management options together with favourable policies that allow smallholder African farmers to incorporate alternative crop and nutrient strategies into their farming systems to increase and sustain production.

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ORGANIC MATTER MANAGEMENT: FROM SCIENCE TO PRACTICE

CHERYL A. PALM, HERBERT K. MURWIRA[1] and SIMON E. CARTER

Tropical Soil Biology and Fertility Program (TSBF), P.O. Box 30592, Nairobi, Kenya
and [1]TSBF, c/o ACFD, Box A469, Avondale, Harare, Zimbabwe

SUMMARY

Organic inputs have provided the main source of nutrient for crops in most traditional farming systems in Africa. Organic materials influence nutrient availability by nutrients added, through mineralization-immobilization patterns, as an energy source for microbial activities, as precursors to soil organic matter, and by reducing phosphorus sorption of the soil. These organic nutrient sources are increasingly being produced in insufficient quantities and qualities to meet crop demands, however. The shortfall in nutrient supply is often met from applications of inorganic fertilisers where available.

The challenge is to combine organics of differing quality with mineral fertilisers to optimise nutrient availability to plants. A systematic framework for investigating the combined use of organic and inorganic nutrient sources includes farm surveys, characterization of the quality of organic materials, assessment of the fertilizer equivalency value based on the quality of organics, and experimental designs for determining optimal combinations of nutrient sources. The desired outcome are tools that can be used by researchers, extensionists, and farmers for assessing options of using scarce resources for maintaining soil fertility and improving crop yields.

INTRODUCTION

Organic inputs are often proposed as alternatives to mineral fertilizers. However the traditional organic inputs such as crop residues and animal manures cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials, and high labour demands for processing and application. Most farmers fall within the two extremes of the organic to inorganic fertilizer continuum and use a combination of organic and inorganic inputs. Crop yields still fall short of their potential because of inadequate nutrient inputs, the inappropriate quality of the organic materials, and inefficient combinations.

Given the high cost and uncertain accessibility of inorganic fertilizers the goal should be to provide as much of the nutrients as possible through organic materials, making up the shortfall of the limiting nutrients through fertilizers. These goals would change as inorganic fertilizers become more affordable or available. The beneficial effects of the combined use of organic and inorganic nutrients on soil fertility, crop yields and soil organic matter (SOM) maintenance have been repeatedly shown in field trials, yet there are no predictive guidelines for their management.

The success of combined nutrient management depends on several factors, including the availability and affordability of different types of inorganic fertilizers, the types and quantities of organic materials available, and the rates and proportions at which the two nutrient sources are combined. Most studies have included animal manures and crop residues as the organic additions while there has been relatively little research on the use of alternative, higher quality organic resources, such as leguminous cover crops and agroforestry species.

A systematic approach that includes organic materials of different qualities and their combinations with inorganic nutrients is needed to develop guidelines for the selection and efficient management of these scarce resources.

EFFECTS OF ORGANIC MATERIALS ON NUTRIENT AVAILABILITY

Organic inputs can influence nutrient availability:

(i) by the total nutrients added,
(ii) by controlling the net mineralization-immobilization patterns,
(iii) as a source of C and energy to drive microbial activities,
(iv) as precursors to SOM fractions, and
(v) through interactions with the mineral soil in completing toxic cations and reducing the phosphorus (P) sorption capacity of the soil.

In addition to these direct effects on nutrient availability, organic materials can affect root growth, pests, and soil physical properties that in turn influence nutrient acquisition and plant growth. The net effect of these different mechanisms on nutrient availability and plant growth differ with climatic regime, soil type, and quality and quantity of organic inputs.

Sources of Nutrients

Organic inputs such as manures, cover crops, and green manures have generally been assessed in terms of their nitrogen (N) concentration, while relatively little attention has been paid to other macronutrients and micronutrients present in organic materials. Organic inputs should be considered as complete fertilizers (NPK) perhaps the best being those containing or releasing the nutrients in the ratios and rates required by crops.

Nutrient Contents

The nutrient contents of organic materials, ranging from crop residues to agro-industrial wastes, vary widely. Table 1 compares the nutrients contained in a variety of organic materials and the nutrients required to produce a modest two Mg crop of maize grain plus three Mg of stover. Although all the nutrients in the organic materials will not be available to a crop, the information can be used for an initial assessment of the type and amount of organic materials that are appropriate for a given cropping system and yield goal. These estimates can then be adjusted knowing that crop recovery of N supplied by high quality leguminous green manures is rarely more than 20% (Giller and Cadisch, 1995) while that recovered from lower quality cereal stover is generally much lower.

Some organic materials such as poultry manures contain sufficient nutrients in 1 to 2 Mg for a 2 Mg maize crop, while others such as crop residues require almost 10 Mg to match that contained in the 2 Mg maize crop. Cattle manure varies tremendously in its quality and fertilizer value. Extremes are found in manure obtained from commercial dairy farms compared to that from the communal areas of Zimbabwe (Mugwira and Mukurumbira, 1984). It is the latter, low-quality manures, that predominate on smallholder farms of Sub-Saharan Africa (Probert *et al.*, 1995). In comparison, many leguminous trees and cover crops contain sufficient N in 2 or 3 Mg of leafy material (Giller and Cadish, 1995).

As a general rule. many organic materials when applied in modest amounts, i.e. less than 5 Mg dry matter ha^{-1}, contain sufficient N to match that of a 2 Mg crop of maize but they cannot meet P requirements and must be supplement by inorganic P in areas where P is deficient (Palm, 1995).

Quantities of Organic Materials Available to Farmers

How do the amounts of organic materials required to meet crop nutrient requirements compare to the amounts available to farmers? Average millet stover production of 1.3 Mg ha^{-1} in the Sahel is less than the 2 Mg of mulch recommended (Bationo *et al.*, 1995). Crop residues also have competing uses, primarily as feed for livestock, that reduce the amounts available for soil fertility management. An average of less than 700 kg ha^{-1} of manure, ranging from 450 to 1600 kg ha^{-1}, is available for semi-arid West Africa. This is much less than the 3 to 7 Mg ha^{-1} recommended for replenishing nutrients removed by crop harvest (Fernandez-Rivera *et al.*, 1995). Manure production by zero-grazed cattle in Kenya has been estimated as

Table 1. Average nutrient contents on a dry matter basis of selected plant materials and manures collected in East and Southern Africa.

Material	N	P	K
	---------- kg Mg ----------		
Crop residues			
Maize stover	6	>1	7
Bean trash	7	>1	14
Banana leaves	19	2	22
Sweet potatoes leaves	23	3.6	-
Sugar cane trash	8	>1	10
Coffe husks	16	4	-
Refuse compost	20	7	20
Animal manures			
Cattle			
High Quality	23	11	6
Low Quality	7	1	8
Chicken	48	18	18
Farmyard Chicken	24	7	14
Leguminous tree (leaves)			
Caliandra calothyrsus	34	2	11
Gliricidia sepium	33	1.5	21
Leucaena leucocephala	34	1.5	21
Sesbania sesban	34	1.5	11
Senna spectabilis (non-N2-fixing)	33	2	16
Non-leguminous tree/shrubs (leaves)			
Chromolaena ordorata	38	2.4	15
Grevillea robusta	14	>1	6
Lantana camara	27	2.4	21
Tithonia diversifolia	36	2.7	43
Leguminous cover crops			
Crotalaria ochroleuca	42	1.6	9
Dolichos lablab	41	2.2	1.3
Mucuna pruriens	35	2.0	7
Nutrients required by 2 Mg maize grain	**80**	**18**	**60**

The TSBF database is the source of all data unless otherwise noted.

Source, Nandwa (unpublished data).

Source, Mugwira and Mukurumbira, 1984

1 to 1.5 Mg animal^{-1} yr^{-1} (Strobel, 1987). Two animals would be needed to supply a 2 Mg maize crop, if the manure were of high quality, but eight animals are required if the quality is low.

Increasingly the traditional nutrient sources for soil fertility management are produced in insufficient quantities and quality to meet crop demands. Alternative higher quality sources must be found but there must also be niches on farms, or the vicinity, where they can be produced (Garrity and Flinn, 1988). Leguminous plant materials provide higher quality organic inputs to meet N demands, if not P, but incorporating non-food legumes in the farming system requires a sacrifice of space or time that is normally devoted to crop production. Additional labour requirements for planting, transporting, and incorporating these materials is also high (Ruhigwa *et al.*, 1995). As such, legumes for soil fertility improvement have not been widely adopted by farmers (Garrity and Flinn, 1988; Giller and Wilson, 1991). The economic and social trade-offs of improved soil fertility using legumes and other high quality organic materials must be properly assessed in comparison to that of the management of crop residues and animal manures.

Even if crop residues and other low quality organic materials can be obtained in sufficient quantities, net N and probably P immobilization will occur, exacerbating the nutrient deficiencies, at least temporarily. The negative effects can be offset by combining with inorganic N (Msumali and Racz, 1978) or high quality organic materials with N contents greater than 2% and P greater than 0.3% (Smith *et al.*, 1993). There are no guidelines as to the amounts of inorganics or high quality materials needed to offset these negative effects; though as much as 100 kg N ha^{-1} of fertilizer N can be needed to overcome the immobilization resulting from mulching with maize stover.

Although there is some degree of predictive capacity relating nutrient release patterns to organic resource quality, there has been little attempt to relate organic resource quality to fertilizer equivalency values. Frequent claims state that green manures have fertilizer equivalency values of 50 to 100kg N ha^{-1} (Meelu and Morris, 1985; Ladha *et al.*, 1988) but many trials do not provide sufficient information that allows one to relate the fertilizer equivalency to the quality of the organic materials. Often there is no information given on the amount of the green manure added, its nutrient content, or C constituents. Indeed as pointed out by Bouldin (1988), the green manure might be a replacement for a limiting nutrient, usually N, and in such cases a fertilizer equivalency value is useful. Or the green manure may have additional nutrient or physical factors that influence the uptake and utilization efficiencies (van Noordwijk and van den Geijn, 1996) and cannot be explained by the addition of N. In such cases, the fertilizer equivalency value is not very useful.

COMBINING ORGANIC AND INORGANIC NUTRIENT SOURCES

Because the role of organics is varied and complex, there is a big challenge to utilize organics of differing quality in combination with inorganic fertilizers to optimize nutrient availability to plants. This requires knowing how the nutrient content and C quality of organic materials will add to, compensate for, or reduce, nutrient availability from inorganic fertilizers. The term interaction is frequently used to describe the net effects of the combined use of organic and inorganic sources. This term implies to some, a magic effect of organic materials, whereas to others it merely means a statistical interaction. A better phrase than interactions might be "added benefits" (or disadvantages) resulting from the combined use of organic and inorganic inputs compared to inorganics alone. In general, the nutrients supplied by the addition of organics are additive to those supplied by inorganic nutrient sources (Paustian *et al.*, 1992; Jones *et al.*, 1996). Added benefits, or disadvantages, of combined nutrient additions are probably more related to the quality of the organic material and its effects on nutrient availability.

Unfortunately, there has been little synthesis of the integrated effects of organic materials on net nutrient availability that could provide guidelines for combined nutrient management. An examination of past field trials, and soil + crop simulation models where the processes are integrated, may provide a starting point for assessing the relative importance of the various effects with different quality organic materials.

The original intent of this paper was to review and synthesize information from the numerous trials that have been conducted using combinations of organic and inorganic nutrient sources. It quickly became apparent that most trials did not permit interpretation and extrapolation that led to management guidelines because of their experimental designs.

Numerous trials have compared the yields from a given amount of inorganic fertilizer (A), an organic material (B), and their combination (A+B), and in many situations (A+B) produced higher yields than A or B alone. It should not be surprising that the combination does better because more total nutrients have been added than in A or B alone. Nutrients from the organic sources are considered in an additive manner (1A+1B) to that of the inorganic source, rather than looking at the substitution value (xA+yB), where the sum of x and y equal 1). Critical information on the nutrient content and quality of the organic is often not provided. Despite some design flaws, a number of observations can be made on the combination of organic inputs of varying qualities and inorganic fertilisers on crop yields and nutrient use efficiency.

It is commonly believed that combining organics with the inorganic fertilizer will increase synchrony and reduce losses by the conversion of the inorganic N into organic forms. Studies have generally looked at organic inputs of lower quality, such as crop residues. There are trade-offs between possible reductions in yields from the use of organic materials and greater potential nutrient losses with the use of inorganic nutrients alone. Is it possible that high quality organic materials can reduce losses of inorganic N without reducing yields considerably?

FRAMEWORK FOR INVESTIGATING THE COMBINED USE OF ORGANIC AND INORGANIC INPUTS

The capacity to make practical recommendations on the use of organic materials as a source of nutrients for crops will be limited until the different factors that affect yields are separated and accounted for through appropriate trials and the organic resources are sufficiently characterized. This is a complex task. To advance from the current empirical status to a predictive capacity for the selection and management of combined organic and inorganic inputs, a few knowledge gaps must be filled, which requires appropriate hypotheses and experimental designs. A systematic framework is proposed for the investigation of combined organic and inorganic inputs (Figure 1).

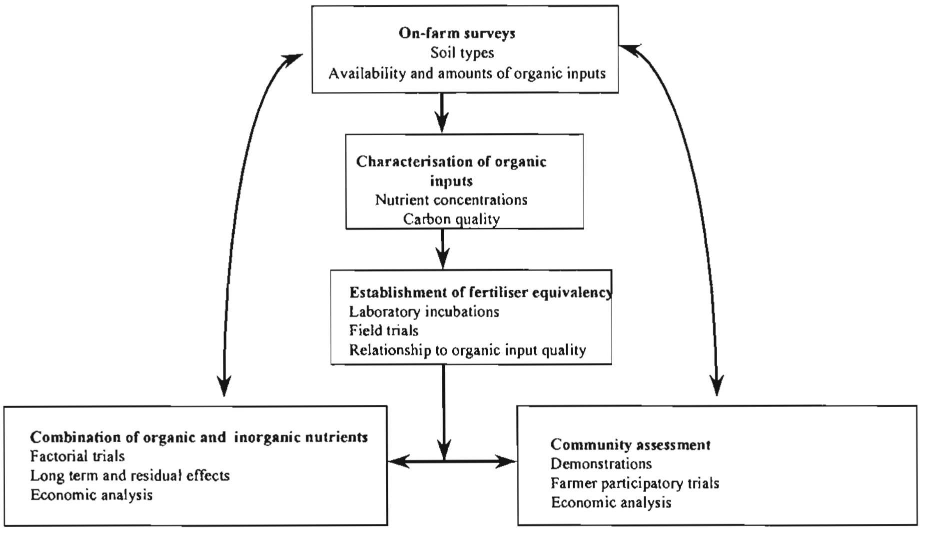

Figure 1. A systematic framework for investigating the combined use of organic and inorganic nutrient sources

An initial step is to identify available organic materials and soil types in the target area. The soils of the area must also be characterized in terms of the primary limiting nutrients. This can be done by soil tests or limiting nutrient trials.

Organic materials that have been identified should then be characterized for their quality parameters. A minimum list of parameters that should be included are macronutrient concentrations, lignin, soluble C, ash, and soluble polyphenols (if the N concentration is greater than 1.8%). Standardized methods for these analyses are also recommended (Palm and Rowland, 1997). Once a sufficient number of materials of the same species has been characterized to indicate the possible range in quality within a species, then it might be possible to categorize a plant material into a specific quality grouping without analyzing the material.

Fertilizer equivalency or nutrient substitution values of organic materials can then be determined and related to the quality of the material. Such information could be obtained through a combination of laboratory incubations and field trials.

Incubations establish the amount of different organic materials needed to attain similar soil available nutrient levels for a given amount of fertilizer. Field trials test recommendations from the incubations on different soils and climates and models extrapolate to other types of organic materials and environments.

Field trials usually relate the yields obtained from organic inputs to that obtained from an inorganic response curve. One must be certain of the limiting or co-limiting nutrients of a particular soil and then decide if the trial will assess the nutrient equivalency of one or multiple nutrients. If only one nutrient is to be assessed then the other nutrients must be supplied in unlimiting quantities in the inorganic response curve and the organic treatments. If multiple nutrients are to be assessed, additional multiple nutrient response curves must be included. Rates of nutrients applied from the organic sources must be on the responsive part of the fertilizer response curves, if not, then trials will not be useful.

The outcome of these types of trials will permit grouping of organic materials into like categories, based on their quality, that have similar nutrient substitution capacities per unit of added material. As an example, the recommendation might say that for materials with N content of 4%, lignin content < 5% and polyphenol < 35 then 4 Mg of materials is needed to produce an N equivalency of 80 kg N. This type of material containing 160 kg N would have an N application efficiency 50% of that of the fertiliser. These recommendations would, of course, differ with soil, climate, and crop.

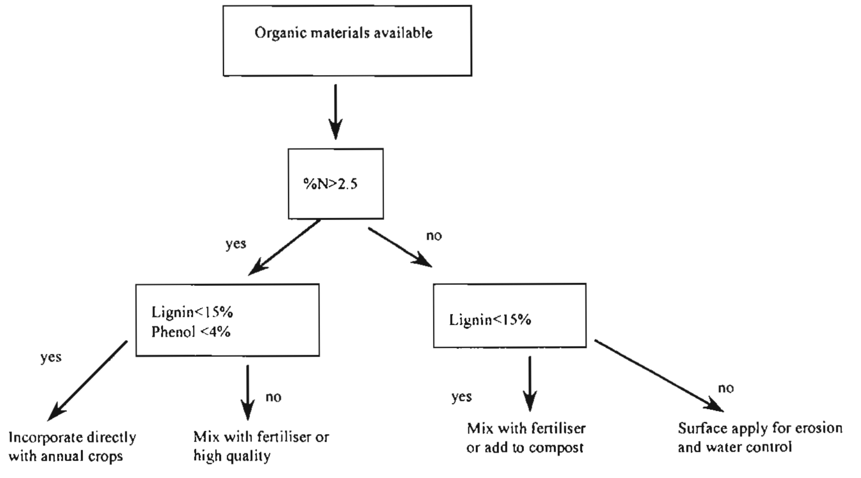

Figure 2. Decision tree on use of organic materials of different quality

Once fertilizer equivalency values have been established for different groups of plant materials, trials can determine the substitutive effect of different quality organics at different proportions of organic to inorganic sources. These trials could be factorial with several rates of both the organic and inorganic materials or substitutive in which the organic and inorganic are added in at different proportions but the total amount of nutrient added is the same (Mittal *et al.*, 1992). Both types of trials have merit.

A factorial arrangement of treatments provides a means for comparing different rates but has the limitation that most of the combined treatments are additive rather than substitutive in nature. The number of treatments quickly becomes prohibitive if more than one organic material is assessed in which case confounded designs can be used. For assessing low quality materials perhaps only one rate of organic material, that normally used by farmers, should be used with several rates of the inorganic to determine how much inorganic fertiliser is needed to overcome the negative effect of the low-quality organic.

The other design in which the total amount of nutrients added is the same but the proportion of organic to inorganic source changes is useful to determine the optimal combinations in terms of economics, nutrient use efficiency, and residual effects. This design will indicate if the two nutrient sources are merely substitutes or is there some additional benefit or disadvantage to be derived from the organic material. Economic analyses of the various organic-inorganic combinations should be conducted under current conditions and future scenarios, to indicate realistic management options.

These trials should be planned for the long term to assess residual effects and changes in SOM composition as they relate to the quality of the organic material and the proportion of organic to inorganic. Until such trials are conducted that link the quality of the organic material to its fertilizer equivalency value and its effect on the longer term composition of SOM and crop yields there will be no means of providing guidelines for the combination and efficient use of organic and inorganic inputs.

The desired outcome of the research process detailed above are fairly simple tools that can be used by researchers, extensionists, and farmers for assessing different ways of using scarce resources for maintaining soil fertility and improving crop yields. An example of one such tool is a preliminary decision tree on the uses of organic material of different quality for N management (Figure 2). The decision tree is a current best bet based on research results. It can be modified as more information becomes available but more importantly implemented with farmers' and modified based on their experiences and available resources.

LINKING ORGANIC MATTER MANAGEMENT WITH FARM PRACTICE

The above sections have so far detailed a biophysical approach for investigating the combined use of organic and inorganic nutrient sources. The emphasis has so far been on characterising the quality of organics, an assessment of the fertiliser equivalency based on the quality of the organics, and the experimental designs for determining optimal combinations of nutrient sources. For research on organic matter management to be context sensitive, it is essential that the approach should include farm surveys to characterise the farmer's circumstances and practices first. An initial step is to conduct surveys, that include interviews and visual assessment of the farm vicinity and community, on the availability and quantities of organic materials and fertilizer. Emphasis should be placed on alternative, high-quality materials that exist in the landscape or for niches to plant non-food crop legumes. The surveys should also assess the farmers' current soil fertility management practices, constraints and opportunities. Farmer involvement should however be a continuous process at all levels of on-farm experimentation.

Local farmers are rational and manage resources available to them in a systematic fashion, albeit determined by a complexity of socio-economic and environmental conditions. The types of nutrient management strategies that farmers adopt depend on factors such as soil type and wealth rank. Work on wealth ranking has shown how households with more labour, land, livestock and off-farm income are able to use greater quantities and a wider variety of nutrient sources than poorer households (Carter *et al.*, 1993).

The risk and uncertainty in the environment often dictate that soil management practices should be dynamic. In view of the complexity and uncertainty in the farmer's environment, it is important to identify the constraints and opportunities for modifying and changing practices. Many opportunities exist for improving the efficiency with which nutrients are managed on-farm. A more integrated use of organic and inorganic nutrient sources is one possibility which farmers are already exploring. In north-east Zimbabwe, farmers apply organic and inorganic nutrient inputs differentially to different agro-ecological niches depending on soil nutrient status and perceived returns to nutrient applications (Carter and Murwira, 1995). The fine-tuning of nutrient management strategies to crop and soil type is an important lesson to be gained from farmers.

CONCLUSIONS

Many farmers in Sub-Saharan Africa, and their colleagues worldwide, are currently combining organic and inorganic sources of nutrients to try to meet crop demands. Yields obtained are far below their potential because of inadequate amounts added, the low quality of the organic materials, and inappropriate or inefficient combinations. Given the high cost and uncertain accessibility of inorganic inputs, the goal should be to provide much of the nutrients through organics and make up the shortfall of the limiting nutrients through inorganic fertilizers. Where the quality and quality of organic materials is low, there is a need to find alternative high quality organic materials which can be incorporated in the current farming systems.

Despite numerous field trials combining organic and inorganic inputs at present it is not possible to recommend guidelines for combining organic and inorganic nutrients, because of inadequate experimental design and little information on the quality of organic inputs. Inorganic fertilizers can offset the negative effects of low quality organics but how much cannot be specified. Higher quality organic materials can substitute for inorganic fertilizers, but there are no prescriptive guidelines that relate the quality of the organic material to its nutrient substitution value.

Prescriptive guidelines are possible once links are made between the quality of the organic materials and their short-term fertilizer equivalency value and longer term residual effects through SOM formation. These guidelines must also incorporate farmer perceptions and circumstances, including available resources, resource allocation, farm niches, soil types and limiting nutrients.

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DISCUSSION: KEY ISSUES WITH SOIL FERTILITY RESEARCH

Questions to Roland Buresh

From: George Kanyama-Phiri
You indicated that when soil acidity is considered you need several sites to draw meaningful and widely-applicable relationships. How many sites (or data points) would you consider adequate?

Response:
It is important that the sites are distributed over a range of the factor. In selecting sites, aim to select some extremes with high and low levels of the factor. For a simple correlation perhaps eight to ten sites (data points) are sufficient.

From: George Kanyama-Phiri
Your presentation related largely to improved fallows. Does the issue of relationships between biomass production and residual fertility effects on crop yields equally apply to relay cropping based on one season?

Response:
The principle of possible relationship between biomass production and yield of following maize crops should apply in a relay cropping system. The exception may be when competition from high biomass production suppresses crop yield.

Comment from: Cheryl Palm
There is a need to package research information. Soil pH is an indicator of potential growth for some species (the cover crops and legume trees mentioned). We need to package trial information to reach those that decide on tree and cover crop selections. Also we need to know the client and where one will run trials. pH is easy to measure -- we must know pH at our trial sites.

Question to Cheryl Palm

From: Herbert Dhliwayo
In most participatory rural appraisal work, the "Farmer Practice" is absent in the list of experimental treatments. Did you include the farmer practice and, if not, please indicate how the farmer practice can be incorporated?

Response:
That is a good point. In the first set of trials where extension workers modified an on-station trial there was no farmer control. But then the farmers evaluated yields and said there was no farmer practice. The second generation of trials included the farmer practice as a control as well as a no-input control.

Comment from: Suzgo A. Kumwenda
While the Soil Fertility Network is underway it is a great opportunity for scientists to gather as much information as possible. However, it is essential to isolate best bet technologies that can be worked with the farmers.

THE IMPACT OF LEGUMES RELAY-INTERCROPPED INTO MAIZE AT DOMBOSHAVA, ZIMBABWE

PETER JERANYAMA[1], ORAN B. HESTERMAN[1] and STEPHEN R. WADDINGTON[2]

[1]Department of Crop and Soil Sciences, Michigan State University, Plant and Soil Science Building, East Lansing, MI 48824, USA and [2]CIMMYT-Zimbabwe, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe

SUMMARY

The impact of relay-intercropping a food legume (cowpea, Vigna unguiculata *L.) and a tropical forage legume (sunnhemp,* Crotalaria juncea *L.) into maize was evaluated at Domboshava in Zimbabwe. For both legumes the accumulation of dry matter was greatest at 75 days after relay-intercropping. Herbage biomass (averaged over two years) was 2.3 Mg ha^{-1} for cowpea and 3.1 Mg ha^{-1} for sunnhemp. Highest total nitrogen (N) accumulation in the legume biomass was 111 kg N ha^{-1} for sunnhemp and 59 kg N ha^{-1} for cowpea. Relay-intercropped maize fertilized with 60 kg N ha^{-1} had grain yields equal to or better than those of a sole maize crop at the same fertilizer rate. However at the other N rates, maize yields were reduced indicating competition between the maize and the legume. In the subsequent year, maize following maize relay-intercropped with the legume produced 20% more grain yield than the sole maize control. The grain N content of a subsequent maize crop was improved by 82% relative to the sole maize control. The legume replaced up to 36 kg N ha^{-1} of the N requirements in the subsequent maize crop.*

INTRODUCTION

While increased maize production in Africa will continue to put emphasis on the use of inorganic fertilizers, green manure cover crops are a source of plant nutrients that can be produced and used within local environments. Green manures offer a practical complement to inorganic fertilizers (Blackie and Jones, 1993).

Green manures were recommended in Zimbabwe (then Rhodesia) in the 1950's to help supply the nitrogen (N) needs of maize (Tattersfield, 1982). Then inorganic fertilizers were not recommended and the ratio of maize to legume green manure area reached 4:1, and seed for green manures was scarce. The increasing availability of cheap inorganic fertilizers after World War II replaced the legume green manure practice (Tattersfield, 1982).

Increasing real inorganic fertilizer costs will see most smallholder maize produced with very little or no fertilizer inputs. But the growing of legume green manures on fallow land has been rejected by smallholders because of the labour and land constraints. Therefore there is greater potential to integrate legume green manures in the existing maize cropping systems as intercrops. If legumes are interseeded on time, growth competition with the maize crop can be reduced at the same time that plant biomass and N can be accumulated by the legume cover crop. This technology is unlikely to benefit the current maize companion crop, but will benefit a subsequent maize crop.

Legume cover crops are included in cropping systems because they reduce soil erosion (Scott, Mt.Pleasant, Burt and Otis, 1987), smother weeds (Stute and Posner, 1993), conserve soil moisture (Utomo, Frye, and Blevins, 1990) and fix biological nitrogen (Giller, McDonagh and Cadisch, 1994). A legume cover crop may contribute N to a subsequent non-leguminous crop, reducing N fertilizer needs by 100 kg N ha^{-1} and more in some cases (Giller and Wilson, 1991; Hesterman, Griffin, Williams, Harris and Christenson, 1992). Biological N contribution is probably the main reason why farmers include legume cover crops in cropping systems. However, cover crops can also deplete the soil moisture necessary for grain production in semi-arid areas (Badaruddin and Meyer, 1989) and can compete for light and nutrients with the revenue crop. There is a need therefore to develop green manure strategies that comply successfully with the overarching necessity of water conservation in dryland cropping systems.

Annual herbaceous legumes may provide opportunities for cover crops that provide biological N and at the same time reduce water deficit problems associated with the longer-lived woody perennial legumes being promoted in agroforestry. However, the supply of herbage biomass from herbaceous plants will likely be insufficient to overcome soil N deficiencies on smallholder farms. The integration of small amounts of inorganic N fertilizer with the organic materials available offers a strategy to meet the N needs of smallholder crops.

The objectives of this study were to:

- Quantify legume biomass and N accumulation of a food and forage legume relay-intercropped into

maize
- Evaluate the impact of relay-intercropped legumes on companion maize yield and growth, and
- Measure the response of a subsequent maize crop to relay-intercropped legumes and compare this with the response to inorganic fertilizer.

MATERIALS AND METHODS

Management

Maize (hybrid R215) was hand-planted at Domboshava, near to Harare, on tractor disc-ploughed land in two cropping years (1995/96 and 1996/97). An initial fertilizer of 22 kg N ha^{-1}, 38.5 kg P ha^{-1} and 19.5 kg P ha^{-1} was applied as Compound D (8 14 7). Additional N fertilizer at 0, 60 and 120 kg N ha^{-1} as NH_4NO_3, was applied in designated plots to the soil surface as a dollop about 48 days after planting, when the moisture level in the ground was at field capacity. Maize plant spacing was 0.9m between rows and 0.5m between stations within a row, at two plants per station. Each plot was 10m x 6.4m. The experiment was weeded by hand-hoes throughout the period whenever it was necessary.

Two legumes, cowpea (*Vigna unguiculata* L.) (a food legume) and sunnhemp (*Crotalaria juncea* L.) (a tropical forage legume) were relay-intercropped into maize (two rows of legume between two rows of maize) in each of the two years at approximately 28 days after maize planting in appropriate plots. Legumes were seeded at within-row spacings of 10 cm, achieving a plant population density of 111 000 plants per hectare. In addition, a plot with maize alone with no fertilizer or legume was included in each replicate as a control.

Above-ground biomass of the legumes was determined by sampling at 45, 60 and 75 days after relay-intercropping (DAP) from a $0.09m^2$ quadrat. The legumes were separated from weeds and the legumes were dried at 60 ^{0}C for four days and the dry matter yield determined.

Maize grain was harvested from a 1.8m and 4m section of the centre two rows in each plot so that the area harvested was $7.2m^2$. Grain yields were adjusted to 125 g kg^{-1} moisture content. Maize stover was harvested from a single centre-most row in a 0.9m and 4m section and yields were expressed as dry matter.

In the subsequent year, maize following maize with relay-intercropped legume were established. This maize was fertilized with two split applications of 0, 46, 92 and 138 kg N ha^{-1}, initially as Compound D at planting and NH_4NO_3 as a side dress at about knee height (eight leaf stage).

Plant and Chemical Analysis

Total N in the maize grain, stover and legume biomass was determined by a modified macro-Kjeldahl method in 1996 and a micro-Kjeldahl analysis in 1997. Plant material were ground in a Wiley mill to pass through a 2-mm screen. Plant samples of 0.5 g were digested in 25 cm^3 of 18M H_2SO_4 in the presence of a kjeltab with selenium as catalyst in 1996, while in 1997, 0.1g of plant sample was digested in 4 ml of 18M H_2SO_4 with 1.5g KSO_4 and 0.075 g Se catalyst. Following digestion, total NH_4^+ was determined by mixing the digest with $100cm^3$ of 40% NaOH followed by distillation into 50 cm^3 of 4% Boric acid. Amount of N (NH_4^+) was then determined by back titration using a standardised HCl in 1996 and calorimetry in 1997. Total N contents were calculated as the product of dry matter yield and nitrogen concentration.

Statistical Analysis

The experiment in the inter-seeding year was analyzed as a randomized complete block design (RCBD) for maize grain, total above-ground biomass, grain N content and total plant N-uptake. Data were analyzed as a repeated measures design with a first-order auto-regression correlation type [AR(1)] for the legume herbage biomass (DM) and legume N content in proc mixed (SAS Institute, 1997).

In the subsequent year, data were analyzed as a RCBD, with a split-plot arrangement and replicated three times. The first year crops [maize + 1st-yr N or maize (legume +1st-yr N)] were whole plots and 2nd-yr N rates as subplots. Analysis of variance using Proc GLM of SAS (1997) was used to identify treatment effects. Significant effects due to the 1st-yr crop were further partitioned using single degree of freedom orthogonal contrasts. Response to N fertilizer rate of 2nd-yr were determined by evaluating linear and quadratic trends from single degree of freedom comparisons. Whenever trends were significant, regression equations were calculated to determine fertilizer replacement values of relay-intercropped legumes in the preceding year.

RESULTS AND DISCUSSION

Legume Dry Matter and N Content

Due to a significant interaction between sampling date (DAP) and legume type, data are presented as effects of legume type and sampling date on dry matter yield and N content. Because the highest legume herbage biomass and N content were obtained at 75 DAP, data presented are only those at this sampling period (Table 1). In 1996, sunnhemp had the highest dry matter yield of 2.03 Mg ha^{-1}. In 1997, cowpea had the highest herbage biomass (3.1

Table 1. Legume herbage biomass and N content at 75 days after relay-intercropping.

Year	Cowpea		Sunnhemp	
	DM (Mg ha^{-1})	N (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})
1996	1.15	30.97	2.03	52.12
1997	3.10	110.68	1.99	59.11

Mg ha^{-1}) and at this time cowpea was already podding. Therefore the cowpea herbage biomass in 1997 was associated with grain yield from the pods. These amounts of herbage biomass are similar to those noted with pigeon pea (*Cajanus cajan* L.) (2.07-3.21 Mg ha^{-1}; Kwatpata, 1984) and cowpea grain (0.8-1.5 Mg ha^{-1}; Mariga, 1990).

Sunnhemp had an N content of up to 55 kg ha^{-1}, while the highest N accumulation was 111 kg ha^{-1}, with cowpea (Table 1). The N content in these intercropped legumes compared very well with other measurements in the tropics which have shown that green manure legumes can often accumulate 100-200 kg N ha^{-1} in 100-150 days (Giller and Wilson, 1991). Measurements recorded by Giller and Wilson (1991) are from sole legume crops, and are based on true N fixation from isotope studies. In our study, N content was measured as the product of N concentration in the legume biomass and herbage dry matter yield and our method will likely overestimate genuine N fixation. On average, N concentrations in the above-ground biomass were 32 g N kg^{-1} for cowpea and 28 g N kg^{-1} for sunnhemp.

Maize Relay-Intercropped Yields

Relay-intercropping of either cowpea or sunnhemp into unfertilized maize resulted in a reduction of maize grain yield by about 12% in 1996 (Table 2), and 7 % in 1997 (Table 3). Grain yields were not reduced when legumes were relay-intercropped into maize fertilized with 60 kg N ha^{-1}, in both years. Relay-intercropping into maize fertilized with 120 kg N ha^{-1} resulted in a maize grain yield reduction of 18% in 1996 (Table 2) and 32% in 1997 (Table 3).

Total above-ground maize biomass was reduced by 8% in each year when sunnhemp was relay-intercropped into unfertilized maize (data not shown). Total biomass was either maintained or slightly improved (by 1-10%) when unfertilized maize was relay-intercropped with cowpea. Like with grain yield, total above-ground biomass did not result in higher yields when fertilized by more than 60 kg N ha^{-1}.

Grain N content was not significantly (P = 0.05) reduced in unfertilized maize inter-seeded with legumes in both years (Tables 2 and 3). A significant grain N content reduction of 34% at 120 kg N ha^{-1} was noted with maize relay-intercropped with legumes in 1997 (Table 3).

Subsequent Year

In the subsequent year, legume type did not affect maize grain yield, grain N uptake or total above-ground biomass and total N uptake of maize. Data presented are effects of legume (combined) and 2nd yr N rate on yield. Maize following maize that had been relay-intercropped with legume had a 20% grain yield improvement relative to the control [maize following maize with no legume and no N] (Table 4). Grain yield also responded linearly to N fertilizer. Other researchers have noted similar yield

Table 2. The effect of fertilizer N on grain yield, grain N content, total above-ground biomass and total N uptake of maize relay intercropped with legumes in 1996.

Nitrogen applied (kg ha^{-1})	Grain yield (Mg ha^{-1})		Grain N uptake (kg ha^{-1})	
	No legume	With legume	No legume	With legume
0	1.45c	1.27c	15.47b	16.72b
60	2.35a	2.26ab	26.66a	27.52a
120	2.51a	2.06b	31.12a	27.08a

Data associated with the same letter are not significantly different at P = 0.05.

Table 3. The effect of fertilizer N on grain yield, grain N content and total above-ground biomass of maize relay intercropped with legumes in 1997.

Nitrogen applied (kg ha^{-1})	Grain yield (Mg ha^{-1})		Grain N uptake (kg ha^{-1})	
	No legume	With legume	No legume	With legume
0	1.92c	1.79c	20.01c	17.02c
60	5.16b	5.66b	53.54b	50.46b
120	6.58a	4.51b	79.73a	52.59b

Data associated with the same letter are not significantly different at P = 0.05.

Table 4. Effect of relayed legume on the subsequent maize grain yield and total above-ground maize biomass in Domboshava in 1997.

Legume (1996) + Nitrogen rate (kg ha^{-1})	Grain Yield (Mg ha^{-1})	Total above-ground biomass (Mg ha^{-1})
0	1.98 (120)	6.21 (94)
46	3.40 (206)	7.77 (118)
92	4.04 (245)	7.97 (121)
138	4.46 (270)	8.66 (131)
Control	1.65 (100%)	6.60 (100%)
LSD (0.05)	0.68	1.23

increases, for example Agboola and Fayemi (1972) working with pigeon pea, mucuna (*Calopogium mucunoides* L.) and cowpea, obtained a yield increase of 10-30% in subsequent maize crops.

Total above-ground biomass was lower by 6% relative to the control. Total biomass was improved relative to the control by a modest application of fertilizer (Table 4). Grain N content for unfertilized maize following maize inter-seeded with legume was associated with an 82% increase in N uptake relative to the control (Table 5). Grain N content showed the greatest positive response to legumes in the previous year. Similar responses for grain N content have been reported by Hesterman, Sheaffer and Fuller (1986) and Hargrove (1986) in the temperate regions. Total N uptake was 38% higher in the subsequent year compared to the control and overall, N uptake was improved with the application of N fertilizer (Table 5).

Table 5. Effect of relayed legume on the subsequent maize grain N uptake and total maize plant N uptake in Domboshava in 1997.

Legume (1996) + Nitrogen rate (kg ha^{-1})	Grain N content (kg ha^{-1})	Total plant N-uptake (kg ha^{-1})
0	26.00 (182)	54.18 (138)
46	25.20 (177)	52.16 (133)
92	30.64 (215)	57.45 (147)
138	34.81 (244)	66.84 (171)
Control	14.25 (100%)	39.18 (100%)
LSD (0.05)	9.57	10.95

For the cropping systems under examination to be acceptable, there will have to be a convincing improvement of yield or N uptake in the subsequent year, while there should be an acceptable small yield reduction or maintenance in the inter-seeding year. One way to assess improvements in the subsequent year is to calculate fertilizer replacement values (FRV). For an FRV to be acceptable by the farmer, the yield of a subsequent crop should be significantly higher than that of the control. FRVs were calculated for grain yield, grain N content and total N uptake (Table 6). At the most FRVs were 36 kg N ha^{-1} and the lowest value was for grain yield, indicating that modest benefits were derived from this system (Table 6).

Table 6. Fertilizer Replacement Values (FRV) due to relayed legume in the previous maize crop.

Parameter	Fertilizer Replacement Values (kg N ha^{-1})
Grain Yield	11
Total above-ground biomass	-
Grain N content	36
Total plant N-uptake	34

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AGRONOMIC PERFORMANCE AND ECONOMIC IMPLICATIONS OF MAIZE, SUNFLOWER AND GROUNDNUT SEQUENCES ON SANDY-SOIL SMALLHOLDER FARMS OF ZIMBABWE

MONICA MURATA and DANISILE HIKWA

Department of Research and Specialist Services, Agronomy Institute, Box CY550, Causeway, Harare, Zimbabwe

SUMMARY

Two sets of trials were conducted for three seasons, beginning the 1994/95 cropping season, to establish the place of sunflower in the sequencing of crops by smallholder farmers and determine its soil N and P requirements in those sequences. Productivity of the cropping sequences was also measured and economic implications of the N and P rates evaluated on all crops. In the first trial varying rates of P_2O_5 (30, 60, 90 and 120 kg ha^{-1}) with zero as control, were assessed in crop sequences that were structured such that sunflower would follow two crops of maize (MZ-MZ-SF). In the second trial, three nitrogen rates (30, 60 and 90 kg ha^{-1} N) were applied to sunflower every year, with non application as the control. The sequences were structured such that beginning with the second season, every cropping season would have the following sequences: sunflower after maize; sunflower after groundnut; maize after groundnut; maize after sunflower; groundnut after maize and groundnut after sunflower.

Farm fields selected in Natural Regions (NR) II and IV were classified as deficient in N (<20 ppm N) and P (<15 ppm P_2O_5). In the first two seasons sunflower did not respond to applied P. But good responses (P0.01) were observed in the third season, indicating the positive effects of P build-up in the soil. At NR IV locations, maize following another crop of maize performed better than that which followed sunflower at the various P rates, and a similar trend was observed in season three at the NR II location. In sunflower, significant increases in seed yield peaked at the 30 kg P_2O_5 ha^{-1} rate. Maize was more responsive to P application, with responses up to 90 kg P_2O_5 ha^{-1} recorded in some years. To cut down on costs, where both crops are included in a system it may be worthwhile to apply the P to the maize and let a subsequent sunflower crop use the residual P; especially on fields where a grower deliberately targets P build-up or its management. With better rainfall distribution, soil pH and soil available P also increased. This demonstrates the great influence exerted by interactions between P application and seasonal rainfall amount and its distribution on performance of crops.

Nitrogen management on sunflower rotated with maize or groundnut showed a peak N requirement for the crop at 60 kg ha^{-1} across locations. There were also notable differences in performance between the sequences. Sunflower or maize planted after groundnuts, on average, produced the highest kernel or grain yields irrespective of the N rate, showing the positive influence of a legume in the system. Where no N was applied, monetary returns from growing sunflower or maize after groundnut were much higher than when those same crops were rotated with each other, when N was not applied.

BACKGROUND

The predominantly light textured soils of the communal areas have been extensively cropped with little or no addition of fertilizers, leading to severe depletion of nutrients especially nitrogen and phosphorus (Grant, 1970; Mashiringwani, 1983). Grant (1981) demonstrated that it was difficult to obtain good crop yields on these soils without regular applications of inorganic fertilizer, manure or lime. Leaching, especially of N and volatilization are high in these soils. For instance, net annual losses of more than 30 kg N ha^{-1} were estimated for some eastern and southern African countries, including Zimbabwe (Smaling, 1993; Stoorvogel, Smaling and Janssen, 1993). Zimbabwe has a history of agricultural research, including soil fertility, for more than fifty years, but most of the early research was targeted at the large-scale farmer who could afford relatively large quantities of inorganic fertilizers. In an effort to improve research services to the smallholders, the 1980s saw a greater emphasis on use of inorganic fertilizers in soil fertility management on sandy soils with smallholders. Research carried out for several seasons in the 1980s on depleted sandy soils of smallholders showed considerable variation in crop yield response to N and P fertilizer depending on location and season (Agronomy Institute, 1994). Factors such as cropping history of the land, soil nutrient levels, rainfall amount and distribution do influence some of the responses to inorganic fertilizers on these soils (Hikwa, 1990). This was partly because research fields were changed every year, instead of researchers remaining on the same field long enough to evaluate subsequent effects of applied fertilizers, especially P.

Although most farmers have seen the benefits of using fertilizers, adoption lags behind and is limited by cash constraints, uncertainty about the season's rainfall and the economic importance of the particular crop to the farmer (Huchu and Sithole, 1993) and inadequate decision-support information on returns to investment in inorganic fertilizers. Therefore, rather than base fertilizer recommendations on the face value of soil analysis, which often suggests large requirements for inorganic fertilizers, we need to pay more attention to fertilizer-use-efficiency of the limited amounts that farmers can buy.

Given that background, this project was designed to consider sequencing of crops as a complimentary soil fertility management strategy that would enable the rotated crops to benefit from the nutrient build up. In the case of N, the contribution of legumes to the yield of the maize or sunflower was assessed. In the process of identifying suitable cropping sequences for sunflower in the current cropping systems of the smallholders, modest N and P budgets that are likely to promote reasonable yield levels without exerting pressure on the farmers' expenditure on inorganic fertilizers were assessed. In addition, the economics of the system and other opportunity costs were quantified.

METHODS

Two trials were conducted for three seasons, beginning the 1994/95 cropping season.

Trial 1: Assessment of Cumulative Effects of Applied P and its Subsequent Residual Benefits in a Maize-Maize-Sunflower Sequence

A field was selected at two farm locations in Gutu (Natural Region IV) and Zvimba (Natural Region II), and Makoholi Station (Natural Region IV). Natural Regions are broadly classified by rainfall: NRI 900-1000mm p.a.; NRII 750-900mm p.a.; NRIII 650-750mm p.a.; NRIV 450-650mm p.a. and NRV <650mm p.a. In all three fields, P tested low (<15 ppm, Bray P). Varying rates of P_2O_5 (30, 60, 90 and 120 kg ha^{-1}) with zero as control were assessed in crop sequences which were structured such that sunflower would follow two crops of maize (MZ-MZ-SF). The source of P was single superphosphate (SSP, 18.5% P_2O_5). Three seasons of maize and sunflower cropping were done at all three locations using a randomized complete block design with four replicates for each crop. Both crops were planted at a spacing of 90 cm x 30 cm, and both received uniform dressings of 60 kg N ha^{-1} as ammonium nitrate (34.5% N) and 30 kg K_2O ha^{-1} as muriate of potash (60% K_2O). In the first season, phosphate was band-applied and incorporated into the soil. In the second and third seasons, the method of P application was changed to broadcasting to ensure uniform build-up in the soil on each field. All the K and half of the N were applied at planting, with the other half of N being applied at 4 - 6 weeks after crop emergence.

Trial 2: Nitrogen Management on Sunflower in a Three-Course Crop Sequence Involving Maize, Groundnut and Sunflower

Selected fields had low mineral N (< 20 ppm after incubation). Three nitrogen rates (30, 60 and 90 kg N ha^{-1}) as ammonium nitrate were applied to the sunflower crop only every year, with non application as the control. The crop sequences were structured such that beginning with the second season onwards, every cropping season would have the following sequences:- sunflower after maize; sunflower after groundnut; maize after groundnut; maize after sunflower; groundnut after maize and groundnut after sunflower. For maize, 60 kg N ha^{-1} was applied to all plots except for the zero N plots while groundnut plots received 20 kg N ha^{-1} of starter nitrogen, again except for the zero N plots. The trial design was a split plot, with the crop sequence as main plot, while the N levels on sunflower determined the number of sub-plots, that were arranged in randomized complete blocks, with three replicates, making 12 subplots within each main plot.

For both trials, a gross plot of sunflower or maize consisted of six rows of 6 m length, spaced at 0.9 m apart, whereas that of groundnut comprised 12 rows of 6 m length at 0.45 m apart. Grain yields were measured from net plots of 14.4 m^2. The trial results were analyzed using analysis of variance. Economic returns of each sequence cycle and N level were analyzed using partial budgets.

RESULTS

a) Trial 1: P Management in MZ-MZ-SF System

Total rainfall at each site for the three respective seasons was as follows:-Gutu = 368mm, 722mm and 861mm; Makoholi =400mm, 873mm and 859mm and Zvimba =323mm, 928mm and 913mm.

Sunflower performance -- Sunflower kernel yields from the three cropping seasons and for each P treatment are given in Table 1. Except for Makoholi, seed yields were generally higher during the third season than during the first two seasons. This was because of the more favourably distributed rainfall. During the second season, sunflower in Zvimba was destroyed by tip wilters (sucking pests of *Anoplecnemis* spp.), resulting in 57 to 65% losses of the potential capitula (heads), while reasonable yields were obtained at the other two sites.

A significant kernel yield response to applied phosphorus was observed at Gutu in season two (1995/96) and at all sites in the third season (1996/97). Generally, kernel yield peaked at the 30 kg P_2O_5 ha^{-1} rate at the NR IV sites (Gutu and Makoholi), showing no marked advantage to applying higher rates. In Zvimba, there was no consistent response. The largest increases from added P (at 30 kg P_2O_5 ha^{-1} for Gutu and Makoholi and 60 kg P_2O_5 ha^{-1} for Zvimba) were 42.4%, 32.6% and 55.7% for Gutu, Makoholi and Zvimba, respectively.

Maize performance -- Maize grain yield data from the three sites are in Table 2. Maize yields for the NRII (Zvimba) site are for the 1995/96 and 1996/97 seasons only as the first season's crop was affected by a long-season dry spell at this site. In NR IV (Gutu and Makoholi), yields were generally higher in season two because of better rainfall distribution during the growing season than in seasons one and three, whereas in NR II, yields were better in the third season. Maize following another crop of maize performed better than that following a sunflower crop at almost all the P rates at the two NR IV locations in the last two seasons of sequencing (Table 2). At the NR II location, trends were not consistent; in year 2 (1995/96) of sequencing, maize had better grain yields following sunflower (SF-MZ), whereas in year 3 (1996/97), better maize grain yields were attained after another maize crop (SF-MZ-MZ sequence) (Table 2).

A significant P_2O_5 x sequence x season interaction was observed at the Gutu site. Maize grain yield peaked at the 30 kg P_2O_5 ha^{-1} rate in the first and third seasons, and at the 60 kg P_2O_5 ha^{-1} rate in the second season. Overall, sequencing maize with maize produced higher yields than sequencing maize with sunflower at this site. With the maize-maize sequence in 1995/96 season, yield increased with increase in P application to a rate of 60 kg P_2O_5 ha^{-1} whereas with the maize after sunflower sequence, peak yield was with the 90 kg P_2O_5 ha^{-1} rate. The same trend was observed in the 1996/97 season, but the peak yields were achieved with lower rates of P application (Table 2).

At Makoholi there was no merit in applying a rate above 30 kg P_2O_5 ha^{-1} in all seasons. The maize-maize sequence also produced significantly higher grain yields than the maize after sunflower sequence in both seasons, and a P_2O_5 x sequence x season interaction was also observed at this site (Table 2).

Although the peak yields varied between seasons and cropping sequences, the application of 60 kg P_2O_5 ha^{-1} was overall sufficient to produce maximum yields in Zvimba. In the 1995/96 season, growing maize after sunflower produced higher grain yields than growing maize after maize, but the reverse trend was observed in the following season, with one exception (90 kg P_2O_5 ha^{-1} at this site (Table 2).

Table 1. Effect of P rates on kernel yield of sunflower (kg ha^{-1})

P_2O_5 rate (kg ha^{-1})	Site		
	Gutu	Makoholi	Zvimba
1994/95 Season			
0	230	754	545
30	246	892	634
60	158	867	589
90	94	667	646
120	121	802	565
Mean	170	797	596
SE mean	*99.9*	*140.5*	*65.4*
F-test	*0.4 ns*	*0.4 ns*	*0.4 ns*
1995/96 Season			
0	210	525	34
30	713	727	46
60	714	708	92
90	797	602	46
120	752	600	82
Mean	637	633	60
SE mean	*140*	*125.9*	*16.5*
F-test	*3.0**	*0.4 ns*	*2.3 ns*
1996/97 Season			
0	738	375	432
30	1150	659	758
60	1151	583	643
90	1015	649	744
120	954	685	956
Mean	1002	590	707
SE mean	*86.5*	*86.05*	*131.3*
F-test	*4.0***	*4.0***	*0.6**

Despite attempts to raise the pH to an optimum of 5.3 on the 0.1*M* $CaCl_2$ scale for sunflower by liming with 600 kg ha^{-1} dolomitic lime ($CaCO_3$ + $MgCO_3$) at the beginning of each cropping season, the soils remained strongly acidic (pH 4.2 - 4.5) in Zvimba and Gutu at the end of the first cropping season. The pH increased by the end of the second cropping season, with pH values ranging from 4.5 to 5.0 in Gutu; 5.4 to 5.8 in Makoholi and from 4.5 to 4.7 in Zvimba. Soil available P also improved with increases in soil pH. Average extractable P levels of the soils after the second cropping season also revealed that addition

Table 2. Effects of P rates and sequences on grain yield (kg ha^{-1}) of maize

	P_2O_5 Rate				
	0	30	60	90	120
Season	**GUTU**				
1994/95	699	1 164	995	983	1 010
1995/96	1 998	2 539	2 861	2 242	2 605
1996/97	1 199	2 316	1 810	1 805	1 854
Sequence(1995/96)					
Mz - Mz	1 537	1 917	2 404	1 399	1 880
Sf - Mz	1 160	1 786	1 452	1 825	1 735
Sequence(1996/97)					
Mz - Mz	1 310	2 686	1 438	2 154	2 407
Sf - Mz	1 088	1 945	2 181	1 455	1 301
Sem(season) = 67.0			*Sem(P-rates) = 86.5*		
Sem(sequence) = 67.0			*Sem(interaction) = 116.1*		
*f-test season = 64.1****					
*f-test P_2O_5 x Sequence x Season interaction = 2.76**					
Season	**MAKOHOLI**				
1994/95	1 932	1 932	1 882	1 503	1 634
1995/96	2 323	2 974	2 270	2 047	2 757
1996/97	1 096	1 721	1 512	1 268	1 496
Sequence(1995/96)					
Mz- Mz	2 584	2 839	2 378	1 829	2 542
Sf - Mz	1 671	2 065	1 774	1 722	1 850
Sequence(1996/97)					
Mz - Mz	1 240	2 203	1 989	1 605	1 997
Sf - Mz	952	1 239	1 035	930	994
Sem(season) = 66.9			*Sem(Season x Sequence Interaction) = 159*		
Sem(P_2O_5 x Sequence x Season interaction) = 113					
*F-test season 14.4****					
*F-test P_2O_5 x Sequence x Season interaction 2.76**					
*F-test Season x Sequence Interaction 15.0****					
Season	**ZVIMBA**				
1995/96	2 757	2 947	2 997	2 585	3 197
1996/97	3 498	3 491	4 319	4 453	3 977
Sequence(1995/96)					
Mz-Mz	1 815	1 611	1 815	1 444	2 045
SF-Mz	3 700	4 282	4 179	3 726	4 350
Sequence(1996/97)					
Mz-Mz	4 171	4 002	4 503	4 104	4 485
SF-Mz	2 824	2 980	135	4 801	3 469
Sem (sequence) = 188			*Sem (season) = 187*		
Sem (Season x sequence interaction) = 265					
*F-test sequence = 10.1***					
*F-test season = 15.6****					
*F-test Season x sequence interaction = 30.0****					

*NB Mz-Mz - Maize followed another crop of maize

SF-Mz - Maize followed a sunflower crop

of P significantly (P=0.01) increased the P content of the soils at all three sites. However, because of the low initial P, the P content was still marginal (13 to 22 ppm) at Gutu, adequate (27.7 to 44.2 ppm) at Makoholi and marginal to adequate (22.9 to 39 ppm) at Zvimba even after the second season. As a result of the increase in soil P, rates higher than 30 kg P_2O_5 ha^{-1} were not needed for maximum kernel production of sunflower in the second and third seasons.

The average soil P levels following P application in the maize plots revealed that for the maize-maize sequence, addition of 90 kg P_2O_5 ha^{-1} attained the highest increase in soil P levels (15.1 to 32.2 ppm) at all sites. For the sunflower-maize sequence, the increases in soil P levels were significant and of a higher magnitude, but the actual crop response to P varied from site to site.

b) Trial 2: Nitrogen Management in a Three-Course Sequence that Includes Maize, Sunflower and Groundnut

Sunflower performance -- For plots receiving no N, mean kernel yields of sunflower ranged from 657 to 899 kg ha^{-1} in the sunflower after groundnut (GN-SF) sequence and from 230 to 725 kg ha^{-1} in the sunflower after maize (MZ-SF) sequence. On average (except for Gutu), at 30 and 60 kg N ha^{-1}, there were notable yield differences among sequences, with the GN-SF sequence producing significantly higher kernel yields of sunflower than the MZ-SF sequence (Table 3). Performance of the legume sequence is in agreement with what other re-

Table 3. Net returns (Z$ ha^{-1}) of sunflower after groundnut (GN-SF) or sunflower after maize(MZ-SF) at various N rates at Gutu, Makoholi and Zvimba (*Data pooled over 1995/96 and 1996/97 seasons)*

Sequence and N rate, kg ha^{-1}	Adjusted yield (x 0.9) kg ha^{-1}	Net returns over cash[1] costs, Z$ ha^{-1}	Net returns over all[2] costs, Z$ ha^{-1}
GUTU			
GN-SF (ON)	899	1184	788
MZ-SF (0N)	725	931	475
GN-SF (30N)	1335	1599	1047
MZ-SF (30N)	1225	1439	887
GN-SF (60N)	1409	1489	937
MZ-SF (60N)	1527	1660	1108
GN-SF (90N)	1240	1027	1437
MZ-SF (30N)	1523	475	885
MAKOHOLI			
GN-SF (ON)	743	957	501
MZ-SF (0N)	630	794	338
GN-SF (30N)	1285	1526	974
MZ-SF (30N)	687	601	49
GN-SF (60N)	1698	1908	1356
MZ-SF (60N)	1255	1266	714
GN-SF (90N)	1309	1127	575
MZ-SF (30N)	893	524	-28
ZVIMBA			
GN-SF (ON)	657	833	377
MZ-SF (0N)	230	214	-242
GN-SF (30N)	800	823	271
MZ-SF (30N)	680	649	97
GN-SF (60N)	1088	1024	472
MZ-SF (60N)	604	322	-230
GN-SF (90N)	1167	921	369
MZ-SF (30N)	515	-24	-576

[1]Costs include fertilizer (except for zero) and seed purchases
[2]Costs include cash and labour costs

searchers (Baker and Klages, 1983; Brisov, 1969; Muresan, 1972) in temperate zones have reported; that sunflower produced the highest kernel yields following legumes.

Maize performance -- Large increases in grain yields of maize were obtained when maize that followed sunflower (SF-MZ) received nitrogen compared to no N application (Table 4), with average yield increases being 245% at Gutu, 132% at Zvimba and 137% at Makoholi. When N was applied to maize following groundnuts(GN-MZ), there were smaller grain yield increases of maize (63.9, 44.6 and 49.9% at Gutu, Zvimba and Makoholi respectively, when compared to maize after sunflower (SF-MZ) (Table 4). Comparison of yield differences in plots receiving no N revealed that sequencing maize with groundnuts resulted in maize grain yield increases of 10.8% at Makoholi, through 58% at Zvimba to 167.6% at Gutu, compared to when maize followed sunflower (Table 4). This further confirms the positive influence of legumes in rotations.

Groundnut performance -- The trends in the groundnut after sunflower (SF-GN) and groundnut after maize (MZ-GN) sequences had no consistent pattern. For both seasons and both sequences, applying 20 kg N ha^{-1} as starter nitrogen did not significantly increase groundnut kernel yields significantly (Table 5). This is because soil pests such as nematodes as well as leaf diseases affected the groundnut. There is a need to measure these pests and diseases that are common with both sunflower and groundnuts, in the future.

Changes in pH and P levels -- In the sunflower plots, soil analysis results revealed that in Gutu, the soil acidity status at all doses of N was medium acidic (pH 5.0 to 5.5) after the first cropping season and strongly acid (pH 4.5 to 5.0) after the second cropping season, suggesting a dropping in pH. Available soil P in the same plots was marginal (15 to 30 ppm) after both cropping seasons, and the values were slightly better after the second cropping season. At Makoholi, the soil was strongly acid (pH 4.5 to 5.0) after the first cropping season and medium acid (pH 5.0 to 5.5) after the second season. Available P was marginal to adequate (29.4 to 43.6 ppm) after both cropping seasons. In Zvimba, pH values were in the strongly acidic category for both cropping seasons, and available P ranged from deficient to marginal (14 to 25 ppm).

At Gutu, soil pH improved in the maize plots from strongly acid in the first cropping season to slightly acid after the second cropping season whereas available P was in the marginal category in both seasons. The same trend was observed for both parameters at Makoholi. At Zvimba, pH values were in the strongly acid category for both seasons, and available P was deficient to marginal. Soil acidity and P content in groundnut plots for each site were similar to those in the maize plots at the respective sites.

Preliminary Economics

A preliminary economic analysis was conducted on the yield results, and returns from growing sunflower at all three sites are shown in Tables 3 to 5. At all the sites we calculate that with unfertilised sunflower, returns were better when it was sequenced with groundnuts than with maize. Irrespective of the fertilizer regime, the sunflower after groundnut sequence gave better returns than the sunflower after maize (Table 3). Except for the Gutu site, application

Table 4. Net returns (Zim$ ha^{-1}) of maize after groundnut (GN-MZ) or after sunflower (SF-MZ) at Gutu, Makoholi and Zvimba (*Data pooled over 1995/96 and 1996/97 seasons)*

	GN-MZ 0 N	GN-MZ 60 N	SF-MZ 0 N	SF-MZ 60 N
		GUTU		
Adjusted yield (kg ha^{-1})	2 783	4 562	1 040	3 588
Net returns over cash costs	3 140	4 840	1 048	3 672
Net returns over all costs (including labour)	2 504	4 108	412	2 940
		MAKOHOLI		
Adjusted Yyeld (kg ha^{-1})	1 126	1 688	1 016	2 409
Net returns over cash costs	1 151	1 392	1 015	2 257
Net returns over all costs (including labour)	515	660	379	1 525
		ZVIMBA		
Adjusted Yyeld (kg ha^{-1})	3 377	4 884	2 135	4 956
Net returns over cash costs	3 852	5 227	2 362	5 313
Net returns over all costs (including labour)	3 216	4 495	1 726	4 581

Table 5. Net returns (Zim$ ha^{-1}) of groundnut after maize (MZ-GN) or after sunflower (GN-SF) at Gutu, Makoholi and Zvimba (*Data pooled over 1995/96 and 1996/97 seasons)*

	MZ-GN 0N	MZ-GN 20N	SF-GN 0N	SF-GN 20N
		GUTU		
Adjusted yield (kg ha^{-1})	947	1 148	1 302	1 266
Net returns over cash costs	3 059	3 639	4 337	4 064
Net returns over all costs (including labour)	1 991	2 547	3 269	2 972
		MAKOHOLI		
Adjusted yield (kg ha^{-1})	630	679	314	370
Net returns over cash costs	1 918	1 950	780	838
Net returns over all costs (including labour)	850	858	-288	-254
		ZVIMBA		
Adjusted yield (kg ha^{-1})	957	1 031	909	1 037
Net returns over cash costs	3 095	3 218	2 992	3 239
Net returns over all costs (including labour)	2 027	2 126	1 854	2 147

of 60 kg N ha^{-1} to sunflower grown after groundnut gave the highest net benefits. The same result was observed with the sunflower after maize sequence at Gutu and Makoholi.. Overall, benefits were similar when either 30 kg N ha^{-1} was applied to sunflower following a groundnut crop or 60 kg N ha^{-1} was applied to sunflower following a maize crop (Table 3).

Benefits accrued from sequencing maize with either sunflower or groundnut are shown in Table 4. When no N was applied, maize following groundnut produced better returns than maize after sunflower. With the application of 60 kg N ha^{-1}, returns at Makoholi and Zvimba were superior in the maize after sunflower sequence and *vice-versa* at Gutu.

On average, returns from groundnuts were not influenced by nitrogen rate given only as starter N (Table 5), but sequencing groundnuts with maize produced better returns in Zvimba and Makoholi, whereas groundnuts grown after a sunflower crop dominated the other sequence at Gutu. Negative returns were obtained at Makoholi when average yields were below 400 kg ha^{-1} (Table 5).

CONCLUSIONS

Rainfall amount and its distribution had a great influence on crop response to P and hence on kernel and grain yields of sunflower and maize. With the better rainfall distribution in the second season (1995/96), soil pH and available P increased and yields generally increased. In the third season (1996/97), too much rainfall caused waterlogging and general yield reductions, with yield increases observed only at the NR II site in that season.

Results from the P trial indicate a species difference in response to P. Maize was more responsive to P application, with responses up to 90 kg P_2O_5 ha^{-1} recorded in some years. For sunflower, significant increases in kernel yield peaked at the 30 kg P_2O_5 ha^{-1} rate. In a system where both crops are included, it may be worthwhile to invest in higher rates of P on the maize and *vice versa* on the sunflower, or even apply the P to the maize and let the subsequent sunflower crop use the residual P. We propose to assess the effects of the residual P applied to maize on the performance of the subsequent sunflower crop for the next two seasons (1997/98 to 1998/99) on this trial. Correction of soil pH will be standard in all treatments.

The relationship between P availability and pH and crop responses in rotations needs further elucidation. Low pH increases the possibility of an Al-P precipitation that could render P unavailable to the plant even where P levels are high in the soil

(Mukurumbira and Dhliwayo, 1996). Grant, Tanner and Madziva (1973) in their review on soil acidity factors affecting maize yields in Zimbabwe concluded that differences in responses to lime were also associated with Mg and Mo deficiencies and toxicities of Mn and Al. They ascribed yield reduction on strongly acid soils to Al toxicity. This means a deliberate strategy to manage pH, while assessing crop response to P is necessary. A third trial (phased in year three [1996/97]) aims to generate additional information on that aspect, while at the same time showing smallholder farmers the need to manage soil acidity to get maximum benefit from fertilizer application.

Crop yield response to applied N was also influenced by the rainfall amount and distribution rather than the N rates on their own *per se*. With better rainfall distribution in the second season, crop yields improved in NR IV, whereas with more rainfall in the third season, the possibility of nutrient leaching was higher, resulting in reduced yields. Other than the influence of moisture, the responses to N are often associated with availability of other nutrients (most commonly P, and to an extent, S, K or Zn) and these have to be corrected to realize the full potential of applied N. Available P content at Gutu and Zvimba generally ranged from deficient to marginal. In environments with a variable climate, the potential yield of the crops also varies from season to season, with the result that fertilizer responses also vary. For this trial, another season (1997/98) is proposed. There is a need to collaborate with crop modellers in the use and collection of additional data for modelling and assessing long term risks under such dynamic weather conditions.

The preliminary economic analysis revealed that irrespective of the N rate, the sunflower crop grown after groundnut gave better returns than the one grown after maize. Benefits from applying 30 kg N ha^{-1} to sunflower following a groundnut crop were comparable to those attained when 60 kg N ha^{-1} was applied to sunflower following a maize crop. This shows that inclusion of a legume can and does contribute to the N budget and reduces the need to apply high rates of inorganic N directly to sunflowers.

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PRODUCTIVITY AND PROFITABILITY OF MAIZE + GROUNDNUT ROTATIONS WHEN COMPARED TO CONTINUOUS MAIZE UNDER SMALLHOLDER MANAGEMENT IN ZIMBABWE

STEPHEN R. WADDINGTON, JOHANNES KARIGWINDI and JOHN CHIFAMBA

CIMMYT Maize Programme and Natural Resources Group, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe

SUMMARY

We trace the yield and economic performance of a maize + groundnut rotation compared to continuous maize both when inorganic fertilizer is applied to maize and when it is not, under current management by smallholder farmers in Zimbabwe over five years. The aim was to determine whether the yield of groundnut and yield improvements of maize after groundnut are sufficient to justify farmers using the rotation.

We planted the trial at the AGRITEX Training Centre, Domboshava, with farmers at three on-farm sites in Chinyika Resettlement Area, and at three on-farm sites in Chiduku Communal Area and adjacent resettlement areas, mostly on sandy soils. Experimental treatments were: continuous maize (year-after-year) with inorganic fertilizer; continuous maize without fertilizer; maize-maize-groundnut-maize-maize-groundnut rotation with fertilizer on maize; the rotation without fertilizer; continuous groundnut without fertilizer; and a maize-groundnut intercrop (year-after-year) with fertilizer on the maize. Fertilizer practice was from farmer surveys in Mangwende Communal Area.

The grain yields from continuous maize without fertilizer declined over the years, at a rate of around 0.1 t ha^{-1} per year. Averaged over the six on-farm sites the grain yield of maize without fertilizer declined to 0.50 t ha^{-1} in 1996/97. The maize yield responses to inorganic fertilizer on-farm were highly variable, although under adequate rainfall the responses were moderate (up to 29 kg grain kg N^{-1}).

At Domboshava, with no inorganic fertilizer applied to maize, the inclusion of a groundnut rotation (producing 260 to 355 kg ha^{-1} of shelled grain) almost doubled the grain yield of the following maize crop (in 1995/96) from 2.46 t ha^{-1} to 4.61 t ha^{-1}. In plots where inorganic fertilizer was applied to maize, the rotation produced even more additional maize grain yield (an increase of 2.93 t ha^{-1}). Small effects of the groundnut on maize persisted in the second year of maize following groundnut (1996/97).

At two on-farm sites in 1996/97, with inorganic fertilizer the maize grain yields after groundnut were less than yields after continuous maize. Without fertilizer, inclusion of groundnut in the rotation raised maize grain yields at all three on-farm sites by an average of 0.25 t ha^{-1}, but overall yields were only around 0.6 t ha^{-1}.

In a calculation of discounted net benefits (DNBs) for the groundnut and two subsequent years with maize at Domboshava the returns over cash (i.e., seed and fertilizer) costs were greater for the rotation system than for the continuous maize plots, irrespective of whether inorganic fertilizer was applied. However, when labour costs were added the continuous maize plus fertilizer application showed better returns than the rotation, while the returns for the rotation and continuous maize without fertilizer were almost the same.

At the on-farm sites the rotation was far less profitable than at Domboshava, because of the low groundnut yields, little yield improvement for maize following groundnut, and the high labour cost associated with growing the groundnuts. DNBs over cash costs were positive at all sites but were higher for the rotation at only one out of the three sites. For the rotation the DNBs over all costs (including labour valued at a local casual worker wage) were always negative or close to zero. At two sites it was far more profitable to grow continuous maize, especially with fertilizer. Our preliminary findings of the low yield, marginal to zero profitability, and high labour cost of groundnut production support and explain the general trend by smallholder farmers to growing reduced areas of groundnut in Zimbabwe.

INTRODUCTION

Because groundnut can fix large amounts of N (Giller, McDonagh and Cadisch, 1994) and is widely accepted by local farmers as an important source of protein, it is one of the most useful grain legumes to help maintain the soil fertility and productivity of smallholder maize-based cropping systems in southern Africa. For many years the rotation of maize with groundnut has been the most common legume + cereal crop sequence on smallholder farms in sub-humid parts of Zimbabwe (e.g., Shumba, 1983;

Metelerkamp, 1987). However, both the area planted to groundnut and the yields have declined (Dendere, 1987; Metelerkamp, 1987). Reasons for this include use of saved seed with low yield potential, late planting and low plant population densities, lack of fertilizer use and the high labour requirement for production, resulting in low profitability (see Shumba, 1983, 1986; Metelerkamp, 1987; Natarajan and Zharare, 1994). Groundnut forms part of a rotation when land is relatively short, labour is plentiful and farmers are at least partly subsistence orientated.

Under favourable management and when groundnut residues are incorporated on sandy soils, groundnut in the rotation can double the yield of the following maize, particularly when that maize is grown with little or no N fertilizer (e.g., Mukurumbira, 1985; McDonagh, Toomsan, Limpinuntana and Giller, 1993). Yet there is a growing realization that on most smallholder fields where the grain and biomass yields from grain legumes are very poor and where both the legume grain and most of the legume stover are removed from the field, there may be little or no net N contribution by the legume to the soil and so little improvement in yield of the subsequent maize (see Giller, Cadisch, Ehaliotis, Adams, Sakala and Mafongoya, 1997; MacColl, 1989). Thus for the farmer the decision to plant more of the groundnut in a rotation will be based primarily on whether the farmer puts a greater value on the often low-yielding grain legume than on maize. As land becomes the scarce resource the value for the farmer will shift increasingly to the high yield potential cereal, at least until the productivity of the land declines substantially.

There are also doubts about the economics of farmers investing more in groundnut production. Work by Shumba, Bernstein and Waddington (1990) showed that for the Mangwende communal area of Zimbabwe it was less profitable to invest in the most promising inputs and practices to raise groundnut productivity (improved seed, early planting and weeding, NPK fertilizer + gypsum) than to invest in maize production.

In 1992/93 we began a trial on station and on-farm to gauge the longer-term crop yield and soil fertility effects of the maize + groundnut rotation compared to continuous maize both when inorganic fertilizer is applied to maize and when it is not. These were under management by smallholder farmers in the unimodal rainfall zones of northeastern Zimbabwe. In this paper we trace the yield and economic performance of the rotation compared to continuous maize to decide whether groundnut yields and yield improvements for maize after groundnut are sufficient to justify farmers using this rotation.

MATERIALS AND METHODS

We planted the trial at the AGRITEX Training Centre, Domboshava and with farmers at six on-farm sites. Three were in Chinyika Resettlement Area and three in Chiduku Communal Area and adjacent resettlement areas, in Zimbabwe Natural Regions II and III. In 1996/97 the trial was in the third, fourth or fifth year after it began, depending on the site.

For a detailed description of the experimental treatments, methods used and information on the chemical and physical characteristics of the soils at the trial sites see Karigwindi, Waddington and Chifamba (1996) and Waddington and Karigwindi (1996). Yield trends for all the treatments are described in Waddington, Karigwindi and Chifamba (1997). The sites were chosen with farmers to be representative of the principal maize fields used by each farmer. They have predominantly sandy soils (loamy sands, sandy loams and sandy clay loams) derived from granite, with low pH (pH 4.2 - 4.7, in $CaCl_2$), carbon usually below 1%, low P, low cation exchange capacity (CEC) and low amounts of several cations. The sites have been cropped for various lengths of time, estimated to be between 16 years (sites in Chinyika) to over 60 years in Chiduku. Maize had been grown on each field in the year before starting the trial.

The trial was arranged in a randomised complete block design with two replicates at each site. Experimental treatments were:

1. *Continuous maize (year-after-year)*
   Current farmer level of compound D (275 kg ha^{-1} applied as a dollop on the soil surface 14 days after crop emergence) and 70 kg N ha^{-1} topdress ammonium nitrate fertilizer applied when the crop reached approx. 60 cm tall, providing 92 kg N ha^{-1}, 17 kg P ha^{-1} and 16 kg K ha^{-1} per year.
2. *Continuous maize (year-after-year)*
   No fertilizer applied.
3. *Maize-Maize-Groundnut-Maize-Maize-Groundnut rotation (one crop per year)*
   Current farmer level of fertilizer on maize as in 1, no fertilizer on groundnut.
4. *Maize-Maize-Groundnut-Maize-Maize-Groundnut rotation (one crop per year)*
   No fertilizer applied.
5. *Continuous groundnut (year-after-year)*
   No fertilizer applied.
6. *Maize-Groundnut intercrop (year-after-year)*
   Current farmer level of fertilizer on maize as in 1, no fertilizer on groundnut. Two rows of maize to one row of groundnut.

The fertilizer rates used in these treatments were obtained from detailed agronomic monitoring and surveys with farmers in Mangwende Communal Area in Natural Region II (Waddington, Mudhara, Hlatshwayo and Kunjeku, 1991). These treatments are summarised in Table 1.

Table 1. Summary of experimental treatments in the maize + groundnut rotation trial, Zimbabwe

Treatment	Three Year Rotation	Fertilizer
T1	Maize - Maize - Maize	Yes
T2	Maize - Maize - Maize	No
T3	Maize - Maize - Groundnut	Yes, on maize
T4	Maize - Maize - Groundnut	No
T5	Groundnut - Groundnut - Groundnut	No
T6	Maize+G'nut - Maize+G'nut - Maize+G'nut	Yes, on maize

The plot size was 10.8 x 10.5 m (113.4 m^2) for maize and for groundnut. Seed of R215 or SC501 hybrid maize was planted to give a plant population density of 44 440 plants per ha. Groundnut (usually the small and bushy 'Spanish' type, widely used by smallholders) were planted to give a plant population density of approximately 160 000 plants per ha. The intercrop plots were as for solecrop maize, except that every third maize row was replaced by two rows of groundnut.

Management of both the on station and on-farm sites was representative of farmer management in the area. Those on farmer's fields were managed jointly by farmers and research staff. Land preparation was by an ox-drawn plough and planting methods, weeding and other management followed farmer practice. Weeds were removed twice using hand-hoes.

Maize and groundnut grain were harvested from whole plot areas of 113.4 m^2 each year. Maize grain yields are reported per hectare at 12.5% moisture content and groundnut grain as sun-dried mass per hectare. Above-ground non-grain maize biomass (stover) was measured from two adjacent middle rows (24 plants, 5.4 m^2) per plot. Groundnut haulms were taken from the entire plot, weighed and are reported as sun-dried mass per hectare. Maize grain yields were used in single-site analyses of variance for each year. Results are presented as year-to-year trends in grain and stover yields.

Budgets were developed for the maize + groundnut rotation using methods given in CIMMYT (1988), with discounting procedures from Gittinger (1984). The discount rate for year 0 = 1, year 1 = 1/(1+interest rate), year 2 = 1/(1+interest rate)^2. The bank deposit interest rate (in 1996 and 1997) = 23% per year. Information on costs of seed and fertilizer was obtained from suppliers for 1996. Labour data for maize and groundnut were collected from six farmers in Hwedza and Chiduku during January and February 1997, and combined with older data from Mangwende Communal Area. These labour data were used at Domboshava and the on-farm sites. Cash inputs and outputs were valued at local prices; i.e., Harare prices for Domboshava, and Chinyika and Chiduku prices for the on-farm sites and include any transport costs to the place of purchase or sale. Costs and labour data are reported with the budget tables.

RESULTS AND DISCUSSION

Yield Trends

Domboshava Training Centre -- 1996/97 was the fifth season of this trial at Domboshava. The grain yields of continuous crops of maize without inorganic fertilizer (T2) have decreased from 1992/93 and 1993/94 (between 2.78 and 6.15 t ha^{-1}) through to a low of 1.03 t ha^{-1} in 1996/97 (Figure 1). Part of this may be due to maize cropping for five years without fertilizer but the grain yield of continuous

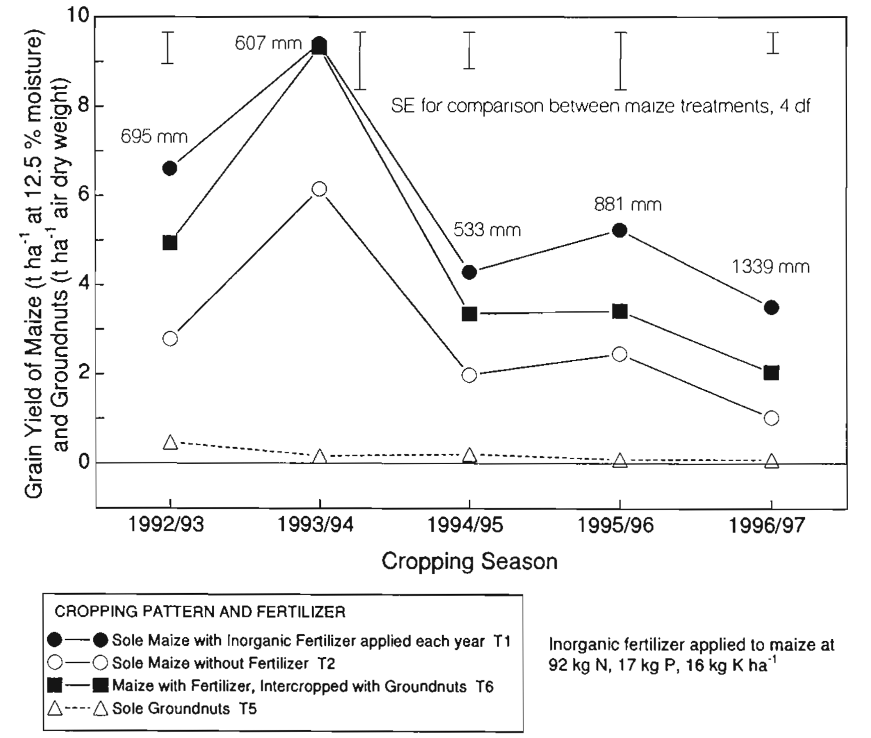

Figure 1. Trends for maize grain yield, with and without inorganic fertilizer, and groundnut grain yield over five years at Domboshava, Zimbabwe, 1992 - 1997.

maize with fertilizer (T1) has also declined (Figure 1). The low yields were also associated with extremes of rainfall (low in 1994/95; high in 1995/96 and very high in 1996/97, Figure 1). Maize grain yield responses to the inorganic N fertilizer (calculated for 92 kg N ha^{-1} applied compared to zero N applied) fell to between 25 and 30 kg grain kg N^{-1} in the last three years (Table 2).

Table 2. Maize grain yield response to N fertilizer (kg grain kg N^{-1}, calculated for 92 kg N ha^{-1} compared to zero N applied) in the maize + groundnut rotation at Domboshava

Cropping Season	Continuous maize (T1)	Maize after groundnut (T3)
1992/93	41.6	-
1993/94	35.3	-
1994/95	25.2	-
1995/96	30.2	38.7
1996/97	26.9	24.1

Grain yields of maize are now available for two years of maize following groundnut in the rotation (T3 and T4) (Figure 2). With no inorganic fertilizer applied to maize, the inclusion of a rotation with groundnut (T4) (producing 260 to 355 kg ha^{-1} of shelled grain) almost doubled the grain yield of the following maize crop (1995/96) from 2.46 t ha^{-1} to 4.61 t ha^{-1}, an increase of 2.15 t ha^{-1} (Figure 2). We estimate that at the Domboshava site in 1995/96 at least 86 kg of inorganic N ha^{-1} would have been needed to obtain that yield increase with continuous maize. In plots where inorganic fertilizer was applied to maize, the rotation (T3) produced even more additional maize grain yield (2.93 t ha^{-1}) (Figure 2). Small effects of the groundnuts on maize persisted in the second year of maize following groundnut (1996/97). These were larger where fertilizer was not applied (T4); 0.50 t ha^{-1} (49 % increase in grain yield) (Figure 2).

The yield of maize with fertilizer in the maize + groundnut intercrop (T6) closely followed the yield from continuous sole-crop maize (T1) over the five years but at a lower yield level (see Figure 1). Continuous groundnut crops (T5) gave very low yields (falling from 470 kg shelled grain ha^{-1} in 1992/93 to a low of just 84 kg ha^{-1} in 1996/97 (Figure 1). Reasons for this decline are not clear.

On-Farm Sites in Chinyika and Chiduku -- Across-year trends in maize grain yields at the on-farm sites are shown in Figures 3 and 4. Averaged over the six on-farm sites the grain yield of maize without fertilizer (T2) declined from 2.16 t ha^{-1} in 1993/94, through 0.79 t ha^{-1} in 1994/95 and 0.75 t ha^{-1} in 1995/96 to 0.50 t ha^{-1} in 1996/97, indicating a decline of approximately 0.1 t ha^{-1} per year for the last three years. However there was considerable variation in the yields from site to site (Figure 3) and most of the decline in yield depended on the change in yield at Mr. V. Mutsindikwa's site. There was also considerable variation in the response in maize yield to fertilizer over the years (Figure 4).

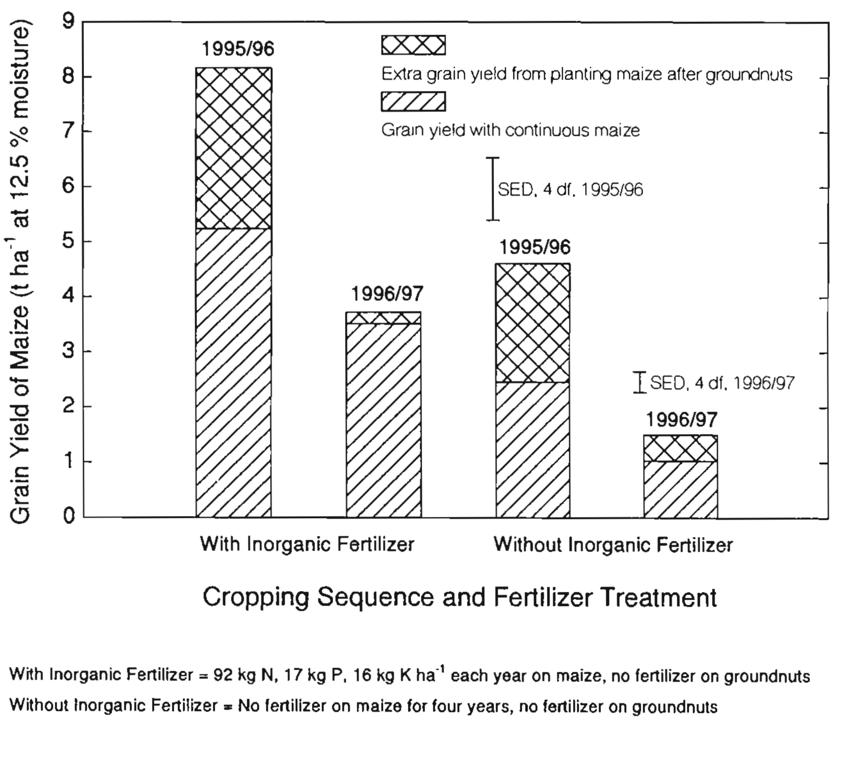

Figure 2. Extra grain yield for maize following its rotation with groundnuts (T3,T4) in 1994/95 compared with continuous maize (T1,T2), in a long-term trial at Domboshava.

Variation was closely associated with rainfall. The very low response to fertilizer in 1994/95 was mainly due to intermittent drought during early development of the crops that became severe throughout grain filling. Season rainfall totals of just 290 mm to 355 mm were recorded for 1994/95. The apparently relatively high response to fertilizer N (29 kg grain kg N^{-1}) calculated for 1995/96 was probably due to some N remaining available in the soil from that applied in the previous dry year. In contrast to the dry conditions of 1994/95 both 1995/96 and 1996/97 were wet years. The rainfall for 1995/96 was around 500 - 800 mm in Chiduku/Hwedza and over 1100 mm in Chinyika. The lowest grain yields without fertilizer (T2) achieved so far (average of 0.5 t ha^{-1} in 1996/97) came in an extremely wet year with very heavy rain throughout January and early February (and a total season rainfall of 963 mm in Chinyika and 808 mm in Chiduku). These low yields were perhaps partly the result of leaching of nutrients and denitrification, but certainly competition from weeds that the farmers could not remove because waterlogging at some sites was important, particularly in 1996/97. The field belonging to Mr. Vincent Mutsindikwa in Bingaguru is on the edge of a dambo and it was subjected to severe waterlogging through February and March 1996 and January to April 1997. This severely reduced the growth of groundnut and maize and reduced the response of maize to the fertilizer. At other sites the heavy leaching-rains produced symptoms of other nutrient deficiencies, especially Mg, when NPK fertilizer was applied. Symptoms of Mg deficiency were especially severe at Mr. J. Singano's field in Chiduku and this was confirmed by previous soil chemical analysis.

As at Domboshava, groundnut grain yields for the continuous sole crop (T5) were low at all sites and were trending downward, averaging 250 kg ha^{-1} in 1993/94, 189 kg ha^{-1} in 1994/95, 70 kg ha^{-1} in 1995/96 and 73 kg ha^{-1} in 1996/97. At some sites intercropped groundnut (T6) gave less than 10 kg grain ha^{-1}.

In the rotation (T3 and T4), the grain yield of groundnut was usually below 100 kg ha^{-1} (Table 3). There was a small benefit from growing groundnut after maize that had received NPK fertilizer (T3) compared to after unfertilized maize (T4) (Table 3). However, at most sites the above-ground haulm yields were still below 0.5 t ha^{-1}.

At three of the on-farm sites in 1996/97 we grew maize after the relatively poor groundnut crops (T3 and T4) and these

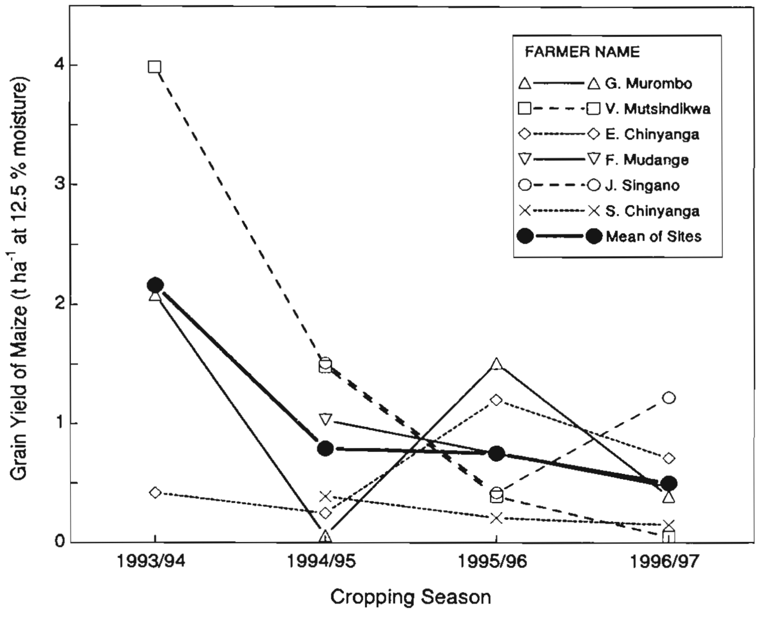

Figure 3. Grain yield of maize without inorganic fertilizer (T1) in the first four years of a long term trial at six on-farm locations in Chinyika and Chiduku, Zimbabwe.

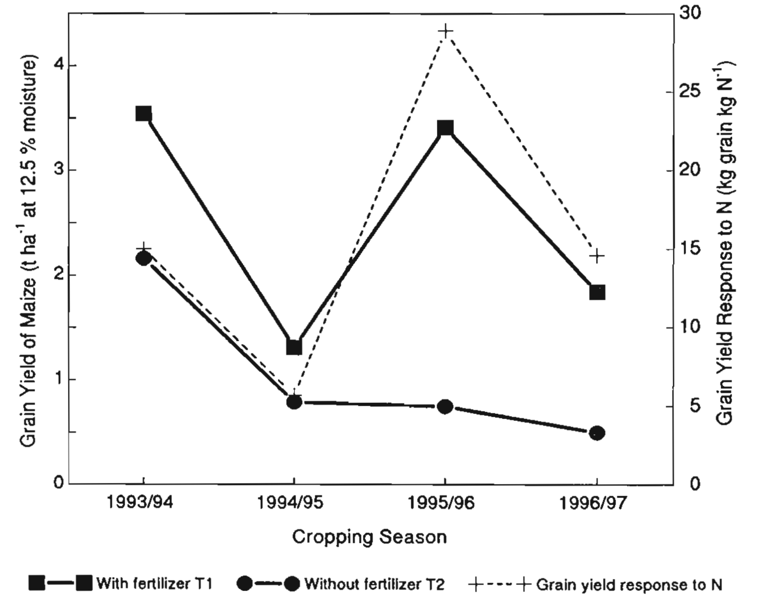

Figure 4. Trends for maize grain yield and yield response to 92 kg N ha^{-1} fertilizer in a long term trial, averaged over six on-farm locations in Chinyika and Chiduku, Zimbabwe

Table 3. Groundnut grain and above-ground haulm yields (kg ha^{-1} air dry weight) when grown after maize in a maize+groundnut+maize rotation at six on-farm sites in Chinyika and Chiduku, 1995/96 or 1996/97

Site (Farmer)	Grain		Haulms	
	With fertilizer on maize (T3)	Without fertilizer on maize (T4)	With fertilizer on maize (T3)	Without fertilizer on maize (T4)
Chinyika-Chinyudze (G. Murombo)	64.8	111.1	484.0	583.0
Chinyika-Bingaguru (V. Mutsindikwa)	199.0	92.6	708.0	435.0
Chinyika-Bingaguru (F. Mudange)	63.9	98.3	215.2	380.1
Chiduku-Valley (E. Chinyanga)	136.1	73.1	790.0	384.0
Chiduku-Valley (J. Singano)	79.4	68.3	255.3	216.5
Chiduku-Hill (S. Chinyanga)	67.5	24.7	159.6	62.6
Mean	101.8	78.0	435.4	343.5

yields are shown in Figure 5. With inorganic fertilizer the maize grain yields after groundnut (T3) declined at two sites compared to after continuous maize (T1). Without fertilizer, inclusion of groundnut in the rotation (T4) raised maize grain yields at all three sites (Figure 5) by an average of 0.25 t ha^{-1}, but overall yields were only around 0.6 t ha^{-1}.

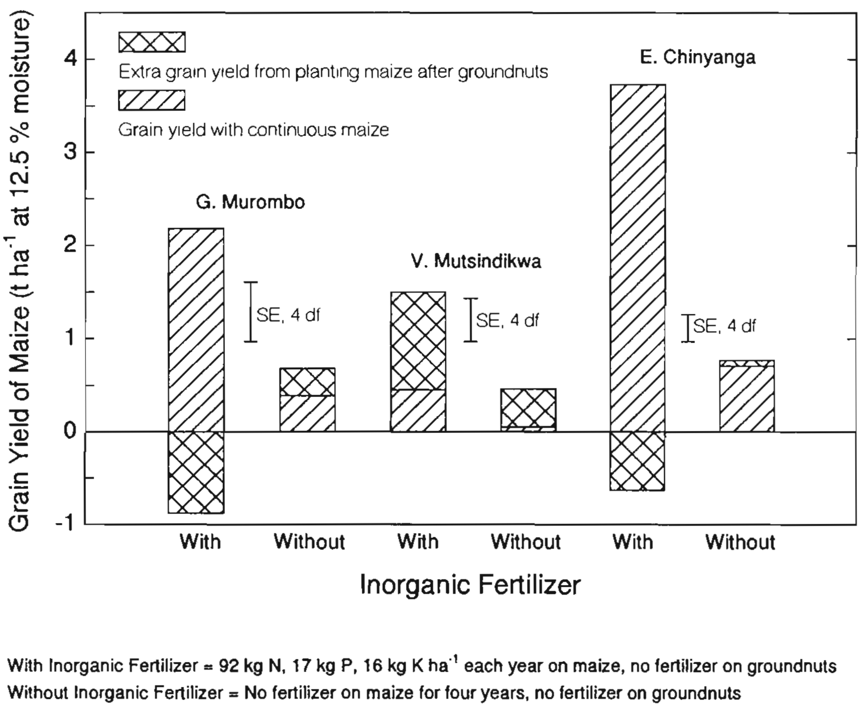

Figure 5. Extra grain yield of maize following its rotation with groundnuts (T3,T4) compared with continuous maize (T1,T2) at three on-farm sites in Zimbabwe, 1996/97.

Economic Assessment

Domboshava Training Centre -- At Domboshava we did a preliminary economic assessment of system productivity for the five crop + input combinations over three years (the year with groundnut in the rotation and the two subsequent years with maize). The grain yields for the analysis are given in Table 4 and the budget is in Table 5. This analysis takes the point of view of a farmer who in 1994/95 is selecting which time path or trajectory of treatments to choose. Because groundnut is a low yielding crop with high labour requirements the interpretation of the results depend on how family labour is valued. Returns over cash (i.e., seed and fertilizer) costs were higher for the rotation system (T3 and T4) than for the continuous maize (T1 and T2) plots, with or without inorganic fertilizer (Table 5), indicating that farmers acutely short of cash may find the rotation attractive. However, when labour costs (valued using a local casual worker wage) were added the continuous maize with fertilizer system (T1) showed higher returns than the rotation (T3) while the returns for the rotation and continuous maize without fertilizer (treatments T4 and T2) were almost identical. Groundnut grain yields need to be raised by only 117 kg ha^{-1} with fertilizer on maize (for T3) and just 13 kg ha^{-1} without (for T4) to bring the discounted net benefits (DNBs) to those from continuous maize. These should be readily achievable with small improvements in management of the groundnut.

On-Farm Sites in Chinyika and Chiduku -- Separate budgets were calculated for each of the three on-farm sites with maize after groundnut (T3 and T4), with similar objectives to the analysis for Domboshava. The total DNBs and interpretations are summarised in Table 6. Generally at these on-farm sites the rotation was far less economic than at Domboshava. DNBs over cash costs were positive at all sites but were higher for the rotation (T3 and T4) at only one of the three sites, the one belonging to Mr. Mutsindikwa in Bingaguru (Table 6). They were much lower at the other two sites (E. Chinyanga and G. Murombo). For the rotation (T3 and T4) the DNBs over all costs were always negative or close to zero (Table 6). At Mr. Mutsindikwa's all the cropping patterns had negative DNBs. At the other two sites it was most profitable to grow continuous maize with fertilizer (T1). Only at one site were small, achievable increases in

Table 4. Summary of maize and groundnut grain yields (kg ha^{-1}) in the maize + groundnut rotation trial at Domboshava, Zimbabwe

			1994/95		1995/96		1996/97	
Treatment	Three Year Rotation	Fertilizer	Maize	G'nut	Maize	G'nut	Maize	G'nut
T1	Maize - Maize - Maize	Yes	4295	0	5240	0	3508	0
T2	Maize - Maize - Maize	No	1980	0	2460	0	1030	0
T3	Maize - Maize - Groundnut	Yes	0	355	8165	0	3723	0
T4	Maize - Maize - Groundnut	No	0	257	4610	0	1504	0
T6	Maize+G'nut - Maize+G'nut - Maize+G'nut	Yes	3350	11	3415	17	2050	44

Table 5. Budget for a groundnut (1994/95) and maize (1995/96 and 1996/97) rotation at Domboshava, Zimbabwe. All calculations are Zimbabwe $ and done with prices from 1996

	With Inorganic Fertilizer		Without Inorganic Fertilizer		Inter-crop
	Continuous (T1)	Rotation (T3)	Continuous (T2)	Rotation (T4)	(T6)
1994/95 Crop	***(Maize)***	***(Groundnut)***	***(Maize)***	***(Groundnut)***	***(Maize + g'nut)***
Maize yield, kg/ha	4295	0	1980	0	3350
Adjusted maize yield, kg/ha	3866	0	1782	0	3015
Gnut yield, kg/ha	0	355	0	257	11
Adjusted gnut yield, kg/ha	0	319	0	231	10
Fertilizer cost, $/ha	1127	0	0	0	751
Maize + gnut seed cost, $/ha	166	350	166	350	231
Total cash costs, $/ha	1293	350	166	350	982
Maize + gnut labour costs, $/ha	1248	2316	984	1974	1280
Total costs, $/ha	2541	2666	1150	2324	2262
Output value, $/ha	4639	1595	2138	1155	3668
Net benefit over cash costs, $/ha	3346	1245	1972	805	2686
Net benefit over all costs, $/ha	2098	-1071	988	-1169	1406
1995/96 Crop	***(Maize)***	***(Maize)***	***(Maize)***	***(Maize)***	***(Maize + g'nut)***
Maize yield, kg/ha	5240	8165	2460	4610	3415
Adjusted maize yield, kg/ha	4716	7348	2214	4149	3073
Gnut yield, kg/ha	0	0	0	0	17
Adjusted gnut yield, kg/ha	0	0	0	0	15
Fertilizer cost, $/ha	1127	1127	0	0	751
Maize + gnut seed cost, $/ha	166	166	166	166	231
Total cash costs, $/ha	1293	1293	166	166	982
Maize + gnut labour costs, $/ha	1332	1500	984	1152	1300
Total costs, $/ha	2625	2793	1150	1318	2282
Output value, $/ha	5659	8818	2657	4979	3763
Discounted net ben. over cash costs, $/ha	3550	6118	2025	3913	2261
Discounted net benefit over all costs, $/ha	2467	4898	1225	2976	1204
1996/97 Crop	***(Maize)***	***(Maize)***	***(Maize)***	***(Maize)***	***(Maize + g'nut)***
Maize yield, kg/ha	3508	3723	1030	1504	2050
Adjusted maize yield, kg/ha	3157	3351	927	1354	1845
Gnut yield, kg/ha	0	0	0	0	44
Adjusted gnut yield, kg/ha	0	0	0	0	40
Fertilizer cost, $/ha	1127	1127	0	0	751
Maize + gnut seed cost, $/ha	166	166	166	166	231
Total cash costs, $/ha	1293	1293	166	166	982
Maize + gnut labour costs, $/ha	1164	1164	900	900	1294
Total costs, $/ha	2457	2457	1066	1066	2276
Output value, $/ha	3788	4021	1112	1625	2434
Discounted net ben. over cash costs, $/ha	1652	1807	626	966	962
Discounted net benefit over all costs, $/ha	881	1036	30	370	105
1994/95 + 1995/96 + 1996/97 combined					
Total discounted net benefit (net present value) over cash costs, $/ha	**8548**	**9170**	**4623**	**5684**	**5909**
Total discounted net benefit (net present value) over all costs, $/ha	**5446**	**4863**	**2243**	**2177**	**2715**
Extra groundnut yield needed to make DNB over all costs equal to those for continuous maize (T1 or T2)	117 kg/ha		13 kg/ha		

Price and labour data for Domboshava, used in Table 5:

GMB buying price Grade A white maize 1 Oct 1996 Z$1200 per t.
GMB buying price shelled groundnut 1 Oct 1996 Z$5000 per t.
Compound D fertilizer price October 1996 Z$2260 per t.
Ammonium nitrate fertilizer price October 1996 Z$2490 per t.
(Total fertilizer on maize = 92 kg N ha^{-1}, 17 kg P ha^{-1} and 16 kg K ha^{-1} per year)
Maize seed price 25 kg/ha = Z$166.00
Using saved groundnut seed price 70 kg/ha = Z$350.00. (New groundnut seed price 70 kg/ha = Z$896.00)
Local daily casual worker wage rate 1996 = Z$ 12 per day.
Labour for maize:
- Land preparation = 4 person-days/ha
- Planting = 9 person-days/ha
- Fertilizer (basal + top) = 8 person-days/ha
- Weeding (2 handweedings) = 24 person-days/ha
- Cutting/stooking = 12 person-days/ha
- Remove ears= 19 person-days/ha
- Shell/bag = 7 person-days/t grain

Labour for groundnut:
- Land preparation = 4 person-days/ha
- Planting = 18 person-days/ha
- Weeding (2 handweedings) = 57 person-days/ha
- Pulling = 18 person-days/ha
- Plucking = 20 person-days/100 kg grain
- Shelling = 7 person-days/100 kg grain

Discount rate for year 0 = 1, year 1 = 1/(1+interest rate), year 2 = $1/(1+\text{interest rate})^2$
Interest rate for one year = 23%

groundnut able to pay for the rotation. At the other sites we calculate that groundnut grain yields would have to increase by over 1000 kg ha^{-1} with fertilizer (T3) and by almost 400 kg ha^{-1} without (T4) (Table 6), which will be difficult to achieve. The intercrop (T6) was slightly inferior to continuous maize with fertilizer (T1).

CONCLUSIONS

It is too early to completely answer the objectives of this research but here we make some preliminary conclusions.

- Grain yields from continuous maize without fertilizer on the sandy soils are low (below 1 t ha^{-1}) and appear to be declining, at a rate estimated to be around 0.1 t ha^{-1} per year, although the contribution from soil infertility as distinct from other factors (especially rainfall) is unclear.
- Maize yield responses to inorganic fertilizer at the

Table 6. Summary of total discounted net benefits for a groundnut (1995/96) and maize (1996/97) rotation at three on-farm sites in Chinyika and Chiduku, Zimbabwe

Farmer, and Total Discounted Net Benefit[1]	With Inorganic Fertilizer: Continuous (T1)	With Inorganic Fertilizer: Rotation (T3)	Without Inorganic Fertilizer: Continuous (T2)	Without Inorganic Fertilizer: Rotation (T4)	Inter-crop (T6)	Findings
V. Mutsindikwa Over cash costs, Z$/ha	351	**1004**	270	446	733	Rotation (T3 and T4) gives higher DNB over cash costs than continuous maize (T1 and T2), both with and without fertilizer. Cash constrained farmers should use groundnut + maize rotation.
Over all costs, Z$/ha	-1500	-1618	-1234	**-1042**	-1331	DNB over all costs are -ve for all crop patterns indicating not profitable. Without fertilizer on maize the rotation (T4) is less unprofitable than continuous maize (T2), indicating that without fertilizer it is better to use the rotation. Small achievable increases in groundnut yield (22.5 kg/ha) will pay for the rotation with fertilizer.
E. Chinyanga Over cash costs, Z$/ha	**8356**	2539	2171	713	4407	Continuous maize (T1 and T2) gives much greater DNB over cash costs than rotation, especially where fertilizer is applied (T1).
Over all costs, Z$/ha	**6092**	60	562	-1375	2077	DNB over all costs are very large for continuous maize with fertilizer (T1). DNBs for the rotation are low, and -ve without fertilizer (T4). Increases in groundnut yield needed to pay for the rotation are large (1151 kg/ha with fertilizer and 370 kg/ha without) and will be difficult to get on farm. Continuous maize, preferably with fertilizer (T1), is recommended.
G. Murombo Over cash costs, Z $/ha	**7102**	144	2245	783	2772	Continuous maize (T1 and T2) gives much greater DNB over cash costs than rotation, especially where fertilizer is applied (T1).
Over all costs, Z$/ha	**3306**	-2023	665	-1416	1922	DNB over all costs are -ve for the rotation with and without fertilizer (T3 and T4). Increases in groundnut yield needed to pay for the rotation are large (1017 kg/ha with fertilizer and 397 kg/ha without) and will be difficult to get on farm. Continuous maize, preferably with fertilizer (T1), is recommended.

[1] DNB or net present value

Price and labour data for the on-farm sites, used in Table 6:
These were as used for Domboshava except,
Local selling price white maize early 1997 Z$1570 per t.
Local selling price shelled groundnut early 1997 Z$5240 per t.
Compound D fertilizer price early 1997 Z$2880 per t.
Ammonium nitrate fertilizer price early 1997 Z$3000 per t.
(Total fertilizer on maize = 92 kg N ha^{-1}, 17 kg P ha^{-1} and 16 kg K ha^{-1} per year)
Maize seed price 25 kg/ha = Z$185.00
Using saved groundnut seed price 70 kg/ha = Z$367.00.

on-farm locations were highly variable, but under adequate rainfall the responses were moderate to good.

- Rainfall extremes (both very wet and very dry years) reduce maize grain yields without fertilizer to critically low levels approaching 0.5 t ha^{-1}.
- Maize grain yields can almost double when maize follows groundnut on sandy soils derived from granite under station conditions even where most of the groundnut haulms are removed, particularly where inorganic fertilizer is not applied, and when those soils are reasonably fertile.
- Indications are that continuous groundnut plots give successively lower grain yields and are not sustainable.
- On smallholder fields, groundnut growth and yields are extremely low (less than 0.5 t ha^{-1} of above-ground haulms) and effects on subsequent maize very variable.
- On farm the groundnut rotation effect is more consistent when no fertilizer is applied to maize.
- Because of the low groundnut yields and little yield improvement for maize following groundnut on farm, and the high labour cost associated with growing the groundnuts, the rotation is far less profitable than continuous maize, especially when the maize is grown with fertilizer.
- At some on-farm sites the extra groundnut grain yields required to match the profitability of the continuous maize with fertilizer are over 1 t ha^{-1} and will be virtually impossible to achieve.

GENERAL DISCUSSION

Overall our results on station at Domboshava are promising, showing that groundnut can substantially raise the yield of maize in rotation under simulated smallholder field conditions. These conditions included no fertilizer for groundnut, and where most of the groundnut haulms (and maize stover) were grazed by animals. Presumably much of the rotation effect was from leaf fall and the root system of groundnut (see Giller *et al.*, 1997).

On farm the preliminary results from three sites were far less encouraging and reflect not only the extremely poor groundnut yields attainable but the low maize yields compared to the high labour inputs to grow groundnuts. Nevertheless there is little doubt that the excessive rainfall in both the 1995/96 and 1996/97 seasons depressed the yields of groundnut and maize and so reduced the net benefits from what would be achievable in more average rainfall years. One such on-farm site is V. Mutsindikwa's farm where in earlier years such as 1994/95 groundnut had yielded over 400 kg ha^{-1} of shelled grain, against less than 100 kg ha^{-1} in 1995/96.

In the economic assessment the profitability of groundnut was highly sensitive to how the high labour requirements for producing groundnut are valued. In our calculations we assigned labour either a zero monetary value (benefits over cash costs only) or the local casual worker wage rate in Chiduku or Chinyika. The local casual worker rate almost certainly overestimates the monetary value of labour used to produce groundnuts because almost all the labour is normally supplied by female members within the household. However, from our first calculations extremely low or zero monetary values for labour are necessary for the rotation to be remotely profitable.

Our preliminary findings about the low yield, marginal to zero profitability and high labour cost of groundnut production support the general trend by farmers to growing smaller areas of groundnut. Our preliminary results underline the need for research to a) increase the yields of groundnut on smallholder fields and b) reduce the associated labour costs in producing groundnuts, without adding much to cash costs. In our discussions with farmers it is clear that neither the researchers nor the farmers have a clear idea about how to do this. The challenge will need us to work together to identify what is possible and through which interventions. While groundnut grown on smallholder fields in Zimbabwe rarely responds well to added fertilizers some promising interventions to raise groundnut yield involve improving the base soil fertility of groundnut fields in rotations (see Metelerkamp, 1987). Liming, the application of gypsum and use of animal manure in rotations are helpful. Preliminary results from current work by Tagwira, Chikowo and Murwira (1996) show that applications of P, Zn, Ca, or Mg raise yields at many but not all sites. The Soil Fertility Network also must search for alternative grain legumes that farmers want to grow and which are more robust under their conditions. Work on naturally-nodulating soyabean, which is generating a lot of interest by farmers, and on pigeonpea is reported elsewhere in these proceedings, as are plans for the Soil Fertility Network to screen a wide range of annual legumes for adaptation to Malawi and Zimbabwe.

We and the farmers plan to continue our maize-groundnut rotations for another three or more years on farm to trace the longer term benefits. At the end of next season (1997/98) we will be able to report yields and net benefits from the rotation at the other on-farm sites.

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UNDERSOWING MAIZE WITH *SESBANIA SESBAN* IN SOUTHERN MALAWI: 1. TREE GROWTH, BIOMASS YIELDS AND MAIZE RESPONSES TO N SOURCE AT THREE LANDSCAPE POSITIONS

A. DICKENS K. PHIRI[1], GEORGE Y. KANYAMA-PHIRI[1] and SIEGLINDE S. SNAPP[2]

[1]Bunda College of Agriculture, P.O. Box 219, Lilongwe [2]ICRISAT, P.O. Box 1096, Lilongwe, Malawi

SUMMARY

Many soils of Sub-Saharan Africa are depleted of soil organic matter, an important source for organic nitrogen and phosphorus. This organic matter depletion arises largely from continuous maize cultivation on small land holdings. The situation is usually aggravated by high human population pressure which forces farmers to cultivate on steep and fragile slopes that are vulnerable to runoff and soil erosion. The objectives of this study were [1] to determine growth, survival, biomass and quality of Sesbania at three landscape positions, and [2] to assess agronomic yields of maize in response to nitrogen source and landscape position.

An on-farm experiment consisted of three landscape positions combined factorially with three nitrogen sources in a randomized complete block design involving 40 farmers who served as blocks (replicates). The three landscape positions were: valley bottom (0 - 12%), dambo margins (0 - 12%), and steep slopes (>12%). Sesbania sesban and CAN served as organic and inorganic N sources, respectively, while the control treatment received no external source of N.

Plant survival, number of primary branches per plant, stem diameter, leafy and woody dry matter yields and stack volume of Sesbania were significantly different at the three landscape positions, as was maize grain yield. Maize grain yield from the inorganic source of N was significantly higher (P<0.05) than maize yield from the control source though not significantly different from the organic source. These results indicate that there is potential for tree legumes to contribute to soil fertility under relay intercropping of maize and Sesbania sesban.

INTRODUCTION

Crop yields in sub-Saharan Africa have been declining steadily over the years. This decline may be attributed to a number of biophysical limits to agricultural production prevailing on a given cropping field at a given landscape position. Some of these biophysical limits include small landholding sizes that do not allow for crop rotation; steepness of land that renders the soil vulnerable to erosion; shallowness and stoniness of the soil, thereby rendering it difficult for cultivation, root growth and crop development; and degree of organic matter depletion as a measure of soil fertility status of a particular field at a given landscape position. Soil moisture, soil nutrients and organic matter depletion lead to net annual losses of nitrogen, phosphorus and potassium (NPK) resulting from long-term continuous arable cropping on the same piece of land (Stoorvogel *et al.*, 1993). Nutrient depletion is particularly pronounced in southern Malawi where population densities are as high as 126 persons per square kilometre (Malawi Government, 1993). Current density estimates are much higher (Kanyama-Phiri *et al.* 1997). Depletion of NPK has also been reported in the densely populated humid and sub-humid highlands of Eastern Africa (Smaling, 1993; Smaling *et al.*, 1992).

Because of land limitation, arable cultivation has extended to dambos and their margins, areas previously set aside for grazing and dry season cultivation. The word dambo is widely used in the southern African countries of Malawi, Zambia and Zimbabwe. In South Africa these areas are referred to as vleis. Dambos are characterized by broad, gentle sloping valleys or depressions which are seasonally waterlogged for a large part of the year (Jiah, 1993). Dambo soils vary from coarse sands to heavy clays and it is usually the dominance of the latter that brings about waterlogging problems. Because of seasonal waterlogging, dambos may be unsuitable for arable cultivation. In Malawi, Dambos account for 12% (259,000ha) of total land area (Kanyama-Phiri, 1993, citing Mzembe, 1997).

The increase in human population in sub-Saharan Africa has led to reclamation of steep slopes along the landscape; areas generally considered to be of marginal value for arable cultivation (Banda *et al.*, 1994). In Malawi, 45 % of the total land area has a slope of over 12 % and Shaxson *et al.* (1977) described such areas as non arable. Under the Government Land Husbandry Policy, any land with slopes greater than 12% is classified as non arable (Shaxson *et al.*, 1977). Our earlier study (Kanyama-Phiri *et al.*, 1995) demonstrated that 6 to 10% of the fields of farm families in Songani catchment area are on steep slopes, in excess of 12%. In the adjacent catchment area (Kasonga) within the same EPA, the situation is more acute with 96% of the fields sited on slopes ranging from 13 to 51% (Kanyama-Phiri *et al.*, 1995). Country-wide, 45% of total land area is above 12% slope (Shaxson *et al.*, 1977). This provided sufficient justification for the evaluation of different landscape positions in terms of their influence on tree growth, biomass yield and maize production. However, in the face of increasing population pressure more and more of this area is being brought under cultivation, hence ways have to be found to make such a cultivation environmentally friendly so that soil erosion risks are minimised and soil fertility is maintained (Banda *et al.*, 1994).

The areas at or near dambos may lose their fertility status because of either waterlogging in the case of clays or high leaching of essential nutrients especially nitrogen and phosphorus in the case of coarse sandy soils. Nitrogen and phosphorus deficiency remain the major limiting nutrients to increased food production (Jama *et al.*, 1977; Saka *et al.*, 1995). Use of inorganic fertilizer is increasingly seen as a solution to the problem of restoring soil fertility. However, the 300% increase in the purchase price of inorganic fertilizers has limited their use by smallholder farmers. Over the past decade, the prices have gone up by more than ten times in Malawi (ADMARC pers. comm.). The cheapest source of nitrogen is soil organic matter. However, weeds and maize stover, which provide the bulk of soil organic matter are extremely low in organic nitrogen (<15%). To build up soil nitrogen, mixed intercropping of cereals with herbaceous legumes such as groundnuts (*Arachis hypogaea*), soyabeans (*Glycine max)* and phaseolus beans or tree legumes such as pigeon pea (*Cajanus cajan*) has been advocated (MacColl, 1989).

Tree legumes such as pigeon peas have the ability to fix atmospheric nitrogen (Onim *et al.*, 1990; Giller *et al.* 1996). The deep rooting habit of pigeon pea has an added advantage of mining nutrients from deeper soil horizons thereby enriching the upper surface of the soil through leaf fall and litter decomposition (Van Noordwijk, 1989; MecKonnen *et al.*, 1996). The practice of intercropping cereals with legumes provides an opportunity for testing relevant agroforestry technologies. On-station studies in southern Malawi (Maghembe *et al.*, 1997) demonstrated the potential of *Sesbania sesban* as an intercrop with maize, as well as in improved fallows (Kwesiga and Coe, 1994).

Fast growing sesbania is deep rooted, and like pigeon pea, has the potential to capture and recycle subsoil nitrates otherwise unavailable to shallow rooted crops such as maize (Hatermink *et al.*, 1996). *Sesbania* requires rainfall ranging from 500 to 2000 mm, favours cool temperatures and can tolerate acid, saline and water-logged soils (Bunderson *et al.*, 1995). Sesbania is found at elevations ranging from 0 - 2300 m above sea level (Brewbaker *et al.*,1990; Bunderson *et al.*, 1995). It nodulates heavily and fixes atmospheric nitrogen. Nitrogen fixation rates of 350 kg/ha/yr for Sesbania have been reported in India (ICRAF-NFTA, 1989). Green leaf manure yields under alley farming situations in India have varied from 1 to 4 tonnes/ha/yr, with estimates of N contributions from green leaf manure ranging from 50 - 150 kg/ha/yr (Ibid). Maghembe *et al.*, (1997) reported that in one season, Sesbania can yield 500 to 800 kg of leafy biomass per hectare. This range was able to increase yields from 2.9 t/ha without trees to 3.6 t/ha with trees. Sesbania, as reported by Bunderson *et al.*, (1995), can also be used in short term rotations, an important consideration under land limiting conditions. It is easy to eradicate at the end of a two-year growth period when it is cut close to the ground. It will die and rot rapidly (Kanyama-Phiri *et al.*, 1993).

Nitrogen fixation and N losses through leaching and denitrification vary across landscape positions due to differences in soil physical properties (Mahler *et al.*, 1979). In addition to direct N losses, soil properties can reduce N recovery through their influence on plant growth. Compact soil layers and subsoil phosphorus deficiencies in eroded landscape positions may restrict root growth, thereby restricting water and N uptake (Pan and Hopkins, 1991).

Denitrification and leaching are responsible for substantial N losses in Malawi's agro-ecologies (MacColl, 1989). However data are scarce. One new approach may be complementary use of inorganic fertilizer and organic sources, especially green manure from MPTS such as *Sesbania sesban* (Snapp *et al.*, 1997). This approach could reduce the dependence on inorganics by almost 50% thereby saving on cost of inorganic fertilizer. This study was conducted to evaluate the growth, survival and biomass production from Sesbania; and to determine the effect of N source on maize yields at the three landscape positions.

MATERIALS AND METHODS

Site Characteristics

A two-year study was conducted on 40 farmers' fields in Songani watershed, Malosa Extension Planning Area (EPA), Zomba Rural Development Project (RDP) of Machinga Agricultural Development Division (MADD) in southern Malawi (15^0 18.5' South latitude, and 35^0 23.5' East longitude). The area has an elevation of 785m above sea level and receives an average annual rainfall of 1197 mm per annum. In the 1993/94 and 1994/95 seasons, however, this area experienced drought, but the situation normalized in the 1995/96 and 1996/97 seasons (Figure 1). The rainfall season normally extends from October to April. The soil is classified as either a sandy-loam or clay-loam with pH ranging from 5.1 to 6.9.

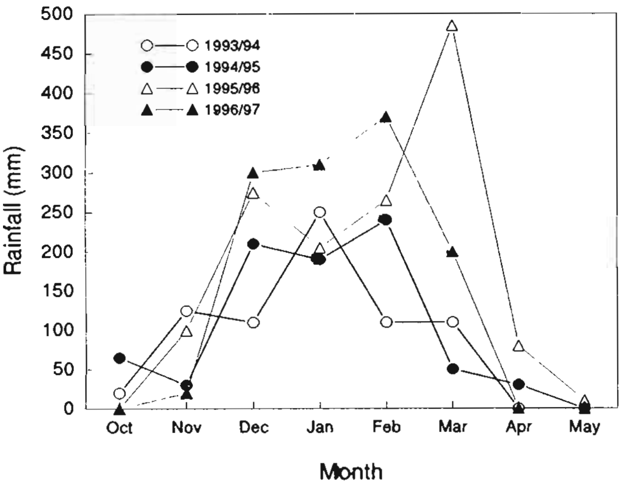

Figure 1. Rainfall distribution for Malosa EPA over four years.

Farmer Selection

Farmers were selected during the diagnostic study (Kanyama-Phiri *et al.*, 1995), using a farmer guided, land transect method (Mascarenhas, 1991). Three landscape positions, dambo valley bottom (0 - 12% slope), dambo margins (0 - 12% slope) and steep slopes (>12% slope), were identified on each transect. The three landscape positions were typical of the terrain of southern Malawi. For each of the three landscape positions, the farmers' fields were randomly located to represent maize-based farming systems in the study area. These farm sizes varied from 0.40 to 0.64 ha (Malosa EPA annual reports, 1993). The majority of farmers grew local maize which averaged 500 kg ha^{-1}, depending on soil fertility. There is chronic food insecurity in the area.

Experimental Design

The experiment was researcher designed and farmer managed. It consisted of three landscape positions and three N sources combined factorially in a randomized complete block design with the farmers serving as replicates at each landscape position. The three landscape positions served as main plots. The N sources (sub-plots) were: no fertilizer (control), organic fertilizer and in-organic fertilizer (120kg N ha^{-1}). Gross plots measured 15 m x 15 m; net plots were 10 m x 10 m. Sesbania sesban (L.) Merr. served as the organic N source, whereas calcium ammonium nitrate (CAN) was the inorganic N source.

Soil Sampling and Analysis

All plots were sampled at 0 - 15 cm, 15 - 30 cm, 30 - 45 cm and 45 - 60 cm prior to the initiation of the experiment to establish initial soil fertility status before the transplanting of the multipurpose tree species (Table 1, part 2 of our paper in this volume). Soil samples were oven dried and ground to pass through a 2 mm sieve.

Determination of N was done by the Kjeldahl digestion method according to Anderson and Ingram (1993). Phosphorus was extracted by the Mehlich 3 extraction method. Organic C was analysed using acid dichromate digestion (Anderson and Ingram, 1993). Soil pH was determined in H_2O. The soil was also analysed for texture (% sand, % silt and % clay).

Crop and Tree Management

A Malawi maize hybrid (MH18) was used as a test crop in this study. This semi-flint hybrid was developed for uniformity of growth, early maturity, high grain yields, good storability and poundability. The last two attributes are particularly desired by smallholder farmers. Three maize seeds were sown at planting stations spaced at 0.9 m within ridges and 0.9 m between ridges.

This planting pattern gave a maize plant population of 36,000 ha^{-1}. Sixty kg of nitrogen per ha were applied at maize planting followed by top dressing with a similar amount when the maize had reached a height of 60 cm. Crop management practices such as weeding and banking were carried out twice in consultation with the farmers when the maize had reached 30 cm and 60 cm.

Bare-rooted seedlings of *Sesbania sesban* (L.) Merr. were raised in a nursery for two months before trans-

Table 1. Yield and Yield components of maize at three landscape positions (n = 40 farmers)

	Year 1			Year 2		
Response	Valley Bottom (0-12 %)	Dambo Margins (0-12%)	Steep Slope (>12%)	Valley Bottom (0-12%)	Dambo Margins (0-12%)	Steep Slope (>12%)
Grain Yield (kg/ha)	1334^{a}	1095^{ab}	515^{b}	1961^{a}	1598^{ab}	718^{b}
Stover (kg/ha)	1688^{a}	1791^{a}	1019^{b}	2541^{a}	1020^{b}	736^{c}
Harvest index	0.4	0.4	0.3	0.43	0.37	0.35
Seed size (g)	28.5	25.3	28.2	24.2^{a}	24.8^{a}	21.0^{b}

abc means for each response variable in a given year and row with different superscripts are significantly different (P <0.05) planting when the maize was first weeded. To minimize competition between maize and Sesbania, one seedling was transplanted in the furrow, at a spacing of 0.75 m within the furrow and 1.82 m between the trees, skipping one furrow in between. Where the seedling had failed to establish, supplying was done to give a final population of 7,400 trees per hectare (Maghembe *et al.*, 1997). A similar procedure was followed in the second season of the study. Growth of trees was monitored at monthly intervals for height, stem diameter at 20 cm above ground and number of primary branches per plant.

Crop and Tree Harvesting

Maize grain yield and yield components were harvested from net plots of 100 m^2 in all the treatments. The yield components included stover weight, seed size (100 seeds), cob length and harvest index. All yields were expressed on an oven dry weight basis (60^0C).

After harvesting of maize the trees were left to grow until they were 10 months old, just a month to the onset of the rains for the next growing season. Tree harvesting was done from net plots of $100m^2$. The trees were cut at crown level and hand-stripped of leafy biomass (leaves, flowers, pods and twigs of less than 50 mm diameter). The leafy biomass from the net plot was weighed fresh then sub-sampled for determination of nitrogen and dry matter yields. Fifteen-cm wood lengths were taken from the base, middle and tip-sections of three stems selected at random within the net plot for dry matter, N and P determination. A stack volume of 1-m wood length was recorded for each net plot.

Thereafter, all trees from the rest of the plot were felled and hand stripped of the leafy biomass which was then placed uniformly in the furrows. Ridges were then constructed so that the incorporated biomass was fully covered with soil to minimize volatilization of nitrogen. Leafy and woody samples from Sesbania were oven dried at 70^0C and 105^0C respectively. Thereafter, they were ground to pass through a 1mm screen for N and P determination by the modified Kjeldahl digestion method (Anderson and Ingram, 1993).

Statistical Analysis

All data were subject to statistical analyses of variance, using the MSTAT package. Where F tests were significant, means were separated by the Duncan's Multiple Range test. Regression analyses were carried out to determine relationships between treatments and maize grain yields.

RESULTS AND DISCUSSION

In the first year of our study, we established baseline data on the level of maize production at which the smallholder farmers were operating in the three landscape positions identified, i.e., the valley bottoms, the dambo margins and the steep slopes. We also investigated the growth components and establishment of the multipurpose tree, *Sesbania sesban*.

Initial Soil Fertility Status

Initial soil fertility status showed that those fields on steep slopes had less total N (0.9 gm/kg) than those fields on the valley bottom (1.4 gm/kg) and dambo margins (1.1 gm/kg) slopes. A similar trend of reduced fertility status for steeper sites compared to lower landscape positions was observed for organic carbon values (2.11, 1.53 and 0.87%) and phosphorus contents (14, 10 and 4 mg/kg). More detailed soil characterization is presented in part 2 of this paper, Phiri, *et al.*, (this volume). This appears to confirm that the differences in the maize grain yields and the maize grain to stover ratios on the different fields by landscape position may have been attributed to soil fertility differences.

Maize Yield and Yield Components

In years 1 and 2, maize grain yields from those fields located on the valley bottom were significantly ($P < 0.05$) higher than those from the fields located on the steep slopes (Table 1). Neither of these two landscape positions gave maize grain yields that differed significantly from those fields located on the dambo margins. It is also important to note, however, that maize grain yields on steep slopes were below one t/ha, and insufficient to support a farm family for the year. Most farm families have between six and eight children.

There are two possible explanations for these low maize grain yields on steep slopes. First, the fields have been subjected to continuous arable cultivation due to limited land holdings. Because of continuous land cultivation, many fields located on steep slopes had evidence of loss of topsoil to erosion especially where few or no conservation measures were undertaken. Banda *et al.* (1994) recorded up to 21.6 t of soil loss per ha on fields of 44% slope where no conventional structures such as contour ridges were used. Maize stover yields and seed size responses to landscape positions followed a similar trend established by the maize grain yields for the two years. There were no significant differences in the harvest indices of maize attributed to landscape position.

The high maize grain to stover dry matter yield ratio (1:2) in the steep slopes suggests that the crop under these conditions was diverting most of the photosynthate to stover at the expense of grain production. Corresponding ratios for the fields on the valley bottom (1:1.3) and dambo margins (1:1.6) appear to suggest a shift in allocation of photosynthates in favour of grain production. Steep slopes are usually vulnerable to soil erosion and hence poor in soil fertility.

The comparison of the effects of N source on yield and yield components of maize (Table 2) was based on a subset of 20 farmers' fields. As expected, maize grain yields from the inorganic N source (120 kg ha^{-1}) were significantly ($p < 0.05$) higher than those from either the organic N source (*Sesbania sesban*) or the control (where no external inputs of N were applied). The significant differences in maize grain yields between the organic N source and the control were also detected at the 5% level. These results clearly suggest that through tree incorporation the smallholder farmers were able to increase maize grain yields three-fold (494 to 1698 kg ha^{-1}). Similarly, when the inorganic source was applied then the farmers were able to achieve a four-fold increase (494 to 2136 $kgha^{-1}$).

Table 2. Yield and yield components of maize as affected by nitrogen source (n = 20 farmers)

Nitrogen source	Grain yield (kg/ha)	Stover yield (kg/ha)	Seed size (g/100 seed)	Harvest Index
Inorganic	2126[a]	1869[a]	30.4[a]	0.50[a]
Organic	1698[b]	1688[b]	23.3[b]	0.45[a]
Control	494[c]	739[c]	20.9[b]	0.19[b]

ab means followed by different superscript in a column are significantly different ($P < 0.05$).

These results clearly demonstrate that without additional inputs of N, farmers cannot maintain high levels of production from the MH18 maize hybrid variety. Overall, the N source was contributing 33 kg N ha^{-1}. This amount of organic N, however, was far below the current national recommendation for production of maize hybrids (96 kg ha^{-1}) or the levels applied in this study (120 kg ha^{-1}). This means therefore that for the organic source to yield similar quantities of maize grain to the inorganic source the current levels of organic N should have increased by more than 100%. Maize stover yield response to N source was similar to that of grain yield. However, in terms of seed size the inorganic source recorded 30.4 g/100 seeds which was significantly higher than the 23.3 g/100 seeds from the organic source and 20.9 g/100 seeds from the control sources.

There were no significant differences in the harvest indices (HI) between the inorganic (0.50) and the organic sources of N (0.45). However, the two values differed significantly ($p < 0.05$) from the control (0.19). The lack of significant differences between the HI of inorganic and organic sources point to the potential of the sesbania biomass to provide N equivalents sufficient to support maize grain yields comparable to those produced by the inorganic source. On the contrary, the significant differences in the harvest indices between the control and the organic or the inorganic sources confirm that high grain yields can not be achieved without external inputs of N. Maghembe *et al.* (1997) on a research station trial in the same ecology reported up to 2 t extra of maize grain per hectare from external inputs of N from *Sesbania sesban* and *Sesbania macrantha.*

Tree Growth, Percent Survival, Stack Volume and Dry Matter Yields

There were no significant differences in incremental height of Sesbania attributed to landscape position (Figure 2). Basal stem diameter at 20 cm from the ground and number of primary branches per plant were not significantly influenced by landscape position between January and June (Figures 3 and 4). However, between July and October, those trees established on the valley bottom had significantly ($p < 0.05$) higher basal stem diameter and number of primary branches per plant than their counterparts established on either the dambo margins or steep slopes.

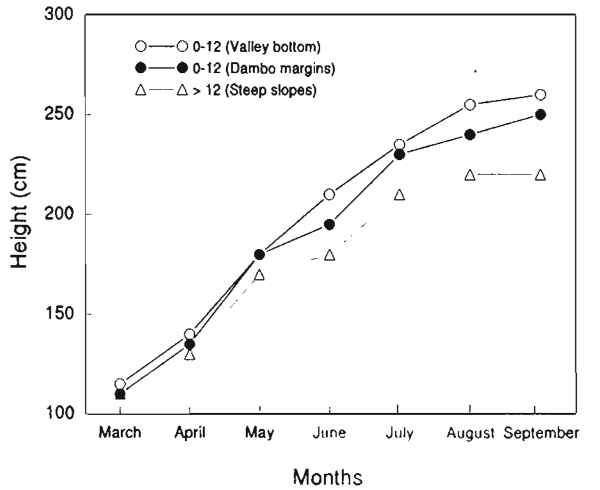

Figure 2. Height of Sesbania plant at seven months from transplanting.

The superior growth of Sesbania trees on the valley bottom may have resulted from better moisture availability and deeper soils with high organic matter content which is characteristic of dambos. Smallholder farmers normally take advantage of the extended period of moisture availability in the valley bottoms by growing vegetable crops during the dry season. Our sesbania technology under study could also take advantage of these moisture regimes. Incremental height, basal stem diameter and number of primary branches per plant in 1996 were similar to those for 1997 (Figures 5, 6 and 7). However, the

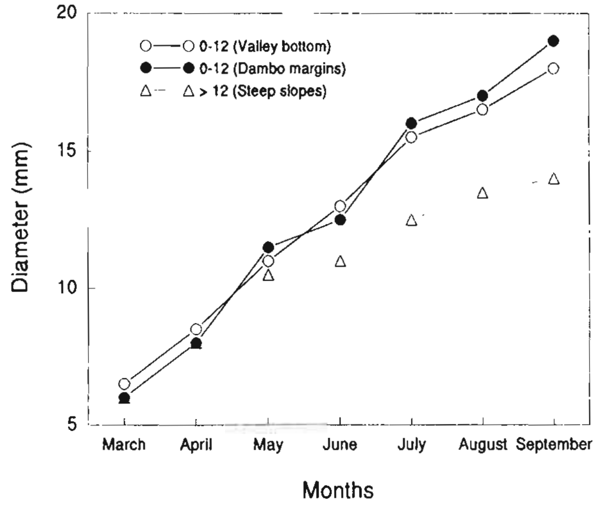

Figure 3. Stem diameter of Sesbania plant at seven months from transplanting.

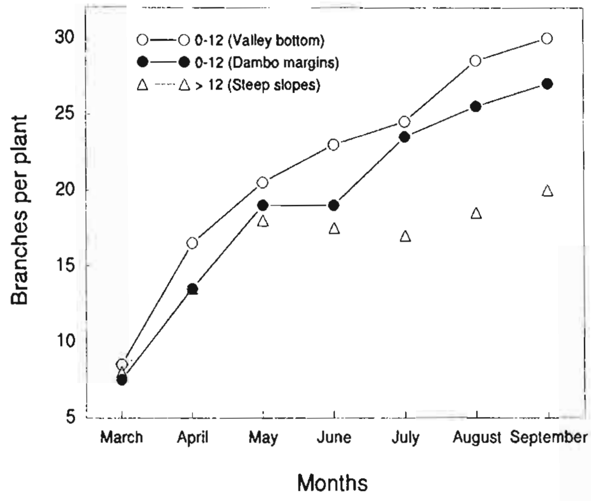

Figure 4. Primary branches per Sesbania plant at seven months from transplanting.

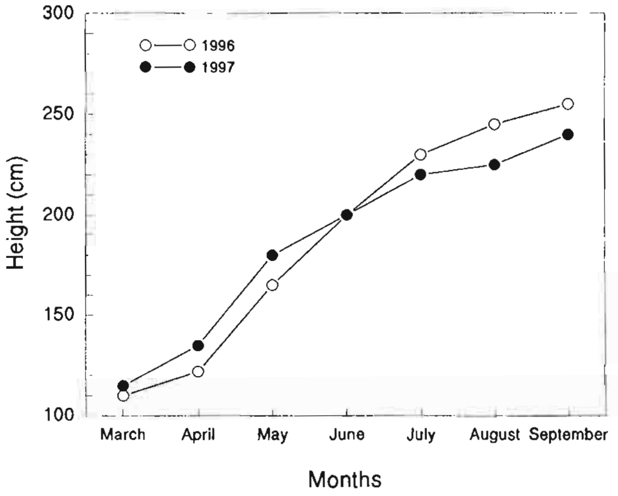

Figure 5. Height of Sesbania in 1996 and 1997 seasons.

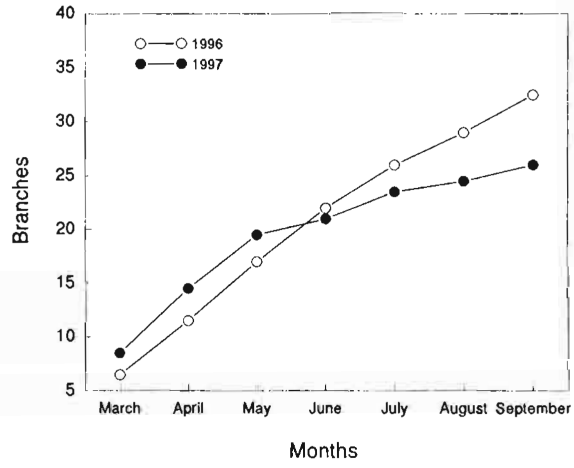

Figure 6. Branches per Sesbania plant in 1996 and 1997 seasons.

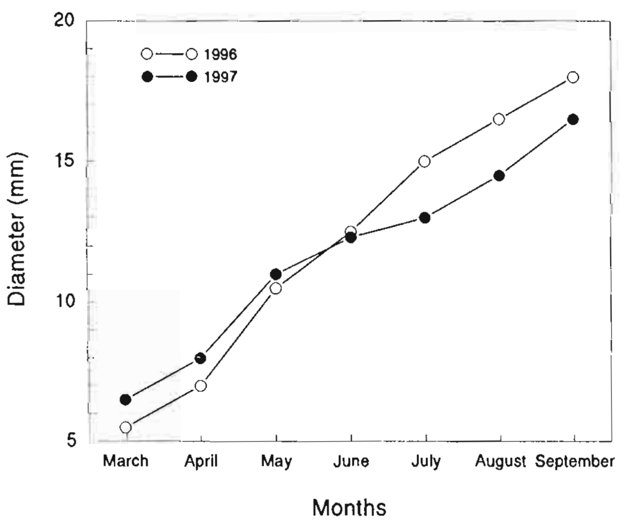

Figure 7. Diameter of Sesbania in 1996 and 1997 seasons.

number of primary branches per plant between August and October were significantly higher in 1996 than in 1997. This could reflect differences in rainfall distribution (Figure 1). Rainfall was evenly distributed in 1996, but most of the rainfall for 1997 was concentrated in the first three months.

The analysis of variance demonstrated significant ($p<0.01$) differences in tree growth, number of primary branches per plant, stem diameter and survival of *Sesbania sesban* attributed to landscape position effects. Significant F-tests for leafy biomass yields, woody biomass yields and stack volume were observed at the 5 percent level. Therefore, there is insufficient evidence to support the hypothesis that *Sesbania sesban* established and yielded the same biomass irrespective of landscape position effects.

Height, number of primary branches per plant, stem diameter and percent survival of Sesbania growing on valley bottom and dambo margins were significantly greater than those growing on fields with steep slopes ($p<0.05$) (Table 3). Leafy and woody biomass yields and stack volume of sesbania from the dambo margins were similar to those either on valley bottoms or from steep slopes (Table 5). However, significant differences were observed between the Sesbania trees growing on the valley bottom and those on steep slopes ($p<0.05$).

Table 3. Growth and survival of Sesbania at three landscape positions (n = 33 farmers)

Variable	Valley Bottom (0 - 12%)	Dambo Margins (0 - 12%)	Steep Slope (>12%)	CV (%)
Height (m)	3.42[a]	3.01[a]	1.92[b]	36.4
Primary branches per plant	40.1[a]	33.3[a]	19.3[b]	44.4
Stem diameter at 20cm (mm)	29.1[a]	24.2[a]	13.2[b]	42.1
% Survival	91.3[a]	84.9[a]	50.8[b]	27.4

a b Means followed by the same letter in a row are not significantly different (P < 0.05).

Table 4. Biomass yield of Sesbania at three landscape positions (n = 33 farmers)

Variable	Valley Bottom (0 - 12%)	Dambo Margins (0 - 12%)	Steep Slope (>12%)	CV (%)
Leafy biomass Yield (kg/ha)	2146[a]	1237[ab]	679[b]	106.2
Woody biomass Yield (kg/ha)	5171[a]	2501[ab]	1097[b]	124.9
Stack volume (m^{-3}/ha)	460[a]	250[ab]	130[b]	117.8

a b Means followed by the same letter in a row are not significantly different (P < 0.05).

Table 5. Quality of leafy biomass of Sesbania in relation to landscape position (n = 33 farmers)

Response variable	Valley Bottom (0 - 12%)	Dambo Margin (0 - 12%)	Steep Slope (> 12%)	CV (%)
% N	2.61[a]	2.17[b]	2.36ab	17.68
% P	0.42	0.37	0.39	15.90
N yield (kg/ha)	58.9[a]	26.1[ab]	15.9[b]	115.0
P Yield (kg/ha)	9.13	4.72	2.96	116.1

Means followed by different superscripts in a row are significantly different (P < 0.05)

One likely explanation for the poor tree performance on the steep slopes is that such areas had generally shallow and eroded soils with rocky outcrops that made it difficult for the roots of Sesbania to develop successfully (unpublished data).

On the valley bottom and dambo margins, the soils were generally deep and held soil moisture well into the dry season. Researchers elsewhere (Brewbaker *et al.*, 1990 and Bunderson *et al.*, 1995) have demonstrated that *Sesbania sesban* can establish successfully on varied soil environments. This generalization did not hold true under the conditions of our study as poor establishment was observed on steep slopes. During the establishment year (1995/96 season), the study area received sufficient rainfall (Figure 1.). This may also have contributed to successful tree growth and establishment especially in the valley bottoms and dambo margins that held moisture longer than those fields located on steep slopes. The deep soils of the two landscape positions also made it possible for the Sesbania to root deeply and thus presumably extract soil moisture and nutrients from deeper horizons (Hatermink *et al.*, 1996 and Meckonnen *et al.*, 1996). This further suggests that there is greater opportunity to intercrop Sesbania as a soil fertility management technology, as demonstrated by its high leafy biomass yields produced in the valley bottom and the dambo margins.

The benefits of this relay intercropping technology would go beyond soil fertility improvement from the leafy biomass. Indeed, the results have further demonstrated an added benefit from woody biomass (Table 4). After only ten months of growth in the field, woody biomass from the valley bottom averaged 5171 kg/ha compared to 2501 kg/ha from the valley bottom dambo margins and 1097 kg/ha from the steep slopes.

These yields translated into stack volumes of 460, 250 and 130 m^3 per hectare respectively. These amounts of woody material would, to some extent, reduce the dependency by smallholder farmers on fuelwood and construction material from the Zomba mountain forest reserve that is being deforested. This study has confirmed on-station results (Maghembe *et al.*, 1997) that relay intercropping of Sesbania with maize, has great potential for soil fertility improvement in the densely populated areas of southern Malawi.

The effect of farmer management could not be detected because of the experimental design used, where each farmer-site was a replicate. The small landholdings of farmers in the area provided insufficient space for replication at each site. We expect that there was very large variation in farmer management as evidenced from the large coefficients of variation (Table 4). However, the on-farm participatory approach to research used here allowed farmers to participate in the management of the experiments. This strategy was intended to facilitate the adoption of the intercropping technology (Kanyama-Phiri, *et al.*, 1995).

There were significant differences in plant survival ($P < 0.05$) attributed to N source (Table 3). Trees on steep slopes had 50.8 % survival which was significantly less than the 84.9 % survival recorded for the dambo margins and 91.3 % for valley bottoms. Hocking and Islam (1995) attributed tree mortality in order of frequency to livestock browsing, physical damage during cultivation or harvesting of arable crops, pests and diseases, drought and flooding. In our study, however, animals were confined throughout the year and that excluded livestock damage as one of the causes for low survival of trees. We expect that the other factors applied equally to the three landscape positions. However, effects of farmer management were not significant.

In the second year of our study the focus shifted from the establishment of baseline data for maize production and tree legume establishment to the response by maize to nitrogen source at various landscape positions. This objective was developed from the diagnostic study (Kanyama-Phiri *et al.*, 1995) which revealed that soil fertility was the primary constraint to smallholder maize production in the study area and that this constraint is compounded by small landholding sizes that have been generally depleted of organic matter by continuous cultivation and soil erosion, especially on the steep slopes. Therefore, an organic source would not only replenish the much needed organic matter, but would also reduce the total dependency by the smallholder farmers on inorganic fertilizers which have been extremely expensive lately (ADMARC, 1995, pers. comm.).

On the average, at tree incorporation, the leafy biomass from the valley bottom contained 2.61% N, the valley margin 2.17% N and steep slopes contained 2.36% N. These values translated into N yields of 58.9, 26.1 and 15.9 kg/ha (Table 5). The large coefficients of variation reflect differences in the management of fields under farmer managed trials.

Figure 2 indicates that there was a significantly ($P<0.001$) positive linear relationship ($r= 0.68$) between the maize grain yields and amount of N from the leafy biomass incorporated and the maize grain yields. The positive linear relationship confirms that there were additional nitrogen inputs from sesbania during the growing season and therefore the sesbania technology involving intercropping maize with the tree legume has potential for increasing maize production. The presence of outlier farmers, however, suggests that such a relationship was not a perfect one. In one case a farmer had incorporated only one t of leafy biomass and yet four t of maize grain were produced per hectare.

It is possible under researcher-designed and farmer-managed experiments to find a few farmers who may have applied green or cattle manure or some inorganic fertilizer without our knowledge. This may have been the case in our study especially for the farmer who realised 4 t/ha of maize grain from only one t of leafy biomass/ha. The highest dry matter yield (6 t/ha, approximately) observed in another farmer's field resulted in approximately 5 t of maize grain per hectare.

This was expected since with this amount of leafy biomass incorporated there was more than 1809 kg of organic nitrogen per hectare contributed from the sesbania which is almost twice the amount in the national N fertilizer recommendation. However we also treated this farmer as an outlier because out of the 33 farmers it was the only field that achieved such an incredible tonnage of biomass, with the majority of the farmers averaging less than 2 tonnes of leafy biomass per hectare.

CONCLUSIONS

This study has demonstrated the difficulties associated with the growth, establishment and survival of Sesbania on the steep slopes of Zomba RDP, southern Malawi, particularly in the Songani catchment of Malosa EPA. But the opportunity appears to exist for the introduction of relay intercropping technology involving Sesbania in the valley bottom and dambo margin landscape positions. This is the first report that we are aware of which quantifies under on farm conditions the production of biomass, tree growth and leaf quality. Values were about one half of results from stations.

The study has indicated that with good management and non-limiting precipitation smallholder farmers can generate sufficient biomass on the valley bottoms to reduce their dependence on inorganic inputs by more than 50%. This is important because most of the smallholder farmers in the study area cannot afford inorganic fertilizers. Under the conditions of this study, we conclude that relay intercropping technology has the potential to increase smallholder maize production in southern Malawi. The differences in nitrogen yields between the steep slopes and the valley bottom landscape positions were significant.

Nitrogen yields from the Dambo margins were similar to those either from the valley bottom or steep slopes. This means that smallholder farmers whose fields are located on the valley bottom would only need to top dress their maize with 38kg N ha^{-1}, thus cutting down inorganic fertilizer requirements by 50%. The amount of organic nitrogen input for the other two landscape positions met less than two thirds of the requirement for hybrid maize. However, the relay intercrop with *Sesbania sesban* would provide sufficient N for the growing of local maize.

Phosphorous per cent and yield were similar at the three landscape positions and fell far short of the national recommendation of 25 kg/ha for hybrid maize in Malawi. This suggests that Sesbania produced insufficient phosphorous to support maize production.

The widespread intercropping of maize with tree and herbaceous legumes and the incorporation of crop residues by smallholder farmers in the study area provide another opportunity for easy adoption of the sesbania technology in southern Malawi.

ACKNOWLEDGEMENT

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UNDERSOWING MAIZE WITH *SESBANIA SESBAN* IN SOUTHERN MALAWI: 2. NITRATE DYNAMICS IN RELATION TO N SOURCE AT THREE LANDSCAPE POSITIONS

REBBIE H. PHIRI[1], SIEGLINDE SNAPP[2] and GEORGE Y. KANYAMA-PHIRI[1]

[1]Bunda College of Agriculture, P.O. Box 219, Lilongwe and [2]ICRISAT, P.O. Box 1096, Lilongwe, Malawi

SUMMARY

A study was conducted in 40 farmers' fields in Zomba Rural Development Project, southern Malawi to measure nitrate-N dynamics in different landscape positions as influenced by N source. The landscape positions were dambo margin, valley bottom and steep slopes. Nitrogen sources consisted of an inorganic fertilizer, organic fertilizer and a control. The inorganic fertilizer plot received 120 kg N ha^{-1}. The organic fertilizer plot was a relay intercropping system of Sesbania sesban biomass applied at the rate of 500-3000 kg ha^{-1}, depending on tree growth the previous year.

Nitrate availability varied across the maize growing season. The highest nitrate levels (16 mg kg^{-1}) were observed at 85 days after maize planting (DAP) and decreased markedly (7 mg kg^{-1}) towards the end of the growing season. There were no significant differences in topsoil nitrate among the three landscape positions. However, nitrate in the subsoil was consistently highest at the valley bottom sites and lowest at the steep slope sites. This was expected due to higher soil organic C and total N at lower landscape position sites compared to eroded slopes. There was greater nitrate accumulation in the N input plots (both inorganic and organic) than the zero N control. Similarities in nitrate dynamics in the topsoil over the season suggested similar release patterns from organic and inorganic sources. In the subsoil, by contrast, nitrate at the end of the growing season accumulated 2-fold higher in the inorganic N treatment than any other treatment (12 mg kg^{-1} compared to about 5 mg kg^{-1}). This was in part due to higher N inputs in the fertilizer treatment. Subsoil nitrate accumulation indicated the potential for nitrate leaching with use of inorganic N fertilizer, particularly for valley bottom sites.

INTRODUCTION

Soil erosion and degradation of other natural resources resulting from increasing land pressure have become serious problems in Malawi. The consequences have been a rapid decline in soil fertility, crop yields and firewood for domestic fuel. Acute land pressure over the last 10-15 years has resulted in accelerated clearance of indigenous forests and the cultivation of maize and other crops on very steep slopes of up to 50% (Maida, 1988). The Ministry of Agriculture does not recommend cultivation of annual crops on slopes exceeding 12% (Kanyama Phiri *et al.*, 1994; Shaxson *et al.*, 1977). In the course of the rapid decline in soil fertility, nitrogen has become the most limiting nutrient to maize production in Malawi (Saka *et al.*, 1995).

Practices of incorporating organic matter into the soil are widely used in Southern Malawi. However the most common sources such as crop residues and weeds are low in nitrogen, the most essential macroelement (Brogan, 1991; Kanyama-Phiri, *et al.*, 1997). Use of inorganic fertilizer is increasingly seen as a solution to the problem of restoring soil fertility and providing food for people. But over the past five years, the cost of farm inputs, especially inorganic fertilizers has more than doubled in Malawi (ADMARC, pers comm. 1995).

There has been interest in recent years to use alternative sources of N such as tree legume species to enhance N and C inputs into cropping systems through biomass production, biological N fixation (BNF) and recycling of N. Nitrogen fixation by legumes plays a central role in enhancement and maintenance of soil fertility where N fertilizers are not affordable or cannot readily be used. Trees have root systems that extend far more deeply than those of annual crops and this enhances the opportunity for complementary use of resources, especially nutrients that may be recycled from below annual crop root zones (Hartemink *et al.*, 1996). When properly managed legumes can provide an important source of high quality organic inputs, to supply nitrogen and improve N buffering capacity and productivity of the soil (Giller *et al.*, 1994). Data on legume performance, biomass quality and N release in smallholder fields of Southern Africa, however, is very limited (Snapp, *et al.*, in press).

The wide-scale and systematic integration into maize-based cropping systems of *Sesbania sesban* is a promising alternative. *Sesbania sesban* contributes to the nitrogen economy of the soil through nitrogen fixation and nitrogen recycling from deep in the profile (Yamoah, 1988). Foliage of *Sesbania sesban* is an excellent source of high quality green manure and organic N. In Java, yields of 5 t biomass per hectare have been achieved in only six or seven months (Bhat, 1971). Ghai *et al.*, (1985) reported that *Sesbania sesban* within a growth period of 100 days produces sufficient biomass which when incorporated into the soil supplies between 39 and 85 kg N ha^{-1}. *Sesbania sesban* is productive in alley cropping systems (Yamoah and Burleigh, 1990). The amount of nitrogen input and improved cycling efficiency achieved by *Sesbania* species has not been characterised for the range of on-farm conditions in the Southern Africa smallholder sector. This is an important point because legumes often produce much lower amounts of biomass under low fertility and high stress environments on-farm.

Nitrogen dynamics, including fixation and losses through leaching and denitrification, vary across landscape positions. In addition to direct losses of N, soil properties can reduce N recovery through their influence on plant growth. Compact soil layers and subsoil phosphorus deficiencies in eroded landscape positions may restrict root growth, thereby restricting water and N uptake (Pan and Hopkins, 1991). A study to evaluate the effect of slope position on N fixation by peas (*Pisum* spp). (Mahler *et al.*, 1979) showed that there was greater N fixation by peas growing at the bottom than at the top and the side slopes. The greater N fixation by peas on the bottom slope were apparently related to greater root penetration and higher soil water. In a similar environment, Fiez *et al.*, (1994) observed that N, dry matter accumulation and grain yields decreased from bottom land through midslope to ridgetop. Lower yields at the ridgetop were attributed to less efficient water extraction from the soil profile which they assumed was an indication of less root penetration. In the landscapes of southern Malawi the valley bottom positions are near drainage lines, designated as'dambos'. Fields that are on relatively flat sites (less than 12% slope) and are further from dambos than the valley bottom sites are designated as dambo margin sites. Thus agriculture is carried out on three major landscape positions in undulating watersheds of southern Malawi: 1) valley bottom sites (nearest the drainage lines, 0-12% slopes), 2) dambo margins (0-12% slopes, away from dambos) and 3) steep sites (> 12% slopes).

Due to variation in soil characteristics across landscape positions, N requirements can vary widely within a locality. However farmers typically apply a single rate of N across a field resulting in areas of over and under application which may affect crop production, water quality and income. Past research in Malawi has not clearly quantified N requirements across landscape positions. Hence there is need to quantify soil N dynamics and N requirements in maize-based cropping systems as influenced by landscape positions as well as N source.

The objectives of this study were to monitor nitrate as a measure of N availability over time at different landscape positions and to evaluate nitrate dynamics in the soil following incorporation of *Sesbania* leaf biomass, in comparison to N from an inorganic source and soil N in the absence of inputs.

MATERIALS AND METHODS

Site Description

A field study was conducted in 40 farmers' fields for two cropping seasons in Songani, and an in-depth study of N source effects on a subset of 20 fields. Songani (15^{0} 181/2'S, 35 ^{0} 231/2'E) is in Malosa Extension Planning Area (EPA) in Zomba Rural Development Project (RDP), southern Malawi. The area is at an elevation of 856 metres above sea level and receives an average annual rainfall of 1139 mm. The area has soils that have been classified as Alfisols and Ultisols (Kanyama Phiri *et al.*, 1997) and have generally sandy loam textures (from sandy to clay loam). The cropping system is dominated by maize, the staple food crop in Malawi. Major intercrop species include cassava and pigeon peas. For this study, three different landscape positions were identified along six transects (Kanyama Phiri *et al.*, 1994). These landscape positions were valley bottom sites, dambo margins and steep sites.

Experimental Layout

The experimental design in all farmers' fields was a randomized complete block with each farm site as a replicate (see Phiri *et al.* 1997 this volume). There was an inorganic fertilizer plot and a zero input control plot at all 40 farm sites, with the addition of an organic fertilizer plot at 20 of the sites. Each plot measured 10 m by 10 m in which three MH18 hybrid maize plants were planted at 91 cm apart within ridge rows and 91 cm between ridges (following farmer practice in southern Malawi). The inorganic fertilizer treatment received 120 kg N ha^{-1} as calcium ammonium nitrate applied using the banding method and a split application, whereas the zero N control received no fertilizer. The relatively high level of N fertilizer (92 kg ha^{-1} is the Malawi Govenment recommendation for N fertilizer applied to maize) was chosen to maximize N supply and observe maize yields under these conditions. The first application of fertilizer was at 14 days after emergence (DAE), after initial soil sampling for nitrate. The second application of fertilizer was at 35 DAE. The organic treatment plots were implemented on a subset of 20 farm fields, consisting of a relay intercropped *Sesbania sesban* system (see Phiri, *et al.*, this volume). Note that this plot had been used to grow *Sesbania sesban* as a relay intercrop with maize in the previous season, and leafy biomass produced at each site was incorporated the previous October. *Sesbania* was transplanted when the maize crop was about 60 cm high in the 1995/96 cropping season at a density of 7 400 plants ha^{-1}. Before the 1996/97 cropping season the *Sesbania*, then 10 months old, was harvested in all organic fertilizer plots. *Sesbania* leaves were stripped manually and incorporated into the soil in October, before maize was planted. Nitrogen inputs varied for the *Sesbania* treatment, as shown in Table 1 as mean values for the three landscape positions.

Table 1. Nitrogen (kg/ha) inputs at different landscape positions in the 1996/97 season, near Zomba, Malawi. Mean of 20 field sites for comparison of N sources.

Landscape position	Estimate of soil N supply	Nitrogen source		
		0N	Organic N	Inorganic N
Valley bottom	58	0	59	120
Dambo margin	34	0	26	120
Steep slope	18	0	16	120

To estimate soil N supply at each site, N uptake by maize in the zero N control plot was measured. Maize plant biomass was sampled at the milk stage, where three plants were randomly chosen per plot. Plants were dried (60^0 C) and ground to pass a 1 mm mesh. Nitrogen was determined using a wet digestion method (Anderson and Ingram, 1993) and N accumulated by maize determined (Table 1).

Soil Sampling and Analysis

Soil samples were collected from the 0-15 cm, 15-30 cm, 30-45 and 45-60 cm depths using a composite of 10 subsamples to measure nitrate dynamics. These nitrate measurements were conducted four times during the growing season: at 10, 50, 85 and 130 days after planting (DAP). Prior to planting, initial soil samples were taken from 0-15, 15-30, 30-45 and 45-60 cm depth increments using a soil corer. From these soil cores organic carbon, total N, P, soil texture and bulk density were measured and soil moisture retention curves (water content at 1/3 and 15 bars on a pressure plate apparatus) developed. Saturated hydraulic conductivity was measured on one 6-cm diameter core per depth increment (Table 2). Nitrate from a 2 M KCl extract was determined using ultraviolet direct detection and P was determined using the Mehlich 3 extraction method (Anderson and Ingram, 1993; Wendt 1993). Soil pH was determined in 1:2.5 soil:water. Soil texture was determined using suspension after dispersal in sodium hexametaphosphate. Organic carbon was determined by wet acid digestion and colorimetric method (Anderson and Ingram, 1993). To determine soil bulk density, pits were dug at each site to 1 metre depth and volume cores were driven horizontally into the side of the pit at intervals. Soil samples for bulk density were oven dried at 105^oC for about 48 hours and after attaining a constant weight the bulk density was calculated.

RESULTS AND DISCUSSION

Site Soil Characteristics and Yield Potential

Chemical and physical properties of the soil differed among landscape positions (Table 2). The organic carbon of the surface 15 cm was highest in the valley bottom and lowest in the steep slopes. The bulk density was highest in the steep slopes. This is not surprising as steep slope sites were generally very shallow soils. Phosphorus availability among the landscape positions ranked valley bottom >dambo margin > steep slopes. Inorganic N was also highest in the valley bottom. Estimates of soil N supply from zero N plots (maize uptake of N) were higher in the valley bottom, intermediate in the dambo margin and lowest in the steep slopes (Table 1). This can be attributed to the higher organic C and total N in the bottom valley and dambo margin positions compared to the steep slope sites. High soil organic matter is expected to have enhanced soil N supply. These results show that there is variation in chemical and physical properties of the soil among landscape positions.

The fertility of the lower landscape positions was confirmed by the mean maize yield measurements which were 1333 kg ha^{-1} for valley bottom, 1095 kg ha^{-1} for dambo margin and 515 kg ha^{-1} for steep slopes in the 1995/96 season. A similar pattern of yield response to landscape position was observed in 1996/97 (see Phiri, *et al.*, this volume).

Table 2. Soil characteristics (0-15 cm) at different landscape positions in Songani catchment. Mean of 40 farm field sites, before experimentation started (October, 1995).

Characteristic	Landscape position		
	Valley bottom	Dambo margin	Steep slope
Total N, g kg^{-1}	1.4	1.1	0.9
Organic C, g kg^{-1}	21.1	15.3	8.7
P, mg kg^{-1}	14	10	4
pH	6.5	6.1	5.3
Bulk density, g cm^{-3}	1.3	1.2	1.4
Hydraulic conductivity, ml hr^{-1}	5.4	7.2	7.2
Texture:			
%sand	45	40	36
%silt	18	27	22
%clay	37	32	42

Nitrate Dynamics and Landscape Position

Nitrate levels were generally high (~14 mg kg^{-1}) in the top soil layer (0-15 cm) (Figure 1). A similar nitrate distribution pattern was observed by Itimu and Giller (1997) in central Malawi. The level of soil nitrate we observed was higher than findings of Barrios *et al.*, (1997) from a similar ecology in eastern Zambia. However, generally the soils had high soil organic carbon and total N in this Southern Malawi watershed, compared to eastern Zambia which may explain the relatively high soil nitrate values reported here.

Patterns of nitrate dynamics over the season as influenced by landscape position are shown in Figures 1 and 2. Overall nitrate values were low initially in the top soil (0-15 cm), approximately 11 mg kg^{-1} at 10 and 50 days after planting (DAP), then nitrate values increased to about 15 mg kg^{-1} and finally were 7 mg kg^{-1} at the end of the season. Overall, there was no significant effect of landscape position in the top soil. It appears that soil mineralization of N, organic inputs and fertilizer application have maintained nitrate values in the top soil throughout most of the growing season. This demonstrates high soil nitrogen mineralization potential, as maize uptake of N occurs throughout the season as well as other N sinks such as leaching and denitrification. This is a similar pattern to that observed by Moutonnet and Fardeau (1997) over a maize growing season for a Calcic Fluvisol type of soil.

It was somewhat surprising that mean nitrate in the topsoil of steep slope sites was not lower than the sites located at the valley bottom or dambo margin (Figure 1). This is in contrast to a study carried out in the USA (Elliot and de Jong, 1992) where variation in N mineralization among landscape positions was largely due to variation in soil characteristics across landscape positions. Mean organic N inputs from *Sesbania* and soil organic C, total N were lower at the steep sites, which would be expected to reduce soil nitrate levels (Table 1). However, low maize growth at these degraded soil sites would reduce N removal over the season. Soil nitrate measurements indicate a net value; a function of soil N release and inputs minus plant N uptake and other sinks such as leaching. Thus lower growth (by one-third, see maize yield data and maize N uptake, Table 1) at steep sites could enhance soil nitrate by removing less than was removed at other sites with higher productivity. However, there was relatively high variability associated with topsoil nitrate (compared to subsoil), which may have reduced the ability to distinguish landscape position effects (Figure 1).

We observed a similar pattern of nitrate accumulation and decline at the end of the growing season at the lower soil depths (15-45 cm) as in the top soil. The one major exception was the field site on steep slopes (Figure 2). At this landscape position soil nitrate declined steadily over the season. This can be explained by the significantly lower organic carbon and total N values of the steep slope sites compared to dambo and valley bottom sites (Table 2). Erosion may have contributed significantly to these low soil N values. This suggests that there was limited N from soil mineralization in this landscape position. Such conditions were observed by Fiez *et al.*, (1994) in Pullman, Washington, USA where higher average values for N mineralization were greater in the valley bottom compared to steep slope positions.

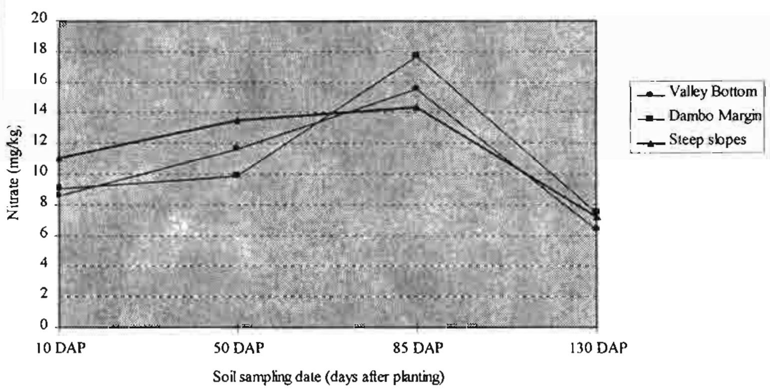

Figure 1. Nitrate dynamics over the maize growing season in relation to landscape position at 0-15 cm soil depths near Zomba, Malawi.

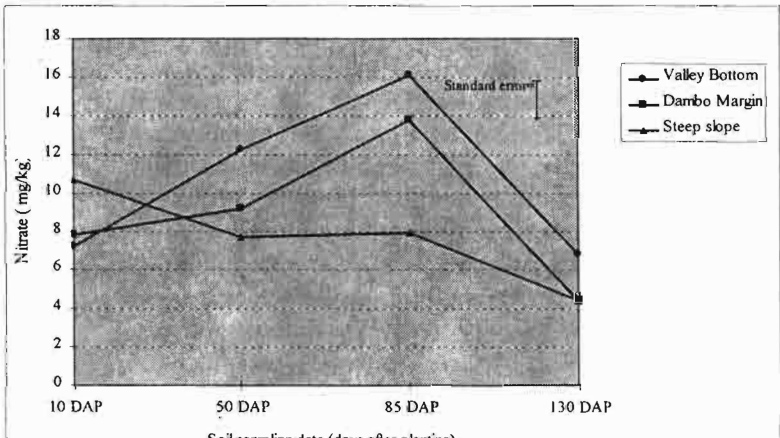

Figure 2. Nitrate dynamics over the maize growing season in relation to landscape position at 15-45 cm soil depths. Standard error given is an overall estimate of variability (n=40).

In the subsoil, the valley bottom had consistently higher nitrate values over the growing season (Figure 2), compared to dambo margin and steep slope site positions. This could be attributed to the higher organic carbon and N values of this landscape position (Table 2). Possibly, less drainage in the valley bottom occurred as shown by hydraulic conductivity values in Table 2. Thus less leaching of nitrate occurred and nitrate accumulated in the subsoil. Saturated soils are a consistent feature of valley bottom sites (unpublished data) which may have reduced leaching. However, anaerobic conditions should increase substantially denitrification as well and contribute to lower nitrate (Jury and Nielsen, 1989). Taken together, these data suggested that leaching, and not denitrification, determined soil nitrate in the subsoil layer (15-45 cm). The importance of leaching versus denitrification as a N loss process in similar environments has been suggested by others (Jones, 1976; Thornton *et al.*, 1995). However, almost no data has been published before our report regarding nitrate accumulation on-farm in southern Africa landscape environments, to evaluate the validity of this hypothesis.

Nitrate Dynamics and N Source

Patterns of nitrate over the 1996/97 season as influenced by N source are shown in Figures 3 and 4. Within 10 DAP there was no significant difference in nitrate at 0-15 cm soil depth in all plots (Figure 3). As might be expected between 10 and 50 DAP there was greater nitrate accumulation in the N input treatments than in the 0 N control. This trend continued up to 85 DAP. Thereafter both the inorganic and organic source declined sharply. This can be attributed to various sinks for N, the most important of which were presumably plant uptake and leaching beyond the root zone. Note that maize yields from the two N input sources (inorganic and organic) were about three-fold higher than in the 0 N control (Phiri, *et al.*, this volume). Soil nitrate dynamics from the N input treatments indicated soil N accumulation over the same period that maize plants were taking up N. This suggested a lack of synchrony and over-supply of N by input treatments to meet maize yield potential under these on-farm, stressed conditions.

By the last day of sampling the soil profile had low levels of nitrate. The one notable exception was the inorganic N treatment which had high nitrate levels at 15-45 cm at the end of the season. This suggests that the N from fertilizer had leached from the 0-15 cm to the lower depth. Leaching can result in appreciable loss of top soil nitrate (Poss and Saragoni, 1992) and accumulation of nitrate in the subsoil (Jones, 1976).

It is interesting that the *Sesbania* organic N source provided enough N to support maize yields which were not significantly different from 120 kg N ha^{-1} (Phiri *et al.*, 1997, this volume). Yet, there was no evidence of leaching in the *Sesbania* treatment. *Sesbania* treatment N inputs were, however, lower than the N fertilizer treatment (Table 1). This suggested that *Sesbania* can be used as an N source and substitute for inorganic N sources. Sesbania has been shown to be superior to other legume trees in increasing soil inorganic N and N mineralization (Barrios *et al.* 1997). *Sesbania* leaves are high quality, low in lignin and polyphenols with a narrow C:N ratio, indicating N is

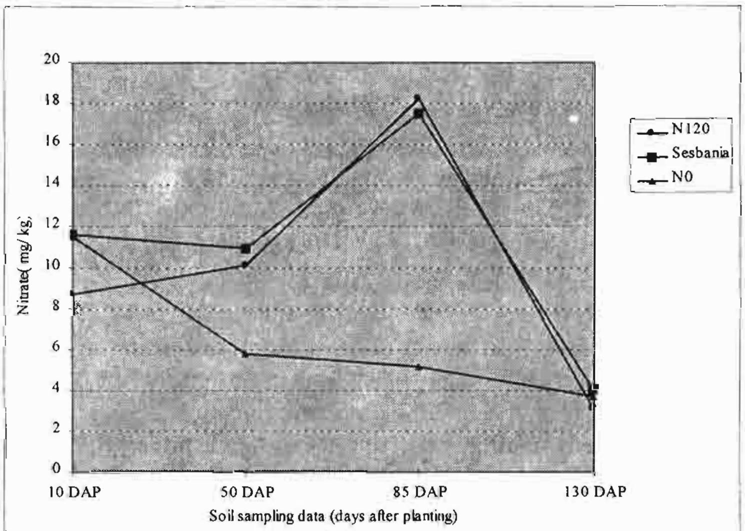

Figure 3. Nitrate dynamics over the maize growing season in relation to N sources at 0-15 cm soil depths.

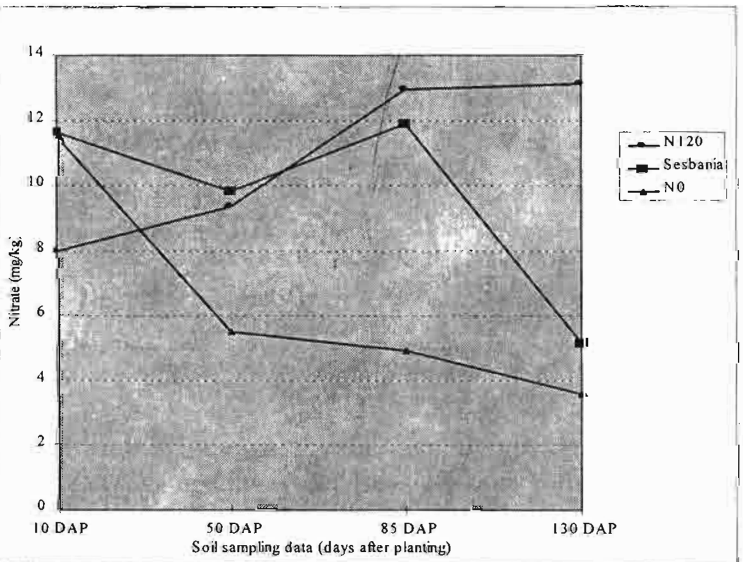

Figure 4. Nitrate dynamics over the maize growing season in relation to N sources at 15-45 cm soil depths.

rapidly released from *Sesbania* leaves.

CONCLUSIONS

The study has also shown that nitrate availability tends to diminish towards the end of the growing season. This indicates the importance of monitoring nitrate dynamics early in the growing season. There was a limited effect of landscape position on nitrate dynamics in the topsoil, irrespective of N source. This was somewhat surprising as steep slope sites had low soil organic matter and limited N inputs from *Sesbania* compared to other landscape positions, but maize growth and N uptake was also low at steep sites. Soil nitrate over the growing season in the subsoil, in contrast to the topsoil, was substantially lower at steep slope sites compared to lower landscape positions. This was presumably primarily to reduce soil N mineralization at these degraded soil sites.

High soil nitrate levels in the middle of the season in plots with organic and inorganic N sources compared to zero N input plots suggested that the N release pattern was similar from the two N sources studied. This indicated that a *Sesbania* relay intercrop system was able to substitute for an inorganic source and supply sufficient soil N for maize production. The two-fold higher accumulation of nitrate in the subsoil at the end of the season in inorganic N treatments compared to other treatments suggested the potential of fertilizer treatments to leach nitrate beyond the crop root system. An interesting observation was that farm sites which were consistently water-logged nonetheless accumulated nitrate. Leaching, not denitrification, is suggested as a major N loss under on-farm conditions in this watershed.

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DISCUSSION: INTERCROPS AND ROTATIONS

Questions to Peter Jeranyama

From: Danisile Hikwa
Cowpea is a crop that farmers use for both grain and leaf. If it is used as a green manure that requires to be ploughed under at a certain growth stage, there is likely to be a conflict of interest and it is unlikely that farmers will use the crop as a true "green manure". How do you plan to get around that problem at the technology transfer stage? Should you really be calling the cowpea a green manure crop?

Response:
There are different ways of managing legume green manures and one of them is not to plough under the plants but leave them on the soil surface and incorporation will be done during the next season's normal ploughing. There is also a need to see whether the differences between incorporation and non-incorporation of green manure almost simulate a grazing and a non-grazing system.

From: Herbert Dhliwayo
My understanding of green manure crops is that the green manure crop is ploughed under in order for the benefits to be realised. In your work no ploughing under was done. This could be due to several reasons such as the green manure crop types used and implements appropriate for incorporating such crops. I do hope that you consider such issues in your future plans.

Response:
While conventional wisdom tells us to plough green manures under, it does not necessarily follow that ploughing under is the only way to benefit from legume green manures. Leaving green manure residues on the surface of the soil helps to delay N loss from the green manures before the maize crop is ready to take up N.

From: Robert Gilbert
You presented data for legume biomass and N added at 75 days after planting (DAP), yet then you stated that you let the crop grow and farmers harvest the grain. How do you know how much N was actually added to the system, or calculate fertilizer equivalency values?

Response:
Seventy five DAP is about the optimum period to quantify legume N for the system under study since the legumes were relayed 30 days after maize was planted. Seventy-five DAP comes close to mid May and usually active growth is arrested after mid May when the first frost begins.

From: Alfred Mutukuso
What happened to the weed data collected during the trial? What effect could it have on responses by cowpea and sunnhemp?

Response:
Weed data were collected but were not processed before this meeting. In general the weed growth and biomass were reduced especially under the broad-leafed cowpea.

Comment from: Gideon Tsododo
Develop user-friendly mechanisms for putting across your results to farmers.
This is an important area to be considered.

Questions to Monica Murata

From: Larry Harrington
How well do your sites represent the Natural Regions in Zimbabwe? Do you have characterization data?

Response:
Before site selection we sampled 40 farms per district, then selected representative sites. We also did a site characterisation at each trial site.

From: Ishmael Pompi
It seems you have no trials in NRIII.

Response:
We had sites in Chiwundura (NRIII) but we had to abandon them. Our host farmer declined to continue after his wife died from a short illness. He believed that she had been bewitched because of hosting our trials.

From: Ken Giller
At one site you found that maize after sunflower gave poorer yields than maize after maize, but at another site you found the opposite. Did you take measurements of any parameters that might help to explain these effects?

Response:
We have taken soil and foliar samples which are currently being analysed.

Questions to Stephen Waddington

From: Peter Jeranyama
What discount rate did you use for net present value in your economic analysis?

Response:
We used year 0 = 1, year 1 = 1/(1 + interest rate), year 2 = 1/(1+ int. rate)^2. The interest rate was 23% per year.

From: Ken Giller
Have you collected soil samples which might be used to help explain the yield declines in maize?

Response:
We have and these will be analysed later in 1997. We wanted to send samples from several years to the lab at the same time, to help compare results.

From: Antony van de Loo
How come the response of maize yield after groundnut is more distinct when NOT applying inorganic fertilizer compared to applying fertilizer?

Response:
We are not sure, but it is probably a function of a very wet year where lots of N may have leached reducing responses in the + fertilizer plots. But the benefits without fertilizer were not large in terms of grain yield, only as percentage increases.

From: Cheryl Palm
How can we explain the declining yields? They do not appear to be related to rainfall.

Response:
Extremes of rainfall (< 500 mm and > ca. 800 mm) are associated with low maize and groundnut yields in these trials. It is really too early to establish a clear trend in yield due to soil fertility. But we do need to remove the moisture variation.

Questions to Dickens Phiri

From: Batson Zambezi
How much maize + Sesbania (or other tree species) intercropping is being practiced by smallholder farmers in Malawi?

Response:
In the study area farmers intercrop maize with pigeon peas, cowpeas, cassava and many other crops. It is an existing system.

From: Rob Gilbert
What was the effect of Sesbania on the present maize when intercopped?

Response:
During the first three to four weeks the maize grew vigorously and was very green in colour. But these benefits didn't last long because of too much rain between January and March which leached most of the nutrients, particularly nitrogen.

From: Herbert Dhliwayo
Sesbania seems to provide beneficial N effects on maize yields. Does Malawi have indigenous Sesbania? If so are indigenous Sesbania used in this work, and how do they express their N-effect on maize production?

Response:
Malawi has indigenous Sesbania that are most common in Mangochi and Phalula areas along Zalewa Road. In this study *Sesbania sesban* (Mangochi cultivar) is being used. The trend indicates that Sesbania has a positive effect on maize growth and yields.

From: Ishmael Pompi
What is the best time for decomposing the residues? Is it at the end of the dry season in October?

Response:
October-incorporation is in keeping with the normal farmer practice of land preparation which is at its peak at that time, even though the soils are dry and hard.

UNDERSOWING GREEN MANURES FOR SOIL FERTILITY ENHANCEMENT IN THE MAIZE-BASED CROPPING SYSTEMS OF MALAWI

ROBERT A. GILBERT

Rockefeller Foundation - Malawi, P.O. Box 30721, Lilongwe 3, Malawi

SUMMARY

Malawi's burgeoning human population has led to declining per capita food production and declining soil fertility in continuously cropped maize systems. The use of inorganic fertilisers has fallen as the N:grain price ratio has risen. The challenge for agronomists in Malawi is to design, evaluate and disseminate cropping systems that will increase soil fertility and maize yields in regions where maize is planted every season. While green manure systems can accumulate > 200 kg N ha^{-1} when sole cropped, the magnitude of biomass produced and N_2 fixed by green manures when undersown to maize is not known.

An on-farm experimental program was established in the 1996/97 season at 11 sites in central and southern Malawi to determine if intercropped green manures can produce the minimum biomass (> 2000 kg ha^{-1}) necessary to improve soil fertility without reducing maize yields. Three factors (species selection, time of undersowing, and seeding rate) were examined in a 3 x 2 x 2 factorial experiment in a randomized complete block design. There were two replicates at each site. The factors were:

A. Crop undersown	**B. Time of undersowing**	**C. Seeding rate**
1. Crotalaria juncea (CJ)	1. First weeding (T1)	1. Low (S1)
2. Mucuna pruriens (MP)	2. Second weeding (T2)	2. Medium (S2)
3. Lablab purpureus (LP) or Tephrosia vogelii (TV)		

Crotalaria and Mucuna were grown at every site, while Lablab and Tephrosia were alternated as the third green manure species at a site. Lablab was grown at lowland sites while Tephrosia was planted at highland sites.

Preliminary results after one season of growth indicate that Tephrosia, Crotalaria and Mucuna, when undersown early, can produce significant amounts of biomass (> 2000 kg ha^{-1}) when intercropped with maize at low-fertility sites in Malawi. Tephrosia undersown at T1 yielded the most biomass, peaking at 6646 kg ha^{-1} at Bvumbwe. The Tephrosia biomass produced was strongly correlated to rainfall received at a site. Mucuna, with an aggressive climbing growth habit, was very competitive with maize when undersown at first weeding. The MP T1 S2 treatment reduced maize yields by 60% compared to sole maize controls. Lablab failed to yield more than 1000 kg ha^{-1} at any of the sites tested. Broadcasting small-seeded Crotalaria and Tephrosia led to low survival rates (< 40%) for these species. The increased seed costs of broadcasting must be weighed against the labour advantages of this planting method.

In the 1997/98 season, the experimental plots will be split and fertiliser added to half the plots to determine whether small amounts of organic plus inorganic amendments can significantly increase maize yields. Future research will compare promising undersown green manure treatments (e.g. TV T1 S1, TV T1 S2, or CJ T1 S2) to other leguminous interventions (e.g. maize/pigeonpea intercrops or soybean rotations) on the basis of N added to the soil system and economic net benefit. In this way Malawian farmers can choose the organic matter technology that best suits their needs.

INTRODUCTION

Malawi's population has more than doubled in the past 20 years, while indices of food production have remained stable, leading to a rapid decline in food production per capita (Figure 1). In densely populated southern regions (> 200 people km^{-2}), average cropped area is < 1.0 ha per family and 90% of this land is planted to maize (Carr, 1994). Continuous maize cropping in central and southern Malawi has led to increased soil erosion and an overall decline in soil fertility, as evidenced by increasing soil nutrient deficiencies (Matabwa and Wendt, 1993) and reduced maize N use efficiency. The use of inorganic fertiliser on maize has been largely uneconomic since the removal of government subsidies (Benson, 1997). As fertiliser prices rise, organic sources of fertility may become an increasingly important option for increasing soil fertility and maize yields.

The challenge for agronomists in Malawi is to design, evaluate and disseminate cropping systems that will increase soil fertility and maize yields in regions where maize is planted every season. Since the 4-5 month rainy season does not allow sequential cropping, intercropping systems with grain legumes

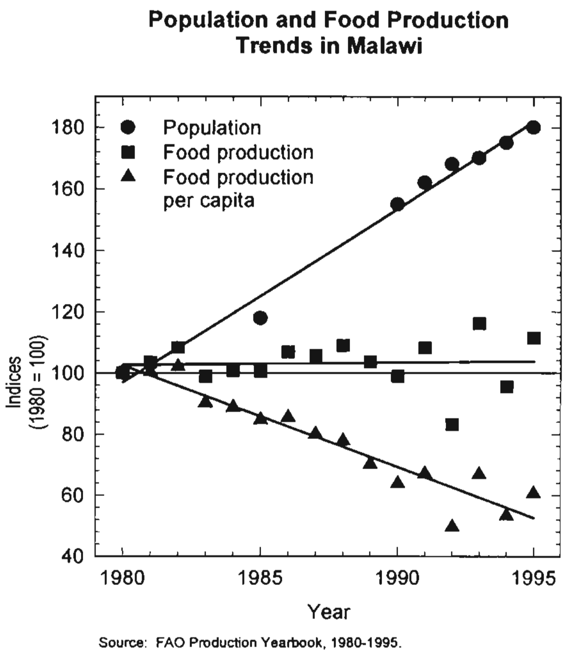


Figure 1. Population and food production trends in Malawi, 1980-1995.

and multipurpose shrubs have been advocated. One technology that has been less thoroughly examined is the undersowing of green manure species into maize.

The promotion of green manures in Malawi is certainly not new. Davy (1925) names *Tephrosia vogelii*, *Crotalaria juncea* and *Mucuna pruriens* as promising green manure species for Nyasaland. *Crotalaria* and *Mucuna* were found to have a greater positive effect on maize yields than other green manures used extensively in crop rotations in Zimbabwe through the 1950s (Rattray and Ellis, 1952). *Crotalaria* and *Mucuna* have been shown to be excellent N_2-fixers in a wide range of environments (Bowen *et al.*, 1988; Kolar *et al.*, 1993; MacColl, 1990; Yost *et al.*, 1985). *Tephrosia* has been less well-researched. It is renowned as a fish poison and has the advantage of being unpalatable to livestock and remaining green in the dry season. In recent intercropping studies, Kumwenda (1996) found that *Crotalaria* had a higher dry matter yield and total N content than *Mucuna* intercropped to maize, however *Mucuna* was planted later than *Crotalaria* in this study.

Green manures have the potential to accumulate up to 250 kg N ha^{-1} yr^{-1} (Giller and Wilson, 1991; Peoples and Herridge, 1990), resulting in subsequent cereal yield increases of 600 - 4100 kg ha^{-1} (Peoples and Herridge, 1990). However these figures are for sole-cropped green manure species. The N benefits and best management options for green manure species undersown to maize in Malawi have not yet been elucidated. The key question for undersown green manure technology is whether it can increase maize yields using agronomic management practices that fit into existing farming systems.

To answer this question, an on-farm experimental program was established in the 1996/97 growing season at 11 sites in central and southern Malawi. The objective of the experiment in the first season was to determine if intercropped green manures can produce enough biomass to increase soil fertility (> 2000 kg ha^{-1}) without reducing maize yields. Three management factors (crop species, time of undersowing and seeding rate) that farmers could easily control were examined in this factorial experiment.

MATERIALS AND METHODS

Experimental Design

The on-farm experiment used a randomized complete block design with a factorial structure. Table 1 outlines the treatments used. At each site, the treatments included three green manure species x two times of undersowing x two seeding rates, plus a control sole maize plot. Two replicates of 13 plots each were placed at each site.

Table 1. Treatments used for the undersowing green manure experiment in Malawi.

Species Used	Time of undersowing	Seed rate (kg ha^{-1})		
			1. Low (S1)	2. High (S2)
1. *Crotalaria juncea* (CJ)	1. 2 WAP* maize (T1)			
2. *Mucuna pruriens* (MP)	2. 6 WAP maize (T2)	CJ:	20	40
3. *Lablab purpureus* (LP)		MP:	35	70
4. *Tephrosia vogelii* (TV)		LP:	10	20
5. Sole maize (MZ)		TV:	20	40

*Weeks after planting

The species were selected based on their potential to produce biomass and fix N_2 under Malawian agroecological conditions. *Crotalaria* and *Mucuna* were planted at all sites, while *Lablab* was replaced by *Tephrosia* at the sites that had higher elevations and lower temperatures. The times of undersowing at two (T1) and six (T2) weeks after planting maize were chosen to coincide with the times of first (T1) and second (T2) maize weeding. Thus the operation of weeding covered the seeds with soil, leading to extremely low labour requirements for this planting system. Low (S1) and medium (S2) seeding rates were chosen that were likely to be affordable for smallholder farmers. The smaller-seeded *Crotalaria* (28,800 seeds kg^{-1}) and *Tephrosia* (19,600 seeds kg^{-1}) were undersown by broadcasting the seed onto the side of the ridge and then covering it with soil during manual weeding operations. The larger-seeded *Lablab* (4,600 seeds kg^{-1}) and *Mucuna* (860 seeds kg^{-1}) were planted either at one station between maize hills (S1) or two stations between maize (S2).

Land was ploughed manually at all sites into ridges 0.90 m apart, and unfertilized maize was planted at three seeds per hill in planting stations 0.75 m apart on the ridge.

Sites

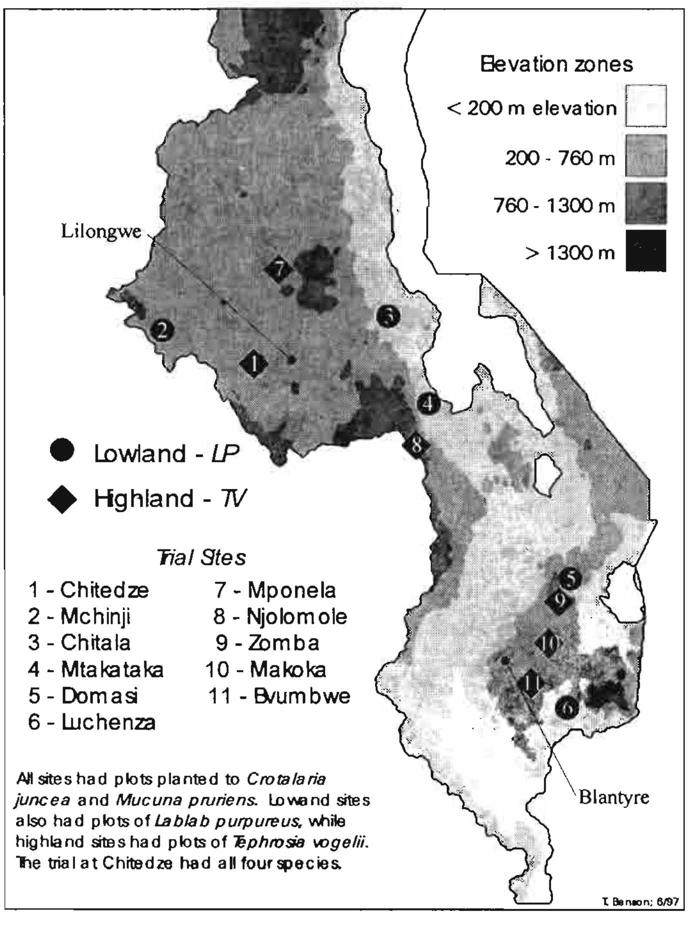
Eleven sites were chosen in central and southern Malawi, where human population growth has led to declining fallow periods (Figure 2). All sites were identified through farmer interviews as having been planted to unfertilized maize for at least two seasons. These sites were chosen to examine the benefits of green manures in regions that had been continuously cropped to maize. The sites were on farmer's fields and the experiment was researcher designed and managed.

Measurements

Plant growth -- The plot size at all sites except Chitedze was six ridges (0.9 m apart) x 7 m (37.8 m^2). At Chitedze, plot size was larger (8 ridges x 7.5 m = 54 m^2) to accommodate destructive plant growth measurements. For these plant growth samples, a 1.35 m^2 subsample of plants was taken from each plot at 3-4 week intervals throughout the growing season. Plant samples were separated into leaves, stems and reproductive organs and dried at 70 °C for 48 hours. Dry matter of leaves, stems, reproductive parts and total biomass was calculated for each species in each plot.

Maize grain yield and green manure biomass at harvest -- For green manure and maize harvest measurements, a net plot of 4 ridges x 6 m (21.6 m^2) was used. All green manure plants in the plot were cut and fresh weight of the net plot green manure biomass was taken immediately, along with the fresh weight of a 2-3 plant sub-sample. The green manure plants were then laid in the furrow and incorporated by lightly covering with soil. The sub-sample was dried and used to calculate total dry biomass added. The same procedure was followed at maize harvest except that all the maize grain was removed for measurement and correction to 12.5% moisture content. Maize stover was not incorporated with the green manure biomass due to its low N content (high C:N ratio) and tendency to lead to net immobilization of N in the soil when incorporated.

Figure 2
Green-manure undersowing trial
central and southern Malawi, 1996-97



Data analysis -- The green manure biomass and maize yield data was analyzed for significant differences between treatments using the GENSTAT program. In addition, the Partial Land Equivalent Ratio (PLER) was calculated for maize grain as the fraction of grain obtained in intercropping treatments compared to the monocropped control:

PLER = X_i/X_m where:
X_i = maize intercrop yield
X_m = maize sole crop yield

Bars associated with data points on the figures indicate standard errors of the means.

RESULTS AND DISCUSSION

Target Biomass Concept

To judge the results of the green manure technology in the first season of growth, a screening method for treatment effect on maize yield in subsequent seasons was used. For the purposes of this paper, the green manure treatments were compared on their ability to reach a target biomass when intercropped. It was assumed that to be effective the green manure systems needed to add > 30 kg fertiliser-equivalent N ha^{-1}. This amount of inorganic N input is judged to be the minimum needed if Malawi is to increase maize production (Benson, 1997). If green manure N is approximately half as effective as fertiliser N (Giller and Cadisch, 1995) then 60 kg N ha^{-1} is needed in the incorporated biomass. At an average of 3% N in the biomass, this implies a target biomass of 2000 kg ha^{-1}. This target will vary with the %N of the biomass, and %N_2 fixed by the legumes, which can vary from 5-90% (Peoples and Herridge, 1991). Preferably, the 60 kg N ha^{-1} added would be input from atmospheric N_2 fixation. Thus if only 50% of legume N is fixed, the target would be 4000 kg ha^{-1}. Finally, the synchrony of release of green manure N and maize N uptake will affect the efficiency of N use by the maize - and thus the target biomass needed.

Two caveats must also be issued when using this concept. This biomass must be produced without significant reduction in maize yield, which would be unacceptable to farmers. In evaluating these technologies, it was assumed that a drop of > 20% (PLER < 0.8) in the first season would be unacceptable. Secondly, the cost of producing this biomass (e.g. seed and labour costs) must be less than the cost of 30 kg N ha^{-1} from urea (currently $30 in Malawi), or the technology will compare unfavourably with inorganic fertilisers. The economics of the more promising green manure treatments will be addressed in future research.

In all figures of green manure biomass in this paper, the target biomass is indicated by a solid black line at 2000 kg ha^{-1}.

Plant Growth

Plant growth for green manures and maize at Chitedze is shown in Figures 3-5. The data series are of different length since the plots were incorporated at times of estimated maximum green manure biomass, which differed among species. *Crotalaria* (CJ), *Mucuna* (MP) and *Tephrosia* (TV) exceeded the target biomass when undersown to maize at T1 (Figure 3), while *Lablab* (LP) peaked at only 700 kg ha^{-1}. When undersown at T2 (Figure 4), none of the green manure species attained 1000 kg ha^{-1} of biomass at Chitedze, indicating a very low soil fertility benefit with late undersowing at this site. Chitedze was the only site where sole green manure crops were grown (Figure 5). Sole *Crotalaria* (4695 kg ha^{-1}), *Mucuna* (6215 kg ha^{-1}) and *Tephrosia* (5936 kg ha^{-1}) all produced significant biomass when grown as sole crops. However, the maize yield following these sole crops in 1997/98 will need to be more than double the sole maize yield to make up for the lost year of maize grain production in green manure rotational systems. *Lablab* was disappointing at all sites as both an intercrop and sole crop, producing < 1000 kg ha^{-1}. It was the only green manure species that was parasitized by *Alectra vogelii*, which reduced its growth rate and was partially responsible for the low total biomass. Note also the low biomass production of maize (< 3000 kg ha^{-1}). Unfertilized maize production in Malawi is becoming increasingly constrained by declining soil fertility.

The different growth habits of the green manures have practical implications for their management. While *Mucuna* produces copious biomass, it tends to smother the maize (see below). While *Tephrosia* is

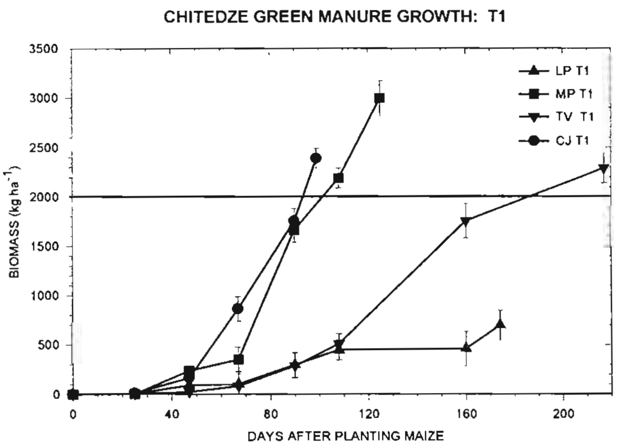


Figure 3. Green manure growth (kg ha^{-1}) when undersown early (T1) at the Chitedze site, 1996/97.

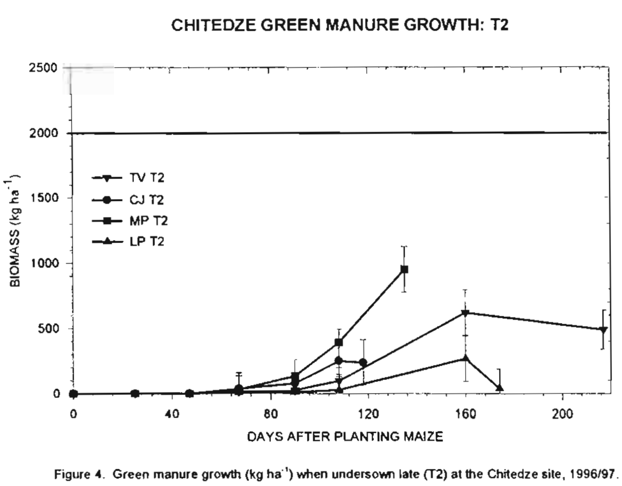


Figure 4. Green manure growth (kg ha^{-1}) when undersown late (T2) at the Chitedze site, 1996/97.

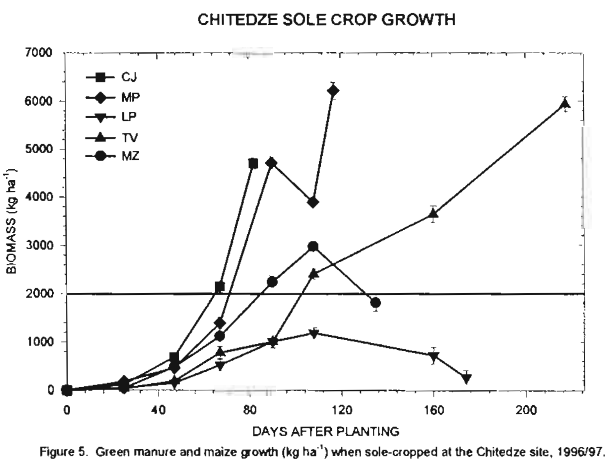


Figure 5. Green manure and maize growth (kg ha^{-1}) when sole-cropped at the Chitedze site, 1996/97.

not competitive with maize due to its slow growth rate, neither does it out-compete weeds, and thus it is difficult to keep weed-free. The growth habit of *Crotalaria* appears ideal for maize intercropping, since it is not too competitive with the maize, yet also shades out weeds. However its short growth duration (to maximum green biomass) makes incorporation problematic since it occurs while the maize is still growing. The early incorporation of Crotalaria also means there is a higher potential for loss of N due to mineralization and leaching under late-season rainfall. One management option not explored in this study would be to incorporate the green manures after they have set seed. However, this would be well after peak green biomass, and the senesced leaves incorporated would be much lower in %N, thus raising the risk of net immobilization of N and little to no benefit for subsequent maize yields.

Green Manure Establishment and Survival
Table 2 shows establishment and survival rates for *Crotalaria, Mucuna, Tephrosia* and *Lablab,* averaged for all treatments over all sites. (Species selection was significant in the analysis of variance of survival rate for all sites, while seeding rate and time of undersowing were not). The large-seeded *Mucuna* exhibited excellent establishment (> 90%) and survival at most sites. At Domasi and Makoka, however, severe mortality (12-19% survival) was caused by disease. This calls into question the robustness of *Mucuna* undersowing technology, especially at sites prone to vine rot diseases such as *Phytopthora dreschleri*. *Crotalaria* and *Tephrosia*, which were broadcast, had low establishment rates (27 - 62%) but similar survival rates within a given plot, indicating low mortality after germination. Broadcasting the seed of these species increases the seed cost, which must be weighed against the labour advantages of this planting method. While *Lablab* establishment was > 70%, average survival was < 30%. Poor growth and parasitism by *A. vogelii* was partly responsible for this low survival rate.

Table 2. Green manure establishment (E) and survival (S) rates, %.

	CJ		MP		LP		TV	
	E	S	E	S	E	S	E	S
Average	50	35	92	74	73	26	35	27
Standard Deviation	10.8	10.4	4.7	30.1	4.9	14.2	11.8	9.0

Green Manure Biomass and Maize Grain Yields
Figures 6a and 6b show green manure biomass and maize yield at Mponela - one of the higher-yielding sole maize sites (sole grain yield > 1200 kg ha^{-1}). The *Mucuna* treatments averaged > 2500 kg ha^{-1} of biomass, however this had a deleterious effect on maize yield compared to the monocrop. *Crotalaria* and *Tephrosia* undersown early also exceeded the target biomass. Figures 7a and 7b show the same data for Mtakataka, a lakeshore site with sole maize yields < 500 kg ha^{-1}. Early-planted *Mucuna* and *Crotalaria* exceeded 2000 kg ha^{-1}, however the MP T1 S2 treatment was extremely competitive with maize. Since 1996/97 was a good rainfall season, the low maize yield (< 1000 kg ha^{-1}) on all plots show the level of soil fertility at this site.

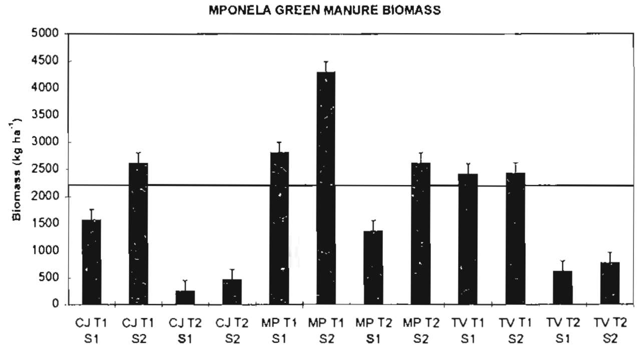


Figure 6a. Green manure biomass (kg ha^{-1}) at the Mponela site, 1996/97.

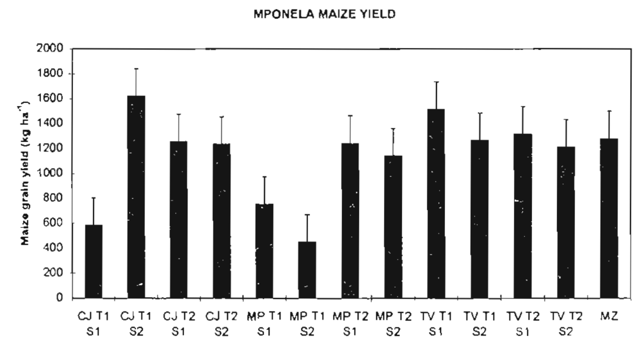


Figure 6b. Maize yield (kg ha^{-1}) at the Mponela site, 1996/97

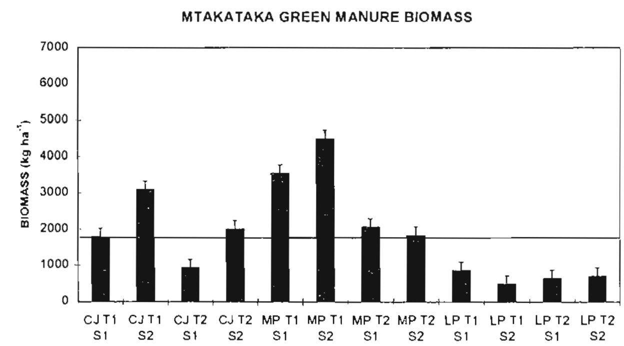


Figure 7a. Green manure biomass (kg ha^{-1}) at the Mtakataka site, 1996/97.

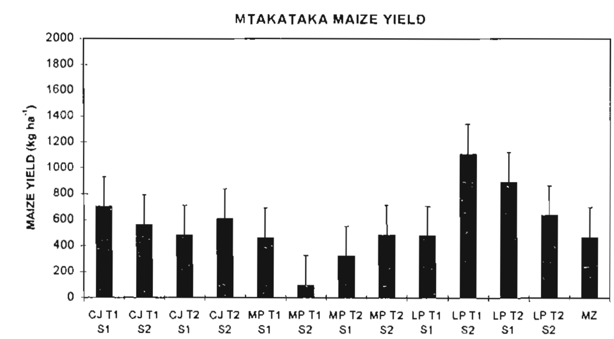


Figure 7b Maize yields (kg ha^{-1}) at the Mtakataka site, 1996/97

Crotalaria and *Mucuna* biomass, for all treatments averaged at 11 sites, is presented in Figure 8. Treatments exceeding the target at > 50% of the sites were CJ T1 S2, MP T1 S1 and MP T1 S2. CJ T2 S2, MP T2 S1 and MP T2 S2 produced > 2000 kg ha^{-1} at 45% of the sites. There was a clear trend towards increased growth and biomass production with earlier planting and higher seeding rates. However, earlier undersowing of the green manures (T1) led to lower maize production, when expressed as a fraction of the sole maize yield (Figure 9). *Mucuna* sown early at high densities (MP T1 S2) caused maize yield reductions of 60% compared to monocropped maize.

When the biomass data for *Tephrosia* was compared across sites, it became clear that biomass production was linearly correlated to precipitation received (Figure 10). Average T1 biomass at Bvumbwe (1760 mm rainfall) was 2.9 times that at Chitedze (787 mm). The response curve for the T1 undersowing date had a steeper slope (4.35 kg biomass mm^{-1}) than T2 (1.86 kg mm^{-1}), indicating the response to rainfall was muted in the T2 treatments, most likely due to increased competition with maize when undersown later. The correlation between rainfall and biomass did not hold for the other species tested. Biotic factors such as vine rot reduced *Mucuna* biomass in high rainfall environments, whereas the short growth duration of *Crotalaria* did not enable it to make full use of the available soil moisture.

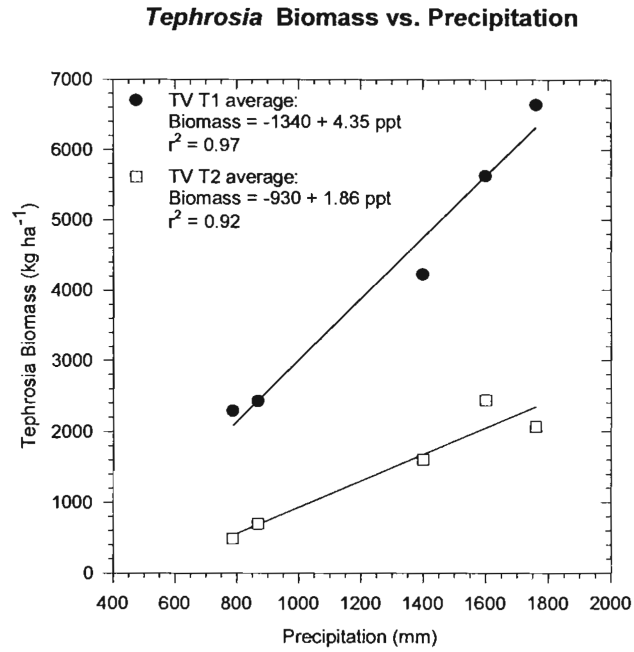


Figure 10. *Tephrosia* biomass production as a function of rainfall received at a site.

When averaged across all sites, *Tephrosia* undersown at T1 produced the greatest biomass of the treatments tested (Figure 11). This was achieved with < 20% drop in maize yield associated with these treatments (Figure 12), due to the temporal complimentarity in the growth habits of *Tephrosia* and maize.

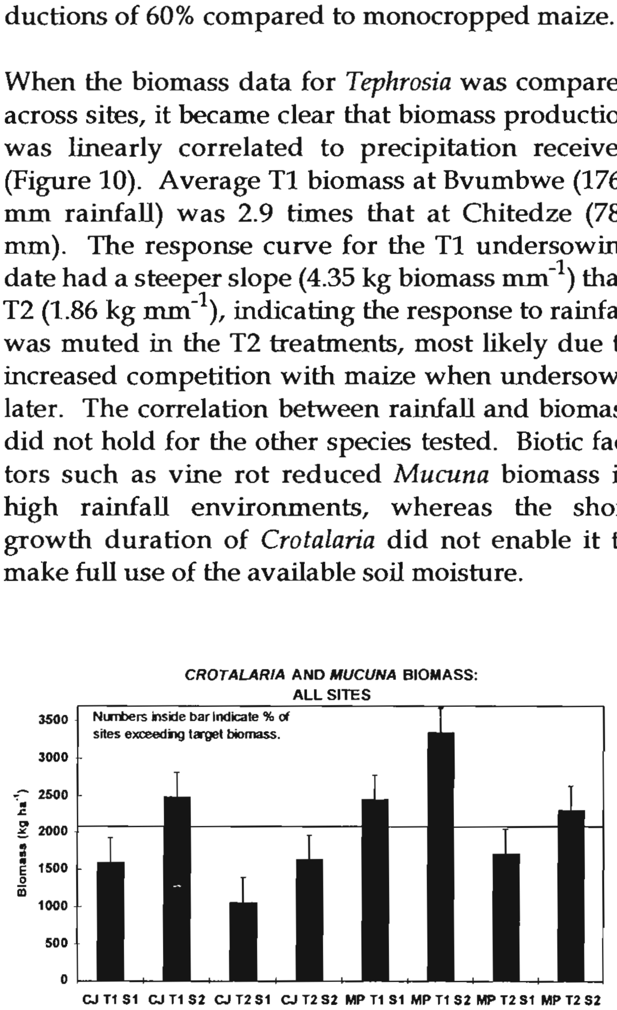


Figure 8. *Crotalaria* and *Mucuna* biomass, averaged at all 11 sites, 1996/97.

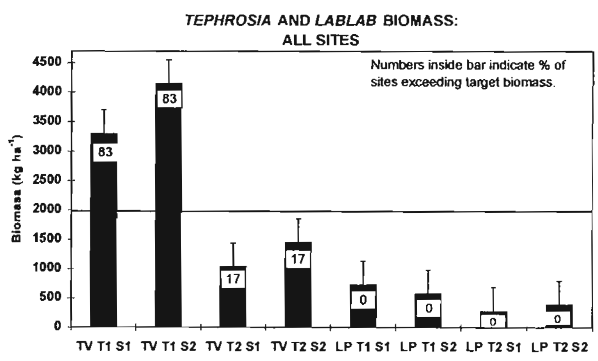


Figure 11. *Tephrosia* and *Lablab* biomass, averaged at all sites, 1996/97.

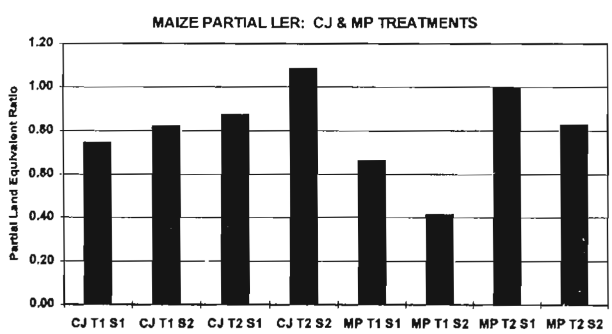


Figure 9. Maize partial LER for the *Crotalaria* and *Mucuna* treatments, averaged at all 11 sites, 1996/97.

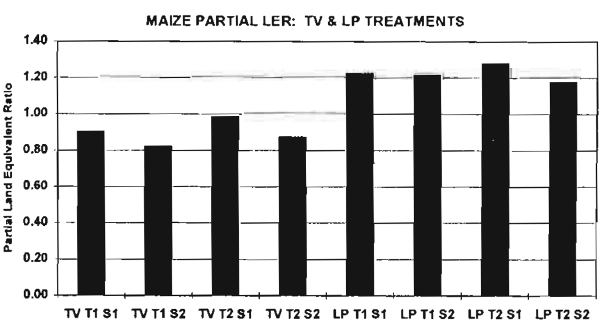


Figure 12. Maize partial LER for the *Tephrosia* and *Lablab* treatments, averaged at all sites, 1996/97.

CONCLUSIONS

There are several preliminary conclusions that may be drawn from the 1996/97 data:

- *Tephrosia, Crotalaria* and *Mucuna* have the potential to produce significant quantities (> 2000 kg ha^{-1}) of biomass when intercropped with maize at sites that have been continuously cropped to unfertilized maize in central and southern Malawi.
- *Tephrosia* undersown early produced the greatest biomass, and was not too competitive with maize (PLER > 80%).
- *Tephrosia* biomass produced was linearly correlated to rainfall received. The benefits from undersowing *Tephrosia* thus will be greatest in high rainfall areas.
- *Mucuna*, especially sown early, can be excessively competitive with maize due to its aggressive climbing growth habit. *Mucuna* may be better suited to rotational systems in areas without of fungal diseases.
- *Lablab* did not produce adequate biomass when intercropped with maize at any of the sites selected.
- Broadcasting the small-seeded *Crotalaria* and *Tephrosia* at first or second weeding leads to low establishment rates (< 50%). This raises seed cost, which may outweigh the labour advantages to this method.

The most promising treatments identified from this study are TV T1 S2, TV T1 S1, and CJ T1 S2. However, biomass production has been used as a substitute for N added in this paper (N analyses of plant samples are ongoing). A full evaluation of maize yield response to this incorporated biomass in subsequent seasons is necessary.

In the 1997/98 season, the green manure plots will be split and half the area-specific fertiliser rate applied to determine the interaction between organic and inorganic amendments. At present in Malawi, farmers do not have enough cash to afford the recommended rate of fertiliser, nor enough land to use improved fallows to provide N-rich biomass to restore soil fertility. However, if farmers use the small amounts of both organic and inorganic fertility sources they can acquire, they may be able to significantly increase maize productivity.

FUTURE RESEARCH THRUSTS

There are several research themes that should be pursued. Only four species were used in this study, and there are several promising species such as *Canavalia ensiformis, Desmodium uncinatum* and *Neonotonia wightii* that should be screened for biomass production when intercropped with maize. More importantly, the most promising green manure technologies (e.g. TV T1 S1, CJ T1 S2) should be part of a leguminous intervention "best bets" comparison with grain legume intercrops and leguminous crop rotations. These interventions should be compared at the same site in the same year with control maize plots based on N added to the system, economic net benefit and human caloric output. Malawian farmers and policy makers should know exactly how different organic matter technologies will affect both their short-term profits and longer-term soil fertility.

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PERFORMANCE OF GREEN MANURE LEGUMES ON EXHAUSTED SOILS IN NORTHERN ZIMBABWE: A SOIL FERTILITY NETWORK TRIAL

DANISILE HIKWA, MONICA MURATA, FANUEL TAGWIRA, CORNELIUS CHIDUZA, HERBERT MURWIRA, LUCIA MUZA, and STEPHEN R. WADDINGTON

SUMMARY

We ran a simple trial with farmers in northern Zimbabwe during 1996/97 to test three green manures for biomass production on fields that farmers reported to be too exhausted to grow maize. Sunnhemp and fish bean were inconsistent in plant establishment, growth and biomass production. Velvet bean produced more than 4 t/ha of above-ground biomass dry weight at eight out of 12 sites, most of which were moderately acidic. At only two sites were the biomass yields below 1 t/ha. These results provide further evidence for the promising performance of velvet bean on poor granitic sand soils in the wetter zones of northern Zimbabwe. Wider assessments with more farmers are needed.

BACKGROUND

The problem of poor soil fertility in the smallholder sector of Zimbabwe has been well documented (Grant, 1970; Chavunduka, 1978; Grant, 1981; Mashiringwani 1983). Few options for the amelioration of soil fertility are available for smallholders, resulting in abandonment of depleted lands in an effort to help them recover productivity. Fallowing cycles in most areas are now too short build up soil fertility to a level that can sustain meaningful crop productivity while communal farmers rarely have the option to move to new land. The rising cost of inorganic fertilizer means fewer smallholder farmers can afford reasonable quantities that can increase crop yields beyond subsistence levels. The major organic resource, cattle manure, is also becoming less available because of a declining smallholder cattle herd affected by closely recurring droughts and shortage of land. The production "economies of scale" also make total reliance on inorganic fertilizers uneconomic for most growers in this sector.

This background makes it imperative for researchers to work closely with farmers and extension agents to come up with options that raise fertilizer-use-efficiency, as well as identifying other supplemental sources of nutrients that are not capital intensive. Use of green manure legumes presents an opportunity to focus on the latter.

Herbaceous green manures were extensively used from the 1920's to the 1940's by large-scale commercial growers in Zimbabwe (Rattray and Ellis, 1952; Saunder, 1959; Metelerkamp, 1988). Although there was no deliberate effort (with documented evidence) to promote the use of green manures by the smallholder sector, there were informal reports that some smallholders did use some green manures such as sunnhemp to maintain soil fertility.

In 1989/90 and 1990/91, the Agronomy Institute (1993) of the Department of Research and Specialist Services, "revisited" the use of green manure, targeted at the smallholders on sandy soils. Five species (Dolichos lab, sunnhemp, soybean, cowpea and sunflower) were grown and ploughed under as green manures, and followed by a maize test crop. At a Natural Region[1] (NR) IV site, nitrogen measured in biomass at flowering was 26.7, 40.7, 41.2, 41.9 and 46.7 kg N/ha for soybean, sunnhemp, sunflower, cowpea and Dolichos, respectively. Supplementation of N derived from green manures with 40 kg/ha of inorganic N raised maize grain yields by between 148 and 233% compared to plots where the inorganic N was applied without green manures. This work demonstrated the positive effect of combining limited amounts of inorganic fertilizer with green manures but it was temporarily shelved for several reasons. One of these was the inclusion of crops such as soybeans, cowpea and sunflower which would cause a conflict of interest on use (green manure vs. yield gain) for farmers. A need to screen other non-food legumes arose.

The socio-economic constraints that limit purchase of inorganic fertilizers by smallholders necessitated a revival of green manure work. With the assumption that land availability was now a constraint and that smallholders are not able to fallow pieces of land for long periods, Muza (1996) began to evaluate relay-undersowing of green manures into a maize crop. Her aim was to allow the green manures to flower at or after the maturity of maize, enabling the plough-

[1] *A broad classification of Natural Regions is based on rainfall: NR I 900-1 000mm p.a.; NR II 750-900mm p.a; NR III 650-750mm p.a.; NR IV 450-650mm p.a. and NR V < 650mm p.a.*

ing under of their biomass after maize harvest; to benefit the subsequent maize crop.

Expected advantages of green manures included:
a) provision of supplementary nutrients to inorganic fertilizers, especially N
b) soil organic matter management
c) potential use in improved fallows instead of the current "natural" fallows practised by farmers.

However, there are also recognized constraints to growing leguminous green manures on sandy soils in Zimbabwe. High soil acidity on most of the fields that have been cultivated without liming, make growth and productivity of legumes difficult. Legumes have a high P requirement for them to grow successfully. Implicitly, an investment in P (and lime) would probably be a pre-requisite to growing most of the legumes successfully. It was also necessary to identify legumes that could produce "acceptable" levels of biomass under these conditions. While there have been suggestions within SoilFertNet that a biomass of 5t/ha and above would make a meaningful contribution to yield of a subsequent crop, baseline data to support this suggestion as well as comparative performance of the subsequent maize test crop under smallholder conditions have not been documented.

With this background members of SoilFertNet designed a small, simple network observational trial that was implemented with farmers.

METHODS

The Network observation trial began in the 1996/97 season with the objectives of:

a) assessing potential biomass production from three green manure legumes (with P application or without P) on fields with low soil fertility
b) comparing yields of subsequent maize crops planted (in 1997/98) after the three legumes

Two fields each were identified with farmers in seven communal and resettlement areas: Gokwe South (NRIV), Nyamazura (NRIII), Chiduku (NR IIb), Chihota (NR IIb), Mangwende (NR IIa), Guruve (NR II) and Zvimba (NR IIa). Careful discussions took place with farmers to select fields that farmers said were now abandoned by the farmer because of poor soil fertility or where the maize grain yields in the specific fields had been on average less than 500 kg/ha in recent seasons. Target areas were basically NR II and III locations on smallholder farms, but one NR IV location was included.

Sole crops of velvet bean (*Mucuna pruriens*), sunnhemp (*Crotalaria juncea*), Fish bean (*Tephrosia vogelii*) and maize (hybrid R215) were planted in the 1996/97 season, with 100 kg P_2O_5/ha or without P in non-replicated plots of $100m^2$ each. The source of P was single superphosphate (18.5% P_2O_5) applied just before planting. A very low rate of around 20 kg N/ha was applied to all plots. Planting arrangements were 45 cm between rows and 15 cm in the row for velvet bean (target density about 148 000 plants/ha); 45 kg/ha seed rate for sunnhemp; 1 m x 1m spacing for Fish bean and 90 cm x 30 cm for maize (target density about 37 000 plants/ha). Planting was done with the farmer at the time suggested by farmers. In most cases this was early to mid December -- after farmers had planted most of their maize.

Total above-ground biomass was measured from whole plots towards the end of the rainy season in April or May. Samples were taken and dried to convert the biomass measurements to dry weight. Because of faster flowering, sunnhemp biomass was measured earlier at some sites. Legume biomass was then incorporated into the soil, or retained on the soil surface at some sites, depending on local decisions made by farmers and researchers. The grain yield and above-ground biomass were measured for maize after physiological maturity.

RESULTS

No data are available for two fields in Guruve because the farmer incorporated the legumes before measuring the biomass. The average pH across our sandy sites was 4.3 (in 0.01 M $CaCl_2$). Grain yield and total above-ground biomass yield of maize on these depleted soils was highly variable, ranging from zero to 2.1 t/ha and 4.6 t/ha, grain and total biomass, respectively (Table 1). Maize grain yields were below 0.5 t/ha at nine out of 12 sites. Incessant and excessive rains that characterized the 1996/967 season throughout January and the first half of February promoted widespread waterlogging that affected growth of maize.

Among the legumes, velvet bean performed the best. Six fields where P was applied attained a biomass greater than 4 t/ha, while a total of four fields without P also produced more than 4 t/ha (Table 2). Despite its widespread use as a green manure crop in the 1920's and 1930's, sunnhemp's performance in this particular observation was highly variable; with four fields recording no biomass (Table 2). Plant dieback after emergence was reported at most sites.

Of the three legumes, Fish bean performed the worst, recording zero biomass at eight out of the twelve sites, while the other fields (with one exception) produced no meaningful biomass (Table 2).

Table 1. First-season maize grain and above-ground biomass dry matter yields (kg/ha) on exhausted sandy soils in northern Zimbabwe, 1996/97 season

Communal Area	+ P		- P	
	Grain	Total above-ground DM	Grain	Total above-ground DM
Gokwe South (1)	289	1290	877	1568
Gokwe South (2)	34	750	42	1086
Nyamazura (1)	380	-	310	-
Nyamazura (2)	0	-	0	-
Chiduku (1)	25	220	0	210
Chiduku (2)	7	346	1.5	282
Mangwende (1)	0	233	0	234
Mangwende (2)	277	1125	318	1125
Zvimba (1)	1979	4597	1024	2353
Zvimba (2)	403	1913	465	1038
Chihota (1)	2101	3837	254	1339
Chihota (2)	916	2557	536	1838

DISCUSSION

Results from this observational trial indicate a good potential for farmers to use velvet bean as a green manure on exhausted soils under favourable rainfall conditions. Velvet bean was able to produce reasonable biomass under fairly acidic conditions and warrants further work in replicated trials and widespread testing with farmers, perhaps in combination with lime. However, the "choking"/twining effect reported by Muza (1996) on maize may preclude its widespread use as an intercrop. Its potential use seems greater as a sole-crop in improved fallows. We have yet to see how helpful this biomass will be to the subsequent maize crop to be grown during 1997/98.

Table 2. Biomass production (kg/ha, dry weight) by three green manure legumes, on exhausted sandy soils in northern Zimbabwe, 1996/97 season

Communal Area	Velvet bean		Sunnhemp		Fish bean	
	+ P	- P	+ P	- P	+ P	- P
Gokwe South (1)	2368	1916	1688	858	0	0
Gokwe South (2)	1826	1964	809	1000	0	0
Nyazura (1)	8020	7240	0	0	0	0
Nyazura (2)	6490	6610	0	0	0	0
Chiduku (1)	1757	1865	grazed	grazed	70	34
Chiduku (2)	4538	2703	116	13	64	66
Mangwende (1)	318	317	311	290	145	145
Mangwende (2)	5351	5250	5000	5040	3127	3125
Zvimba (1)	2410	1260	0	0	0	0
Zvimba (2)	850	1620	0	0	0	0
Chihota (1)	10665	5290	8460	2315	0	0
Chihota (2)	4275	3405	505	550	0	0

The highly variable performance of sunnhemp casts doubts on its suitability for use on highly acid soils. There may be high genetic variability in the species and possibly the accession used (whose origins were unknown but was obtained from commercial sources in Harare) was unsuitable.

Tephrosia performed badly and may not be suitable for conditions under which it was tested. It was difficult to establish and grew very slowly. We recognize that the number of green manure legumes included in the observation was limited. There is scope for expanding the legume base to provide a wider selection for farmers. This flexibility can and should be built into future SoilFertNet trials to allow participating members to source and test more legumes as potential green manures.

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BIOMASS PRODUCTION BY LEGUME GREEN MANURES ON EXHAUSTED SOILS IN MALAWI: A SOIL FERTILITY NETWORK TRIAL

JOHN D.T. KUMWENDA and ROBERT GILBERT

Chitedze Research Station, P.O. Box 158, Lilongwe, Malawi

SUMMARY

A SoilFertNet trial was initiated in the 1996/97 growing season to determine if Mucuna pruriens, Crotalaria juncea *or* Tephrosia vogelii *could produce significant quantities of biomass at on-farm sites where maize yields had been greatly depressed due to declining soil fertility. At the five SoilFertNet sites in Malawi,* Mucuna *yielded the most biomass, averaging 7370 kg ha^{-1} with P and 5700 kg ha^{-1} without.* Crotalaria *produced 3600 - 5900 kg ha^{-1}, and* Tephrosia *1500 - 4700 kg ha^{-1}. These values are higher than Zimbabwe, indicating a higher level of soil fertility even on relatively exhausted sites in Malawi. In the 1997/98 season maize will be planted on all plots to examine the residual fertility benefits of the green manure rotation.*

INTRODUCTION

The limiting factor to increased cereal production in the majority of Malawian soils is low soil N level, which would indicate a promising niche for the introduction of legumes. However, the land pressure in Malawi is great enough to provide a disincentive to rotations. Any green manure rotational system must provide a large maize yield response (more than doubling continuous maize yields) to justify the use of green manures in rotation. To do this, the green manure species must be able to produce large quantities of biomass on marginal lands.

OBJECTIVES

The central hypothesis of this trial was that green manure species must produce a minimum of 5 t ha^{-1} of biomass per year to have a significant effect on subsequent maize yields. As with the Zimbabwe SoilFertNet Trial (see this volume) the objectives of this experiment were twofold.

1. To assess the potential biomass production from *Tephrosia vogelii, Crotalaria juncea* and *Mucuna pruriens* when grown as fallow.
2. To compare the yield of subsequent maize crops grown following the green manures to continuously cropped maize.

MATERIALS AND METHODS

Planting

There were eight treatments planted in the 1996/97 season. There were two factors studied: 4 species x 2 P_2O_5 levels (Table 1).

Table 1.

Species	P_2O_5 level
1. *Tephrosia vogelii* (TV)	1. No P_2O_5 (-P)
2. *Crotalaria juncea* (CJ)	2. 100 kg ha^{-1} P_2O_5 (+P)
3. *Mucuna pruriens* (MP)	
4. Maize (MZ)	

20 kg N ha^{-1} basal dressing was applied to all eight plots just before planting. All species were planted on ridges 90 cm apart (note the difference from the Zimbabwe trials), with the following plant spacing (Table 2).

Table 2.

Species	Spacing
Tephrosia vogelii	90 cm x 45 cm, 3 seeds hill^{-1}
Crotalaria juncea	45 kg ha^{-1}, broadcast
Mucuna pruriens	90 cm x 15 cm, 1 seed hill^{-1}
Maize	90 cm x 90 cm, 3 seeds hill^{-1}

Measurements

In the 1996-97 season, all six legume plots were split into early-incorporated and late-incorporated treatments. Total above-ground biomass was measured for the early-incorporated legumes, which were cut at maximum biomass at mid-flowering stage, which occurred at approximately 80-90 days after planting. Seed yield of *Mucuna* and *Crotalaria* was also measured for the late-incorporated plots, which were cut at physiological maturity. The late-incorporated *Tephrosia* had not yet set seed.

Maize grain yield and above-ground biomass was measured at harvest for the two maize plots. In the 1997-98 season, maize will be grown on all plots to determine the effect of green manure biomass on maize yield.

Sites

There were five sites chosen in Malawi for this SoilFertNet trial. All sites were on-farm, in locations were farmers and extension workers had indicated that maize was low-yielding due to poor soil fertility (as opposed to *Striga* or other causes). The sites were located near Chitedze (2), Lisasadzi, Mbawa and Zombwe.

RESULTS

Green manure biomass at early incorporation, averaged over the five Malawian sites, is shown in Figure 1. *Mucuna pruriens* produced the greatest average biomass, and also the greatest response to added P. *Mucuna* averaged 5700 kg ha^{-1} without P and 7400 kg ha^{-1} with P added. The range of biomass for *Mucuna* was 3400 kg ha^{-1} on sandy soils at Mbawa to 9100 kg ha^{-1} at Zombwe. Low biomass production at Mbawa was in part due to late planting. *Mucuna* should be regarded as a very promising green manure fallow species for Malawi, since it produces lush growth and is not attacked by pests. *Crotalaria juncea* ranked second in biomass production, ranging from 3600 to 5900 kg ha^{-1}. *Tephrosia* growth was poor at some sites, ranging from 1500 to 4700 kg ha^{-1}. *Tephrosia* also showed no P response. Although *Tephrosia* biomass was low, the time of incorporation was later for this slower-growing species, which might lead to fewer problems of synchrony of N release from green manure residues with uptake of N by maize.

Seed and grain yields for maize, *Mucuna* and *Crotalaria* are shown in Figure 2. Note that maize yields at these sites were low, averaging 1000 kg ha^{-1} without P. The addition of 100 kg P_2O_5 was not economic for maize production, increasing maize yields by 350 kg ha^{-1} (a 980 kg ha^{-1} increase would be required to pay for the cost of the applied P). Note also that both *Crotalaria* and *Mucuna* outyielded maize. The *Mucuna* seed yields of 2000 kg ha^{-1} represent a significant economic advantage to this rotation, and may provide an incentive to farmers to rotate *Mucuna*. However, this seed would only be harvested with a late incorporation date, implying a lower maize yield benefit the following season. We will get maize yield response data in the 1997-98 season to early and late incorporated *Mucuna* to help determine the best way to manage this promising legume.

CONCLUSIONS

Overall, the biomass production of these green manure legumes was higher at the Malawian sites than in Zimbabwe (see this volume). This indicates that the Malawian soils at these sites are less "exhausted" than those at the Zimbabwean sites -- they tend to have higher pH, clay content, water holding capacity, CEC, etc. *Mucuna pruriens* produced the greatest amount of biomass and highest seed yield of the three legumes examined.

In the 1997-98 season the legume plots will be split again and low levels of fertilizer (35 kg of N and 10 kg of P_2O_5) applied to the plots where green manures were grown in 1996-97. These plots with inorganic and organic amendments together will be compared to continuous maize with double the fertilizer rate (69 and 20 kg of N and P_2O_5). We hope that the addition of green manures will reduce the amount of fertilizer needed to achieve good, sustained maize yields.

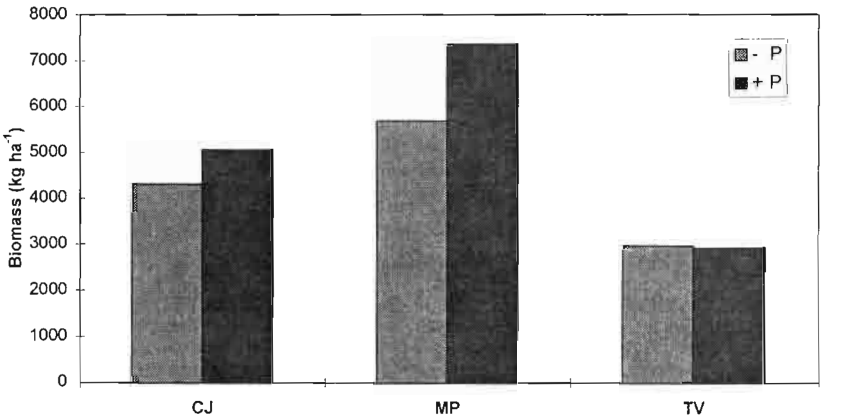

Figure 1. Average green manure biomass for *Crotalaria juncea* (CJ), *Mucuna pruriens* (MP) and *Tephrosia vogelii* (TV) at the 5 Malawi SFNET sites.

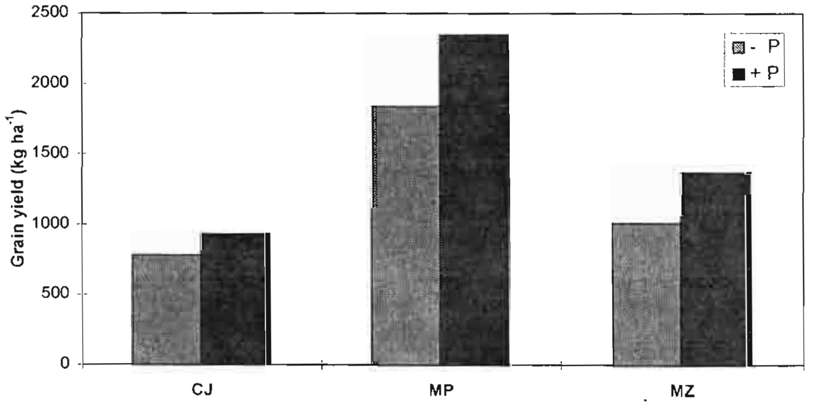

Figure 2. Seed or grain yield for *Crotalaria juncea* (CJ), *Mucuna pruriens* (MP) or maize (MZ) at the 5 Malawi SFNET sites.

GREEN MANURING CROPS IN A MAIZE BASED COMMUNAL AREA, MANGWENDE: EXPERIENCES USING PARTICIPATORY APPROACHES

CHINANISO CHIBUDU

Farming Systems Research Unit, Department of Research and Specialist Services, P.O. Box CY 550, Causeway, Harare, Zimbabwe

SUMMARY

This paper reports on how green manuring trials were started, implemented and evaluated in Mangwende communal area from 1992 to 1996. The trials followed an impact study carried out in 1992 by the Farming Systems Research Unit which revealed that soil fertility technologies developed in the 1980s had not been adopted (Chikura, Mudhara, Mombeshora, Chibudu and Jeranyama, 1992). Farmers were not involved in problem identification, trial design, implementation and evaluation with the older work. Hence a Participatory Rural Appraisal exercise was conducted with farmers to identify problems and opportunities in soil fertility management. Farmers identified problems of low soil fertility and low maize yields, coupled with cash constraints for buying fertilizers. The poor soils, known as 'shapa', were associated with Striga *(witchweed). Farmers, researchers and extensionists formulated and set up trials to screen legumes that could improve soil fertility, reduce* Striga *infestation and improve maize yields. The legumes tested were velvet bean, sunnhemp, cowpea and dolichos and were planted in either rotations or intercropping systems with maize.*

Results showed that green manure crops such as velvet bean, sunnhemp and cowpea could improve soil fertility, reduce Striga *incidence and subsequently increasing maize yields. Farmers preferred to use velvet bean for improving soils in rotation but not intercropped with maize because it choked the maize making it difficult to harvest the maize crop. Cowpea was preferred by farmers for* Striga *control because it also provided grain for food. Contributions of green manures to the soil nutrient status require investigation. Seed production by the green manures and their storage should be clarified to have a sustainable green manuring programme. The need to strengthen farmer research capabilities was identified.*

INTRODUCTION

Background

Mangwende communal area is in Natural Region II with a mean annual rainfall of 850 mm. The soils are mainly coarse- to medium-grained sands with low water holding capacity and low cation exchange capacity. Crops grown include maize, groundnuts, sunflower, cowpeas and beans.

Evolution of the Participatory Trials

An impact assessment study carried out by the Farming Systems Research Unit (FSRU) in 1992 (Chikura, *et al.*, 1992), showed that (a) adoption of soil fertility recommendations was minimal, (b) farmer involvement in trial formulation, implementation and evaluation was low and was limited to providing land for trials. In line with the current thinking of encouraging farmer participation in trial formulation, implementation and evaluation, a participatory rural appraisal (PRA) exercise was carried out by FSRU focusing on soil fertility. Through group meetings, transect walks and household interviews, we got information on soils and their management in the area. Farmers indicated that they had soil fertility problems that resulted in low maize yields on the most sandy soils known as the 'shapa'. The 'shapa' soils were associated with the *Striga* weed. Based on these findings, trials were formulated by two farmer research groups with the researchers as facilitators. Researchers suggested the use of green manures such as velvet beans, sunnhemp and dolichos for soil fertility improvement. Farmers suggested using cowpeas for suppressing *Striga*. The objectives were to:

- Test various legumes for their ability to improve soil fertility and consequently improve maize yields in intercropping and rotational cropping systems, and
- Identify legumes that can decrease incidence of *Striga* in nutrient depleted sand soils and thereby increase maize productivity.

METHODS

Site Selection

The trials were conducted in the Musami area of Mangwende by farmers and researchers. Site selection was based on problem prevalence, land availability and willingness of the host farmer to share results with other farmers. Each trial was conducted on two sites.

Treatments and Layout

Maize rotated with green manure crops -- Two trials were conducted. The first trial was to test green manure crops for their ability to improve soil nutrient status and consequently improve yields of maize rotated with these green manure legumes. The treatments were maize planted after sunnhemp, velvet bean or dolichos, following one year of maize with or without fertilizer. Maize spacing was 90 cm by 30 cm. Sunnhemp was drilled in rows 45 cm apart. Sole cowpea was spaced at 45 cm between rows and 20 cm within rows. Velvet bean was spaced at 45 cm and 20 cm. No fertilizers were applied to maize that followed the green manure crops.

Maize intercropped with velvet bean or cowpea compared to maize planted after cowpea, velvet bean or fallow -- The second experiment was to test the ability of legumes to reduce *Striga* incidence in a maize crop. The treatments were: maize intercropped with velvet bean or cowpeas, and maize following velvet bean, cowpeas or a fallow.

In intercrops, the cowpeas and velvet bean were alternated with maize plants in the same row and were planted at the same time with maize. Simple non-replicated trials were used so that farmers could understand the trial.

Roles and Activities in Participatory Experimentation

Farmers identified the problems together with the researchers and opportunities for improvement were discussed by farmers, researchers and extensionists. Seed for velvet beans, dolichos and sunnhemp was supplied by researchers. Farmers did the planting, weeding, harvesting and yield processing with the help of field research assistants. Researchers did soil sampling and analysis. At midseason farmers, researchers and extensionists toured and evaluated the trials. After harvesting and data processing workshops were held for participating farmers to report on their results and plans for the following season to fellow farmers, researchers and extensionists.

RESULTS

Rainfall Distribution

Table 1 gives the rainfall distribution during the period of the trials (1993-1996). The 1993/94 and 1994/95 seasons had below average total rainfall from October to May. The seasons were short and rainfall ended in March.

Trial 1: Maize Rotated With Green Manure Crops

Soil nutrient status -- The initial pH (in 0.01M calcium chloride) for sites 1 and 2 were 4.4 and 5.0 respectively. Initial available nitrogen was 16 for site 1 and 18 ppm for site 2. Available phosphorus was 12 for site 1 and 16 ppm for site 2. Soil nutrient status and pH after growing the green manure crops are shown in Table 2. The soil remained strongly acid to medium acid, (pH 4.1 to 5.8) at both sites. In site 2, available N increased from 18ppm before the trial began to 46ppm after growing the velvet bean.

Table 1. Rainfall distribution (mm) from the 1993/94 to 1995/96 seasons.

	Season		
Month	1995/96	1994/95	1993/94
October	30	52	0
November	23	13	65
December	126	179	97
January	375	208	89
February	168	96	58
March	46	3.5	0
April	0	0	0
May	91	0	0
TOTAL(mm)	859	551.5	309

Table 2. Available nitrogen (N) and phosphorus (P) and pH after growing green manure crops in the 1994/95 season.

	Site 1			Site 2		
Treatment	pH	Available N (ppm)	Available P_2O_5 (ppm)	pH	Available N (ppm)	Available P_2O_5 (ppm)
Sunhemp	4.5	23	10	5.7	28	10
Dolichos	4.4	15	5	4.8	18	24
Velvet bean	4.1	21	11	5.2	46	26
maize + fertilizer	4.6	23	7	5.0	22	24
maize no fertilizer	4.4	15	8	5.8	12	15
Fallow	4.8	14	2	5.0	15	7

Maize yields - At both sites, the maize crop following velvet bean green manure attained grain yield comparable to the maize crop to which 350 kg compound D and 250 kg/ha ammonium nitrate had been applied (Table 3). Sunnhemp also had a positive in-

Table 3. Grain yield (t/ha) of maize after the three green manure crops compared to maize following maize or a fallow in the 1995/96 season.

Maize after	Site 1	Site 2
Sunhemp	0.50	1.00
Velvet	0.70	1.10
Dolichos	0.25	0.02
Maize + fert.	0.65	1.10
Maize no. fert.	0.15	0.10
Fallow	0.45	0.10

fluence on yield (Table 3). Where maize followed dolichos green manure or the one-year of fallow, there was no yield improvement. Dolichos had poor establishment and therefore, little biomass was ploughed under in the 1993/94 season. As a result, farmers did not include dolichos in the trial the following year because of its poor performance. On average, the maize yields were low, probably because of poor rainfall distribution in the 1994/95 season (Table 1).

Biomass production -- In the 1995/96 season farmers assessed biomass production of velvet bean, sunnhemp and cowpea using a scoring system of 1-10 (Table 4). When biomass was averaged over the two sites, cowpea produced the least biomass (Table 4).

Table 4. Farmer assessment of biomass production by green manure crops

Green Manure Crop	Site 1	Site 2	Mean
Sunhemp	8	5	6.5
Velvet bean	4	8	6
Cowpea	2	6	4

Scoring key (1-10) where 1=least biomass 10 =highest biomass

Trial 2: Maize Intercropped With Velvet Bean and Cowpea Trials

Farmers' perception -- Farmers indicated that *Striga* was suppressed where cowpea was intercropped with maize. They also had an extra benefit of cowpea yield from the intercropped cowpeas of between 0.2 and 0.3 t/ha (Table 5). Intercropping of maize and velvet bean was unpopular with farmers because the velvet bean intertwined with the maize plants causing harvesting problems. However maize yields were relatively higher in the intercrops with cowpea and velvet bean than those of the non-fertilized maize (Table 5).

Table 5. Grain yield (t/ha) of maize when intercropped with velvet bean or cowpeas in the 1995/96 season.

	Site 1		Site 2	
maize/velvet	1.0		1.0	
maize/cowpea	1.5	(0.3)	1.4	(0.2)
sole maize (no fertilizer)	0.8		1.0	
sole maize fertilized	2.1		1.7	

Maize, velvet bean and maize/cowpea intercrops had higher yields than maize after a sole green manure crop or maize after maize. The fallow treatments, even after fertilizing the maize crop, gave lower yields than the maize/velvet bean and maize/cowpea intercrop (Table 6).

Participatory Approach in Experimentation

Farmers demonstrated their ability to identify problems, and to design and evaluate technology using yield data, observations and scoring. It was noted that some farmers lacked an analytical approach and the designs were often too simple for unit comparison. There were too many treatments in the trials. Methods of measurement for reaching sound conclusions were inadequate. For example, soil nutrient dynamics and *Striga* incidence were not measured adequately; only yield data was recorded. Data collection by farmers often missed the objectives of the trial. There is a need for farmers to relate trial evaluation to objectives and hence the need to strengthen and develop farmer experimentation capabilities.

AREAS FOR FUTURE RESEARCH

We need to quantify nutrient contributions to the soil by the green manure crops. Nutrient levels and dynamics in the soil should be measured to quantify the benefits of green manure crops.

In the trials reported, the effect of velvet bean and cowpea on *Striga* incidence was based on observation; hence the need to quantify the effects of cowpeas and velvet bean on *Striga* incidence over at least four seasons.

Seed production and storage methods for the green manure crops should be developed for a sustainable green manuring programme in the communal areas.

CONCLUSION

Improvement of maize grain yields by the ploughing in of green manures was demonstrated; particularly with velvet bean. However the effectiveness of dolichos for improving maize yields is questionable and this needs further investigation. The soil pH did

Table 6. Grain yield of maize after sole green manure crops, intercropping and fallowing in the 1995/96 season at two sites in Mangwende. [cowpea yields in brackets]

	Maize grain yield (t/ha)	
Treatment	Site 1	Site 2
Velvet bean	1.83	2.52
Cowpea	4.46	6.12
Maize velvet intercrop	6.77	6.37
Maize cowpea intercrop	6.29 (0.25)	6.91 (0.48)
Maize fertilizer	5.28	5.39
Maize fertilized	5.97	6.09
Previous fallow	2.18	2.22
Fallow maize fertilized	3.56	3.70

not increase by ploughing-under the green manure crops. From farmers' observations, the use of cowpea in improving maize yields in *Striga*-infested fields was demonstrated, but further research is required to validate this. Intercropping of velvet bean with maize was not popular with farmers because of the twining effect of velvet bean. Sole crops of velvet bean for improving soil were acceptable to farmers.

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DISCUSSION: GREEN MANURES

Questions to Robert Gilbert

From: Ishmail Pompi
Is 3% N in the biomass for all green manures or only for certain tree species?

Response :
The figure of 3% N is a temporary estimate used for the average of leaves, stem and reproductive parts for the four species studied. Once the plant tissue analysis is finished, the exact % N will be known and the target biomass to add 60 kg N per ha will be adjusted.

From: Ken Giller
When we think about moving these ideas of undersowing green manures into the farmers' hands we might be better to consider sowing the *Mucuna* late and just letting it grow on after maize harvest, or not turning in the *Crotalaria* but letting it dry in the field. Can you comment on *Tephrosia*, because there is great interest in it in Malawi but very little quantitative information?

Response:
Tephrosia Vogelii presents several advantages as a green manure, as it grows throughout the dry season and it is unpalatable to livestock. While several researchers (from MAFE and ICRAF, George Kanyama-Phiri and myself), have begun research on undersowing *Tephrosia*, quantitative data on biomass is lacking. It has become increasingly clear that *Tephrosia* is not competitive with maize and to produce adequate biomass it should be undersown as early as possible.

From: Peter Jeranyama
Treatment LPT_1S_2 had higher maize grain yield relative to the control. How do you explain this difference?

Response:
Lablab growth was very poor (< 1000 kg per ha biomass) at all sites, so it was not very competitive with maize. The difference in maize yields in LP treatments from the control are most likely due to the variability of unfertilized maize growth on farm.

From: Roland Buresh
What hypotheses concerning soil and climate effects on the performance of green manures were used in the selection of sites in the Soil Fert Net trials?

Response:
For the Malawi efforts it was assumed that these green manure rotations would be mostly appropriate for lower population density areas in central and northern Malawi. Within this region exhausted sites with low unfertilized maize yields were chosen. The null hypothesis was that the three species chosen could produce large amounts of biomass (5 - 10t per ha) even on depleted sites in Malawian agroecologies.

Question to Danisile Hikwa

From: Larry Harrington
How can we forecast longer-term changes in soil quality in exhausted soils from treatments?

Response:
These are not easy to forecast. However, the forecast can be based on measurements from treatments if they are evaluated for at least two, and where possible, three seasons rather than just one. The actual changes can be quantified through comparing the baseline soil charaterization data and initial yield (grain and above-ground residue biomass) to the subsequent soil and yield data. By the second or third season, there should be clear indicators of what to expect in the longer term. Moreover, the farmers themselves will assess the treatments and react positively to the most promising to improve the productivity of their depleted lands, even in the longer term.

Question to Chinaniso Chibudu

From: Sheunesu Mpepereki
You highlighted some shortcomings of farmers in conducting research, e.g. collecting and analysing data. Do you seriously expect them to handle these aspects? You mentioned that maybe they do not have instruments. What is the nature of the experiments that farmers can handle? What sort of observations can they make? How do researchers complement farmers' research efforts?

Response:
While farmers have some shortcomings in conducting research and analysing data, the ability to do that was demonstrated. Researchers need to strengthen these capabilities where farmers fall short. Yes farmers can handle better some aspects like problem identification, planting, weeding, fertilizing and evaluating the crop. Evaluation can be done in their own way or at the researchers' suggestion. Farmers can handle experiments with few treatments and they can make observations on growth, compatibility with the cropping systems and socio-economic circumstances. Researchers can help in setting up and evaluating parallel designed trials.

PIGEONPEA IN ZIMBABWE: A NEW CROP WITH POTENTIAL

PAUL MAPFUMO[1], SHEUNESU MPEPEREKI[1] and PARAMU MAFONGOYA[2]

[1]Department of Soil Science and Agricultural Engineering, University of Zimbabwe, P.O. Box MP167 Mount Pleasant, Harare, Zimbabwe
[2]ICRAF-Zambia, P.O. Box 510046, Chipata, Zambia

SUMMARY

A study to investigate the potential contribution of pigeonpea to soil fertility management in smallholder farming systems was initiated at Domboshava and in Murewa Communal Area during the 1996/97 cropping season. Its main focus is on biological nitrogen fixation and pigeonpea residue management. A participatory rural appraisal was first conducted to investigate the current role of legumes in soil fertility management in the farming systems. Limited use of legumes was revealed and was attributed to unavailability of seed and over-emphasis on maize production. The population levels of pigeonpea-nodulating rhizobia in 21 different soils were determined. The rhizobial populations were low (1-121 cells/g soil), but there were indications of a rapid population build-up after one season of growing pigeonpea. Short, medium and long duration pigeonpeas were grown, and their residual effects on a subsequent maize crop will be tested in the 1997/98 season. Pigeonpea and maize biomass yields were assessed during the 1996/97 cropping season. Both maize and pigeonpea biomass yields were greatly reduced due to waterlogging, but long duration pigeonpea showed better recovery. The pigeonpea biomass yields ranged from 30 kg/ha for short duration to 9200 kg/ha for long duration. Although pigeonpea performance proved promising on the relatively infertile soils, there is need to determine optimum plant populations. Utilization aspects of the crop also need attention.

INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a grain legume which belongs to the tribe Phaseolae of the family Leguminosae. Cultivation of pigeonpea started in Asia some 3000 years ago, and the crop was known in Egypt between 2400 and 2200 B.C. (Rowe, 1980). The plant is naturally a bushy perennial but is predominantly grown as an annual. The crop offers high quality food and fodder with crude protein content in grain averaging 22 percent. It improves soil fertility through its ability to fix atmospheric nitrogen and recycle nutrients. Pigeonpea is ranked sixth on the grain legume list of importance, with 90 percent of the world production coming from the Indian sub-continent (Nene and Sheila, 1990). In Africa considerable amounts of pigeonpea are produced in Kenya, Uganda and Malawi (Nene and Sheila, 1990).

THE CASE FOR PIGEONPEA IN ZIMBABWE

Declining soil fertility has undermined crop production capacity and threatened food security in smallholder farming systems of southern Africa. In the wake of ever-increasing inorganic fertilizer prices, scientists have called for enhancement of those soil biological processes that optimize nutrient cycling as well as minimize and efficiently utilize external inputs (Anderson and Ingram, 1993; Kumwenda, Waddington, Snapp, Jones and Blackie, 1995). The capacity of nitrogen-fixing legumes to contribute significantly to soil fertility and sustain smallholder agriculture has been documented (Giller and Wilson, 1991; Giller, McDonagh and Cadisch, 1994). Selection of appropriate legumes in such interventions is, however, crucial for Zimbabwean smallholder farming. In this study pigeonpea is perceived to have a number of advantages as a soil improving crop.

Adaptability

Major reasons for the success of pigeonpea in subsistence agricultural systems in the semi-arid tropics include its ability to grow on relatively infertile soils, tolerance to drought and other severe environmental or biotic stresses (Whiteman, Byth and Wallis, 1985). All pigeonpea species grow at altitudes ranging from 0 to 1500 metres (van der Maesen, 1990). Different maturity types ranging from extra-early (90 days) to late (>180 days) do occur. The existence of the different maturity types greatly contributes towards the crop's adaptation to different agro-climatic environments (Reddy, 1990), and its suitability in different cropping systems. The crop, therefore, has potential in Zimbabwe's different agro-ecological regions which are largely under subhumid and semi-arid environments.

Nitrogen Fixation

Pigeonpea is a legume that biologically fixes nitrogen through symbiotic association with rhizobia. Varieties and maturity groups differ in the quantity of nitrogen they can fix (Kumar Rao and Dart, 1987). Values of up to 200 kg N/ha have been reported (Kumar Rao, 1990). Large residual effects of N on subsequent crops, and maize yield increases of up to 57 percent have been recorded (Kumar Rao, Dart and Sastry, 1983). In Malawi, studies on maize in short rotations with groundnut, soyabean, lab-lab, sunflower and pigeonpea revealed that the highest N contribution was from pigeonpea which gave a net N of 23 to 110 kg/ha (MacColl, 1989). However, according to Kumar Rao (1990), limited work has been done on biological nitrogen fixation (BNF) of pigeonpea. Prevalence of pigeonpea-nodulating rhizobia in the N-deficient soils of Zimbabwe will largely determine the success of the crop in the cropping systems.

N Returns to Cropping Systems

The high biomass yield potential of pigeonpea ensures high N benefits from BNF if residues are returned to the soil. Pigeonpea, especially the long duration types, has a low N harvest index if grain is considered as the sole or main form of nutrient export from cropping systems. This gives it a distinct advantage over other commonly grown grain legumes as a soil fertility ameliorant (Table 1).

Table 1. N harvest indices (in grain) for some commonly cultivated grain legumes.

Legume crop	N harvest index (Percent)
Cowpea	61
Soyabean	75
Groundnut	80
Faba bean	76
Chickpea	73
Pigeonpea (short duration)	52
Pigeonpea (long duration)	21

(Source: Whiteman *et al.*, 1985)

The development of pigeonpea is characterized by considerable leaf-fall during the crop's reproductive phase. Because of its high biomass potential, this results in high residual benefits on subsequent cereal crops, and may also reduce N harvests by browsing livestock. Fallen leaves have been reported to contribute up to 40 kg N/ha (Whiteman *et al.*, 1985). Pigeonpea also has a deep taproot system which enables mobilization and recycling of leached nutrients (Johansen, 1990).

Versatility

Pigeonpea can be used as a grain, fodder or green manure crop. Perennial pigeonpea can additionally provide firewood. Various farmer needs can thus be addressed through use of a single crop.

The crop is relatively new in Zimbabwe and there is a new thrust to promote it. On-going research on pigeonpea includes: adaptation and grain yield potential trials for various maturity groups (Manyowa, 1996); soil dynamics and maize response under pigeonpea improved fallows (Nyakanda, 1996); performance of pigeonpea as a multipurpose tree in agroforestry systems (SADC/ICRAF Programme). Although agronomic-type research has also been done in the past (Mills, 1961; Natarajan and Mafongoya, 1992; Dzowela and Hove, 1995), none of these have focused on BNF of pigeonpea. The potential utilization of the N fixed, through appropriate pigeonpea residue management options, has not been addressed. A basis for a sustainable, legume-based, soil fertility management package for Zimbabwean smallholder farmers is required. A study is being conducted to investigate the potential contribution of pigeonpea to sustainable soil fertility management in smallholder farming systems.

OBJECTIVES

- To determine the nitrogen fixing potential of pigeonpea in local soils.
- To determine the residual effects of pigeonpea on the subsequent maize crop.

MATERIALS AND METHODS

Sites and Soils

The research is being conducted at Domboshava Training Centre (on-station) and in the Mukarakate area of Murewa Communal Area, north-east of Harare. The soils in both areas are granitic sands or sandy loams (predominantly Haplic lixisols under FAO classification).

Participatory Rural Appraisal

A participatory rural appraisal (PRA) exercise was undertaken in Murewa Communal Area to investigate the current role of legumes in soil fertility management and determine feasible ways of using pigeonpea as a soil-improving crop. Farmer workshops were also conducted to capture data on farmer perceptions and attitudes towards the technology, and to evaluate crop performance.

Nitrogen Fixation Potential

Soils were collected from 21 sites covering Zimbabwe's agroecological regions II to V. Four of the soils were from research stations and the rest from Communal Areas.

Pigeonpea-nodulating rhizobia population levels were determined using the most probable number (MPN) plant infection technique (Woomer, 1994). Selected soils were also tested for cowpea-nodulating rhizobia, for comparison. Soils with low, medium and high pigeonpea-nodulating rhizobia populations will be tested for response to inoculation in the next experimental phase. A field experiment to quantify the nitrogen fixed by short, medium and long duration pigeonpea was established at Domboshava. All plants were inoculated. The N-difference method was used. Sorghum varieties of appropriate duration were used as non-fixing reference crops. A non-N-fixing pigeonpea genotype (short duration only) obtained from ICRISAT has also been included. Efforts to use the ^{15}N natural abundance method have been unsuccessful due to the practically low levels of the isotope in Domboshava soils (Mapfumo, unpublished data).

On-station Experiments

An experiment was established on sandy and sandy clay loam soils at Domboshava during the 1996/97 cropping season, with the following objectives:
(i) to determine residual effects of pigeonpea on the following maize crop when all above ground biomass is removed;
(ii) to investigate the effect of time of application of pigeonpea residues on synchronization of N mineralization and N uptake by a maize crop;
(iii) to determine the presence of any synergistic effects when different levels of inorganic N-fertilizers are superimposed on the different organic residue treatments in (i) and (ii) above;
(iv) to quantify N contribution from incorporated residues to the subsequent maize crop.

The experiment was planted on December 6 1996 and is scheduled for two seasons. A long duration pigeonpea (Ex-Marondera), cowpea (Local Mixed) and maize (SC 501) were grown on each soil type to facilitate the following treatments in the second year:

i) incorporation as green manure towards the end of the season (flowering/pod set stage) through ploughing;
ii) incorporation of pigeonpea residues just after harvesting the grain;
iii) incorporation of cowpea residues just after harvesting the grain;
iv) all above ground pigeonpea biomass removed (e.g. for fodder) to assess residual effects of fixed N and leaf fall;
v) cropped to maize instead of pigeonpea (control number 1);
(vi) fallowed (grass/weed fallow) (control 2).

Cowpea was included as a traditional legume which grows relatively well on infertile soils. All the pigeonpea and cowpea received 12.5 kg P/ha and 18 kg S/ha as single superphosphate (SSP). The maize crop (control 1) was given a basal fertilizer of 200 kg/ha Compound D (16.0 kg N/ha; 12.4 kg P/ha; 11.6 kg K/ha; 13 kg S/ha) and top-dressed with 69 kg N/ha in form of ammonium nitrate. The biomass and N generated under the different treatments were measured. Decomposition rates of pigeonpea residues were monitored using litter bags.

During the 1997/98 season maize yield and N uptake response patterns, under the different year 1 treatments, will be monitored.

On-farm Experimentation

The overall objective was to determine the impact of incorporated pigeonpea residues on soil fertility under existing cropping systems.

Twelve on-farm farm sites were selected. Pigeonpea of three maturity durations, namely short, medium, long duration were grown in the 1996/97 cropping season. Maize was also included as a control. Plantings were done on November 29, 1996. The pigeonpea received 12.5 kg P/ha and 18 kg S/ha as SSP. The maize crop received 200 kg/ha compound D (16.0 kg N/ha; 12.4 kg P/ha; 11.6 kg K/ha; 13 kg S/ha) and was top-dressed with 63.8 kg N/ha as ammonium nitrate. Residues for the short duration pigeonpea were incorporated after grain harvest while the other two were incorporated as green manure at flowering. Biomass yields were determined for both crops. Maize yield and N uptake responses on these plots will be tested during the 1997/98 season.

Five farmers were given some long duration pigeonpea seed to grow on their own. The plantings were done between December 19 and 24, 1996. The crop was not fertilized. The crop was assessed for above ground biomass yields plots at flowering stage.

PRELIMINARY RESULTS AND DISCUSSION

The PRA and farmer workshops established the following:

a) Legumes are currently playing a very limited role in soil fertility management in Zimbabwean smallholder farming systems. Over-emphasis on maize production has undermined legume production. There is need for a deliberate national agricultural policy to promote legumes.
b) Up to 40 percent of households were found to fallow part of their land in any one season. Low soil fertility was one of the major reasons for fallowing. Farmers emphasized that they would rather fallow than crop without any form of fertilizer. There is, therefore, room for improved fallows. Observations also showed that a considerable hectarage is abandoned after planting because of failure by smallholder farmers to secure sufficient fertilizers. Farmers would plant and hope to get fertilizer later.
c) Farmers prefer a pigeonpea crop that matures at the same time as most crops (about May) in order to avoid providing extra protection mea-

sures. Early planting was suggested. Farmers also believe that protection mechanisms can be put in place if the majority of farmers adopt the crop. An example was given where farmers in some areas reached a consensus to herd their livestock throughout the dry season to protect horticultural crops. Farmers also prolong the herding period in cotton growing areas.

d) The utilization and marketing aspects of pigeonpea and other legumes critically need attention. A utilization campaign would greatly encourage adoption of legumes. For instance farmers wanted to know the appropriate cooking methods for pigeonpea, and how best it could be fed to cattle. Lack of utilization and marketing opportunities will discourage the production of pigeonpea and hence undermine the crop's potential contribution to soil fertility.

Table 2. Population levels for pigeonpea- and cowpea-nodulating rhizobia in selected Zimbabwean soils.

	MPN			
Site	Pigeonpea	95% CI	Cowpea	95% CI
Chikomba	40	(14 - 116)	nd	
Chinyika (Chinyudze)	6	(2 - 23)	36	(9 - 137)
Chinyika (Govakova)	1	(0 - 3)	16	(4 - 61)
Chiweshe	16	(6 - 47)	61	(16 - 234)
Domboshawa 1	1	(0 - 3)	33	(11 - 95)
Domboshawa 2	5	(2 - 13)	nd	
Kezi	1	(0 - 3)	112	(30 - 428)
Mudzi	5	(2 - 13)	21	(6 - 81)
Murewa 1	1	(0 - 3)	36	(9 - 137)
Murewa 2	5	(2 - 13)	nd	
Shamva 1*	614	(161 - 2333)	159	(42 - 606)
Shamva 2*	121	(42 - 349)	nd	

*Shamva 1 soil was under pigeonpea the previous season while Shamva 2, like the rest of the soils, was under maize; 95% CI = 95% confidence interval; nd = not determined.

Indigenous rhizobia populations in soils were found to be low. This may partly be attributed to the non-existence of pigeonpea in the cropping systems. Cowpea rhizobia counts were relatively higher than for pigeonpea, suggesting their relatively high prevalence in Zimbabwean soils. There was, however, an indication of a rapid build-up of the populations after one season of pigeonpea production (Table 2).

All sites used in the study were low in major plant nutrients, especially P, and strongly acidic (Table 3). Soil organic carbon was low, averaging 0.34 percent. The need for liming should be seriously considered given the critically low pH values.

Both pigeonpea and maize were severely affected by waterlogging at most of the sites. Pigeonpea plant populations were reduced by about 33% and the resultant low populations greatly reduced biomass yields. Only those plots that were less affected by waterlogging gave relatively high yields. The pi-

Table 3. Soil characteristics for the various sites used in the study.

Site	Clay (Percent)	Sand (Percent)	pH ($CaCl_2$)	N (µg/g)	P (µg/g)	C (Percent)	N (Percent)	K	Ca	Mg
								(meq per 100g)		
Domboshawa 1	2	92	4.2	20	4	0.29	0.24	0.08	0.50	0.36
Domboshawa 2	18	76	4.4	42	10	0.59	0.24	0.19	0.92	0.53
Farm 1	4	89	4.2	17	8	0.26	0.13	0.07	0.39	0.15
Farm 2	4	90	4.3	30	2	0.35	0.18	0.09	0.68	0.35
Farm 3	2	92	4.2	25	6	0.33	0.19	0.07	0.60	0.31
Farm 4	4	92	4.1	17	6	0.28	0.15	0.06	0.52	0.21
Farm 5	3	92	4.6	34	10	0.23	0.16	0.06	0.96	0.30
Farm 6	4	86	4.4	26	3	0.40	0.15	0.07	1.19	0.40
Farm 7	5	88	4.1	22	4	0.26	0.24	0.08	0.80	0.33
Farm 8	5	88	4.2	27	2	0.24	0.17	0.06	0.60	0.20
Farm 9	9	82	4.5	31	2	0.44	0.09	0.14	1.39	0.59
Farm 10	9	86	4.6	27	4	0.47	0.24	0.13	2.06	0.75
Farm 11	6	92	4.4	16	8	0.32	0.17	0.10	0.94	0.26
Farm 12	6	90	4.2	18	11	0.32	0.20	0.08	0.85	0.30

Table 4. Biomass yields (kg/ha) for pigeonpea (green manure at flowering stage) and maize, and maize grain yields, obtained from Domboshawa in 1996/97 season.

	Pigeonpea biomass			Maize	
Site	*ICPL87109	ICP9145	Ex-Marondera	biomass	grain
Domboshawa 1	--	--	978	1280	180
Domboshawa 2	--	--	9200	7638	1533
Farm 5	222	406	1250	4278	871
Farm 6	30	414	1133	1848	468
Farm 7	52	101	139	1461	27
Farm 9	314	224	965	1298	230
Farm 10	792	811	2658	6823	1346
Farm 11	834	2882	2939	7809	2810
Farmers' pigeonpea crop[2]					
Chawanda	nd	nd	3052	nd	nd
Chikurunhe	nd	nd	2123	nd	nd
Chirwa	nd	nd	3584	nd	nd
Chirwanemhuka	nd	nd	3744	nd	nd
Mukarakate	nd	nd	3490	nd	nd

*ICPL87109 was harvested at physiological maturity;
[2]a cultivar from National Tested Seeds was used by farmers; nd = not determined

geonpea and maize biomass yields obtained from the different sites are shown in Table 4.

Notable was the growth recovery by long duration pigeonpea late in the season. Maize and short duration pigeonpea did not recover. Observations also showed that the target population of 55556 plants/ha was low, particularly for short duration pigeonpea. Work in Kenya (ICRISAT, 1993) has shown populations of between 166667 and 222222 plants/ha as optimum for short duration genotypes. Farmer plots in Murewa also gave better yields (Table 4) at average final populations of 90277 plants/ha.

The effects of waterlogging and low soil fertility are also reflected in the maize grain yields. Waterlogging apparently suppressed nitrogen fixation of pigeonpea during early growth stages. This was evidenced by chlorosis which was observed only in affected areas. There were no major crop disorders. Pods on the short duration pigeonpea were severely attacked by sucking pests, resulting in little or no pod filling. Field observations also showed that grain yield in long duration types may be greatly reduced by terminal drought. Therefore, planting may need to be done early.

Based on those sites which were less affected by waterlogging, pigeonpea performance is considered promising. There are, however, some key agronomic issues which need further research. Optimum plant populations under low soil fertility and planting dates need to be established. Photosensitivity of the genotypes in relation to planting date may be critical. Appropriate maturity genotypes should be identified for different farmer needs. Short duration genotypes which offer relatively high biomass yields as well as reasonable grain yields (presumably indeterminate types) should also be tested. These may greatly benefit those farmers who grow the crop primarily for seed. Attention should be given to utilization aspects which may offer enough incentives for farmers to adopt the crop.

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NODULATION AND YIELD OF PROMISCUOUS SOYBEAN (*GLYCINE MAX* [L.] MERR.) VARIETIES UNDER FIELD CONDITIONS

PATRICK KASASA[1], SHEUNESU MPEPEREKI[1], and KEN E. GILLER[2]

[1]Department of Soil Science and Agricultural Engineering, University of Zimbabwe and
[2]Department of Biological Sciences, Wye College, University of London, Wye, Ashford, Kent, UK

SUMMARY

Nodulation, dry matter and grain yields of two promiscuous (Magoye and Local) and two specific (Roan and Nyala) soybean varieties grown at three field sites in Zimbabwe were compared. Rhizobial numbers were higher in soils with a history of soybean and ranged from 15 to 11 million cells per gram of soil using Magoye as the trap host. In general nodule numbers did not respond to inoculation in promiscuous varieties and only increased slightly in specific varieties. Promiscuous varieties had comparable grain yields, higher dry matter and lower grain harvest indices compared to specific varieties without inoculation. Our results suggest that promiscuous soybean has potential under low input cropping systems where rhizobia inoculants may not be readily available.

INTRODUCTION

Nitrogen (N) is the most limiting nutrient affecting crop production in Zimbabwe. In smallholder areas the high costs of N-fertilizer coupled with its limited availability seriously hamper crop production. Inclusion of legumes that can fix N biologically in crop rotation sequences could significantly improve N availability and sustain productivity.

Soybean has the capacity to fix nitrogen in symbiosis with rhizobia. On average, the legume has been reported to fix up to half the amount of total nitrogen required for its growth (Wynch and Rains, 1978). In Zimbabwe, soybean has been successfully grown mostly on commercial farms (Mabika and Mariga, 1996). Smallholder and small-scale farmers had limited knowledge of the technologies used in commercial soybean production, which include use of fertilizers, improved soybean varieties and rhizobial inoculants. Also, there has been no sustained extension of the crop in this sector because of a belief that soybean does not do well in the relatively drier smallholder areas dominated by sandy, often acid soils. Rhizobial inoculants were reported to require refrigeration facilities that are largely non-existent in most smallholder homes. However, recent studies have shown that inoculants can be kept viable for up to four months in a cool environment (e.g. a granary) and away from direct sunlight (Mabika and Mariga, 1996).

Since 1980, as a result of the Government's resettlement program, there has been an increase in the area cropped by smallholder and small-scale commercial farmers in agro-ecological areas with a higher potential for soybean growing (Tattersfield, 1996). The major constraint, that of non-availability of rhizobial inoculants can be addressed by either supplying farmers with inoculants or providing soybean varieties that effectively nodulate with indigenous rhizobia. Indigenous rhizobia that nodulate soybean varieties have been reported in Zimbabwean soils (Corby *et al*, 1964 ; Corby, 1967, and Davis and Mpepereki, 1995). Legumes that nodulate effectively with indigenous rhizobia have been described as "promiscuous" because of their lack of specificity in nodulation (Kueneman *et al*, 1984). In Zambia such promiscuous soybean varieties have been grown successfully without inoculation (Javaheri, 1994). Use of promiscuous germplasm obviates the need for rhizobial inoculants which are often difficult for smallholder farmers to acquire (Mabika and Mariga, 1996).

Promiscuous varieties such as Magoye and Hernon 147 are leafy and probably have low harvest indices. The incorporation of crop residues from these varieties could improve soil fertility (Giller and Wilson, 1991). Grain legumes can only help in the maintenance of soil fertility for other subsequent crops in the rotation when they leave behind more N from fixation than the amount of N that is removed in the harvested legume grain crop (Giller and Wilson, 1991). When incorporated, grain legume residues have been reported to decompose rapidly and release N to benefit subsequent crops because they have low C/N ratios (Giller and Wilson, 1991).

Promiscuous soybean varieties with low nitrogen harvest indices could improve soil fertility when crop residues are incorporated. Given the prevailing high market prices for soybean, farmers can generate cash income to finance inputs and other family budgetary needs. The high protein (40%) and oil (20%) content in soybean seeds could help reduce malnutrition if farmers supplement their maize-based staple diets with processed soybean food.

To enable Zimbabwe's small-scale and smallholder farmers to benefit from soybean production, a study was initiated with the following objectives:
(i) to compare nodulation and N fixation of two promiscuous and two specific soybean varieties under smallholder cropping conditions
(ii) to compare dry matter and grain yield of two promiscuous and two specific soybean varieties

MATERIALS AND METHODS

Site Selection and Characterisation

Three sites, two in smallholder areas and one in a commercial farming area with potential for soybean, were selected. The two smallholder sites, Tapera and Hotera are located in Hurungwe district (Natural Region IIB) while a third, Bvochora is in Guruve (Natural Region III). A fourth site at the University of Zimbabwe's Thornpark Farm near Harare (Natural Region IIA) was included as the on-station site to determine yield potentials under high management. Natural Regions (NR) are classified on the basis of amounts of rainfall received; NR II: 900-1200 mm per annum, NR III: 600-900 mm per annum.

Soil Sampling

Composite soil samples were collected from the top 30 cm by digging with a hoe. Samples were placed in clean polythene bags and transported to the laboratory in an ice-cooled box. Prior to sieving (2 mm) in preparation for chemical and physical analysis, subsamples for microbiological analysis were removed and stored in a refrigerator (4°C) for up to 48 h prior to processing.

Rhizobial Populations

Rhizobia populations for the five sites were determined before the beginning of the rainy season using the plant infection Most Probable Number (MPN) technique and the rhizobial numbers were determined using the MPNES computer programme (Woomer, 1994).

Field Experiments

Experiments to determine nodulation and yield responses with and without rhizobial inoculation were laid out in a split-plot design with five replicates. Plots with inoculation were separated from those without inoculation to reduce cross contamination. Treatments were made up of eight combinations of the four varieties (promiscuous Magoye and Local and specific Roan and Nyala) with and without inoculation. The variety Local is probably an unimproved Hernon land race (Tattersfield, personal communication). Compound L fertilizer [N(5); P(18); K(10)] was applied on all plots at a rate of 150 kg ha^{-1}. An initial amount of N was also applied as ammonium nitrate at a rate of 10 kg ha^{-1} to give a total of 17.5 kg N ha^{-1} to meet the plants' initial N requirements.

Planting arrangement was a 45 cm row spacing with a 7 cm within row spacing to give approximately 320 000 plants ha^{-1}. Plots measured 6 m x 5 m. Plots without inoculation were planted first to avoid contamination with the commercial rhizobia inoculant. For the inoculated plots, seed of the four soybean varieties was mixed separately with *Bradyrhizobium japonicum* strain MAR 1491 (= USDA 110) obtained from the Soil Productivity Research Laboratory (Marondera). Mixing was done according to the manufacturer's instructions except that sugar was omitted. Each seed had approximately 10^8 cells. The inoculated seed, which was kept away from the sun was planted into moist soil to a depth of about 2-3 cm and quickly covered.

Thinning was done two weeks after planting in plots that showed signs of overpopulation. No re-planting was done in plots with low plant populations. Weeding was done manually by hoeing two weeks after planting, with uninoculated plots weeded first to avoid cross contamination, but weeds close to the plants were removed by hand to avoid disturbing the young roots. However, because of the above average 1996/97 rainy season weed control was a problem especially during the middle of the growing season when most of the fields were waterlogged.

There were no major disease problems at the three sites. Nyala however showed signs of mild attacks by frog eye after pod-fill. Magoye and Local showed the least signs of attack by disease.

Nodulation of the four soybean varieties was examined seven weeks after planting (the two specific varieties, Nyala and Roan were flowering at this stage). Five randomly-picked plants from the guard rows were carefully dug up with their entire root system. The roots were separated from the plant tops and these were carefully washed with running tap water in the laboratory. Nodule numbers per plant were counted, weighed, oven-dried at 70°C and reweighed.

Sampling for Dry Matter and Grain Yield

All the four varieties matured in 120-134 days in the hotter area of Hurungwe while at Thornpark farm they matured in 141-150 days. At maturity, plants from the inner seven rows out of eleven were harvested leaving 1 m on either side of each row. The plant tops (stover plus pods) from each plot were weighed after drying in the greenhouse at 40°C for two weeks. Fallen leaves from the harvested area were picked and weighed together with the plant tops. The dried plant tops were threshed and the grain from each plot was weighed. The weight of the stover per plot was found by subtracting the weight of the seed from the weight of the plant tops. Subsamples of the grain and the stover were oven dried at 70°C and results are expressed as oven dry weights. Below are field data from the two Hurungwe and the Thornpark sites.

RESULTS

Soil Characteristics

Soils at the study sites were slightly acid with a pH range of 4.8 to 5.5 in 0.01 M $CaCl_2$, with low levels of carbon ranging from 0.59 to 0.97% and nitrogen ranging from 0.025 to 0.06% while at the Thornpark site the soils were more fertile. Soil characteristics are shown in Table 1.

Rhizobial Populations

Rhizobia numbers across sites ranged from as low as 1 to 11 $\times 10^6$ cells g^{-1} of soil depending on the trap host variety and site (Table 2). Numbers ranged from 15 to 11 x 10^6 cells per gram of soil when Magoye was used as a trap host and from 1 to 3.2 x 10^3 cells per gram of soil when Local was used as the trap host.

Field Experiments

Nodulation — Nodule numbers at each of the four sites were not significantly different for the inoculated and uninoculated plots (Table 3). Magoye and Local had lower nodule counts in inoculated plots at the Tapera site. The specific varieties Nyala and Roan slightly responded to inoculation at Tapera. At the Hotera site, inoculated Nyala suffered a slight depression in nodule number while Roan slightly responded to inoculation at all the four sites.

Dry matter — Dry matter (DM) production was significantly higher for the promiscuous compared to the specific soybean varieties at the three sites. For the promiscuous varieties, DM production ranged from 1.97 - 3.66 t/ha at the smallholder sites and from 10.97 -12.52 t/ha at the Thornpark site. Specific varieties produced 1.06 - 1.95 t/ha DM at the smallholder sites and 5.36 - 8.00 t/ha at the Thornpark site (Table 4). Inoculation did not significantly increased dry matter production at all the study sites.

Grain yield — Grain yield for promiscuous and specific varieties did not differ significantly at the smallholder sites (Tapera and Hotera) but was significantly higher for the specific varieties compared to the promiscuous ones at the Thornpark site. The promiscuous varieties yielded between 0.98 - 2.03 t/ha while specific varieties yielded between 0.95 - 2.20 t/ha at the smallholder sites. At the Thornpark site grain yield for the promiscuous varieties ranged from 2.08 - 2.18 t/ha while the specific varieties gave yields between 2.80 - 3.94 t/ha (Table 4).

Table 1. Site and soil characteristics at soybean study sites.

Site	Soil texture	Soil pH ($CaCl_2$)	Organic C (%)	Total N (%)	CEC (meq/100g)
Tapera	loamy sand	4.96	0.82	0.036	6.6
Hotera	loamy sand	4.88	0.59	0.025	5.6
Bvochora	clay	4.7	0.97	0.06	8.3
Thornpark	clay	5.5	1.27	nd	15

nd= not determined

Table 2. Rhizobia population levels at study sites promiscuous soybean as trap hosts.

Site	Magoye (MPN g^{-1} soil dwt)[1]	Local (MPN g^{-1} soil dwt)	Cropping history
Mbizimwenje (Guruve)	15	1.1	Virgin, *Brachystegia* spp. herbaceous legumes
Tapera (Hurungwe)	926	8.7	Maize, sunflower, soybean once
Hotera (Hurungwe)	93	1113	Maize, cotton, soybean (Local)
Chiwara (Guruve)	239300	3281	maize, cotton, soybean
Thornpark (Harare)	11000000	409	maize, soybean inoculated

[1] MPN = most probable number of rhizobial cells.

Table 3. Nodulation of promiscuous and specific soybean varieties in two Hurungwe soils. Numbers are nodules per plant.

Site	Magoye U	Magoye I	Local U	Local I	Nyala U	Nyala I	Roan U	Roan I
Tapera	61[a]	50[a]	73[b]	48[a]	46[a]	55[a]	30[c]	46[a]
Hotera	19[a]	24[a]	18[a]	18[a]	18[a]	8[b]	8[b]	14[c]
Thornpark	30[a]	25[a]	22[a]	28[a]	27[a]	25[a]	28[a]	32[a]
Chiwara	30[a]	26[a]	20[a]	23[a]	24[a]	25[a]	21[a]	24[a]

U = no inoculation; I = inoculated with *B. japonicum* str. MAR 1491.
At each site nodule numbers followed by the same letter are not significantly different ($p \leq 0.05$).

DISCUSSION

Soils at the smallholder study sites were slightly acid, with extremely low levels of carbon and nitrogen, typical of the smallholder area soils whose nitrogen and carbon levels average 0.1%

Table 4. Dry matter and grain yield of promiscuous and specific soybean varieties.

Site/variety	Dry matter U	Dry matter I	Grain yield U	Grain yield I
	(t/ha)			
Tapera				
Magoye	3.08[a]	3.66[a]	1.73[a]	2.03[a]
Local	2.80[a]	3.38[a]	1.77[a]	1.88[a]
Roan	1.49[b]	1.95[b]	1.52[a]	1.70[a]
Nyala	1.68[b]	1.76[b]	2.20[a]	1.89[a]
Hotera				
Magoye	2.59[a]	2.18[a]	1.14[a]	1.13[a]
Local	1.97[ab]	1.93[a]	1.00[a]	0.98[a]
Roan	1.27[b]	1.45[a]	0.84[a]	1.14[a]
Nyala	1.45[b]	1.06[b]	1.07[a]	1.18[a]
Thornpark				
Magoye	12.52[a]	11.54[a]	2.18[a]	2.09[a]
Local	11.51[a]	10.97[a]	2.08[a]	2.09[a]
Roan	5.70[b]	8.00[b]	2.80[b]	3.55[b]
Nyala	5.82[b]	5.36[c]	3.94[c]	3.90[c]

U = no inoculation. I = inoculated
At each site, yields in each column followed by the same letter are not significantly different ($p \leq 0.05$).

and 0.5% respectively (Table 1). Nodulation has been reported to be negatively affected by acidity (Munns *et. al.*, 1981). However nodule numbers per plant in our unlimed experimental plots ranged between 18 to 73 in inoculated and uninoculated promiscuous varieties and 8 to 55 in inoculated and uninoculated specific varieties. Application of lime to reduce acidity could have resulted in an increase in nodule numbers per plant especially in the specific varieties.

Results show that Magoye is relatively "more promiscuous " than Local as shown by the higher numbers of rhizobial cells detected at four of the five sampled sites (Table 2). Soybean rhizobia were detectable even in virgin soils (e.g. at Mbizimwenje, Table 2). Corby *et al.*, (1964); Corby (1967) and Davis and Mpepereki (1995) have reported the presence of indigenous rhizobia in some Zimbabwean soils. The presence of soybean rhizobia in virgin soils confirms these earlier findings. Rhizobial numbers were higher in areas with a history of soybean growing without inoculation than in virgin soils (Table 2). Numbers were highest at Thornpark where soybean had previously been grown with commercial rhizobial inoculation. There is potential therefore to build up indigenous rhizobia populations by growing soybean in these soils.

There were no significant differences between nodule numbers for the inoculated and uninoculated promiscuous and specific varieties at the four sites (Table 3). This suggests that the indigenous rhizobia present in these soils (at Tapera and Hotera) were high enough to ensure adequate soybean nodulation while rhizobia from previous inoculations could have ensured adequate inoculation at the Thornpark site. Javaheri (1996) reported that promiscuity and specificity do not appear to be fixed characteristics but are determined by the interactions between the cultivar, the soil rhizobial populations and the environmental conditions. Rhizobial numbers per plant were significantly lower at the Hotera site than at Tapera (Table 1) for both the inoculated and uninoculated plots. The differences between nodule numbers per plant at the two sites are probably due to differences in soil micro-climate, the Hotera site having shallower and steeper soils. The Tapera site was reported to have been under soybean for more than one season. This could have led to a build up of the rhizobial populations.

Grain yields for the promiscuous varieties Magoye and Local were not significantly different from those of the improved specific varieties Nyala and Roan at the Tapera and Hotera sites for both the inoculated and uninoculated plots (Table 4). The promiscuous varieties suppressed weeds because of their larger leaf area while the specific varieties suffered from competition with weeds. Weed problems, due to excessive rains could have significantly lowered yields of the specific varieties and masked the effect of inoculation. For the fertile Thornpark site, grain yields of the specific varieties were significantly higher than those of the promiscuous varieties although only Roan responded to inoculation.

Dry matter produced by the promiscuous varieties was significantly higher than that produced by the specific varieties at the three sites (Table 4). The DM produced by the promiscuous varieties could improve soil fertility in the smallholder farmers' fields if the stover is incorporated after harvesting. At the Thornpark site dry matter production was higher than at the other sites because of the high soil fertility status (Table 4). At Tapera inoculation significantly increased dry matter production of the promiscuous varieties but not so for both the promiscuous and specific varieties at Hotera (Table 4).

Grain harvest indices (proportion of grain to total above-ground biomass) was higher for the specific varieties as compared to the promiscuous varieties at the three sites. This was expected as the specific varieties (Nyala and Roan) were bred to produce more grain at the expense of stover. Grain harvest indices did not respond to inoculation except for Nyala at the Hotera site (Table 5). In the higher potential soils of Thornpark the promiscuous varieties produced about 85% dry matter stover and only 15% grain (Table 5). For the farmer aiming for grain production, these promiscuous varieties may be less suitable in the high potential soils because of their low grain harvest indices. Incorporation of legume residues however contribute to residual soil fertility and sustainable crop production in the long term.

Table 5. Grain yield as proportion of total above around biomass.

Site/variety	Grain/total biomass U	Grain/total biomass I
	(%)	
Tapera		
Magoye	35.97	35.67
Local	38,73	35.74
Roan	50.49	46.58
Nyala	56.70	51.78
Thornpark		
Magoye	14.83	15.33
Local	15.31	16.00
Roan	32.94	30.74
Nyala	40.37	42.12
Hotera		
Magoye	30.56	34.19
Local	33.67	33.68
Roan	39.81	44.01
Nyala	42.46	52.68

The results on grain yield and dry matter production at the three sites show that it might make economic sense for smallholder farmers to grow promiscuous soybean varieties. This is so because promiscuous varieties gave the same yields as the high yielding specific ones under smallholder area conditions. The promiscuous varieties also gave significantly higher dry matter yields than the specific varieties. If incorporated, the dry matter could improve soil fertility because soybean stover has been reported to decompose rapidly and release N to subsequent crops because of a relatively low C/N ratio (Giller and Wilson, 1991). Smallholder farmers could solve the problems of acquisition, storage and application of the commercial rhizobia inoculum by growing promiscuous varieties. Promiscuous soybean varieties suited to the cropping environments typical of most smallholder areas need to be developed to ensure successful adoption and integration of this legume.

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SCREENING OF SOIL-IMPROVING HERBACEOUS LEGUMES FOR INCLUSION INTO SMALLHOLDER FARMING SYSTEMS IN KENYA

SAMSON N. MAOBE[1], ELIZABETH A. DYCK[2] and JOSEPH G. MUREITHI[3]

[1]Kisii Regional Research Centre, P.O. Box 523, Kisii, Kenya,
[2]Biology Department, Southwest State University, 1501 State St., Marshal, Minnesota 56528, USA,
and [3]KARI-NARL/Rockefeller Foundation, P.O. Box 14733, Nairobi, Kenya

SUMMARY

Smallholder farming in many parts of Kenya is mainly constrained by declining soil fertility. The use of inorganic fertilizers is limited by their high costs and erratic availability. Incorporating green manure legumes into the cropping systems can be a cheaper alternative of alleviating soil infertility and soil erosion. However, a major problem with the use of soil-improving legumes is the lack of species suited to the different agro-ecological zones and soil types of Kenya. In 1994 a Legume Screening Network was formed primarily to identify promising species for the different regions in Kenya. About forty species were screened in eleven sites spread across the country. Identification of promising species was based on biomass production, nodulation and nitrogen fixation, ground cover, pests and disease resistance. The effects of planting and harvesting dates on the species were evaluated. Two years of results identified promising green manure legumes and they included Lablab purpureus *cv Rongai,* Mucuna pruriens, Vicia dasycarpa, Vicia benghalensis, Crotalaria juncea *and* Crotalaria ochreleuca. *Planting at the onset of rains was associated with lower levels of pest infestation and disease incidence. The best harvesting date was the one that gave species a longer growing period. The selected herbaceous legume species are being evaluated under local farming systems with active farmer participation for inclusion in smallholder farming systems.*

INTRODUCTION

About 75% of the land area in Kenya is either arid or semi-arid. The remaining 25% is wetter and is found in the western, central and eastern highlands, and in the coastal lowlands. Agricultural production is concentrated in this 25% of land area that has dense human settlement and a rapid human population growth rate. Almost 90% of the area is under smallholder farming with the average farm size ranging from about 0.5 to 2.0 ha. Farmers mostly practice intensive and continuous cultivation in an attempt to produce enough food for the escalating population. This has put much pressure on land so that there is a rapid decline in soil fertility (Stahl, 1993). The situation is worsened by little or no use of inorganic fertilizers due to their high cost that places them beyond the reach of smallholder farmers. Soil nutrients are annually removed in food harvests without equivalent replacement. This causes a gradual reduction in land productivity which if allowed to continue will result in food shortages and famine.

In the past, the problem of declining soil fertility was addressed through agricultural practices like fallowing, crop rotation, the application of farmyard manure, compost and to some extent the application of inorganic fertilizer. Nowadays, fallowing is no longer possible because of diminishing farm sizes. Introduction of perennial cash crops has reduced chances to rotate crops with contrasting plant nutrition characteristics (Stahl, 1993). The quantities of farmyard manure produced in smallholder farms are small and are not likely to have major impact on soil fertility improvement. Compost-making is labour intensive and it is mostly prepared for kitchen gardens. Production of inorganic fertilizer depends very much on energy which is costly and unlikely to become cheaper soon. Soil-improving herbaceous legumes have been shown to have potential to improve soil fertility in various parts of the world (Fujita, Ofusu and Ogata, 1992). They can be used both as green manures and cover crops. In Kenya, extensive research has been conducted on herbaceous legumes but the focus has been on forage production rather than on soil fertility improvement.

As a result, knowledge is scanty on herbaceous legume species that have potential for soil improvement in most agro-ecological zones (AEZs) and soil types in Kenya. Because of this information gap a Legume Screening Network (LSN) was formed in Kenya in 1994 to screen herbaceous legume species as soil amendments and ultimately identify niches for their introduction into farming systems (Dyck, 1997). The LSN is composed of researchers from the Kenya Agricultural Research Institute (KARI), National Universities, non-governmental organizations (NGOs), and the Ministry of Agriculture, Livestock and Marketing. The first major activity of the Network was implementation of a legume screening trial involving about 40 species. They were evaluated for biomass production, nodulation and nitrogen fixation activity, ground cover, pest and disease

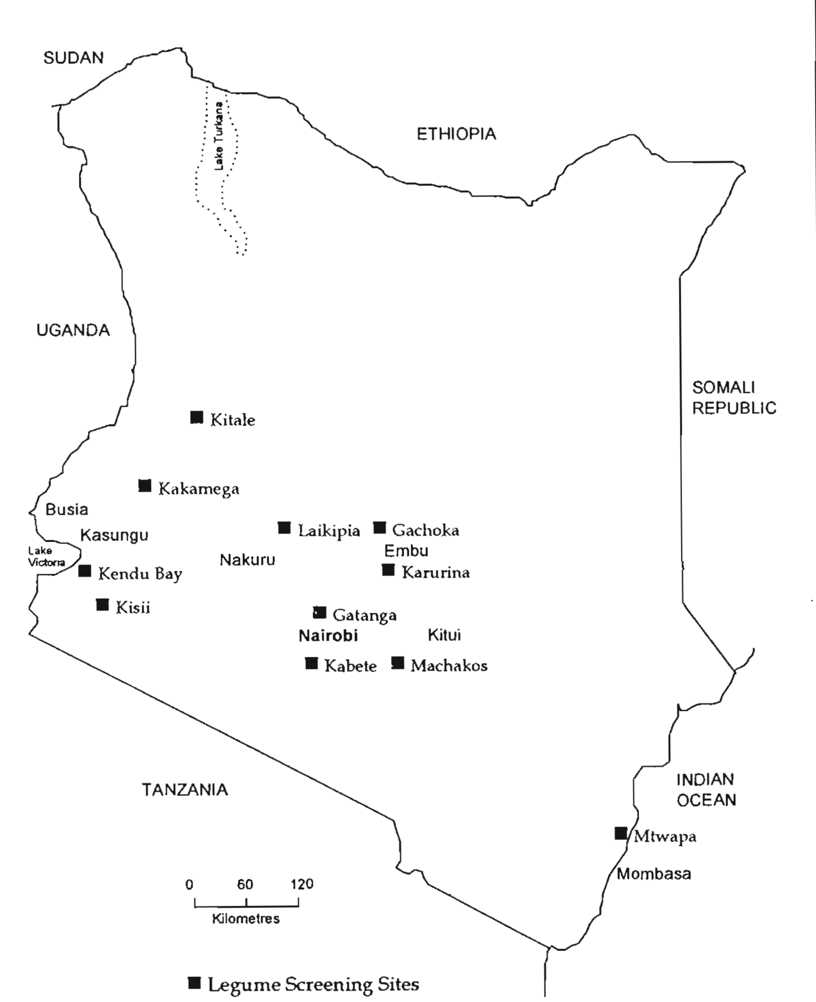

Figure 1. Legume Screening Network sites in Kenya, 1995 to 1997.

resistance. The effect of planting and harvesting dates on the above parameters was investigated. The study was conducted from 1995 to 1997 in Kenya.

MATERIALS AND METHODS

Screening Sites

The trial had a network of 11 sites spread across the country to cover the main agro-ecological zones (AEZ) and soil types found in Kenya (Figure 1). The sites are located in the 25% land area of the country that is arable. In the west of Kenya, screening sites were at Kisii, Kendu Bay, Kakamega and Kitale. In central Kenya, the sites were located at Gatanga and Kabete. The eastern part of the country had screening locations at Gachoka, Karurina (both sites in Embu), Machakos and Matanya (in Laikipia). In the coastal region, a screening site was situated at Mtwapa. Laikipia represented the cool, dry highlands while the Kendu Bay site covered the Lake Victoria basin. Soil types at the sites and names of site supervisors are in Table 1. The selection of the experimental site was based on availability of uniform and secure land to accommodate all the experimental

Table 1. Characteristics of sites used for legume screening trial network in Kenya, 1995 - 97.

Site Name	Supervisor	Data collector	Type	Elevation (masl)	Rainfall (mm)	Soil Type
1. Kendu Bay	E. Dyck, KARI*(1995) P. Tana, KARI (1996)	B. Ngoti, L. Tula, R. Akoth	Farm	1190	1130	vertisol and ferrasol
2. Kisii	S. N. Maobe, KARI	A. Ondicho	Station	1750	2000	nitosol
3. Kakamega	R. Otsyula, KARI (1995) E. Dyck (1996)	E. Okwuosa	Station	1560	1800-2000	nitosol
4. Kitale	B. Kirungu, EAT**	J. Kasiti, P.Shiundu	Farm	1890	1000-1200	ferrasol
5. Laikipia	J. Kiama (MALDM***)	J. Kiama	Station	1842	600	vertisol
6. Karurina	J.Gitari, KARI	P.Maina	Primary school	1280	1100	nitosol
7. Gachoka	J. Gitari, KARI	P.Maina	Farm	1070	950	ferrasol
8. Gatanga	Gatanga E.Dyck, KARI	C.Gitonga, P. Mwaura	Primary School	1500	1100	ferrasol
9. Kabete	E. Dyck, KARI	C. Nekesa	Station	1700	980	nitosol
10. Machakos	C. K.. Gachene, Univ. of Nairobi	M. Makau	Farmers' training centre	1600	750	luvisol
11. Mtwapa	M. Njunie, KARI (1995) H. Saha, KARI (1996)	N.Tsanje	Station	15	1200	acrisol to luvisol

Adapted from Dyck, 1997.

* - Kenya Agricultural Research Institute, ** - Environmental Action Team
***- Ministry of Agriculture Livestock Development and Marketing

plots. Areas where soil maintenance and improvement required urgent attention were given priority in site selection. Some sites were located in farmers' fields, while others were on institutional land.

Treatments

The screening trial consisted of three treatments; (1) herbaceous legume species, (2) planting dates and (3) harvesting dates.

Herbaceous legume species -- These consisted of legumes suitable for green manuring, human food and for feeding livestock (Table 2). Some species were predominantly for green manuring. Most of the species were common at all sites but a few were confined to a few sites because of environmental limitations. The total number of species varied from site to site depending on availability of land and the prevailing agro-ecological conditions. For example, at the Kisii site, where rainfall is well distributed with moderate temperatures, 40 species were screened (Maobe, Dyck and Ondicho, 1997a). At Kendu Bay site where rainfall is low and erratic, and the trial located in a farmer's field, only 17 species were screened (Tana and Ngoti, 1997). Some species were identified through a literature search based on their performance elsewhere with similar climatic conditions. Other species included in the trial were those

Table 2. Legume species, planting method and seed density used in the screening trial in Kenya (1995 - 97).

Species name	Common name	Planting method / density	Species name	Common name	Planting method / density
Arachis hypogaea	groundnut	row, 20 seeds/m^2	*Melilotus alba*	white sweet clover	broadcast, 3 g seed/m^2
Arachis pintoi	wild peanut	row, 20 seeds/ m^2	*Mucuna pruriens*	velvet bean	row, 8 seeds/m^2
Cajunus cajan	pigeon pea	row, 5 seeds/m^2	*Neontonia wightii*	glycine	broadcast, 3 g seed/m^2
Calopogonium mununoides	calopo	broadcast, 3g seed/ m^2	*Pisum sativum* (multiple varieties)	pea, field pea	broadcast, 15 seed/m^2
Canavalia ensiformis	jackbean	row, 10 seed /m^2	*Phaseolus lunatus*	lima bean	row, 3.1 g seed/m^2
Cicer arietinum	chickpea	broadcast, 15 g seed/ m^2	*Phaseolus vulgaris*	common bean	row, 20 seeds/m^2
Crotalaria juncea	sunnhemp	row,4.5g seed/m^2	*Pueraia phaseoloides*	tropical kudzu	broadcast, 3 g seed/m^2
Crotalaria ochroleuca	Tanzanian sunnhemp	row, 3 g seed/m^2	*Stylosanthes guianensis cv cook*	stylo	broadcast, 3 g seed/m^2
Desmodium intortum	greenleaf desmodium	broadcast, 3 g seed/m^2	*Trifolium alexandrinum*	berseem clover	broadcast, 3 g seed/m^2
Desmodium uncinatum	silverleaf desmodium	broadcast, 3g seed/m^2	*Trifolium hirtum*	rose clover	broadcast, 3g seed/m^2
Fagopyrum esculentum (non-leg)	buckwheat	broadcast, 9.5g seeds/m^2	*Trifolium incarnatum*	crimson clover	broadcast,3g seed/m^2
Glycine max	soybean	row, 40 seeds/m^2	*Trifolium subterraneum*	subclover	broadcast, 3g seed/m^2
Lablab purpureus cv Rongai or 1002	hyacinth bean, Njahi	row, 16 seeds/m^2	*Trifolium vesiculosum*	arrowleaf clover	broadcast, 3g seed/m^2
Lupinus albus	sweet while lupine	broadcast, 33 seeds/m^2	*Vicia benghalensi*	purple vetch	broadcast, 6.7 seeds/m^2
Lupinus angustifolius	blue lupine	broadcast, 33 seeds/m^2	*Vicia faba*	faba bean	row, 32 seeds/m^2
Lupinus luteus	yellow lupine	broadcast, 33 seeds/m^2	*Vicia dasycarpa*	lana woolly pod vetch	broadcast, 6.7 seeds/m^2
Macroptilium atropurpureum	siratro	braodcast, 3g seed/m^2	*Vigna sativa*	common vetch	broadcast, 6.7 seeds/m^2
Macrotyloma axillaris	axillare	broadcast, 4.4 g seed/m^2	*Vigna villosa*	hairy vetch	broadcast, 6.7 seeds/m^2
Macrotyloma uniflorum	horse gram	broadcast, 4.5g seed/m^2	*Vigna radiata*	green gram	broadcast, 50 seeds/m^2
Medicago sativa	lucerne, alfalfa	broadcast, 3 g seed/m^2	*Vigna unguiculata*	cowpea	row, 10 seeds/m^2
Medicago trucatula	barrel medic	broadcast, 2.8 g seed/m^2	*Voandzeia subterranean*	bambarra groundnut	row, 20 seeds/m^2

traditionally grown in Kenya such as common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*) and lab lab (*Lablab purpureus cv Rongai*). A few temperate species were included for screening at the cooler sites. Buckwheat (*Fagopyarum esculentum*), a temperate species and a non-legume, was tested at each site because of its widespread use to control weeds and as a cover crop in temperate countries. The various species were planted at the screening sites in 1995. Those that performed poorly in the year were dropped from the trial and replaced with new species in 1996.

Planting dates -- Planting dates varied with individual sites depending on cropping systems and possible niches for the species in those systems. The dates were based on the time when cereal crops (maize, finger millet, and sorghum) were planted and weeded in the region. Sites with adequate and well-distributed rainfall had five to six planting dates while those with low and brief periods of rainfall had just two. These planting dates gave the opportunity to assess how the species would perform when planted in the field at different times. Most of the sites have two growing seasons, the long rainy season (LRS) which begins in January and goes to July, and short rainy season (SRS) which covers September to December. These planting dates are described below:

(i) *Onset of the LRS.* The date represents the time when cereals are planted in the region.

(ii) *First weeding stage of the cereal crops planted at the onset of the LRS.* The date represents possibilities of planting legumes immediately after the first weeding when the field is still clean. This is usually three-to-four weeks after planting the cereal crops.

(iii) *Second weeding stage of the cereal crops.* The planting date represents circumstances where the planting of legumes is possible only soon after second weeding when the field is still clean (i.e., six to eight weeks after first weeding).

(iv) *Onset of the SRS.* The treatment caters for cases where it is not possible to introduce the legumes in the first rainy season but only at the onset of the second rains.

(v) *First weeding stage of cereals planted at the onset of the SRS.* The treatment represents niches similar to those described in (ii) above, but in the second rainy season.

(vi) *Second weeding stage of cereals.* The planting date represents circumstances similar to those described in (iii) , but in the second rainy season.

Harvesting dates -- In this study, the harvesting date represents the length of growing period in the field before harvesting biomass for use either as green manure, mulch or fodder. Harvesting legumes at different dates will give an indication of biomass production relative to duration of growth in the field. The number of harvesting dates in the screening trial was the same at all the sites. However, because of variation of the actual date of planting, harvesting dates differed from site to site. They are briefly described below:

(i) *Harvesting after two months.* This time was for harvesting the faster-growing legumes to avoid smothering companion crops in the intercropping systems.

(ii) *Harvesting after three months.* This may be suitable for harvesting legumes in areas where biomass accumulation after two months was low.

(iii) *Harvesting after six months.* This may be suitable for slow growing herbaceous legumes.

(iv) Harvesting *after 12 months.* This harvesting date is for slow growing perennial legumes.

Experimental Design

The screening trials were laid out in a randomized complete block design. Replicates were limited to two, due to shortage of legume seed. For each treatment, a plot size of 0.5 x 4 m was used. Between plots, paths measuring 0.75 m were maintained. The small plot area made the size of the trial manageable. Some species were planted in rows while others were broadcasted. The planting method used in each case depended on the recommended practice for each species (Table 2). Prior to planting, triple superphosphate fertilizer was applied at the rate of 20 kg P ha^{-1} to all treatments.

Observed Parameters, Sampling Procedures and Measurements

We recorded plant emergence, early plant vigour, onset of flowering, pod formation, average pod count per plant, seed set and production, onset of senescence of plants, pest and disease incidence and growth habit. Measurements were made on emergence count at 4 weeks after planting, percentage ground cover at 4 and 12 weeks after planting, nodulation, nitrogen fixation activity and dry matter production. A quadrat of 0.5 x 0.5 m was used to determine biomass yield. Biomass samples were taken in each plot for the harvesting dates (i.e., after 2, 3, 6 and 12 months of growth). For the creeping species, vines originating from the quadrat area were pulled back and treated as material falling in the sampling area. Despite variability in growth characteristics of species and in planting densities, a common technique for sampling biomass was used. This sampling technique may have exaggerated the biomass yield because of the small sampling area.

In this paper data on the best performing species in the Kisii site are presented. Promising species from the other sites are highlighted.

RESULTS AND DISCUSSION

The screening trial that started in 1995 ended in

February 1997. Analysis of two years of data identified promising species at various sites. The results presented here are mainly for biomass production and nodulation.

Effect of Planting Date on Legume Productivity
In the low potential areas where rainfall is less and poorly distributed, planting of legumes is mostly done at the onset of the first season. In high potential areas where rainfall is higher and well distributed up to six planting dates are possible in one year. Results on effect of planting dates on dry matter production of the best ten legumes at the Kisii site are in Tables 3a and 3b. The results suggest that time of planting had a great effect on productivity of herbaceous legumes. For example planting *V. dasycarpa* (Lana vetch) and *C. juncea* at the first weeding stage of cereals almost doubled their dry matter production compared to planting them at the onset of the long rainy season. Productivity of ground nuts (*Arachis pintoi*) and *C. ochreleuca* was highest when planted at the onset of the long rains. Planting these legumes at the second weeding stage of cereals decreased yield by 77 and 75%, respectively. Some species produced higher dry matter yield in the short rainy season compared to the long rainy season. For example, Vicia species had good performance in the long rains possibly because of high rainfall, compared to the short rainy season. Other species showed less change in dry matter production due to variation of planting date. Legumes planted late after onset of the rains were severely attacked by pests and diseases. The major pests attacking the legumes were aphids, beanfly and wild rabbits.

Effect of Harvesting Date on Legume Productivity
Results on the effect of harvesting date on dry matter yield of top ranking herbaceous legume species are given in Table 4. Based on their biomass production, the species were grouped in two categories; short- and long-duration green manure legumes.

Table 3a. Effect of planting date on dry matter production (t ha^{-1}) of legumes harvested after three months of growth at Kisii, west Kenya in two growing seasons, long rainy season and short rainy season (1995 - 97). a) Long rainy season.

	PLANTING DATES*					
Rank	First		Second		Third	
	Species	Yield	Species	Yield	Species	Yield
1	*Pisum sativum* cv. Trapper pea	7.4	*V. dasycarpa*	10.9	*C. juncea*	6.8
2	*Crotalaria juncea*	6.6	*C. juncea*	10.3	*V. dasycarpa*	5.1
3	*Vicia benghalensis*	6.1	*C. ochreleuca*	7.9	*V. villosa*	6.0
4	*Vicia dasycarpa*	6.0	*L. purpureus*	5.9	*Trifolium vesiculosum*	6.8
5	*Vicia villosa*	5.4	*Glycine max*	5.3	*L. purpureus*	4.4
6	*Mucuna prureins*	4.8	*V. benghalensis*	5.1	*V. benghalensis*	3.8
7	*Arachis pintoi*	4.5	*V. villosa*	4.9	*C. ochreleuca*	2.0
8	*Desmodium uncinatum*	3.9	*M. prureins*	3.8	*F. esculentum*	1.3
9	*Lablab purpureus*	3.7	*Fagopyrum esculentum*	3.2	Austrian	1.1
10	*Pisum sativum* cv. Austrian	3.5	Trapper pea	3.0	*A. pintoi*	1.0

* First - On-set of long rains (Feb/March); Second - First weeding stage of cereal crop (April/May)
Third - Second weeding stage of cereal crop (May/June)

Table 3b. Effect of planting date on dry matter production (t ha^{-1}) of legumes harvested after three months of growth at Kisii, west Kenya in two growing seasons, long rainy season and short rainy season (1995 - 97). b) Short rainy season.

	PLANTING DATES*					
Rank	First		Second		Third	
	Species	Yield	Species	Yield	Species	Yield
1	*Lablab purpureus*	13.4	*Medicago sativa*	4.0	*C. juncea*	6.4
2	*Desmondium uncinatum*	8.1	*V. dasycarpa*	3.1	*C. ochreleuca*	5.6
3	*Neonotonia weightii*	8.1	*V. villosa*	2.6	*L. purpureus*	4.5
4	*Mucuna pruruiens*	7.0	Trapper pea	2.2	*V. benghalensis*	3.2
5	*Trifolium vesiculosum*	6.0	*L. purpureus*	2.2	*Glycine max*	2.8
6	*Crotalaria juncea*	4.8	*V. benghalensis*	2.0	*M. sativa*	2.6
7	*Medicago sativa*	4.6	*T. vesiculosum*	1.7	*Trifolium subterranean*	2.5
8	*Vicia benghalensis*	4.2	*C. juncea*	1.4	*N. weightii*	2.3
9	*V. villosa*	3.5	*V. faba*	1.2	*V. villosa*	2.1
10	*C. ochreleuca*	3.1	*Canavalia ensiformis*	0.5	*V. dyscarpa*	1.9

* First - On-set of short rains (Aug/Sept); Second - First weeding stage of cereal crop (October)
Third - Second weeding stage of cereal crop (Nov/Dec)

Short duration green manure legumes -- Classified under this group are species that produced substantial green manure for incorporation into the soil within a period of two to three months after planting. Such legumes have fast establishment and early growth. Falling into this category was buckwheat, a non-legume that grows rapidly producing flowers within a period of four weeks and senescences after two months. Dry matter production of most of these species more than doubles if they stay in the field for three months compared to two months (Table 4). Among the legumes producing the highest amount of biomass after three months of growth were Lana vetch and *C. juncea*. Crotalaria species had good performance at most sites. In Kisii for instance, *C. juncea* produced 10.3 t ha^{-1} of dry matter and *C. ochreleuca* 7.9 t ha^{-1} of dry matter after a 3-month growth period. *C. ochreleuca* is a vegetable legume in most of western Kenya. So, despite its inferior production compared to that of *C. juncea* it is more popular with farmers. Some legume species in this category senescence after three months of growth. Observations on nodulation showed that Lana vetch had about 100 nodules per plant, and most of them appeared active. Crotalaria species had fewer nodules, about 15 per plant and smaller but they were all active.

Long duration green manure or forage legumes -- Species that require more than six to 12 months or longer to yield substantial amounts of green manure or forage were grouped in this category. Most species in this category had a slow establishment but had improved by the sixth month. However, several species in the short duration category produced enormous biomass when harvested after six months, making them eligible for classification in this group. For example, Lana vetch and Lablab produced 30.5 and 29.5 t ha^{-1} of dry matter, respectively. Perennial legumes like *Macropitilium atropurpureum* (Siratro) did not produce active nodules at some sites, while *Medicago sativa* (lucerne), *Pueraria phaseloides* (Tropical kudzu) and *Stylosanthes guianesis* (stylo) produced active ones.

Farmer Evaluation of the Legumes

To acquaint farmers with the different legume species, they were invited to visit the trial site and requested to participate in the evaluation of the different species (Maobe, Mbugua, Dyck, and Makworo, 1997b; Mbugua, Maobe, Kwach, and Oigo, 1997). Farmers indicated that they preferred a legume that provided human food and had other uses (e.g., for soil fertility improvement, livestock feed, etc.). Legumes with immediate economic value such as soybean were considered the most suitable. The major criteria used by farmers to identify legumes for green manuring were early plant vigour and rapid dry matter production. Buckwheat was ranked high because of its rapid growth, producing flowers within a period of one month. However, some farmers emphasized different selection criteria depending on their circumstances. For example, dairy farmers were interested to know whether the legume species were suitable for feeding to livestock. They were quick to find out whether grain from green manure species were fit for human consumption because the productivity of the common bean, the most popular grain legume crop in the region, was severely affected by the beanfly. Rarely did the farmers consider the nodulation and nitrogen fixa-

Table 4. Effect of harvesting date on dry matter production (t ha^{-1}) of herbaceous legumes at Kisii, south west Kenya (1995 - 97)

	DATE OF HARVEST AFTER PLANTING							
Rank	2 months		3 months		6 months		12 months	
	Species	Yield	Species	Yield	Species	Yield	Species	Yield
1	*Vicia dasycarpa*	4.6	*V. dasycarpa*	10.9	*L. purpureus*	30.5	*S. guainesis*	28.6
2	*Fagopyrum esculentum*	3.8	*C. juncea*	10.3	*V. dayscarpa*	29.5	*L. purpureus*	22.7
3	*Crotalaria juncea*	3.1	*C. ochreleuca*	7.9	*M. pruriens*	23.2	*D. uncinatum*	20.6
4	*Pisum sativum* cv. Prussian	2.8	*L. purpureus*	5.9	*C. juncea*	21.9	*Neonotonia weghtii*	18.1
5	*Pisum sativum* cv. Trapper pea	2.7	*G. max*	5.3	*V. benghalensis*	20.3	*Pueraria phaselodies*	13.6
6	*Glycine max*	2.6	*V. benghalensis*	5.1	*Desmodium uncinatum*	16.1	*Medicago sativa*	7.9
7	*Pisum sativum* cv. Austrian	1.9	*V. villosa*	4.9	*C. ochreleuca*	15.5	*Macropitilium atropurpureum*	7.2
8	*Lablab purpureus*	1.8	*Mucuna pruriens*	3.8	*V. villosa*	15.5	*T. vesiculosum*	6.5
9	*Arachis pintoi*	1.4	*F. esculentum*	3.2	*Trifolium vesiculosum*	12.4	*Canavalia ensiformis*	3.5
10.	*Vicia benghalensis*	1.3	Trapper pea	3.0	*Stylosanthes guianesis*	11.1	*Calopogonium muconoides*	3.2

tion activity as criteria for selection unless reminded of the role they play in nitrogen fixation and consequently improvement of soil fertility.

Results from all the sites indicated that the promising food legumes were *Glycine max* (soybean), lablab, *Cajanus cajan* (pigeon pea), *Vigna radiata* (green gram), *Phaseolus lunatus* (lima bean) and *Macrotyloma uniflorum* (horse gram). Soybean grew vigorously at most of the sites and was ranked high as a food legume across the different agroecological zones. Farmers even requested to be trained on how to process it for human consumption. An important point to note is that most of these grain legumes concentrate more nitrogen in the grain than in the leaves and may therefore not be suitable for green manuring. For them to have an impact on soil fertility improvement then the grains and the leaves have to be incorporated in the soil, an option not likely to be taken by many farmers.

CONCLUSION

The legume screening trial identified species that have potential to grow well and produce substantial amounts of biomass in most agroecological zones in Kenya. Some species provide human food and others produce adequate biomass for green manuring within a short time. Others are perennials suitably classified as long duration green manure species and can provide forage for feeding livestock. Those that seemed to perform well across sites in the short duration category included lab lab, mucuna, *C. juncea* and *C. ochreleuca*. Lana vetch excelled in areas with high and well-distributed rainfall. Species with additional use as human food or forage were more preferred by farmers. Planting and harvesting dates greatly affected dry matter production of most species. Planting at the onset of first rains generally gave more biomass. The best harvesting date was the one that gave the species longer duration in the field. The selected species are being evaluated in local farming systems with active farmer participation, with the ultimate goal of incorporating them into smallholder farming in Kenya.

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DISCUSSION: NEW LEGUMES AND LEGUME SCREENING

Questions to Paul Mapfumo

From: Larry Harrington
Is pigeon pea equally promising for all soil types in all maize-based farming systems?

Response:
Yes, only the magnitude of the yields differ. Short duration types, however, are more affected by occasional stress such as waterlogging.

From: Alfred Mapiki
In the materials and methods you applied inorganic fertilizers to both maize and legumes, including pigeon pea. How practical economically is it for resource-poor farmers to allocate resources to a green manure crop at the expense of food crops?

Also, how suitable are the pigeon pea lines under evaluation for Zimbabwe conditions?

Response:
The pigeon pea crop may not necessarily be a green manure crop. Farmers may apply fertilizer if they get grain from the crop. The importance of building up soil P means we should encourage farmers to use fertilizer on legumes.

There is a current study to evaluate different pigeonpea genotypes. The cultivars used are the best bets from such work.

From: Chinaniso Chibudu
What methods did you use to measure biological N fixation in pigeonpea? Please comment on the performance of pigeonpea compared to reviews of the literature which indicate that pigeonpea performs well in poor soils?

Response:
It involved nodule counts, inoculation response and quantification using the N-difference method. We support the idea that pigeon pea does relatively well on poor soils.

From: Ken Giller
You stated that farmers were initially more interested in short-or medium-duration pigeon pea varieties because of the fear of grazing by animals after maize harvest. Yet the main benefit of pigeon pea over other legumes is its long duration which allows it to use residual moisture for growth and nitrogen fixation into the dry season. Did the farmers change their minds after seeing the benefits of the long-duration varieties?

Response:
Farmers later indicated possible mechanisms to fit the medium to long duration types into the system, e.g. early planting, and subsequent harvests in late May to early June. Use aspects seem to play a crucial role. Farmers say they can protect the crop by delaying the release of livestock for free grazing if pigeon pea is adopted by the majority of farmers.

From: Danisile Hikwa
If farmers are interested in growing pigeonpea the next question is how will they access the seed, considering that there is no pigeonpea seed production in the country at the moment and also there is wide variation in growth duration?

Response:
Many farmers in the study area have already indicated a willingness to grow it. Seed is currently a problem but the future is bright since National Tested Seeds is growing seed for local sale and export (it is a case of increasing the right varieties). The pigeonpea promotion group is making efforts to promote accessibility of seed. Seed cost is Zim$8 per kg. Farmers need 16 kg per ha.

Question to Sheunesu Mpepereki

From: Alfred Mapiki
Soybean yields in Zimbabwe appear so low (1t per ha on average) whether inoculant is applied or not.. Also, the notion that promiscuous soybean does not respond to inoculation and that small-scale farmers cannot adequately handle inoculants is misleading.

Response:
Soybean is grown by very few farmers in the small-scale sector with minimal inputs on very infertile soils - yields are therefore low. In commercial agriculture (99% of soybean), yields average 2t per ha or more with inoculants and of up to 300 kg per ha of fertilizer (NPK). Promiscuous soybean can respond to inoculation in soils with low rhizobia populations. It is a myth that small-scale farmers cannot handle inoculants. I believe they can if proper extension and distribution is in place.

Questions to Samson Maobe

From: Cheryl Palm
How were the legume species selected?
Many of the best bets from Latin America that have been proven on acid soils and in dry conditions were not included.

Response:
Species used were identified through literature and past work, both in Kenya and outside the country.

The screening was not exhaustive in species covered. There is still room to screen more species that are considered better in Kenya.

From: Fanuel Tagwira
What is the adoption rate like for those legumes that farmers can grow for direct economic benefit as opposed to those they grow for improving soil fertility.

Response:
Adoption is variable. Where the farmer can get direct economic benefit from the legumes the adoption rate is greater.

From: Batson Zambezi
To what extent is your work done in collaboration with ICRAF in Kenya?

Response:
The agroforestry species included in the screening trial were selected by ICRAF staff based at Maseno.

BIOMASS PRODUCTION AND MAIZE YIELD UNDER A TREE-BASED IMPROVED FALLOW OF SESBANIA AND PIGEONPEA

CHRISTOPHER NYAKANDA[1], IRVINE K. MARIGA[1], BEN H. DZOWELA[2] and HERBERT MURWIRA[3]

[1]Crop Science Department, University of Zimbabwe, P.O. Box MP 167, Mt. Pleasant, Harare, Zimbabwe; [2]SADC/ ICRAF Agroforestry Project, c/o Department of Research and Specialist Services, P.O. Box CY 594, Causeway, Harare, Zimbabwe and [3]Chemistry and Soils Research Institute, Department of Research and Specialist Services, P.O. Box CY 550, Causeway, Harare, Zimbabwe

SUMMARY

Improved fallows, using appropriate trees or shrubs, have been observed to substantially increase the yields of subsequent maize crops over a period of one to two years. Use of improved fallows has therefore been proposed as an approach to increasing soil productivity, particularly on smallholder farms where inadequate crop residues are returned to the soil and procurement of inorganic fertilisers is difficult. However, due to limited land area for cultivation, there is need to reduce the duration of fallow by establishing them under staple crops, or increase the performance of the established fallows.

In this study, when improved fallows of sesbania and pigeonpea were established under maize in the first year of a two-year fallow period, neither maize yield nor fallow biomass was affected. Similar residual effects were obtained as shown by the similar yields of maize subsequently grown over the fallowed land regardless of whether sole fallow stands were established or whether the fallow species were established under maize. Fallowing for two years gave significantly larger maize yields than fallowing for one year but there were no differences between either the two species or their mixture.

INTRODUCTION

Smallholder farmers on sandy and inherently infertile soils of Zimbabwe occasionally leave part of their land fallow. It is likely that soils of lower fertility are likely to be abandoned in favour of the most productive soils on the farm. Farmers leave some land fallow with the hope that somehow it will regain its fertility. Since fallow land receives no inputs, and is of very restricted duration, the result is a weed-grass fallow with limited woody species. Observations are that land 'rested' under a weed-grass fallow remains infertile and low in organic matter (Grant, 1970; 1981; 1987). Previously, a shifting cultivation system was operated in these farming systems with short periods under crops (2 to 3 years) being interspersed with long periods under bush fallow (Grant, 1981; 1987). The reappearance of indigenous legumes in the genus *Crotelaria* would indicate land that was ready for re-use (Grant, 1981). Due to population pressure, long fallow periods have become unsustainable (Cooper, Leaky, Rao and Reynolds, 1996). There is therefore a strong case for strategies that would result in the successful regeneration of soil fertility and increased organic matter under short duration weedy fallow. One option is to reinforce the weedy fallow through the use of leguminous browse or fast-growing, short duration woody species. Other benefits such as increased grazing would accrue to farmers from such 'improved' fallows.

The usefulness of improved (planted, artificial or enriched) fallows have been demonstrated elsewhere, including Zambia (Kwesiga and Coe, 1994). However, soil processes responsible for increased crop yields after improved fallows and the mechanisms responsible for the lasting effects are unknown (Rao, Kamara, Kwesiga and Duguma, 1990; Sanchez, 1995).

The results reported in this paper are part of a study of nutrient (including organic carbon) and moisture dynamics under improved fallows of sesbania and pigeonpea. This study aims to find out whether mixing the two species of sesbania and pigeonpea may speed up the regeneration process of fallowing. A second aim is to find out whether the period that farmers are denied an annual crop harvest due to fallowing the land can be reduced by the introduction of an improved fallow under a maize crop in the first season.

METHODS AND MATERIALS

An experiment to study the soil fertility dynamics under improved fallows of sesbania and pigeonpea was established in Chinyika on 17 December, 1994. Chinyika is a moderate rainfall area of between 800 to 1000 mm per annum with sandy soils characteristic of most smallholder farms in Zimbabwe. The experiment had the following treatment sequences, with each crop or crop combination indicated occupying the plot in any one season, simulating a rotation fallow and intercrop system:

1. maize, pigeonpea, maize
2. pigeonpea, pigeonpea, maize
3. maize, pigeonpea/maize, maize
4. pigeonpea/maize, pigeonpea/maize, maize
5. maize, sesbania, maize
6. sesbania, sesbania, maize
7. maize, sesbania/maize, maize
8. sesbania/maize, sesbania/maize, maize
9. maize, sesbania/pigeonpea, maize
10. sesbania/pigeonpea, sesbania/pigeonpea, maize
11. maize, sesbania/pigeonpea/maize, maize
12. sesbania/ pigeonpea/ maize, sesbania/ pigeonpea/maize, maize
13. maize, maize, maize

Pigeonpea was established from seed at the same time as maize. However, sesbania was introduced into the experiment on January 5, using 6 weeks old nursery seedlings. Maize was spaced at 0.9 m, x 0.3 m whereas both sesbania and pigeonpea had a spacing of 0.9 x 0.9 m. In instances where maize was established with fallow tree species, it was planted in the same row as the tree species. Intercropping mixtures of sesbania and pigeonpea were in a 50: 50 ratio with sesbania alternating with pigeonpea planting stations.

Maize received 300 kg of Compound D (8 % nitrogen, 14 % P_2O_5, and 7 % K_2O) at planting and an extra 100kg/ha nitrogen in the form of ammonium nitrate was applied eight weeks after planting. Fallow species of sesbania and pigeonpea received no fertiliser.

The experiment was clean-weeded in the first season but was subsequently not weeded until a maize test crop was established in the third season.

Sesbania and pigeonpea were destructively sampled for biomass from 22 October 1996, using a net plot of 1.8 m by 5.4 m (i.e. 2 rows of 6 trees per row). Tree parts were separated into 3: leaves, 8 mm and below branches, and the woody part. These parts were separately weighed and sub-samples oven-dried at 60°C for 48 hours to determine the dry weight of the total sample. Ground litter amount was determined using 3 quadrants of 90 x 90 x90 cm per plot. Sub-samples of litter were also oven-dried and weighed.

Root weights were determined to a depth of 60 cm from selected treatments using the monolith method (Bohn, 1979). Blocks of 90 x 90 cm wide and 30 cm deep were excavated with the dry soil being passed through a four mm sieve to collect the roots. Both between row and in-row monoliths were obtained and an average figure for the roots determined. In plots that had a mixture of the two species, three monoliths were dug, one with a sesbania plant in the middle of it, one with a pigeonpea plant and the third in between rows at the centre of a sesbania and a pigeonpea plant. All roots were oven-dried to obtain weights.

A maize test crop was established over the whole experiment in the third season, after the removal of the improved fallow. The maize received four levels of fertiliser per plot: 0 %, 50 %, 100 % and 150 % of the standard application of 300kg/ha Compound D and 185 kg/ha of ammonium nitrate (34.5 % nitrogen). This corresponds to 0, 26, 42, 68 kg/ha P_2O_5; 0, 10.5, 21, 31.5 kg/ha K_20 and 0, 43.9, 87.3 and 131.7 kg/ha N respectively.

The reported yields are of maize under fallow species in the first season (1994/95), fallow biomass production at the end of the second season/ start of the third season, and maize test crop yields at the end of the third season.

RESULTS

Maize yields were not affected when fallow species of pigeonpea, sesbania and a 50: 50 mixture of the two species were introduced under maize in the first year of establishment (Table 1). In turn, the presence of maize did not affect the biomass production of the fallow averaged over a two-year duration (Table 2).

However, whilst pigeonpea, sesbania and a combination of the two species produced similar biomass over a year or a two year duration, two years produced significantly more biomass, which on average was 19367 kg/ha compared to an average of 5605 kg/ha obtained over one year (Table 3).

Table 1. Effect on maize grain yield of undersowing pigeonpea and sesbania fallow into maize in the first year of fallow establishment

Treatment	Grain Yield (kg/ha)
Maize control	462
Maize with pigeonpea	397
Maize with sesbania	407
Maize with pigeonpea + sesbania mixture	532
SED	82
CV (%)	22
Significance	ns

Duration also had an influence on root biomass to a 60 cm soil depth with an average of 3057 kg/ha being produced over a 2-year period compared to 1598 kg/ha after 1 year (Table 4). There were no species differences in the ratio of root weight at the 31-60 cm depth to weight at the 0 to 30 cm depth (Table 5). Longer duration of fallow however decreased the ratio of roots at 31 to 60 to 0 to 30 cm indicating that the proportion of roots at depth were increasing with age of species. Significant species differences were obtained when root weights were combined with ground litter weights with pigeonpea producing the highest weight of 10159 kg/ha compared with the mixture of pigeonpea and sesbania producing intermediate biomass of 7206 kg/ha and sesbania producing the least biomass: 6460 kg/ha (Table 6). Two year old fallow generally gave higher maize test crop yields when compared to one year old fallow of any of the species at either high or zero fertiliser levels (Tables 7 and 8).

Table 2. Influence of establishment method on biomass production of pigeonpea and sesbania fallow in the first year of fallow establishment

Species	Biomass		
	Undersown Stand	Pure Stand	Mean
Pigeonpea	10758	13282	12020
Sesbania	13237	16624	11930
Pigeonpea + Sesbania Mixture	13793	13223	13508
Mean	12596	12376	
	SED	Significance	CV (%)
Main effect of species	1342	ns	26
Main effect of establishment	1096	ns	
Interaction effect	1898	ns	

Table 4. Influence of duration on pigeonpea and sesbania root biomass production to a 60 cm depth

Species	Root Biomass (kg/ha)		
	1 Year Fallow	2 Year Fallow	Mean
Pigeonpea	1714	2768	2241
Sesbania	1341	3228	2285
Pigeonpea + Sesbania Mixture	1740	3057	2399
Mean	1598 b	3018 a	
	SED	Significance	CV (%)
Main effect of species	242	ns	18
Main effect of duration	198	***	
Interaction effect	343	ns	

*** significant at P < 0.001
Numbers followed by the same letter are not significantly different at P < 0.05

DISCUSSION

Generally, land is limited in the smallholder farming areas of Zimbabwe. Use of improved fallow could therefore be restricted unless farmers obtain immediate and tangible benefits. Introduction of the fallow under annual crop stands would allow farmers to harvest grain during the early part of the fallow. Observations in this study suggest that sesbania and pigeonpea fallows and fallows with a mixture of the species can be introduced (under a maize stand) in the first year of fallow establishment without detrimental effects on the maize yield. Maize yields were low due to the low rainfall received in the 1994/95 cropping season. Similar biomass production was obtained whether fallow species were introduced under maize in the first year or grew as pure stands (Table 2). However, a maize test crop grown at the end of the fallow produced significantly higher yield

Table 3. The effect of duration and species combinations on biomass production of sesbania and pigeonpea

Species	Biomass (kg/ha)		
	1 Year Fallow	2 Year Fallow	Mean
Pigeonpea	6111	17928	12020
Sesbania	4370	19491	11930
Pigeonpea + Sesbania Mixture	6335	20682	13508
Mean	5605 b	19367 a	
	SED	Significance	CV (%)
Main effect of species	1342	ns	26
Main effect of duration	1096	***	
Interaction effect	1898	ns	

*** significant at P < 0.001
Numbers followed by the same letter are not significantly different at P < 0.05

Table 5. Influence of duration and species on the ratio of root biomass for the 31-60/0-30 cm depth

Species	Root Ratio		
	1 Year Fallow	2 Year Fallow	Mean
Pigeonpea	0.44	0.25	0.35
Sesbania	0.47	0.34	0.41
Pigeonpea + Sesbania Mixture	0.38	0.28	0.33
Mean	0.43 a	0.29 b	
	SED	Significance	CV (%)
Main effect of species	0.38	ns	18
Main effect of duration	0.31	***	
Interaction effect	0.054	ns	

*** significant at P < 0.001
Numbers followed by the same letter are not significantly different at P < 0.05

after a pure stand of sesbania compared with pigeonpea and the mixture.

Maize yields were similar after fallow species introduced under a maize crop. Perennial pigeonpea grows slowly during the first three to four months and therefore requires little sacrifice of yield from annual crops in the system in the first year and offers the benefits of tree species in subsequent years (IITA, 1986). Conversely, *Sesbania sesban* is fast growing and is capable of producing high biomass (Kwesiga, 1991). In our study, the fast growth of sesbania did not seem to affect maize productivity. We hypothesized that these striking differences in growth rate between pigeonpea and sesbania, as well as other complementary characteristics (such as abundant rooting in the top soil of sesbania (Young, 1989) compared to the deep-rootedness of perennial pigeonpea (Daniel and Ong, 1990)) could result in complementarity in the mixtures to produce more biomass and regenerate soil fertility faster. However, the biomass produced by mixtures in this study was not different from that in the sole stands. The maize test crop yields obtained were similar for either of the fallow species or the mixture. The two-year-old fallow had significantly more biomass than the one-year-old fallow (Table 3).

No differences existed between sesbania and pigeonpea in the root biomass (Table 4), nor were there any differences in the proportion of roots in the lower horizon (based on the ratio of roots obtained at the 31 to 60 cm depth) when compared with that at the 0 to 30 cm depth (Table 5). The two-year-old fallow of either species, and the mixture, however had a significantly higher proportion of roots in the lower horizon.

Only the roots and litter components of the biomass remain to enrich the soil. Whilst there were no species differences in the amount of root biomass to a 60 cm depth, however pigeonpea produced a significantly high amount of combined litter and root biomass with the mixture producing intermediate biomass (Table 6). Two-year-old fallow also produced significantly more combined litter and root biomass.

The differences in root and litter biomass production produced similar trends in the yield of the maize test crop fertilised at 150 % with pigeonpea producing the highest yield of 5924 kg/ha, compared to 5789 kg/ha for the mixture and 5444 kg/ha for sesbania. Conversely, when the maize test crop was unfertilised (Table 8), sesbania fallow resulted in a slightly

Table 6. Influence of duration on pigeonpea and sesbania root and litter biomass

Species	Biomass (kg/ha)		
	1 Year Fallow	2 Year Fallow	Mean
Pigeonpea	6140	14179	10159 a
Sesbania	3600	9321	6460 b
Pigeonpea + Sesbania Mixture	5024	9387	7206 b
Mean	4922 b	10962 a	
	SED	Significance	CV (%)
Main effect of species	799	**	17
Main effect of duration	652	***	
Interaction effect	1130	ns	

** significant at $P < 0.01$
*** significant at $P < 0.001$
Numbers followed by the same letter are not significantly different at $P < 0.05$

Table 7. The effect of duration and species combinations of pigeonpea and sesbania fallow on yield of unfertilised test crop maize

Species	Maize Grain Yield (kg/ha)		
	1 Year Fallow	2 Year Fallow	Mean
Pigeonpea	810	1663	1236
Sesbania	831	2138	1479
Pigeonpea + Sesbania Mixture	1051	1417	1234
Mean	897 b	1736 a	
	SED	Significance	CV (%)
Main effect of species	293	ns	54
Main effect of duration	239	**	
Interaction effect	414	ns	

** significant at $P < 0.01$
Numbers followed by the same letter are not significantly different at $P < 0.05$

Table 8. The effect of duration and species combinations of pigeonpea and sesbania fallow on yield of test crop maize fertilised at 150 % of the standard recommendation rate (63 kgs P_2O_5, 31.5 K_2O and 131.7 kg/ha nitrogen)

Species	Maize Grain Yield (kg/ha)		
	1 Year Fallow	2 Year Fallow	Mean
Pigeonpea	5405	6443	5924
Sesbania	5031	5858	5444
Pigeonpea + Sesbania Mixture	5517	6060	5789
Mean	5318 b	6120 a	
	SED	Significance	CV (%)
Main effect of species	485	ns	21
Main effect of duration	396	**	
Interaction effect	686	ns	

** significant at $P < 0.01$
Numbers followed by the same letter are not significantly different at $P < 0.05$

higher yield of 1479 kg/ha compared with 1236 kg/ha from pigeonpea (which had the highest combined litter and leaf biomass), and 1234 kg/ha for the mixture. At both fertiliser levels, the two-year-old fallow gave rise to significantly higher maize test crop yields when compared to the one-year-old fallow. There were no differences between the treatments at the intermediate fertiliser levels.

CONCLUSIONS

It is possible to establish sesbania and pigeonpea under maize without significantly affecting maize yields or biomass production from these two fallow species. The fallow species could then be left to grow without maize in the subsequent year.

Whilst the two year old improved fallows resulted in significantly more maize after fallow, there were no differences in the effects of the different species and their mixture.

We suggest that either of the two species studied here could be used as a fallow species over two years before maize is established. A mixture of the two species does not seem to confer any advantages, but a wider range of products could be obtained from the mixture. Besides the provision of various products, the two species would respond differently to environmental stress, enabling the farmers to spread their risks. In this study we observed that sesbania suffers less from frost and waterlogged conditions than does pigeonpea. Under drought conditions, pigeonpea suffers less than sesbania. Other studies have observed that pigeonpea is also more tolerant to infestation by rootknot nematode than is sesbania.

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PERFORMANCE OF THREE LEGUMINOUS MULTIPURPOSE PERENNIAL TREES AND SHRUBS (MPTs) UNDER FARMER MANAGEMENT IN COMMUNAL AREAS OF ZIMBABWE

SAM CHIKURA (with contributions from Maxwell Mudhara and the Chivi and Mangwende field teams)

Department of Research and Specialist Services, Farming Systems Research Unit, P.O. Box CY594, Harare, Zimbabwe

SUMMARY

A project on the production of high quality fodder for use as a dry season supplement to draft animals was initiated by the Farming Systems Research Unit in Chivi, Mangwende and Chihota in Zimbabwe during the 1995/96 season. The project was started after realising that there is a problem to supply quality fodder to draft animals during the dry season. This leads to the animals being in a poor body condition at the start of the rainy season, and hence farmers delay land preparation, which then leads to low crop yields.

Surveys were conducted in the research sites followed by meetings where farmers were taught how they could best manage the trees. Farmers were then asked to volunteer to participate in the project and the volunteers were supplied with seed and polythene bags so that they could establish their own nurseries. The volunteer farmers had the option to choose one, two, three or four species that were on offer. The species were Leucaena leucocephala, Calliandra calothyrsus, Cajanus cajan or Acacia angustissima. *This paper gives preliminary results on how the trees were managed by farmers as well as tree performance during the 1995/96 growing season.*

INTRODUCTION

A Rockefeller Foundation-funded project on the production of high quality fodder for use as dry season supplements to draft animals in communal areas was initiated in 1995/96 season by the Farming Systems Research Unit of the Department of Research and Specialist Services in Zimbabwe. Participatory Rural Appraisals (PRAs) were conducted at the start of project. These were followed by meetings with the farmers in all the study sites. At these meetings farmers were given guidelines on how to raise multipurpose trees (MPTs) and farmers volunteered to participate in the project. The volunteers were then supplied with polythene bags and seeds for establishing their own nurseries.

From the experience gained by ICRAF on biomass production by MPTs, it had been estimated that 200 trees would be sufficient to provide supplementary feed for two draft animals. Therefore each farmer was given enough seed to establish 200 seedlings for each of the tree species that a farmer wished to try. The species on offer were *Leucaena leucocephala, Calliandra calothyrsus, Cajanus cajan and Acacia angustissima.* Each farmer had an option of taking one, two, three or all the four species. There was no need to raise seedlings of pigeon pea since it was going to be planted directly from seed. This paper gives preliminary results on how the three species that were raised in the nurseries performed in the three communal areas.

STUDY AREAS

The study is being conducted in Chivi, Mangwende and Chihota. Chivi communal area is located about 350 km south of Harare. The district has a land area of 315 000 ha and falls in Natural Region IV (27% of the total area) in the extreme north and south, and Region V (63%) in the centre. The rainfall is erratic with an annual mean of 300 mm to 600 mm. Mangwende communal area in Murewa Kubatana District lies about 80 km north east of Harare in Mashonaland East Province. The district has 203 000 ha of land and falls in Natural Region IIa and IIb, with an annual rainfall mean of 800 to 900 mm. Chihota communal area is located about 60 km south east of Harare, under Natural Region II.

NURSERY MANAGEMENT

Some of the farmers who volunteered to participate in the project failed to establish nurseries. Table 1 shows the number of farmers who volunteered to participate in the project and who managed to establish nurseries and some trees.

The number of farmers who volunteered to participate (Table 1) does not include farmers who received pigeon pea only. This is because pigeon pea was directly planted. Most of the farmers who failed to establish nurseries had poor germination of the plants and in some cases they were destroyed by rodents or

Table 1. Summary of farmers' performance			
Area	**Farmers who volunteered to participate**	**Farmers who had some nurseries**	**Farmers with trees**
Chivi Central	23	15	12
Chivi South	24	16	10
Chihota	38	18	13
Mangwende	38	32	18

chickens. Chickens and rodents often affected farmers who established their nurseries at homesteads. Some farmers in Chivi and Chihota could not get water for their seedlings. In some cases farmers had to move long distances to get water. Some seedlings were damaged when people attended funerals and there was no one to water them.

At the start of the project, farmers were taught the most appropriate ways of raising a nursery. For best results farmers were told to mix three parts of leaf litter, one part of well decomposed manure with one part of river sand for use in their nurseries. However, some of the farmers decided to use different soil mixtures, as shown in Table 2.

Table 2. Soil mixtures that were used for establishing nurseries (% of total farmers)			
Soil Mixture	**Chiota**	**Mangwende**	**Chivi**
Recommended mixture	25.0	38.5	40.0
Leaf litter	16.7	61.5	20.0
Pit compost	41.7	0	5.5
Others	16.6	0	33.5

'Others' in Table 2 denotes farmers who used a variety of mixtures, for example some farmers used leaf litter and sand only while in Chihota some farmers used soils collected from the vegetable garden. 'Pit compost' is soil collected from a pit where ash and other household waste are dumped.

The type of soil mixture that was used had a significant effect on the germination of the seedlings. Table 3 shows the mean germination percentage and the standard deviation for the different soil mixtures used. Farmers who used other soil mixtures got the highest germination percentages (Table 3). It is difficult to separate these other mixtures because in most cases each of the mixtures used is different. However each of the different soil mixtures that was used should be tested to come up with the best soil mixture to use. It is also important to note that very little seed of *Calliandra* was made available and so only one farmer used pit compost on this species.

The number of times that the farmers watered the

Table 3. Mean germination % and standard deviation for each of the soil mixtures that were used			
Soil mixture	**Luecaena**	**Acacia**	**Calliandra**
Recommended mixture	53.3 $\pm$ 34.0	50.0 $\pm$ 38.6	54.1 $\pm$ 43.6
Leaf litter	36.1 $\pm$ 25.7	34.7 $\pm$ 23.1	35.9 $\pm$ 24.0
Pit compost	51.4 $\pm$ 37.5	21.4 $\pm$ 36.0	-
Others	56.4 $\pm$ 28.9	73.8 $\pm$ 26.1	59.8 $\pm$ 34.9

Table 4. Average germination (%) and the standard deviation for the different number of waterings per week			
Number of waterings per week	**Leucaena**	**Acacia**	**Calliandra**
1 - 3	34.3 $\pm$ 27.0	31.1 $\pm$ 32.0	35.1 $\pm$ 34.3
4 - 6	44.5 $\pm$ 31.7	30.0 $\pm$ 26.0	
7 - 9	60.3 $\pm$ 30.7	62.2 $\pm$ 32.4	53.4 $\pm$ 28.1
9+	70.0 $\pm$ 22.6	73.2 $\pm$ 19.5	

nurseries was varied. As expected the germination percentage increased with the increase in the frequency of watering (Table 4).

In Chihota, 78.4% of the farmers raised their nurseries at homesteads and the rest did so in gardens. In Mangwende the situation was different as 73.2% of the farmers located the nurseries in gardens. In Chivi only 37.9% raised them in gardens. This had a great effect on the success rates of the farmers. Farmers who established their nurseries at homesteads had problems with rodents and chickens that often destroyed their nurseries. It was also recommended during the meetings that farmers should build raised sheds to protect the seedlings from being scorched by the sun. Table 5 shows how the farmers raised their nurseries.

In Chivi the nurseries were raised at various sites including un-thatched houses and, at times, in home fields. In most cases the practice was done by only one farmer such that it is difficult to separate the individual practices. The results in Table 5 show that most of the farmers in Chihota (83.4%) raised their nurseries in the open. This may be why most farmers from this area failed with their nurseries. Nurseries raised in the open have a higher evapotranspiration rate than those raised in a shed. This meant that they

Table 5. Method of raising nurseries (% of farmers)			
Method	**% in Chihota**	**% in Mangwende**	**% in Chivi**
Raised under a shed	8.3	43.9	18.0
Kept under a tree	8.3	31.7	12.9
Raised in the open	83.4	22.0	19.5
Raised on top of a roof	0	2.4	20.5
Others	0	0	29.1

had to be watered more frequently which most of the farmers could not afford to do.

MANAGEMENT OF TREES

Suggestions on the best way to manage the fodder banks was given to farmers at the start of the project. Farmers were advised that trees can survive in poor soils because, as legumes, they fix their own nitrogen. But the best results can be realised if they are planted in fertile soils. We also pointed out that the trees do not thrive in waterlogged places. The trees could be planted in areas that are not being used for cropping, such as contour bunds. It was stressed that the trees needed to be cared for in their first year of establishment and that it was very important that they are protected from attack by stray livestock, particularly during the dry season.

By the end of December 1995, 71% of the farmers in Chihota, 56% in Mangwende and 34% in Chivi had transplanted their seedlings. Several niches were used, as shown in Table 6. The results in Table 6 shows that most of the farmers in Chihota (26.7%) planted their trees around the homesteads while in Mangwende 28% of the farmers planted them in the waste land and 47.6% on arable fields. This may indicate the different land availability problems in the three areas. In most cases the trees were planted close to the homesteads, along the fence of the home field or on waste land that is close to the homesteads.

Table 6. Where the trees were planted (% of all the farmers)

Where the trees were planted	% in Chihota	% in Mangwende	% in Chivi
Around the homesteads	26.7	4.0	7.1
In the arable fields	13.3	12.0	47.6
Along the contour	13.3	24.0	7.1
On waste land	0	28.0	11.9
Along the fence	20.0	8.0	14.3
In vegetable garden	13.3	20.0	9.5
Others	13.3	4.0	2.4

Farmers used different methods to prepare the land where they transplanted their seedlings (Table 7). The trees were managed differently in each of the areas. Some farmers used manure, others weeded, as shown in Table 8. As will be seen next these management variables had a large impact on the growth rates of the trees.

GROWTH PERFORMANCE

During the month of June 1996 the growth of the trees was estimated by measuring the height of the trees. A sample of at least 25% of all the trees of each species was taken from each of the farmers with surviving trees. An average tree height was then calculated for each of the farmers. All the results presented are a summary of these means. Table 9 summarises the performance of the trees in each area.

Table 7. Method of land preparation

Land preparation	% in Chihota	% in Mangwende	% in Chivi
Planted directly	46.7	24.0	40.5
Weeded before planting	53.3	0.0	19.0
Ploughed	0.0	72.0	2.4
Weeded just after planting	0.0	4.0	38.1

Table 8. Tree management practices (percent of farmers)

Management method	Chihota	Mangwende	Chivi
Did nothing	53.3	72.0	9.5
Weeded	26.7	20.0	59.5
Applied manure	13.3	0.0	4.8
Applied fertilizer	0.0	4.0	0.0
Watered	6.7	4.0	26.2

Table 9. Average growth height of the trees and the range (cm)

Species	Chihota	Mangwende	Chivi
Acacia	11.3 (12-26)	31.0 (18-117)	27.5 (15-175)
Leucaena	13.0 (6-55)	15.4 (13-76)	42.1 (13-233)

There was a shortage of *Calliandra* seeds so very few farmers managed to establish the trees. Because few farmers had access to this species it was not possible to make any meaningful conclusions, and it was left out of this analysis. The wide variation in plant height may be due mainly to different planting dates. Table 10 shows the effect of planting date on plant height.

On average, *Leucaena* that was planted after January performed much better than earlier plantings and *Acacia* that was planted in January performed much better than other planting dates. This can be explained because trees that were transplanted in November to December suffered from a severe dry

Table 10. The effect of planting date on average growth height (cm) and the standard deviation

Planting date	Leucaena	Acacia
November-December 1995	22.7 $\pm$ 28.7	31.3 $\pm$ 36.7
January 1996	37.3 $\pm$ 42.2	38.2 $\pm$ 48.0
Later than January 1996	54.4 $\pm$ 73.8	27.8 $\pm$ 31.8

spell that disturbed their growth. Other factors such as the site where the trees were planted and how they were managed could also to explain the results. Table 11, shows the effect of method of land preparation on the average plant height.

Table 11. Method of land preparation (average growth height in cm) and the standard deviation

Land preparation	Leucaena	Acacia
Planted without preparing the land	44.8 ± 65.0	27.3 ± 50.5
Weeded before planting	24.8 ± 27.8	25.1 ± 43.2
Ploughed	29.5 ± 25.5	38.9 ± 30.9

Leucaena did relatively well when planted where the farmers did not weed. By contrast *Acacia* appears to have benefited from the ploughing of the site before planting. There is a possibility that the kind of land preparation needed depends on where the trees will be transplanted. Table 12 summarises the average growth of the trees planted in different niches.

Table 12. Average growth height of trees planted in different niches and the standard deviation (cm)

Where planted	Leucaena	Acacia
Around the homestead	46.5 ± 85.8	4.7 ± 8.1
In the arable fields	33.3 ± 31.1	61.7 ± 65.4
Along the contours	36.1 ± 87.1	26.3 ± 25.4
On waste lands	41.4 ± 32.6	41.0 ± 20.0
Along the fence	22.2 ± 27.8	17.6 ± 19.0
In vegetable gardens	26.8 ± 28.3	31.2 ± 30.4

It is clear from Table 12 that *Leucaena* did better when planted around the homestead and on waste lands while *Acacia* grew well in the arable fields and on waste lands. The probable reason why there was good performance in arable fields is residual soil fertility from the previously fertilised maize crop. This might be the reason why there was no response to other inputs as shown in Table 13.

The results in Table 13 show that weeding is important during the establishment phase. This is because weeds compete for resources such as moisture and nutrients necessary for the seedlings to get well established.

Table 13. Average tree height for the different management practice and the standard deviation (cm)

Management practice	Luecaena	Acacia
Applied manure	30.5 ± 28.2	
Watering	34.6 ± 32.5	23.5 ± 3.5
Weeding	69.3 ± 63.7	53.6 ± 44.2

The performance of the trees would have been affected by a combination of factors. Table 14 shows the effect of combinations of land preparation method and site on the average height of the trees.

Table 14. Average height of trees planted in different niches with different land preparation method (cm)

Site of planting	Land preparation	Leucaena	Acacia
Around the homestead	Direct planting	58.3 ± 101.0	-
Around the homestead	Ploughed	-	7.0 ± 9.9
Arable land	Direct planting	49.2 ± 39.8	65.3 ± 95.6
Arable fields	Ploughed	27.8 ± 22.1	80.5 ± 51.6
Along the contour	Direct planting	46.6 ± 104.2	16.0 ± 18.3
Along the fence	Direct planting	10.0 ± 14.1	6.5 ± 9.2
Along the fence	Ploughed	37.7 ± 32.9	37.5 ± 7.8
On waste lands	Direct planting	45.0 ± 42.4	-
On waste land	Ploughed	38.4 ± 35.3	41.0 ± 20.0
Vegetable gardens	Direct planting	41.5 ± 58.7	-
Vegetable garden	Ploughed	15.4 ± 9.4	31.8 ± 33.9

The results in Table 14 show that *Leucaena* performed best when planted around the homesteads without any land preparation. This may be because the trees that are planted close to the household get some nutrients from household waste. They also get extra water that is thrown away from the kitchen. The performance of *Acacia* improved when the planting site was ploughed first before planting. Overall, *Acacia* performed well when planted in arable fields that had been ploughed first.

LABOUR ANALYSIS

Data on Labour were collected to estimate the input costs into seedling production. Activities undertaken during nursery management were divided into the following:

⇒Gathering and mixing the soil and organic matter
⇒Filling the soil + organic matter mixture into pots
⇒Watering the nursery pots

Other activities were land preparation and transplanting the trees onto that land. Table 15 only considered the labour used in the nursery, except for watering.

Assuming a six-hour working day and a daily wage of Z$20.00, the cost per seedling (for the two nursery operations) is in Table 16. Here, on average the labour required to raise one seedling costs about Z$1.31. This is excluding the watering of the

Table 15. Total hours per 100 trees seedlings during various operations by communal area

Communal area	Gathering soil and organic material	Filling pots with soil mixtures	Total
ACACIA			
Chihota	20 ±7; n=2	22 ±1, n=2	42
Mangwende	14 ±13; n=15	12 ±12; n=15	26
Chivi	20 ±45; n=17	17 ±42; n=17	37
LEUCAENA			
Chihota	11 ±7; n=6	28 ±28; n=5	39
Mangwende	20 ±30; n=17	15 ±19; n=16	35
Chivi	9 ±10; n=32	12 ±15; n=32	21
CALLIANDRA			
Mangwende	25 ±48; n=7	26 ±48; n=7	51

* n = number of cases

Table 16. Average costs of Labour during the raising of tree seedlings on-farm ($/seedling)

	Chihota	Mangwende	Chivi	Average
Acacia	1.4	0.87	1.23	1.17
Leucaena	1.3	1.16	0.70	1.05
Calliandra	-	1.70	-	1.70

seedlings. These costs go up when one considers the cost of the polythene bag, the seed, etc. Possible ways of reducing these nursery costs need to be explored.

CONCLUSION

In general the trees performed better in Chivi than in the other two communal areas. The problem with the other communal areas might be associated with low pH. There could also be a problem of phosphorous availability which is increased by the low pH. This is because these areas receive higher rainfall than in Chivi. I proposed that trials be initiated during the 1996/97 season to look into these problems.

The results so far have not given conclusive data on the best management practice. This is mainly due to differences in soil types. It will be beneficial in the future to record the soil types on which the trees will have been planted. There were problems in Chivi when the trees were planted on sodic soils and on very sandy soils in Mangwende and Chihota. A proposal has been made to collect soil samples in the places where the trees are planted to check if the trees will have a beneficial effect on the soils.

The soil mixtures used in nurseries were also affected by the quality of the materials used. Thus, in future it is more appropriate to base the recommendations on the quality of materials available for use as potting media in a particular area.

The results for the establishment of pigeon pea are not included in this analysis because there were some problems in data collection. There were few farmers who managed to establish it. This was because it was direct-seeded and in most cases the germination was very poor. However, farmers have shown interest in it and possible ways of improving its establishment will be looked into.

MAIZE CROP YIELDS UNDER INDIVIDUAL SCATTERED TREES

CHIPO C. CHIVAURA-MUSUSA[1], N.J. JARVIS[2] and BRUCE M. CAMPBELL[1]

[1]Department of Biological Sciences, University of Zimbabwe, P.O. Box MP167, Harare, Zimbabwe,
[2]Department of Soil Sciences, Swedish University of Agricultural Sciences, P.O. Box 7014, S-750 07 Uppsala, Sweden

SUMMARY

*At a research site in Zimbabwe, maize (*Zea mays*, variety R201) crop yields were measured under and outside individual trees of* Parinari curatellifolia *and* Acacia sieberana *in the 1992/93, 1994/95 and 1995/96 crop growing seasons and the influence of soil moisture and solar radiation were determined. Rainfall was positively correlated to maize grain yields (R^2= 0.809). Higher yields were harvested in 1992/93 (3.7 t ha^{-1} and 730 mm) and 1995/96 (5 t ha^{-1}, 846 mm) and lower yields in 1994/95 (3.1 t ha^{-1}, 434 mm). Though throughfall was not significantly different from rainfall in the open, there was no consistent pattern with soil moisture under and outside trees. Soil was driest in the drier season (1994/95) but soil moisture was maintained close to field capacity in the wetter seasons (1992/93 and 1995/96). Maize yields were consistently better outside the shade of tree crowns in all the three seasons. Yields under trees were suppressed due to 60-90% interception of solar radiation by the tree crowns.*

INTRODUCTION

In the communal areas of Zimbabwe, mature trees are often left in arable fields or on field margins for various reasons (Campbell, 1987; Wilson, 1989; Campbell, Clarke and Gumbo, 1991). The selective conservation of indigenous trees in fields is a traditional agroforestry practice (Campbell *et al.*, 1991). Some trees have higher soil nutrient status under their canopies (Clarke, 1993; Ingram, 1989; Dunham, 1991) and other trees have been found to increase crop yields (Ingram, 1989) or herbaceous productivity (Kamau, 1989). In other studies higher soil nutrient status (Chivaura-Mususa and Campbell, 1998; Chivaura-Mususa, Jarvis and Campbell, 1997a) was found under trees of both *Acacia sieberana* and *Parinari curatellifolia* and was attributed to large amounts of organic inputs from tree litter, herbaceous litter and animal deposits (Chivaura-Mususa, Frost, Campbell and Kirchmann, 1997b). A greenhouse wheat bioassay test confirmed that soil nutrients were higher around tree canopies than areas as far as 15 m away from the tree bole (Chivaura-Mususa *et al.*, 1997a).

Trees are usually intercropped with maize in the communal arable fields, and despite the positive influence recorded for *Parinari* trees on a maize (*Zea mays*) crop in Zimbabwe (Ingram, 1989), and the positive influence of *P. curatellifolia* and *A. sieberana* trees on wheat crops tested under controlled greenhouse environmental conditions (Chivaura *et al.*, 1997a), farmers do perceive trees as having negative effects on most crops (Musvoto and Campbell, 1995).

Generally maize yields vary with rainfall implying that maize response varies seasonally. The erratic rainfall seasons in Southern Africa, including recurring drought spells, have led to several attempts to relate maize yields to rainfall in Zimbabwe (Robertson, 1971; and Harrington, 1971; Carew 1973; Wilson and Williams, 1973). The rate of maize biomass accumulation is influenced by the amount of light and temperature, but no such studies have been made in Zimbabwe for maize yields in relation to tree-climate interactions. Hence the objectives of this study were to investigate the effects of isolated, mature trees of *A. sieberana* and *P. curatellifolia* on maize crop yields as influenced by tree canopies and to relate crop yields of different crop growing seasons and solar radiation.

Fertilizers were applied to mask any nutrient effects and the tree-maize experiment was initially carried out in the 1992/93 season. Without micro-climatic measurements the trees were found to have a negative impact on crop yields (Chivaura-Mususa *et al.*, 1997a) and investigations were continued in the following seasons (1994/95 and 1995/96) to determine the effects of tree crowns on solar radiation and subsequent effects on maize yields.

STUDY AREA

The study was carried out at Domboshava Agricultural Training Centre, about 30 km north of Harare (31^0 $09^/$ E and 17^0 $36^/$ S, altitude 1 500 m). Domboshava lies in the highlands region (Region II) of Zimbabwe, best suited for intensive crop and livestock production. Rainfall is unimodal with an annual mean of 750-1000 mm. The total monthly rainfall, for the 1992/93, 1994/95 and 1995/96 growing seasons, are shown in Figure 1. The soils are sandy alfisols of 87% sand, 5% silt and 8% clay, and are classified as paraferrallitic in the Zimbabwean system (Thompson and Purves, 1960). Soil organic matter is 1% and 5% under grassland and under wooded land respectively. Total N is higher under wooded land (0.8%) than under grassland (0.15%) whilst pH (in $CaCl_2$ solution) ranges between 4.4 and 5.6 with lower pH under woodland soils.

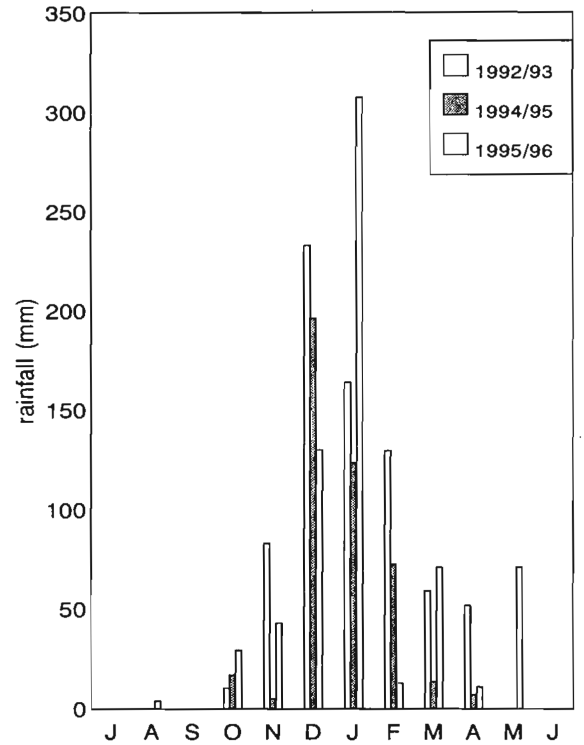

Figure 1. Total annual rainfall (mm) in the 1992/93, 1994/95 and 1995/96 seasons.

The type of vegetation is classified as Parinari woodland which is found mainly on the main plateau at altitudes > 1220 m. The study site was used as a grassland pasture of 1.7 livestock unit ha^{-1} for cattle and sheep. Approximately 30 years earlier the site had been communal arable land which was converted to pasture for the livestock owned by the Training Centre. The scattered nature of mature trees at the study site, mainly of *P. curatellifolia* and *A. sieberana* and few *Syzigium guineense* individuals found may be indicative of the previous arable land-use more than 30 years ago. The trees must have been selectively left standing, isolated and scattered in the main fields, after cutting and clearing for cultivation. There are ten and seven trees ha^{-1} of *A. sieberana* and *P. curatellifolia* individuals. Higher soil nutrient status was found under *A. sieberana* and *P. curatellifolia* trees than soils under grassland on the site (Chivaura-Mususa *et al.*, 1997a).

MATERIALS AND METHODS

Two isolated trees from each species of specified radii and heights (Table 1) at the same site were selected. Trees with shrubs, termitaria or contour ridges in the vicinity were avoided. Rectangular plots (30 x 20 m) were marked out under each tree. Each plot covered the whole crown zone under the tree and extended outward in a southerly direction to include the area as far as 20 m outside the crown. Oxen draught power was used for ploughing the plots around each tree and maize (*Zea mays*, variety R201) was hand-planted in the plots spaced at 90 x 30 cm after a basal application of 300 kg ha^{-1} granular fertilizer compound D (8% N; 14% P_2O_5; 7% K_2O; 6.5% S). A top-dressing of 100 kg N ha^{-1} was added as ammonium nitrate. The different management activities carried out are listed in Table 1.

Table 1. Maize crop management during three seasons, 1992/93, 1994/95 and 1995/1996

Management	1992/1993	1994/95	1995/96
Date of planting	24.11.92	08.12.94	13.11.95
Moisture sampling	Fortnightly	Fortnightly	Weekly
Micro-climate measurements	Non	Full-sun	Random
Tree height			
Acacia sieberana	-	5.2 m	6.1 m
Parinari curatellifolia	-	6.1 m	7.1 m
Tree diameter			
Acacia sieberana	-	6.1 m	6.5 m
Parinari curatellifolia	-	4.4 m	7.0 m
Fertilizers			
Compound D	300 kg ha^{-1}	300 kg ha^{-1}	300 kg ha^{-1}
Ammonium-Nitrate-N	100 kg ha^{-1}	100 kg ha^{-1}	100 kg ha^{-1}
Maize Stalkborer	No control	Controlled	Controlled
Harvest	Week 22	Week 22	Week 22

The crop was harvested in 3 x 3 m (1992/93) and 1 x 2 m (1994/95 and 1995/96) quadrats, under and outside each tree. Above-ground biomass and grain yields (t ha^{-1}) were determined after oven drying at 60^{o}C and were expressed on a dry matter basis. No correction factors were performed on data for (i) grain to 12.5 % moisture content or (ii) for plant density or (iii) diseases. SPSS/PC (1983) and SPSS for windows (1993) was used to determine means on maize crop yields. Regressions were performed (CoStat, 1993) for maize yields and total annual rainfall. Tree cover was related to tree density and was used to calculate expected loss in grain yields due to tree shading. Throughout the experiments in each of the three seasons, soil moisture was measured at regular intervals with gypsum blocks placed randomly under and outside tree canopies. The soil water retention curves measured in the laboratory were fitted to the van Genuchten (1980) equation and the parameter values obtained (Chivaura-Mususa *et al.*, 1997a) were used to derive soil moisture contents from field measurements of soil water tension.

Throughfall and solar radiation were measured in 1994/95 and 1995/96 seasons, but none in 1992/93. Rainfall was measured daily using 2-litre glass bottle collectors capped with a funnel of 196 mm diameter, 3.02 dm^2 area (King and Campbell, 1990). Two bottles were placed under each tree and one bottle outside each tree. Solar radiation ($W\ m^{-2}$) was measured with a portable weather station, an infrared multimeter (Model 510B AG, Everest Interscience, Inc, 1990). Means of the rainfall and solar radiation were calculated (SPSS, 1993). Regressions (CoStat, 1990) for solar radiation under and outside trees were determined for the 1994/95 season only. Correlations (CoStat, 1990) of solar radiation and maize yields were performed for the 1995/96 season only.

RESULTS

Crop yields were largest in the 1995/96 cropping season (with highest total annual rainfall) (Table 2) and maize grain yields were positively correlated to annual rainfall (R^2=0.809, grain yield= 2.5-(0.04 * annual rainfall)). Soil moisture stress was recorded for 1994/95 (Figure 2b), but soil moisture was maintained close to field capacity throughout the crop growing seasons in 1992/93 (Figure 2a) and 1995/96 (Figure 2c). There were no significant correlations found for soil moisture to maize yields. Throughfall under both tree species was less than rainfall in the open but there was no observed correlation with soil moisture stress (Figure 2).

Lower maize yields were measured under trees of both *Acacia sieberana* and *Parinari curatellifolia* individuals for all seasons relative to areas outside tree crowns (Table 3), with an average of 3.1 t ha^{-1} maize grain yield and 5.0 t ha^{-1} maize grain yield under and outside trees, respectively. There was no distinct re-

Table 2. Maize yields at maturity as influenced by individuals of Acacia sieberana and Parinari curatellifolia trees seasonally (standard deviations in parentheses)

Season	Grain yields (t ha^{-1})	Total above-ground biomass (t ha^{-1})	Total rainfall (mm) Annual	Total rainfall (mm) Crop growing period
1992/93	3.7 (1.2)	7.9 (2.5)	730	695
1994/95	3.1 (1.6)	6.3 (2.6)	434	320
1995/96	5.0 (2.3)	10.1 (4.0)	846	695

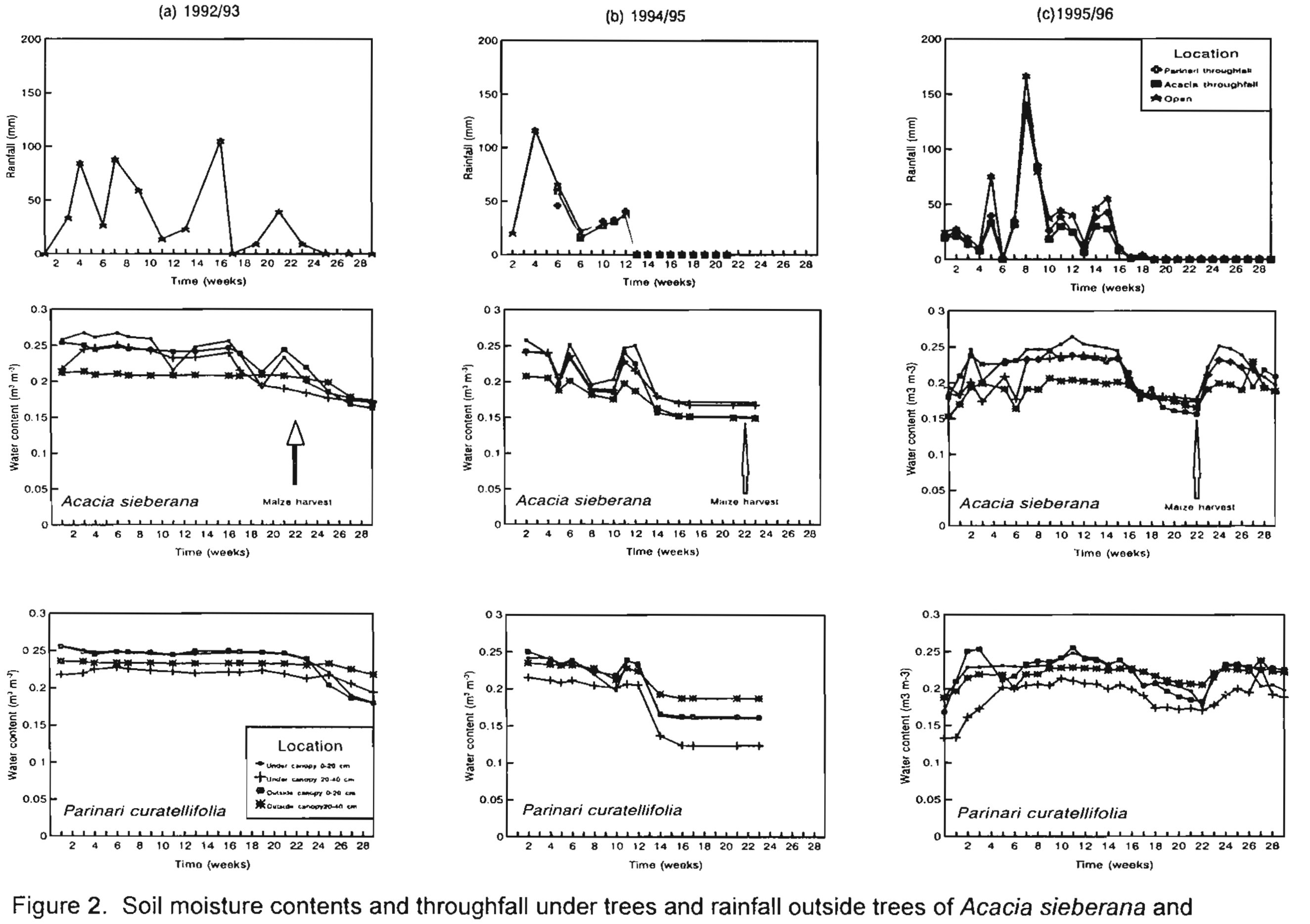

Figure 2. Soil moisture contents and throughfall under trees and rainfall outside trees of *Acacia sieberana* and *Parinari curatellifolia* individuals for (a) 1992/93, (b) 1994/95 and (c) 1995/96 seasons.

Table 3. Maize yields at maturity (t ha^{-1}) as influenced by shading of Acacia sieberana and Parinari curatellifolia tree crowns (standard deviations in parentheses)

	Location and season	Grain yield (t ha^{-1})	Total above-ground biomass (t ha^{-1})	Solar radiation (W m^{-2})
Acacia sieberana	Under canopy			
	1992/93	2.8 (0.5)	6.6 (1.5)	-
	1994/95	2.6 (1.4)	5.5 (2.2)	190 (73)
	1995/96	3.8 (1.4)	8.3 (3.0)	227 (267)
	Outside canopy			
	1992/93	5.1 (0.8)	10.0 (2.2)	-
	1994/95	3.2 (1.9)	6.2 (2.7)	498 (195)
	1995/96	6.7 (1.7)	12.7 (3.4)	547 (373)
Parinari curatellifolia	Under canopy			
	1992/93	3.2 (1.2)	7.3 (3.3)	-
	1994/95	2.7 (1.1)	5.5 (8.1)	85 (14)
	1995/96	3.7 (1.8)	7.6 (3.1)	88 (132)
	Outside canopy			
	1992/93	3.9 (0.9)	7.9 (1.8)	-
	1994/95	4.0 (1.4)	8.1 (2.9)	648 (123)
	1995/96	6.8 (2.3)	13.0 (3.7)	680 (391)

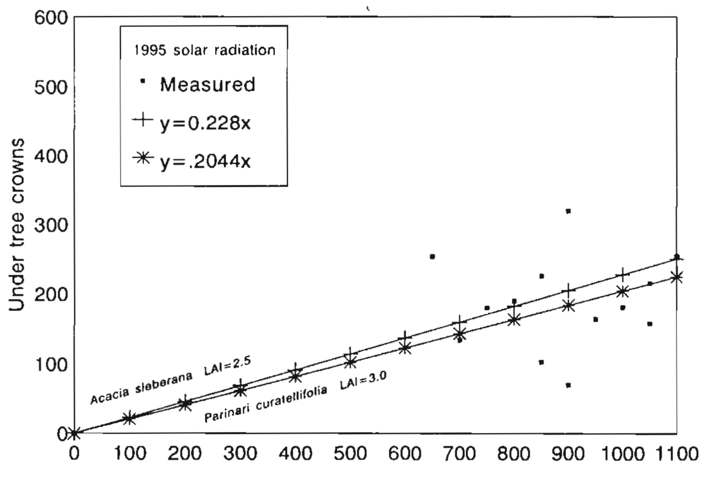

Figure 3. Midday solar radiation interception by tree crowns of *Acacia sieberana* and *Parinari curatellifolia* individuals, linear regressions for the 1994/95 season only.

lationship of crop yields between species and location (Table 3) but generally, larger yields were obtained under trees of *P. curatellifolia* than under trees of *A. sieberana* and the reverse for outside the tree canopies.

Solar radiation measurements ranged from 10-1100 (W m^{-2}), the lowest measurements found under shade of tree crowns, whilst the highest measurements were found under full sun outside the tree shade, and a the solar radiation under trees is linearly related to solar radiation outside trees (Figure 3). Only, 10-40 % solar radiation filtered through the trees and *P. curatellifolia* crowns intercepted more radiation (88%) than *A. sieberana* crowns (59%) due to differences in LAI (Figure 3). A highly significant ($P < 0.001$) positive correlation was found for solar radiation and maize grain yields, $R = 0.822$. On average there was 25% maize yield difference under trees and outside trees. The extent of cover of tree crowns affected the microenvironment, by shading the maize crop and consequently reducing the yields. Maize grain loss was 1.2% and 0.3% due to the presence of *A. sieberana* and *P. curatellifolia* trees, with an average 3% and 1% crown cover, respectively.

DISCUSSION AND CONCLUSIONS

Maize yields varied seasonally, with net maize yields greatly affected by the amount of rainfall as was found in other studies (Wilson and Williams, 1973). Generally, maize yields recorded at the site were higher than the expected yields of ± 2 t ha^{-1} for maize variety R201, due to (i) extrapolation from small quadrat samples (2 and 9 m^2) to a hectare plot, and the use of 4 instead of 3.77 plants m^{-2}. In a hectare plot there will be variability in plant density, especially in the communal areas where crop management is usually poor. Control of diseases such as maize stalkborer resulted in better yields, and high yields of up to 10 t ha^{-1} were possible with the high inorganic fertilizer (124 kg N ha^{-1}) inputs applied to mask the nutrient effects in this study.

Trees reduced maize crop yields in all the three experimental seasons regardless of seasonal rainfall variability. This negative impact of trees on maize yields was in contrast to the better cob volume recorded in Region IV of Zimbabwe of average low rainfall (450-650 mm), under *Parinari curatellifolia* trees (Ingram, 1989), or to higher sorghum yields under *Faidherbia albida* (Dancette and Poulain, 1969). Other studies have also recorded better yields under trees (Farrell, 1990; Felker 1978). In this study tree canopies were found to reduce maize crop yields, as was the case for other crops or herbaceous plants elsewhere (Ward and Cleghorn, 1964; Grunow, Groeneveld and du Toit, 1980; Dye and Spear, 1982; Walker and Noy-Meir, 1982; Verinumbe and Okali, 1985; Walker, Robertson, Penridge and Sharpe, 1986; Somarriba, 1988; Farrell, 1990; Jackson, Strauss, Firestone and Bartolome, 1990). The conflicting results on the influence of trees on understorey vegetation and the conflicting perceptions expressed by farmers themselves on crop productivity under trees, suggest the need for studies that consider a wide range of tree species and a variety of crops. Examples of common trees retained in fields in Zimbabwe are *Diospyros mespiliformis, Ficus* spp. (e.g. *F. capensis*), *Strychnos* spp. (*S. madagascarensis, S. mespiliformis* and *S. spinosa*), *Acacia* spp, (e.g. *A. albida*), *Lonchocarpus capassa* and *Kigelia africana* (Campbell, 1987; Campbell *et al.*, 1991), including species of the current study.

Due to pseudo-replication of only two plots for each species in the present study there were no statistical analyses on variation of crop yields with location around trees. This lack of adequate replication at the study site as well as no replication in different agro-ecological zones of Zimbabwe may cause concern on the validity and applicability of the findings, but the consistent low yields found under trees at Domboshava for the three seasons may be important. The findings of this study confirm what some of the farmers perceive that trees have negative effects on crops through shading effects. There is need to investigate maize crop production under trees on a larger scale.

As was found in this study some farmers perceive trees as having negative effects on crops (Musvoto and Campbell, 1995), and extension workers have encouraged farmers to remove trees from their fields, yet farmers continue to retain one or two trees in their fields (Campbell, Clarke and Gumbo, 1991). This may be due to traditional values that are placed on trees by farmers such as the provision of fruit, fodder, wood, shade, meeting places, and some trees are used for medicines or for performing cultural rituals (Whitlow, 1979; Milton and Bond, 1986; Campbell, 1987; Campbell and du Toit, 1988; Wilson, 1989; Campbell et *al.*, 1991). Trees such as *Acacia sieberana* produce pods which are quality forage for cattle and that is the main reason farmers keep it in their pasture grasslands. Farmers retain *Parinari curatellifolia* for various reasons which include, (i) the whole fruit is fed on by animals and people; (ii) medicines; (iii) potent brews, (iv) as meeting places, and (v) for shade. *P. curatellifolia* is regarded as sacred, with cultural rituals performed, such as asking for rains and good harvests (Wilson, 1989). If socio-economic values can be placed on the traditional roles of trees as perceived by the farmer then it will allow the comparison of these values with the associated ecological values such as crop yield gains or loss. There is need for such a study.

Unlike the higher soil nutrients measured under trees (Chivaura-Mususa and Campbell, 1998, Chivaura-Mususa *et al.*, 1997a) there was maize crop loss due to tree cover. Tree canopies intercepted as much as 90% solar radiation, resulting in reduced surface temperatures under trees and consequently reduction in crop yields. Maize requires high light intensities and cannot maximize production under such reduced radiation. In this study fertilizing the plots with a total of 124 kg inorganic N ha^{-1} was intended to mask nutrient differences found under and outside trees. There is need in future studies to include soil nutrient effects. However, tree-root effects on crops were not investigated. There were no root barriers and therefore nutrient effects cannot be considered as entirely unimportant. Although trees improve soil fertility, any possible effects on maize yields may have been masked in the field study. Possible reasons for reduced understorey production are limiting factors such as moisture (Kennard and Walker, 1973) and radiation and temperature (Tiedemann and Klemmedson, 1977; Verinumbe and Okali, 1985; Farrell, 1990).

The extent to which crop yield was influenced by tree crowns can be correlated to microclimate changes occurring under tree crowns, but beyond the tree crown zone crop yields were not consistent with species from season to season. There is need to investigate below-ground tree-crop associations. The distribution and quantities of tree roots are important in determining the extent to which trees may compete with crops for soil moisture or soil nutrients. Farmers expressed their concern on the physical existence of tree roots in fields and although similarly low yields were found under trees for the two wet seasons (700 mm and 850 mm) and a dry season (400 mm), below-ground competition for soil moisture was not apparent and soil moisture conditions under and outside trees were not consistent. Soil moisture conditions varied with amount of rainfall and its distribution through the season. Although the amount of throughfall was lower than rainfall in the open there was no relationship observed between throughfall and soil moisture stress during the crop growing period.

I conclude that solar radiation was the most important limiting factor under trees for maize crop yields. Another limiting factor was moisture but the moisture stress recorded in 1994/95 drought season was a consequence of macro-climatic changes that occurred seasonally rather than the existence of trees. This study has focused mainly on above-ground tree-crop crown associations, but future studies need to focus on below-ground tree-crop root interactions.

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DISCUSSION: IMPROVED FALLOWS AND TREES

Questions to Christopher Nyakanda

From: Alfred Mapiki
In your factorial treatments some had the test crop grown in combination with Sesbania or pigeon pea. How did you avoid or account for possible shading of the test crop maize by these shrubs, especially in the second year of cropping?

Response:
Fallows were introduced under maize only in the first season. Fallows were then left to grow as pure stands in the second year -- otherwise the biomass amounts in the second year would have prevented the growth of maize.

From: Cheryl Palm
You have compared the test maize to that produced by a one- or two-year fallow. How would the fallows compare to test maize if you add the maize yields of the test crop produced during the entire time, including when the fallows are not producing maize?

Response:
I will sum the total maize yields and compare them to the pure fallow test crop yields.

From: Gideon Tsododo
What is the effect of your yields where the plots are not fenced?

Response:
The experiments were protected using diamond mesh. However, we are proposing studies that will expose some treatment plots to livestock and compare them with protected plots for soil fertility regeneration and general growth recovery.

From: Samson Maobe
How did you handle firewood, was it removed from the plots or incorporated into the soil?

Response:
Only the litter and root biomass remained in the plots for incorporation. The rest was used by the farmers who were happy to use this biomass as supplementary fuel wood.

Questions to Samuel Chikura

From: Patrick Kasasa
1. From your presentation factors like soil fertility, rainfall and temperature could have affected plant heights and biomass production. Should we compare results from such varying conditions or not?
2. Did you measure the nutrient levels at the different sites?

Response:
1. It is not proper to compare results under such conditions, but we did so because of the small sample size.
2. No. I suggested in the paper to take soil samples, but we have no funds to do that.

From: Fanuel Tagwira
How do you come to conclude that in Chihota and Mangwende the trees did not grow well due to low pH?

Response:
We know the soils are acidic so thought it was probably due to low pH.

From: Bernard Kamanga
One of the transparencies showed possible interactions between management practices such as weeding, manuring and watering. How do you explain an interaction between weeding and watering?

Response:
Watering was only necessary for those farmers who planted very early in the season and the seedlings were hit by a dry spell. Weeding would help reduce competition for moisture and other nutrients when the seedlings have not established themselves.

From: Linus Mukurumbira
Is the biomass produced by your trees enough to meet the 2% of own mass per day? We need biomass production to be able to plan for these materials as feed.

Response:
Fodder from these trees will be used only as a supplement to low quality fodder such as crop residues. Work done by ICRAF shows that fodder from 200 trees is enough to supplement two animals.

From: Gideon Tsododo
Fodder production is likely to be adopted by farmers. It is recommended that the study links with fodder treatment and utilisation.

Response:
I agree that it is important to follow up on their use. We were going to do that but we do not have the funds.

Questions to Chipo Chivaura-Mususa

Name: Fanuel Tagwira
Do you think that if you had used a different test crop than maize you would have got different results?

Response:
Yes, results from other studies show that maize is seriously affected by shading. Other crops would probably perform better under shading than maize.

From: Herbert Dhliwayo
1. Soil water measurements are normally used to explain crop performance above ground and this usually follows the rainfall pattern. Please relate the graphs of rainfall and soil water measurements to see if these are consistent with each other. If not, then consider methods used in soil water measurements such as gravimetric techniques and neutron probes and to what soil depths?

2. Yields from transects that cut across the field include different niches such as ant hills, stoney areas, sandy areas, etc. I hope you considered these in your work.

Response:
1. Soil moisture is highly correlated to the rainfall pattern and intensity -- but no significant differences in soil moisture were found between the under-tree zones from the open zone 15m away from the tree-base. There were within season variations in soil moisture that did not correlate to yields by location or zone.

2. Soil moisture was measured by the gypsum block method and calibration for soil moisture content was carried out using the pF values obtained from the Van Genuchten parameters.

3. There is heterogeneity for geology but contours and termite mounds were avoided. There is need to study variability that may influence micro-environmental niches in terms of: (a) Soil nutrients
(b) Soil moisture
(c) Micro-climate
(d) Crop productivity and yields.

From: John Barnes
1. Did you take soil samples at different distances from the tree trunk under the canopy?
2. How do you explain the increased and then decreased yield as you move from the trunk?

Response:
1. No soil samples were taken at different distances.
2. For *Acacia,* other canopy interferences were responsible. But for *Parinari* there are no canopy interferences from other trees. The climate results show a similar trend with yields responding to the microclimate at that particular distance.

From: Paul Mapfumo
A graph showing decrease in yield outside the tree canopy seems to suggest extraction of nutrients from outside the canopy (rest of field) and concentration of their nutrients under the tree canopy as litter falls. What are the implications to crop performance in the rest of the field when one takes this nutrient depletion into consideration?

Response:
There is that possibility of lateral nutrient withdrawal by surrounding trees depleting nutrients in areas outside, but no nutrient characterization was carried out and we cannot correlate our yields with nutrients. There is need also to look at root distribution (both lateral and vertical) to investigate for tree x crop x root interactions.

From: Christopher Nyakanda
Seeing that nutrient status is higher under trees but meantime there are other factors that intervene to reduce yields under the canopy, what are your thoughts about management strategies to exploit the high nutrient status for enhanced crop yield.

Response:
1. Canopy manipulation -- open by lopping branches.
2. Use of trees species with open canopies.
3. Use of crops that produce well under shade, e.g. sorghum.
4. Evaluate the value of trees in fields -- costs and benefits. We are currently modelling the value of trees.

GENERAL DISCUSSION ON CROP AND LEGUME INTERVENTIONS

From: Stephen Waddington
Opening of this discussion:

Soil Fert Net has talked on various occasions about screening more grain and forage legumes. Can we start by deciding if we should set up this work?

From: Ken Giller
Several speakers have indicated that a small number of legumes have been tested as green manures in the Network Region and that we can learn from the Kenyan experience with wider testing. Can we improve the initial selection of legumes to test by using available information (which is currently being collected into a database) and use a simpler screening method so we can test a much wider range of legumes? I think we need to aim to screen hundreds of species and accessions of those species. We cannot exclude species just because one accession failed -- others might be better adapted or have different growth habits. The genetic resources of fodder and shrub legumes held by ILRI, CIAT and ICRAF would be good starting points for screening legumes.

From: Herbert Dhliwayo
We need to use legumes that are robust for the target environment in line with the above statement.

We need to recognise a legumes' requirements for inputs (e.g. fertilizers) and crop management (e.g. weeding and pest control).

Need to tap farmer perceptions of those legumes that are normally grown as minor crops compared to maize.

Need to consider indigenous legumes growing naturally in the target environment for inclusion in the Soil Fertility Network.

From: Sheunesu Mpepereki
1. Farmers expect to improve their cash income from the sale of crops. The legumes selected must partly address this need by farmers.

2. There is need to consider modest inorganic inputs for legume crops to move away from a belief that legumes on their own can solve the soil fertility problems, and to think longer term.

3. Green manure legumes fail to establish in soils that are too depleted to support meaningful crop growth. Then the pH, P and other nutrients must be corrected.

From: Bernard Kamanga
Most work on legume trees for soil fertility improvement uses maize hybrids as test crops and little or no use of local maize varieties. Hybrids have problems with weevils in storage and reduce farmers' adoption potential for the agroforestry systems. Is there a way to incorporate local maize varieties to suit farmers' needs and possibly compare their response to N added through legumes? It is possible that local maize will perform better than the hybrids, hence our need to investigate this.

From: Christopher Nyakanda
In the morning session, strip farming using vetiver grass to control erosion in Kenya was discussed. Use of contour strips can result in concentration of water and thus increased erosion in some instances. The current and extensive work on crop + green manure intercrops and rotations could provide improved soil cover and reduced erosion and thus provide a saving on nutrients that would otherwise have been eroded. Erosion can contribute substantially to loss of nutrients. The presentations at this meeting lack measurements on impact of relay cropping, intercrops or live mulches on soil loss and therefore nutrient loss. We need to collect these data.

PRACTICAL APPROACHES TO SOIL ORGANIC MATTER MANAGEMENT FOR SMALLHOLDER MAIZE PRODUCTION IN SOUTHERN AFRICA

KEN E. GILLER[1], ROB GILBERT[2], LUKE M. MUGWIRA[3], LUCIA MUZA[3], BHARATI K. PATEL[2] and STEPHEN R. WADDINGTON[4]

[1]Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK;
[2]The Rockefeller Foundation, P.O. Box 30721, Lilongwe 3, Malawi;
[3]Department of Research and Specialist Services, P.O. Box CY550, Causeway, Harare, Zimbabwe;
[4]CIMMYT-Zimbabwe, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe

SUMMARY

We review the potential for organic materials to supply nutrients for plant growth and/or to build soil organic matter, and highlight priorities for research. The major problem for utilization of organic manures are the limited quantities available within different cropping systems. Grain legumes often contribute little to soil fertility as much of the N fixed is removed at harvest. Approaches that produce a large amount of N-rich biomass, such as improved legume fallows occupy land which could be used for growing crops and often are not productive on less-fertile soils. Intercropping green manure legumes with maize can give positive benefits without marked reductions in yields of maize when rainfall is not strongly limiting. However, in drought years yields of both maize and the intercropped legumes can be severely reduced due to intercrop competition. Organic amendments decompose rapidly in sandy soils, such that building soil organic matter, or indeed managing nutrient release, are difficult. Greater possibilities exist for both building SOM, and for managing nutrient release by using materials of differing quality, in soils with a greater clay content.

Technical research priorities that we recommend are long-term trials on pigeonpea/maize intercropping in Malawi and on manure management in Zimbabwe. Due to the active interest of a number of organizations in implementing zero-tillage or minimum tillage with smallholder farmers, there is an urgent need to understand and test this approach under realistic farmer conditions and measure its interaction with soil fertility.

Because the major problem of soil fertility in the region is the limited amounts of organic residues or mineral fertilizers available to farmers, a much greater farmer-focus is required in research. Profitable systems that are attractive to farmers in which herbaceous or tree legumes are grown for green manure or fodder require development and testing. A pre-requisite for this may be the screening of a wide-range of green manure and fodder legumes throughout the region to identify species and accessions with additional benefits to those legumes already well-known to farmers.

THE PROBLEM - SOURCES OF ORGANIC MATTER FOR SOIL AMENDMENT

A detailed review of strategies for soil fertility replenishment in Africa has recently been undertaken as part of an assessment of the potential for the "recapitalization" of soil fertility. This review includes papers on P (Buresh, Smithson and Hellums, 1997), N (Giller, Cadisch, Ehaliotis, Adams, Sakala and Mafongoya, 1997) and on interactions between organic manures and mineral fertilizers (Palm, Myers and Nandwa, 1997). The options for replenishing soil P are fairly clear - either rock phosphates or other P fertilizers must be applied because organic manures can rarely supply sufficient P. It is also clear that at least small additions of mineral N fertilizers are required to give acceptable maize yields, but that full advantage must also be taken of all potential sources of organic matter for supplying N and other nutrients. Within the focus of the Soil Fertility Network there are two major problems for managing soil fertility: namely the lack of fertilizer use and the lack of sufficient organic matter for use as a soil amendment.

Here we review the potential sources of organic matter and start to bring together quantitative information from the region (and from other regions where relevant) that allows the evaluation of potential methods of soil organic matter management. Criteria on which future selection of interventions for greater focus by research will be based depend on the potential to raise crop yields and/or soil fertility on a given field **and** the relative contributions to be expected from each technology in particular agro-ecologies. Discussion is focused on the inevitable compromise between using land for production of maize (staple food) or for production of sufficient high-quality organic matter. Parts of this text have been developed from the more general paper of Giller *et al.* (1997).

APPROACHES TO INCREASE INPUTS OF ORGANIC MATTER

Grain Legumes as Sole Crops and Intercrops

The role of leguminous crops in maintaining soil fertility is well-recognized, but has also too frequently been uncritically overestimated. Tropical grain legumes can certainly fix substantial amounts of N given favourable conditions, but the majority of this N is often harvested in the grain. Legumes such as soyabean that have been subjected to intense breeding efforts are very efficient at translocating their N into the grain. The large proportion of the N which is harvested with soyabean means that even when the residues are returned to the soil there is generally a net removal of N from the field (Giller, McDonagh and Cadisch, 1994; Halvin, Kissel, Maddux, Claassen and Long, 1990; Peoples and Craswell, 1992). A major question within the Soil Fert Network region is whether the promiscuous soybean varieties actually contribute more N to the soil than the more highly bred specific varieties (this is the focus of current research e.g. Mpepereki, Makonese and Giller, 1996). Soybeans are potentially an important legume for smallholder farmers in southern Africa. In Malawi, official approval and release of the promiscuous soybean varieties came only in 1996, long after seed had been widely distributed by NGO's and adopted by as many as 100,000 farmers. Yields of soybeans of 1-1.5 t ha^{-1} were sufficiently attractive as an alternative to maize production and soybeans can provide an important source of protein for farmers. In Zimbabwe, there is much current interest in soybean production in the smallholder sector and a major push to extend soybean production by AGRITEX and the University of Zimbabwe (Ishmael Pompi and Sheu Mpepereki). There appears to be an almost inexhaustible market for soybean and attractive prices if proper marketing mechanisms can be put in place. Whether the amounts of N left in the field at harvest by grain legumes such as soybean and groundnut without residue incorporation are significant, especially where animals graze, remains an open question.

Soybean residues at harvest are lignified (~10% lignin) with C:N ratios around 45:1 and these tend to immobilize N on addition to the soil (Toomsan, McDonagh, Limpinuntana and Giller, 1995). By contrast, groundnut residues can contain over 160 kg N ha^{-1}, are less lignified (~5% lignin) and are rich in N as the crop is often harvested while still green. If returned to the soil, groundnut residues can easily lead to the doubling of maize yields on sandy soils (McDonagh, Toomsan, Limpinuntana and Giller, 1993), but even with groundnut there is a net contribution from N_2-fixation only if the legume stover is returned to the soil. The exceptions to this rule are the longer-duration grain legumes such as pigeonpea (*Cajanus cajan*) and indeterminate, small harvest index varieties of cowpea (*Vigna unguiculata*) (Dakora, Aboyinga, Mahama and Apaseku, 1987), which may lose a substantial amount of biomass in the form of roots and leaves that fall before harvest (Giller and Cadisch, 1995). Bambara groundnut (*Vigna subterranea*) also has potential to contribute substantial amounts of N in rotations (Mukurumbira, 1985), but has received relatively little research attention.

Virtually all the information that we have on contributions from N_2-fixation is from research conducted on experimental stations where the crops have been adequately fertilized with P and other nutrients, and often irrigated (Giller and Wilson, 1991). As yields of sole-cropped grain legumes under smallholder conditions in Africa are often pitifully small (<500 kg ha^{-1}), the amounts of N_2 fixed are barely significant. For example, in the Usambara Mountains, northern Tanzania where *Phaseolus vulgaris* is the staple grain legume most farmers' crops lacked nodules due to severe P deficiency and amounts of N_2 fixed were estimated to be as little as 2-8 kg N ha^{-1} (Amijee and Giller, 1997; Giller, Amijee, Brodrick and Edje, 1997). Alleviation of P deficiency by fertilizer addition resulted in substantial enhancement of nodulation. However, only when K fertilizer was also supplied were grain yields raised to 1000 kg ha^{-1} or more at most sites (Smithson, Edje and Giller, 1993) which would result in roughly 50-60 kg N ha^{-1} from N_2-fixation. An effort is currently being made to extend our knowledge of the amounts of N_2-fixation by *Phaseolus vulgaris* on farmers' fields in East Africa using the ^{15}N natural abundance method (Matheson, Wortmann and Giller, unpublished results) and this could usefully be extended to measure amounts of N_2-fixation in a wide range of grain legumes in Zimbabwe and Malawi. Legumes are generally responsive to P as they have a less dense rooting system when compared with cereals and grasses (Giller and Cadisch, 1995). Within our network region P is not a major constraint on many soils in Malawi, though more commonly required for legume production in Zimbabwe.

Amounts of N_2-fixation by grain legumes can also be severely constrained by drought and Ganry (in Wetselaar and Ganry, 1982) found that N_2-fixation by groundnuts over three years in Senegal was almost linearly correlated to total rainfall. Water stress is likely to be a major constraint to legume production and N_2-fixation in many seasons in Malawi and Zimbabwe, and the drought tolerance of cowpea makes it a useful species for marginal rainfall areas (Shumba and Piha, 1991). Water stress is a particular problem when legumes are intercropped with cereals. With good rainfall intercropping of maize and cowpea at Makoholi gave increased productivity compared with the sole crop, although maize yields were reduced slightly, but with poor rains competition for moisture led to severe reductions in yields of intercropped maize (Shumba, Dhilwayo and Mukoko, 1990). After three years of intercropping cowpea and maize without mineral fertilizers at Domboshawa, the high biomass added in cowpea residues (~2 t ha^{-1}) resulted in significantly greater maize yield, although there had been reductions in the yield of maize in the first two seasons (CIMMYT-Zimbabwe, 1996).

Intercropping of grain legumes generally results in the legume deriving a greater proportion of its N from N_2-fixation than when grown alone, but legume dry matter production and N accumulation are usually reduced due to competition from the companion crop (e.g. Nambiar, Rao, Reddy, Floyd, Dart and Willey, 1983) so that the overall amount of N_2 fixed is less. One notable exception again is pigeonpea (*Cajanus cajan*) which has a phenology complementary to that of most cereal crops in that its initial above-ground growth and development is very slow so there is little direct competition between the crops (Dalal, 1974). A sole pigeonpea crop drops up to 40 kg N ha^{-1} in fallen leaves during its growth (Kumar Rao, Dart and Sastry, 1983) and its small harvest index means that a relatively large proportion of the fixed N remains in the field. The leaves that fall have a nitrogen content of < 1.5% N resulting in initial N immobilization for 6 - 8 weeks so that there is only a significant N benefit to subsequent crops (W.D. Sakala, unpublished results). The long-duration of traditional pigeonpea varieties, and their ability to root deeply allows the pigeonpea to grow on after the companion cereal crop has been harvested, utilizing residual moisture in the soils. However, although sole pigeonpea gave clear residual effects on growth of subsequent maize, the residual effects of maize + pigeonpea intercrops were not substantial (Kumar Rao *et al.*, 1983; Kumar Rao, Thompson, Sastry, Giller and Day, 1987), presumably due to reduced inputs of N. Despite claims for substantial 'transfer' of N for grain legumes to companion cereal crops (Eaglesham, Ayanaba, Ranga Rao and Eskew, 1982), other evidence indicates that benefits are limited (Giller, Ormesher and Awah, 1991). Benefits are more likely to accrue to subsequent crops as the main transfer pathway is due to root and nodule senescence and fallen leaves (Ledgard and Giller, 1995). At least small amounts of N fertilization of maize in legume + cereal intercrops.

Pigeonpea is an important legume in southern Malawi, being found intercropped with maize on the majority of smallholder farms where it is grown for both grain and firewood. Sakala (1994) investigated planting arrangements for maize + pigeonpea intercrops and concluded that if pigeonpea is added to the maize without reducing maize density by planting within the rows on the ridges then maize yields were not reduced. Unfortunately when subplots of maize + pigeonpea intercrops were included in the recent demonstration trials of the PAPPA/MAFE project on around 200 farms in Malawi the pigeonpea was planted in alternate rows with maize which does not fit well with farmers' weeding practice and leads to reduced maize yields. Pigeonpea is not traditionally important in Zimbabwe although it has been shown to intercrop well with maize and sunflower at Marondera and Mlezu (Natarajan and Mafongoya, 1992) and has been tested as in alley-cropping trials (Mafongoya, 1995). N contributions and dynamics in maize + pigeonpea systems in Malawi are currently being studied by Webster Sakala and in Zimbabwe by Paul Mapfumo.

Improved Fallows: Green Manures and Agroforestry Species

Direct benefits from N_2-fixation are obviously greater when herbaceous or shrubby legumes are grown specifically to improve soil fertility as green manures or "planted fallows". Amounts of N accumulated by the legume are generally determined in the short-term by the rate of establishment of the legume, and subsequently by the productivity of the legume and the length of the growing period for the green manure or planted fallow.

Early reports of experiments successful in maintaining crop yields using green manures resulted from testing of a rather limited selection of species such as *Mucuna pruriens* var. *utilis*, *Cajanus cajan*, *Crotalaria* spp. and *Canavalia* spp. across a wide range of environments (e.g. Davy, 1925; de Sornay, 1918). Green manures such as *Crotalaria juncea* were exploited extensively to maintain soil fertility on commercial farms in Zimbabwe until mineral N fertilizers became widely available (Rattray and Ellis, 1952). The dense cover formed by creeping legumes such as *Mucuna* and *Pueraria* leads to self-shading and senescence of leaves giving a dense mat of organic matter. Inputs of N from such species based solely on measurements of the standing crop may be underestimated substantially (van Noordwijk and Purnomisidi, 1992). Significant benefits in yields of subsequent crops have been reported even when *Mucuna* was burned to aid the ease of land preparation (Vine, 1953) supporting the suggestion that large amounts of N were contributed to the soil from roots and fallen leaves.

Early examples demonstrated the successful use of planted green manure fallows in restoring soil fertility more rapidly than regeneration of the native vegetation (e.g. Jaiyebo and Moore, 1964). It was also quickly recognised that although green manures gave greater yields of subsequent crops than rotation with grain legumes such as groundnut "they suffer the handicap of occupying the land unproductively for a whole year" (Brown, 1958). Thus additional benefits such as improved weed control or other uses are generally necessary for farmers to spontaneously adopt use of green manures (see below). There has recently been a resurgence of interest in the use of short-term, planted fallows using shrubby legumes such as *Sesbania* and *Tephrosia*, with demonstration of substantial gains in crop yields (e.g. Kwesiga and Coe, 1994).

Intercropping with Green Manures or Trees

Intercropping and relay-cropping of legume green manures has the advantage that food crops are still grown while organic matter is produced for soil amendment. The obvious disadvantages are that the green manures or trees may compete with the crops, and that the amounts of organic matter produced are generally less than when the land is devoted to soil improvement. Whether intercropping with green manures and trees is advantageous thus depends on the balance of the benefits and costs.

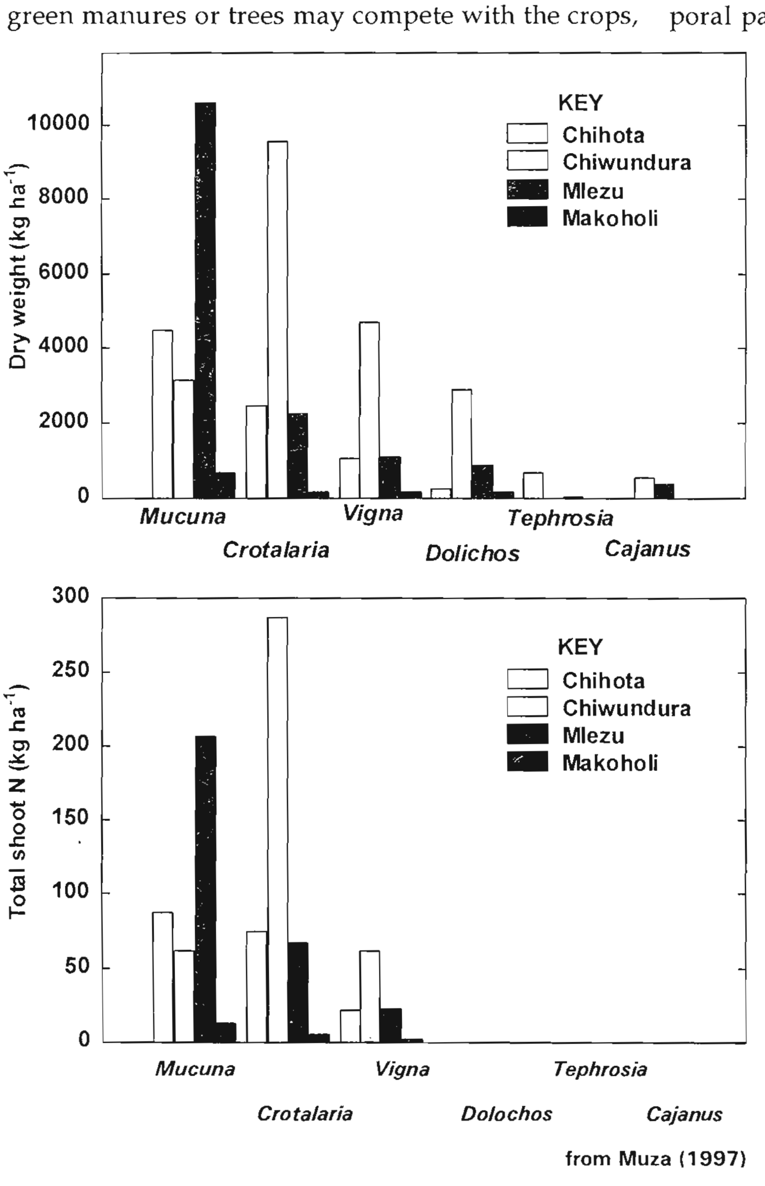

Figure 1 a) Dry matter and b) N accumulation in green manures intercropped with maize in the 1995/96 season at four sites in Zimbabwe. Maize yields were not significantly reduced by intercropping with the green manure legumes and were 1.6 t ha^{-1} at Chihota, 7.6 t ha^{-1} at Mlezu, 4.1 t ha^{-1} at Chiwundura and 2.3 t ha^{-1} at Makoholi (from Muza, 1997).

The net benefits may vary significantly between sites and seasons, depending on the availability of moisture and nutrients. As found with maize + cowpea intercrops in Zimbabwe, cowpea green manure was advantageous when intercropped with millet in a year with adequate rainfall, but the cowpea competed strongly with millet for soil moisture when rainfall was limiting (Franzluebbers, Juo and Manu, 1994). Thus the unpredictable nature of the interactions adds a dangerous extra complication requiring good control of plant densities and spatial and temporal patterns. Relay-planting can reduce the likelihood of competition with the crop where rainfall is limited, but the production of the green manure is then restricted by its ability to utilise residual moisture after the main cropping season. Strip intercropping of cowpea and maize can stabilise yields in the face of unpredictable rainfall. In a wet year the spreading cowpea grows on its own row without major competition for light and nutrients with maize, giving good biomass from the cowpea and good maize production. In a dry year the residues from cowpea raise the soil moisture holding capacity and, since the crops are grown in separate strips there is little intercrop competition and maize yields collapse less than when grown as a sole crop.

In Zimbabwe, recent experiments with green manures intersown with maize have shown similar results. In a drought year (1994/95) all the legumes tested failed completely when sown four weeks after maize, but when rain was abundant several of the species produced large amounts of biomass without any significant reduction of maize yields (Figure 1, Muza, 1997). The most successful legumes were *Mucuna*, *Crotalaria* and cowpea and these produced up to 290 kg N ha^{-1} (Figure 1) in maize which yielded up to 8 t ha^{-1}. In general, the legumes yielded much more when sown four weeks after maize than if sown later, and many completely failed to establish if sown six weeks after maize although when *Cajanus* was sown six weeks after maize at Mlezu in the 1995/6 season it accumulated 2230 kg ha^{-1} of biomass containing 48 kg N ha^{-1} (Muza, 1997). In Malawi, *Crotalaria* and *Mucuna* produced more than 2 t ha^{-1} of biomass when sown two weeks after maize (see

Gilbert, this proceedings). However, *Mucuna* was extremely competitive with maize when planted early at high seeding rates leading to a 60% reduction in maize grain yield. The differing growth habit of green manure species has implications for their management when intercropped. Climbing, aggressive species (e.g. *Mucuna*) should be undersown later than slow-growing species (e.g. *Tephrosia*).

Hedgerow intercropping or alley cropping has been very useful for developing a better understanding of tree-crop interactions (for example see van Noordwijk, 1996), but is now regarded to have little applicability in smallholder agriculture due to the strong crop-tree competition and the intensive management required (Sanchez, 1995; Young, 1989). An exception may be on steeply sloping lands when hedgerows can be planted on contours to help prevent soil erosion, as seen in southern Malawi. The traditional agroforestry practice of farmers who maintain trees such as *Faidherbia albida* in their fields is well documented as a means for maintaining fertile "islands" of soil around the trees (Dancette and Poulain, 1969; Vandenbeldt, 1992). *Faidherbia albida* is an important species in the lakeshore along Lake Malawi and the benefits for crop production have been documented (Saka, Bunderson, Itimu, Phombeya and Mbekeani, 1994). The extent to which this practice actually develops rather than maintains soil fertility is still unclear. Similar effects are seen under the canopies of other N_2-fixing trees such as *Acacia* species and also under trees that cannot fix N_2 (Belsky, Mwonga and Duxbury, 1993; Breman and Kessler, 1995) and the extent to which N_2-fixation contributes to this phenomenon needs detailed investigation. Root systems of trees in arid lands can scavenge for moisture by being very extensive, extending up to 50 m from the trees in some species (Soumaré, Groot, Kone and Radersma, 1993) or by rooting deeply. The potential for intensification of tree planting with species such as *Faidherbia* to enhance the soil N status will depend on the relative importance of N_2-fixation or N acquisition from a wide area in the enhancement of soil fertility (Giller and Cadisch, 1995) and this is currently being investigated by Henry Phombeya in Malawi.

Animal Manures

Cattle manure is an integral component of soil fertility management in many regions of sub-Saharan Africa and the beneficial effects of manure on soil fertility are well-documented. The detailed review of the use of cattle manure in Zimbabwe has drawn together a large amount of information from experiments conducted since 1913 (Mugwira and Murwira, 1997).

The nutrient contents of manures differ due to variation in the animals' diet and in particular due to differences in the ways manure is collected and stored. In regions with a long dry season, the quality of grazing available is often much better during the rains or after fire, resulting in a larger N content in the manure. Crop responses to manure application are often due more to the contribution of P and cations such as Ca and Mg than the addition of N (e.g. Grant, 1967; Hartley, 1937). In Zimbabwe, manure from communal farming areas has much smaller contents of nutrients, in particular P, compared with feedlot manure such that manure from communal areas is considered a poor source of P (Mugwira and Mukurumbira, 1984; Mugwira and Mukurumbira, 1986; Tanner and Mugwira, 1984; Trounce, Tanner and Mandiringana, 1985). Crop responses to manure application observed in farmers' fields are highly variable due to differences among farmers and between regions in the chemical composition of the manures, in the rates of manure application, and in the frequency of application on each field.

Powell (1986) found that dry-season manure had an N content of 0.6% of dry matter compared with 1.89% during the early rainy season, when the quality of diet had improved. The diet may also influence the partitioning of N between faeces and urine; feeding high-quality diets (containing little lignin and polyphenols) results in more N being excreted in the urine than faeces (Reed, Soller and Woodward, 1990; Somda, Powell, Fernández-Rivera and Reed, 1995). Feeds rich in tannins increased the amount of N excreted in the faeces as compared to urine where N is often quickly lost through volatilization. Recent results indicate that the N in manures from animals fed with tannin-rich diets from species such as *Acacia angustissima* or *Calliandra* is very resistant to mineralization in soil (P.L. Mafongoya, unpublished).

Animal management has an important influence on the amount of manure collected and its N content. There are two principal systems for manure collection from animals: those where animals are penned continuously and the manure is collected, stored and transported to the cropped fields and those where animals are allowed to graze in grazing areas during the rains and graze freely during the dry season but corralled at night. In some situations animals are coralled on the cultivated field between harvest time and time of cultivation of the next crop. This system is better economically in terms of manure transport and the effects on soil fertility are generally greater due to the inputs from urine. As cattle which are coralled often graze extensively over large areas, the collection of manure represents an enrichment of fertility from a wide area onto the field where the manure is used.

On sandy soils the trampling of manure by penned cattle can result in exceptionally high sand contents of over 50% due to mixing of sand and soil (Mugwira, 1984). Khombe, Dube and Nyati (1992) measured more sand (49%) in manure from pens with concave floors than in manure from pens with sloping floors (41%). Manure from pens with concrete floors contained less sand than that from pens with earth floors. Storage of manure before application to the field has been shown to influence the N content of the manure. Ammonia may be lost rapidly by volatilization from urine and manures (Murwira, 1995) although the amounts of N lost by volatilization when manure is applied to the soil are small. When manure was stored in heaps or in pits until application, the buried manure had substantially greater contents of N, P and K (Kwayke, 1980). Addition of crop residues or straw to manure reduced N losses and there is certainly scope to improve manure management to enhance its value in supplying nutrients in synchrony with crop demand. It is likely that much N is lost from kraals due to volatilization of ammonia from urine and it may be possible to trap much of this ammonia by using low-quality grass, straw or miombo litter. In many regions, however, there are strong demands for crop residues to use or sell for fodder or as building materials.

Surprisingly, the beneficial effect of manure on N availability for maize grown in granitic sandy soils was due to N released directly after application (Figure 2; Grant, 1967). This N was most likely present as free mineral N in the manure as mineralization studies have shown that the poor quality manures found in Zimbabwe lead to a prolonged period of N immobilization (Murwira and Kirchmann, 1993). Yield responses to manure can be seen in crops for several years after application when the manure is supplied in sufficiently large amounts (Mugwira and Murwira, 1997). However, in a sandy soil in Niger a large part of the N applied in manure was translocated to depths below 1.5 m after application of 13 t ha^{-1} of manure, indicating that smaller, more frequent applications may be a more effective way of using manure (Brouwer and Powell, 1995).

Sandford (1989) estimated that 16 - 47 ha of grazing land were required to produce sufficient manure for sustained maize production of 1 - 3 t ha^{-1}, or between 2 and 17 ha if the animals were confined. In Zimbabwe, similar calculations on the basis of N budgets indicated that 14 ha were required to support annual maize production of 2 t in each hectare of arable land (Swift, Frost, Campbell, Hatton and Wilson, 1989). There is also a danger of long-term degradation of grazing lands as there is substantial nutrient removal over prolonged periods. Considering cattle confined in *bomas*, Probert, Okalebo and Jones (1995) calculated that sufficient manure was available in Machakos, Kenya to supply cropland with only 2.5 t ha^{-1} annually although much larger rates in excess of 38 t ha^{-1} were applied by farmers to a few fields. Thus although manure is an important source of nutrients for crop growth in many cropping systems in Africa, it is widely acknowledged that insufficient manure is available to support crop production.

Provision of Organic Inputs

In summary, there are three basic ways of producing organic inputs rich in N for use in soil fertility improvement: crop sequences and/or fallows with grain legumes or green manures; "simultaneous" intercropping systems where crops and green manures are grown together; or biomass-transfer or 'cut-and-carry' systems. Animals also play a role in converting N poor crop residues into somewhat richer sources of N. All of these methods for producing biomass can be used with either herbaceous green manures or with fast-growing trees. Apart from the cut and carry systems and manure, N is added to the soil from leaves that fall during growth, shoot material returned to the soil when the plants are harvested, and from roots and root exudates. The amounts of N returned below-ground are difficult to quantify and therefore very poorly documented, but often represent the only input of organic residues to the soil.

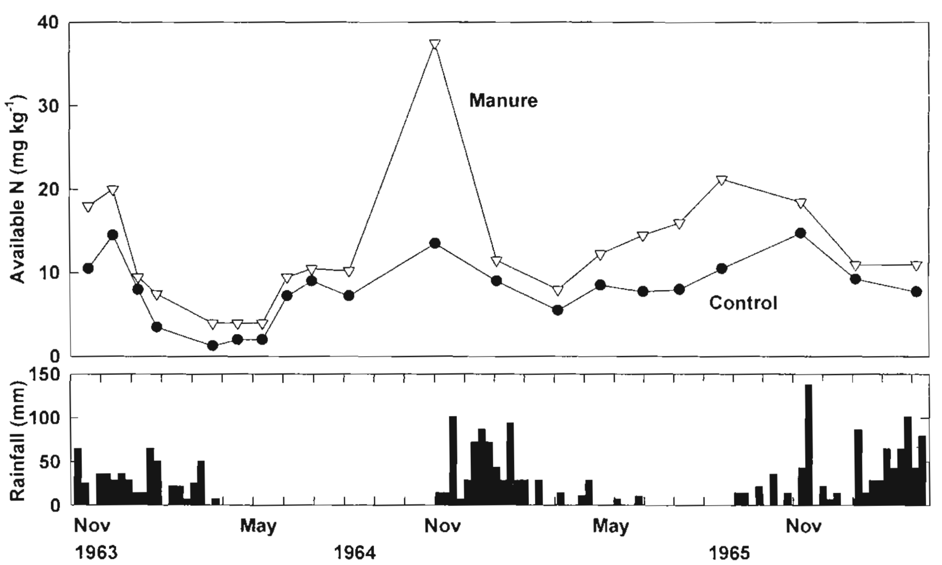

Figure 2. Mineral N in the surface horizons of a sandy granitic soil at Marondera, Zimbabwe without amendment or with manure added showing the flush of N at the beginning of the rains each year (redrawn from Grant, 1967).

The major problem with all these different approaches to provision of organic resources is the limited quantity available unless a substantial investment of land and labour is committed to their generation. Production of adequate biomass is often not possible on the depleted soils that would benefit the most from such inputs.

QUALITY OF ORGANIC MATTER IN RELATION TO SHORT-TERM VERSUS LONG-TERM BENEFITS

Resource Quality Determines Nutrient Release

The chemical composition or quality of organic residues has a major influence on their rates of decomposition and N release when added to soils (Cadisch and Giller, 1997; Swift, Heal and Anderson, 1979). Decomposition follows the "resource cascade" in which the initial input is decomposed and redistributed in soil by the processes of comminution by soil fauna, catabolism by soil micro-organisms and leaching to form new resources which are attacked in turn (Heal, Anderson and Swift, 1997). The rate of decomposition of different chemical constituents within litters depends both on their chemical recalcitrance and the location within the physical structure of the litter. Complex carbohydrates, lignin and polyphenols thus tend to accumulate during decomposition. Although decomposition involves catabolism of substrates, micro-organisms manufacture polymeric molecules which may have increasing recalcitrance, and the resulting SOM is a complex mixture of molecules of plant and microbial origin.

Recent research by Handayanto *et al.* (1995; 1997) has highlighted the importance of reactive polyphenols in binding proteins. The resulting polyphenol-protein complexes appear to be very resistant to microbial degradation resulting in poor availability of N for plant uptake from residues which have a narrow C:N ratio. It is unclear to what extent complexation of polyphenols and proteins is a "fast route" to SOM formation which could be used to build soil N capital. Even if this were possible, it is unfortunate that the complexes formed are recalcitrant and do not appear to act as slow-release fertilizers. Initial experiments in which ^{15}N-labelled residues with a large protein-binding capacity were added to soil indicate that the complexed N is not released over three successive crop cycles (Cadisch, Handayanto, Malama, Beidari and Giller; unpublished results). Thus for supplying crops with N, high quality sources (low C/N ratio, low reactive polyphenols) of organic matter are required, whereas poor quality sources are likely to be more useful for building up soil organic matter.

Increasing Soil Organic Matter

The capacity of a soil to store organic matter (referred to as the "equilibrium level" by Nye and Greenland, 1960) is determined largely by the soil's texture and soil pH (van Noordwijk, Cerri, Woomer, Nugroho and Bernoux, 1997). This maximum capacity to store organic matter relates to the amount of organic residues, microbial biomass and microbial metabolites which can be stabilized. Whilst this storage capacity may be exceeded by applying extremely large amounts of organic inputs, rapid turnover of unprotected organic matter (including turnover of the microbial biomass itself - Ladd, Amato, Grace and van Veen, 1995) will lead to loss of this "excess" organic matter unless it is continually replenished. The relationship between clay and silt content and the soil C and N contents is illustrated in Figure 3. In clay-rich soils the amount of C and N is highly variable, depending on the quantity of organic inputs (often related to rainfall) and the land use and in particular on the intensity of cultivation. The soil C and N content under forest soils can be much greater than soils under grassland or arable cultivation due to surface accumulation of "unprotected" organic matter in the surface horizons. Sandy soils invariably contain a small amount of C and N, irrespective of the land use, due to their lack of capacity to protect organic matter from microbial degradation. There-

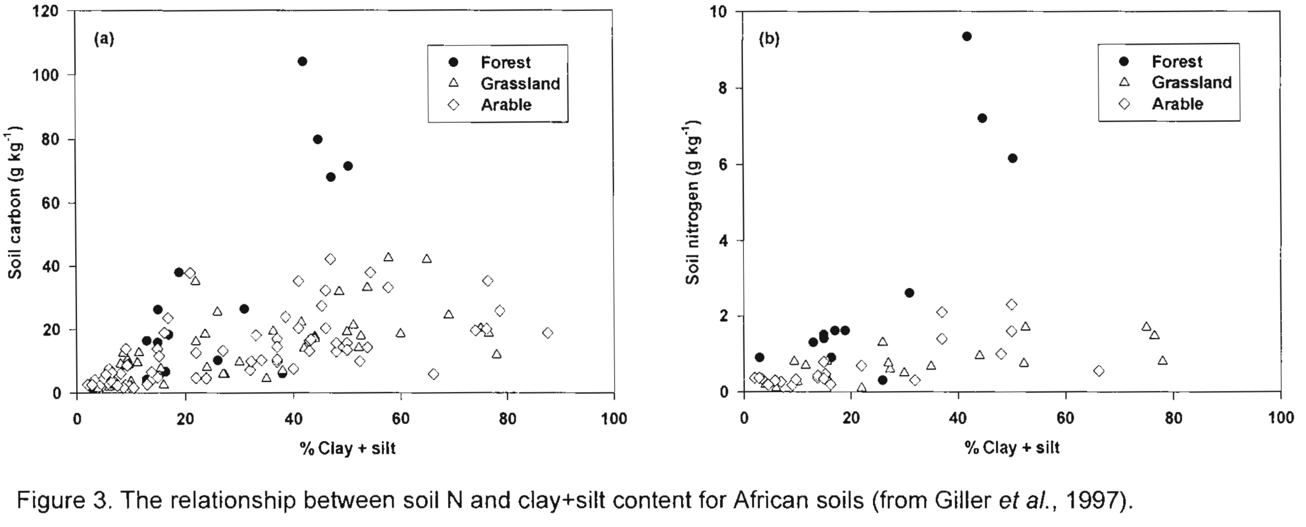

Figure 3. The relationship between soil N and clay+silt content for African soils (from Giller *et al.*, 1997).

fore the degree to which the organic matter content (and hence the soil nitrogen capital) can be built up depends on how much of the protective capacity of the soil is already saturated (Hassink, 1995; Nye and Greenland, 1960/p. 53). Within the Soil Fert Net region, the sandy soils which are widespread in Zimbabwe and on the Kasungu plain of Malawi therefore have a very poor capacity to store SOM. In the granitic sandy savanna soils of Zimbabwe which have roughly 0.5% organic C and a N content below 0.04%, Grant (1967) concluded that SOM was a minor source of N for maize growth and that supplementation with mineral fertilizers or manure was essential to ensure reasonable yields even in the short term.

The positive effects of SOM on crop growth are many (e.g. increasing soil porosity, water infiltration, resistance to erosion, ease of root penetration through soil, etc.) and do not solely depend on the capacity to supply N or other nutrients (de Ridder and van Keulen, 1990). Application of large amounts of N-poor residues, highly lignified residues or residues rich in polyphenols may allow accumulation of amounts of SOM above the clay-determined storage capacity, but this will lead to relative enrichment of the SOM with chemically recalcitrant, passive pools. As such pools must be relatively inert to allow them to accumulate, it is unlikely that they can contribute much directly to N availability for crops, although there will be other benefits due to the effects of increased SOM on soil structure.

Literature on tropical soils abounds with statements which suggest that soil organic matter contents cannot be replenished under cultivation due to the "fast rate of oxidation". There are examples where SOM has been increased depending on the amount of organic residues returned to the soil. For example, Bache and Heathcote (1969) demonstrated addition of cattle manure at 2 t ha^{-1} for 15 years led to small increases in soil C (from 0.24 to 0.43%) and N (from 0.021 to 0.034% N) contents at Samaru, Nigeria and Pichot, Burdin, Charoy and Nabos (1974) found that annual applications of 60 t ha^{-1} of cattle manure only increased soil C from 0.25 to 0.66% after 18 years at Saria, Burkina Faso. At Kabete, Kenya, addition of 10 t ha^{-1} of cattle manure combined with return of all crop residues failed to prevent a decline in the SOM contents in an Alfisol cropped annually to maize and beans (Kapkiyai, Woomer, Qureshi, Smithson and Karanja, 1997).

Managing N-poor Crop Residues

Crop residues poor in N, such as the cereal stovers, are the major sources of organic matter produced in most smallholder food production systems in Africa and therefore are arguably an important resource for maintaining the organic matter contents of soils. Such residues are often burned to aid ploughing and assist in pest control. Farmers in Malawi and Zimbabwe manage maize stover in a wide variety of ways - apart from feeding animals with poor quality cereal straw many farmers use straw and harvest grass to use as bedding for animals in kraals and the residues may help to immobilize mineral N in the manure and prevent it from being lost. Burning of straw by many Malawian farmers is often done to catch small rodents which are a prized source of meat, but will also reduce any potential immobilization from the straw.

Due to their wide C/N ratio and relatively large amounts of C which are readily available for microbial growth, a prolonged immobilization of N in the microbial biomass is induced which deprives crops of available N during the early growing season. Thus although recycling of cereal stover to cropped lands may help to maintain SOM contents, or increase them in degraded soils with the associated benefits of improved soil structure, the short-term N supply must be managed to allow productive cropping. This can be done by use of mineral fertilizers or by addition of other organic resources rich in N, but sufficient amounts of readily-available N must be added to satisfy the immobilization potential of the cereal straws and allow production of both grain and stover. Incorporation of maize straw into the new ridges soon after maize harvest will leave a long period when the soil is moist and decomposition can continue - this will reduce the strength of the immobilization effect at the subsequent rains. However, given the small amounts of maize stover produced on-farm, the problems of immobilization of N should not be overemphasized.

After three years of millet straw incorporation a significant increase in soil N mineralization was observed and there was a significant increase in the soil N content (Pichot, Burdin, Charoy and Nabos, 1974), although the amount of straw applied (10 t ha^{-1}) was equivalent to three years of actual straw production in the system assuming that all of the straw was returned to the soil. Under maize cropping in Zimbabwe the return of realistic amounts of stover (3.4 t ha^{-1}) for four years at Marondera or incorporation of residues for 15 years on a red clay at Harare produced only slight changes in the soil organic C and N contents (Table 1). A key question is how long a pe-

Table 1. Organic C and N contents of two soils in Zimbabwe as influenced by incorporation of maize stover (from Grant, 1970).

	Total N (%)		Total C (%)	
	- stover	+ stover	- stover	+ stover
Sandveld soils - 4 years (Grasslands, Marondera)	0.036	0.038	0.37	0.38
Red clay - 15 years (Harare)	0.116	0.113	1.04	1.14

riod is required before a net benefit is seen after cereal straw incorporation. An alternative approach is to compost all cereal stover or feed it to animals. Both composting of crop residues and feeding to animals help to improve the quality of soil amendments and hence in the ease of handling as the nutrients are in a more "concentrated" form. However, composting is labour intensive, involves N losses, and is only likely to be important for maintaining productivity in home gardens.

Reduced Tillage

Minimum or zero-tillage are further ways by which the SOM store can be increased under intensive cropping. Lack of tillage generally leads to a greater equilibrium SOM content due to better conservation of organic residues within the field, greater physical protection of residues due to the lack of cultivation and reduced losses of SOM through erosion. This gradually leads to an increased SOM and soil N content, which is achieved through reduced rates of N release. Several experiments in Alfisols of West Africa have demonstrated greater SOM and total N contents in soils under zero tillage compared with cultivation after only 2 - 4 years (Kannegieter, 1968; Lal, 1974; Lal, 1976). Yields of maize and legumes were similar in untilled and cultivated plots to which recommended rates of N fertilizers were added (Lal, 1974; Lal, 1976). No comparisons were made in these studies on the effects of reduced tillage without mineral fertilizer inputs and weed control was achieved by using herbicides in untilled plots (Lal, 1976) representing an additional external cost. Dalal (1989) found increases in soil C and N contents in the top 10 cm of a fine-textured Vertisol in tropical Australia after 13 years of zero-tillage when all residues were returned but the increased N contents were marked only when mineral fertilizers were applied. However, on another Vertisol small differences in soil C and N contents were found between zero-tillage and conventional tillage after 8 years only in the surface 2.5 cm, even with N fertilizers and return of all crop residues (Dalal, Strong, Weston, Cooper, Lehane, King and Chicken, 1995). Similarly, Nyborg, Solberg, Malhi and Molina-Ayala (1995) achieved a net addition of N to the soil after 11 years of barley cropping only when fertilizer N was applied to increase plant biomass production.

Thus a substantial improvement in SOM content will be necessary before the net benefits due to mineralization from the larger amount of SOM outweigh the reductions in the net amounts of N mineralization. Other inputs, by using N fertilizers or legume cover crops and herbicides for weed control, will also be required. In fact large benefits in crop production are likely to be found only if full tillage is re-introduced after a long period of reduced tillage, and tillage operations can be used as a strategic way of mining accumulated N for crop production. Legume-based ley systems are one integrated way which periods of zero-tillage can be alternated with periods of cereal cropping with the advantage of providing grazing in alternation with cropping phases which exploit the SOM that has been accumulated.

Improving N Recycling Efficiency in Cropping Systems

Apart from the N conservation which can be achieved by recycling of crop residues to the soil, there is substantial scope for increasing the efficient capture of mineral N. Much emphasis has been focused on the concept of enhancing the synchronization of N release from organic resources with crop demand for N and this is undoubtedly of importance in very wet climates with high potential leaching risks. However, in the seasonally dry climates which prevail over much of Africa, large amounts of mineral N are present in soils at the onset of the rains which can be captured if the crop root systems extend quickly enough (Wild, 1972). The common practice among farmers of planting with the first rains could partly be in recognition of this and simple interventions such as avoiding deficiencies of other major nutrients could help to ensure good root growth.

Obviously the deeper roots penetrate later in the season the more NO_3-N can be recaptured from those depths. Losses of N from leaching were reduced to almost nothing under mixed perennial crops compared with maize under a high rainfall climate due mainly to the constant presence of a deep rooting system (Seyfried and Rao, 1991). In annual cropping this could be mimicked through relay cropping with pigeonpea or other deep rooted cover crop species which may capture free NO_3-N from deeper horizons. The N could then be returned to the soil in the legume residues at the beginning of the next growing season. There is emerging evidence that maize yields are closely correlated to the substantial amounts of mineral N available at the start of the growing season in Malawi (S. Ikerra, unpublished) and that there is substantial N at depths which can be reached by roots of legumes such as pigeonpea (W.D. Sakala, unpublished).

Need for Continual and Multiple Inputs

Simply improving the efficiency with which nutrients are recycled within existing cropping systems cannot alone give the increments in SOM or soil N supply necessary to raise crop production to respectable yields. Repeated additions of high-quality organic residues and/or mineral fertilizers are necessary to increase and maintain crop production. Indeed, a prerequisite for efficient nutrient cycling is a sufficiently deep and dense rooting system to ensure that available N is captured. A certain degree of soil fertility is necessary to ensure this and where crop yields are already poor, inputs of N and other nutrients into the cropping system are necessary to enhance early crop growth and allow capture of free NO_3-N at depth. There are serious doubts as to whether the poorest soils, which farmers are increasingly abandoning, can be rehabilitated by short-term interventions.

The urgency of solutions to meet the growing demand for increased productivity dictate that extra N must be brought into the cropping systems, and this can be provided through the use of fertilizers or through addition of fixed N_2. No single solution can, or should, be recommended as interventions need to be tailored to and developed jointly with farmers with due regard to their wide diversity of farming systems, cultures and needs. The diversity of soils and soil fertility status between fields within single farms or villages must also be recognised and exploited to allow gradual implementation of soil fertility restoration strategies.

PRIORITIES FOR RESEARCH

Long-term Soil Fertility Experiments

The number of long-term experiments in which there is adequate detailed information on the effects of continuous organic residue applications on soil N build-up is still limited for different climates and soils in Africa. Carefully planned and managed trials on land representative of soils in farmers' fields (most experimental stations were established and remain on the more fertile soils) are necessary to establish the long-term effects of new interventions on crop production and soil fertility (Greenland, 1994). Such experiments would give a much more secure basis for modelling exercises to explore the likely effect of different management on the capital store of N in soil. Within the region targeted by Soil Fert Net information on the longer-term effects of organic matter inputs is required. In particular the long-term effects of grain legume + maize rotations and pigeonpea + maize intercrops, of green manures and of animal manures are fairly poorly understood but readily researchable. Simulation modelling can be used for preliminary evaluations of technologies, but hard data is necessary to fully quantify long-term benefits.

Farmer-focused Research

As argued earlier (Giller and Cadisch, 1995), there is perhaps sufficient understanding of both the processes and the resources which are available for the enhancement of soil fertility to make an impact, and yet little direct application of this knowledge in smallholder farming in Africa. The recent resurgence of interest in the use of cover crops such as *Mucuna* in Benin does not represent a new intervention: this had been tried with success by experimenters in West Africa much earlier who expressed dismay at the lack of implementation by smallholders (e.g. Dennison, 1959). The adoption of *Mucuna* green manuring by smallholders indicates that the idea was highlighted by researchers at a time when it fitted farmers' needs well. Indeed the ability of *Mucuna* to establish and grow quickly and smother *Imperata* grass has been the main reason for farmers' interest (Versteeg and Koudokpon, 1992). By contrast, the direct fertilizer effect of *Mucuna* was the primary benefit highlighted by farmers in Honduras although they also recognised the advantages of the reduced labour requirements for weeding and improved moisture conservation (Buckles, 1995). Legumes with alternative uses that are attractive to smallholder farmers need to be identified. For instance, *Tephrosia*, apart from its use as a fish poison, was planted widely by farmers in western Uganda because it deters mole-rats and prevents them from damaging crops (C.S. Wortmann, personal communication).

Better mechanisms are required for sharing of knowledge between all of those involved in trying to improve the productivity of smallholder agriculture (farmers, researchers, extension agents, NGO workers, etc.). Flow of knowledge cannot be achieved through a narrow prescriptive approach, but requires development and testing of a battery of possible interventions for soil fertility improvement suited to the specific agroecological environment together with farmers. The Organic Resource Database, developed by TSBF in collaboration with Wye College, is a collation of information on the quality of organic resources. This database has helped in the development of simple decision trees to guide decisions as to the optimal uses of organic resources of different quality (see Palm, this proceedings).

Increasing the Number of Suitable Legumes for Farmers

Often only one legume has been recommended for use as a green manure species in a given region, when many other species or accessions of those species tested might be more suitable. In Malawi and Zimbabwe researchers are still largely investigating the same restricted number of species tested as early as the 1920's, yet in the genus *Crotalaria* alone there are more than 480 species with 85 subspecies (Polhill, 1982). Whilst it is quite possible that the best legumes were already identified, recent major efforts at germplasm collection and testing for acid soils, for example at CIAT (1993) has led to the identification of many new species and accessions. From knowledge of their adaptation and performance elsewhere, a list of forage legumes which would be worthwhile testing immediately in various environments in Africa has been developed (Thomas and Sumberg, 1995), many of which are useful as green manures. A multi-location screening network to screen legumes for a range of environments and uses is necessary. A collation of information resulting in a database for cover crop and green manure legumes would facilitate the identification and accessing of seed for potential species to be evaluated. The Soil Fert Net has obtained seed of a variety of different legumes to test as green manures which are likely to be well adapted in the region and provide benefits to soil fertility.

Increasing Farmers' Profits

Several of the grain legumes which can be grown by farmers (e.g. groundnut, soybean and Bambara groundnut) currently command favourable prices in Malawi and Zimbabwe. These grains are important as sources of dietary protein, but can also be important sources of income for farmers if yields are sufficient for them to have a surplus. Use of limited quantities of manure on groundnut is thought to be more profitable than when the manure is applied to maize due to the better market price for groundnuts and a marked improvement in groundnut yields (R. Chikowo and F. Tagwira, unpublished results). Identifying the most profitable mechanisms for use of mineral fertilizers and organic manures by farmers should also be a focus of research. Maize grown after groundnut could benefit substantially from the enhanced soil fertility resulting from improved groundnut yields, and targeting of P fertilizers to legumes in cropping sequences might also be advantageous.

TARGETING SOLUTIONS

Even within narrow geographic regions a large variability exists in soil fertility such that the most suitable interventions for farmers might differ between adjacent fields or parts of the same field.

Where pressure for crop land is intense, interventions to improve soil fertility may be best targeted to the fields where the farmer has little potential yield to lose (cf. Versteeg and Koudokpon, 1992). It is fairly common to see unproductive fields planted even though the investment of seed is scarcely warranted, presumably to maintain visible ownership or other reasons. If crops are already failing to yield on certain fields then there is little loss to the farmer to break the cycle and use a legume cover crop or shrub for one or more seasons to boost productivity or rehabilitate the land for cropping. This approach has a potential disadvantage in that if the land is severely degraded, the soil fertility investment required to restore productivity is likely to be much greater and there is a risk that even the most robust legumes may not grow without addition of soil amendments such as P and lime.

The potential interventions that will lead to the build-up of organic matter and the N supplying capacity of the soil are:

- legume fallows
- the islands of fertility associated with *Faidherbia albida* and other legume trees
- legume-based ley systems

When land pressure dictates that fields cannot be rested other means of replenishing the N supply are needed. For the maintenance of soil fertility under continuous cropping, repeated inputs of N must be assured to maintain productivity through:

- legume rotations
- intercropping or relay cropping with green manures
- animal manures
- mineral fertilizers.

Our knowledge of the importance of soil textural properties in the ability to store SOM, and hence N capital should guide our targeting of these different approaches: sandy soils are going to require more frequent additions of high-quality organic matter and/or mineral N fertilizers to sustain yields. Soils with a heavier texture might better be managed using periodic boosts to productivity such as short-term fallows due to their better ability to protect SOM, again together with some mineral fertilizer inputs. In all cases greater inputs of N are required to make a substantial improvement of maize yields under smallholder conditions.

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POTENTIAL BENEFITS FROM INTERACTIONS BETWEEN MINERAL AND ORGANIC NUTRIENT SOURCES

KEN E. GILLER[1], GEORG CADISCH[1] and LUKE M. MUGWIRA[2]

[1]Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK; [2]Department of Research and Specialist Services, P.O. Box CY550, Causeway, Harare, Zimbabwe

SUMMARY

Potential mechanisms for interactions to occur between mineral and organic sources of nutrients are discussed. The most important mechanisms for interactions are considered to be effects of available C on the mineralization or immobilization of N, effects of available C on the availability of P, and effects of P on the capture of mineral N in soil due to increased crop root growth or due to increased N_2-fixation in legumes. The major benefits of using different types of resources are considered to derive from their additive strength (i.e. addition of larger amounts of nutrients) rather than from any true 'interaction', particularly in soils which are not particularly responsive to P.

INTRODUCTION

The combined use of mineral (or 'inorganic') and organic sources of nutrients has been a major emphasis of the research within Soil Fert Net (e.g. see Kumwenda, Waddington, Snapp, Jones and Blackie, 1996). Here we review the potential benefits of combining types of resources, focusing on the likely mechanisms for interactions contrasted with simple additive benefits. A theoretical understanding of what interactions may take place between different nutrient sources is essential to assessment of the short- or long-term benefits to soil fertility. The major interactions are likely to be due to:

1. Effects of the addition of available C on the mineralization/immobilization of N
2. Effects of the addition of available C on the availability of P
3. Effects of P on the capture of mineral N in soil due to increased root growth or due to increased N_2-fixation in legumes.

Other potential interactions are listed in Tables 1 and 2, but the evidence for occurrence of these effects is sparse, tending to be limited to isolated or extreme cases, and their likely short-term impact on soil fertility is small (Palm, Nandwa and Myers, 1998).

Interactions can take place due to a number of mechanisms which can be broadly grouped into direct interactions in nutrient dynamics and those interactions which occur through effects on the plant's ability to capture nutrients.

Table 1. Mechanisms for potential organic/inorganic interactions: effects of addition of available forms of C, N or P on release of C, N and P from soil.

Available Nutrient Added	Effects on Release of: C	N	P
C	Increased mineralization due to true 'priming' effects (Decrease due to induction of nutrient limitations on microbial biomass?)	Increased mineralization due to true 'priming' effects Reduced or delayed release due to stimulation of microbial immobilization	Increased mineralization due to true 'priming' effects Reduced or delayed release due to stimulation of microbial immobilization Reduced P sorption due to organic acids and/or cycling of P in microbial biomass
N	Increased mineralization due to true 'priming' effects	Increased mineralization due to true 'priming' effects Substitution	Increased mineralization due to true 'priming' effects
P	(Increase due to true 'priming' effects - where P highly deficient)	(Increased mineralization due to relief of microbial P deficiency) Increased N_2-fixation by free-living microorganisms	Substitution
Lime	(Increased mineralization due to relief of acidity/Al toxicity to microorganisms)	(Increased mineralization due to relief of acidity/Al toxicity to microorganisms) (Increased N_2-fixation by free-living microorganisms)	(Increased mineralization due to relief of acidity/Al toxicity to microorganisms) Reduced P sorption due to reduction of P fixation

Table 2. Mechanisms for potential organic/inorganic interactions: Effects of addition of organic matter or available forms of N or P on recovery of soil N and P by plants

Soil Amendment	Effects on Plant Uptake of: N	P
Increased soil organic matter content	Improved N uptake due to better root growth and penetration due to improved soil physical properties and longer plant duration due to increased water availability	Reduced P sorption due to interactions between organic matter and P fixation sites or maintenance of P in the microbial biomass
Available N added	Increased recovery due to improved root growth and N capture	Increased recovery due to improved root growth and P capture
Available P added	Increased recovery due to improved root growth and N capture Increased N capture through N_2-fixation	Increased recovery due to improved root growth and P capture
Lime added	Increased recovery due to improved root growth and N capture Increased N capture through N_2-fixation	Increased recovery due to improved root growth and P capture

MINERALIZATION-IMMOBILIZATION TURNOVER OF N

Microbial activity in aerobic soils is invariably C limited. It is widely accepted that the C:N ratio largely determines whether immediate mineralization occurs when an organic resource is added to soil. In fact this is directly dependent on the amount of available C and N in a resource -- a highly lignified material will give little immobilization even though it may have a very wide C:N ratio. A resource such as maize straw will thus cause N immobilization if added with mineral N, but the strength of the immobilization will depend on the amount of readily available C in the maize straw. This is the clearest way that inorganic and organic nutrient sources can interact and can be exploited to benefit crops by synchronizing nutrient release with crop demand (see Itimu, Cadisch, Jones and Giller, this proceedings).

STIMULATION OF C AND N MINERALIZATION DUE TO P ADDITION

In soils which are highly deficient in P plant residues may contain very small concentrations of P. If C:P ratios are very wide then P may effectively limit the rate of decomposition of the organic resource (Gijsman, Alarcón and Thomas, 1997). This is only likely to occur under conditions of extreme P deficiency in strongly P-fixing acid soils, and thus is not likely to be particularly important in most maize-based cropping systems of southern Africa.

EFFECTS OF ORGANIC RESOURCES ON P AVAILABILITY

The potential inorganic/organic interactions for P release are potentially more complex. The mineralization of organic residues releases only small amounts of P in relation to what is supplied from fertilizers (Palm, 1995), though these may be significant in cases of extreme P deficiency. The major interaction from organic residues is derived from effects of increasing availability of P in soils which normally fix free phosphates into unavailable forms. For example, annual application of 14 t ha^{-1} of manure on a sandveld soil not only led to an increase in water soluble P, but also reduced the fixation of fertilizer-P from solution (Table 3). The mechanisms by which such

Table 3. The effects of annual applications of calcium ammonium nitrate (CAN) or 14 t ha^{-1} manure to a sandveld soil on the concentration of water soluble P and on the amount of fertilizer-P fixed from solution (from Grant 1970).

	P released into water suspension (mg l^{-1})			P fixed from 40 mg l^{-1} added (mg l^{-1})		
Treatment/Year	1	4	7	1	4	7
Control	0	0	2	9	7	4
CAN	4	0	0	6	10	8
Manure	8	12	14	-8	-12	-18

effects occur remain to be fully elucidated but could be due to P added in the organic matter occupying P fixation sites, to the release of organic acids which block sites for P fixation and thus increase P availability for crop uptake, or to the maintenance of P in the microbial biomass pool preventing the chemical fixation of P (Oberson, Friesen, Morel, Tiessen and Frossard, 1997). This is another case where residue quality will be very important in determining the effects of the organic matter on P availability as this will regulate rates of P and organic acid release.

EFFECTS OF P AND LIME ON ROOT GROWTH AND PENETRATION

Other very important ways in which interactions between nutrients can occur are in the stimulation of root growth and penetration in soils due to either the overcoming of nutrient deficiencies or toxities in soil. The most obvious example is where severe P deficiency limits the growth of a crop and its capacity to absorb nutrients through limitations to root exploration of soil. A good example of this is with unfertilized maize on P-fixing soils in western Kenya where P additions enhance N recovery by maize due to stimulated root growth (Hartemink, Buresh, Jama and Janssen, 1996). A similar effect occurs where there are large concentrations of aluminium in soil which prevent the penetration of roots beneath an organic-enriched surface horizon and where liming can overcome the toxicity problems. There are well-documented problems of getting the lime to depths below the surface soil horizons where it is required, and more soluble calcium salts are often not freely available.

FURTHER TYPES OF INORGANIC/ORGANIC INTERACTION: EFFECTS OF SPATIAL LOCATION OR MODIFICATIONS OF THE ENVIRONMENT

Essentially there is no reason to suspect an interaction between different sources of the same nutrient unless they have properties which modify the environment in some way; a molecule of NH_4-N is the same whether derived from hydrolysis of urea or from mineralization of organic matter. The subsequent behaviour of the molecules may differ depending on:

1. The spatial location of the molecule - at the 'macro' scale whether placed on the surface or mineralizing from within aggregates in soil. For example, the preferential leaching of recently added fertilizer-N if present in large pores within the soil compared with N mineralizing within soil aggregates (Wild, 1972).
2. The conditions associated with transformations which lead to subsequent differences in availability or behaviour. For example, the conditions created by transformations leading to N release may be critical in determining its subsequent fate -- for example if hydrolysis of large concentrations of urea results in locally increased pH that NH_4-N may be much more susceptible to losses due to volatilization of NH_3.

INTERACTIONS BETWEEN PLANT RESIDUES

Potential interactions in nutrient release between residues of different quality can also occur by mechanisms similar to those described above. For there to be the potential for immediate interactions in decomposition and nutrient release the movement of soluble constituents is necessary from one (or both) residues to sites where they can be utilized by the microbial biomass. In the short-term, decomposition will be predominantly due to bacteria and fast-growing fungi (Mafongoya, Giller and Palm, 1997). The soluble constituents which can move from one residue to the other are soluble forms of C, N or P which can interact by influencing the net balance between mineralization and immobilization of N (and P) and soluble polyphenols which can reduce the availability of N by binding to proteins and preventing N release. During the later stages of decomposition when structural components of the residues are attacked, filamentous fungi can utilize two resources simultaneously by mycelial networks straddling the resources.

CONCLUSIONS

Although there are many ways that interactions between mineral and organic sources of nutrients can occur, the major benefits are likely to be largely additive in most circumstances. Given the lack of a marked response of cereal crops such as maize to P fertilizers in many parts of the region, particularly in Malawi, benefits from N by P interactions may be small. Researchers are encouraged to make additional measurements wherever 'interactions' are suspected to elucidate their importance and the likely mechanisms by which the interactions occur.

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CARBON AND NITROGEN DYNAMICS UNDER SIMULATED MANAGEMENT SYSTEMS

FLORENCE MTAMBANENGWE

Department of Biological Sciences, University of Zimbabwe, Box MP 167, Harare, Zimbabwe

SUMMARY

The influence of four land-use systems on soil organic matter (SOM) dynamics was investigated during a five-year experiment. Changes in total soil organic C, total N and soil microbial biomass (SMB) C and N were monitored under conditions simulating a disturbed savanna ecosystem. This was through a) removal of grass inputs to soil (simulating grazing), b) by removal of tree litter inputs to soil (clearing for pasture), c) by removal of both (clearing for agriculture and settlement), and d) by removal of both plus intensive soil disturbance via tillage. The results indicated that conversion of miombo woodland into other land-uses resulted in a remarkable decline in SOM. Both soil C and N contents were controlled by plot treatment ($p < 0.01$) and by the third year maximum C declines of about 30% were observed in the top 10 cm of soil in some of the treatments. SMB C and N responded to surface organic matter manipulations almost immediately. In treatments where organic matter was physically removed, the SMB size continued to decrease during the experimental period. There was a general positive increase in SOM content in the natural miombo woodland and the simulated grazing treatments compared to the other three treatments although the rate appeared to have slowed during low rainfall years. The declines in soil organic C and N and SMB pools depended upon a) land use management, b) quality of organic input, and c) disruptions in C cycling and magnitude of soil disturbance. These findings suggest that a close monitoring of the active and labile SOM pools may provide an early warning sign to try to minimize SOM declines.

INTRODUCTION

Through the introduction of new crop varieties on soils well supplied with water, fertilizer and pesticides, food production has increased in some commercial farming areas of the tropics. The trend however, has been opposite in most small scale farming systems with food production declining over the years due to poor soil management and low soil fertility (Woomer and Ingram, 1990). The distribution of C and N between different soil organic matter (SOM) fractions of soil is a fundamental index of the soils' capacity to support agricultural production. For this reason, attempts to fractionate SOM into the different soil C fractions that are related to productivity and soil fertility have been made (Jenkinson and Rayner, 1977; Feller, Guiraud, Hetier and Marol, 1983; Parton, Schimel, Cole and Ojima, 1987). The active fraction of soil C and N consists of the microbial biomass pool. This pool acts as a transformation matrix for all the natural organic materials in the soil, as well as a reservoir of plant-labile nutrients (Jenkinson and Ladd, 1981).

Tropical ecosystems have been deteriorating with an increasing removal of natural forest and grass cover and degradation of the soil by nutrient depletion and erosion. Sustainable use of the soil resource is a primary goal of all farming systems. Zimbabwe lies in the savanna belts of Southern Africa and the savanna woodland is an important source of nutrients for small-scale agricultural systems (Swift, Frost, Campbell, Hatton and Wilson, 1989). Arable cultivation is dependent on the soil resource following clearing of the savanna woodland and its nutrient status is improved through the movement of leaf litter between woodland and fields and with manure. Infertile soils are common in the tropics and often in these agricultural systems, SOM mineralization serves as the main source of N and other nutrients.

Decrease in SOM is an indicator of soil fertility decline. Cultivation of a soil previously supporting natural vegetation leads to considerable losses of SOM especially the microbial biomass fraction (Follet and Schimel, 1989). Microbial biomass responds quickly to stresses in the environment or to changes in organic matter inputs. While the benefits of SOM are widely appreciated, the changes in soil physical and chemical properties resultant from a decline in SOM due to land management are poorly understood. Based on such concepts, the Tropical Soil Biology and Fertility (TSBF) Programme proposed a standard field experiment in SOM dynamics aimed to address soil degradation in tropical ecosystems.

The main objective of the study was to investigate short-term soil C and N dynamics under conditions simulating disturbance of the savanna by removal of grass inputs to soil (grazing), removal of tree litter inputs to soil (clearing for pasture) and removal of both (clearing for settlement and agriculture). It also aimed to provide information on the long-term effects of land management on organic matter and to examine strategies designed to minimize soil degradation.

MATERIALS AND METHODS

The study site is a protected savanna woodland situated at the Grasslands Research Station near Marondera (18^0 10'S; 31^0 30'E), 70 km SE of Harare. The site has been undisturbed for over 40 years and fire and large herbivores have been excluded during this time. The deciduous miombo woodland at the site is dominated by leguminous tree species of *Brachystegia spiciformis* and *Julbernardia globifora* with a ground cover of a variety of grasses and shrubs (Wild and Barbosa, 1967). The climate is strongly seasonal with over 80% of the mean annual rainfall of 885 mm falling between November and March. Air temperatures are at a maximum in October (12-27^{0}C) and minimum in July (5-20^{0}C) (King and Campbell, 1994). The soils are strongly leached, acidic, sandy alfisols derived from granite and classified as Kandic Paleustalf (Soil Survey Staff, 1990) (Table 1).

Table 1. Some initial physical and chemical properties of the soil under the miombo woodland at Marondera, Zimbabwe.

Horizon and Depth	Texture (%) Sand	Silt	Clay	Bulk Density (kg dm^{-3})	Total C (%)	Total N (%)	Total P (%)	C:N	pH (H_2O)
A1 0-6 cm	76	5	19	1.28	1.36	0.162	0.078	13	5.8
A2 6-26 cm	80	8	12	1.37	0.63	0.074	0.033	9	5.6
B1 26-45 cm	65	7	28	1.39	0.42	0.048	0.029	9	5.4

The field experiment began in October 1991, at the start of the 1991-92 rain season. An area of 500 m^{-2} was subdivided into 20 5 x 5 m^2 plots and was used for the experiment in the well-studied woodland at Marondera (Campbell, Swift, Hatton and Frost, 1988). Of the 20, four were controls and were placed separately, about one metre from the treated plots.

The following five treatments represent different management of the above-ground inputs (Table 2): 1) grass and tree inputs were not altered, 2) all aboveground shoot material and falling litter removed from the plot regularly (an exploration of the "worst-case" scenario), 3) all aboveground shoot material removed from the plot with monthly tillage to 20 cm (this aimed to investigate the effect of physical disturbance on SOM dynamics), 4) all above ground grass material is regularly removed (tree inputs only) and 5) all above ground tree inputs are regularly removed (grass inputs only).

Table 2. Characteristics of five land management systems carried out in this study.

Treatment	Simulated Land Use Type
Treatment 1	SAVANNA WOODLAND- CONTROL (natural undisturbed woodland)
Treatment 2	ARABLE FIELD- ORGANIC MATTER REMOVAL (with soil disturbance via tillage)
Treatment 3	ARABLE / SETTLEMENT- ORGANIC MATTER REMOVAL (with no soil disturbance)
Treatment 4	GRAZING- TREE INPUTS ONLY (grass material removed)
Treatment 5	PASTURE- GRASS INPUTS ONLY (tree litter removed)

The exclusion of aboveground organic inputs was achieved by keeping the plots free of vegetation via regular weeding and removing falling litter. Root barriers for barring belowground inputs (Woomer, 1991) were not included in this study as they proved to be too costly. Plots were separated by dug-out trenches extending from above the soil surface down to 0.3 m. Soils were collected from the field site (three cores per plot at a depth of 0-10 cm) during the mid rain season and analyzed for total soil organic C and total soil N according to Anderson and Ingram (1989; 1993) and for microbial biomass C and N according to Srivastava and Singh (1989).

A factor of 2.64 was used for the calculations of biomass C (Vance, Brookes and Jenkinson, 1987) and a factor of 1.46 was used for biomass N calculations (Brookes, Landman, Pruden and Jenkinson, 1985). Means for total C and N, SMB C and N between plots were examined for significant differences by year or treatment with a oneway ANOVA. Where appropriate, pairwise comparisons of the means were made with Tukey's range test. Within-plot changes over time were described using linear regression procedures.

RESULTS

Soil Organic C and N

The total C contents in the top 10 cm of the miombo woodland soil in the first sampling season were not significantly different in the different plot treatments ($p > 0.05$) (Table 3). Changes started in the second sampling season. In treatments 2 and 3 where organic materials were physically removed, the average change in SOM content during the five-year sampling period was generally negative and significantly lower compared to other treatments. In the 1993-94 season, there was a 30% decline in C in the top 10 cm in the treatment where organic matter was removed with minimal soil disturbance (treatment 3). The control and the tree-inputs only (treatments 1 and

4) continued to register a general positive increase in soil C contents compared to the other three treatments although the increase was slowed during the drier seasons of 1993-94 and 1995-96 ($p < 0.05$). Removing tree litter from treatment 5 had a negative impact on the SOM dynamics due to massive disturbance of grass tillers. This resulted in huge fluctuations in total C. However, the total percentage C in this treatment was significantly higher than that of treatments 2 and 3 in the 1994-95 and 1995-96 seasons.

Total N in the top 10 cm of the different treatments followed a pattern similar to that of soil C in the first four seasons (Table 3). In the fifth season, there was a significant drop in total N content in all but one plot (treatment 2) ($p < 0.05$). In treatment 3, total N contents decreased during the experimental period. In the tree inputs and control plots (treatments 1 and 4), where the litter layer continued to increase, there were major fluctuations, which were probably related to the amount of precipitation during that period.

Table 3. Total soil organic C and N in the top 10 cm of miombo soil from the different treatments during the middle of the rain season over five years.

Plot treatment	Season 1 1991-92	Season 2 1992-93	Season 3 1993-94	Season 4 1994-95	Season 5 1995-96
			Total Soil Carbon (%)		
Treatment 1	1.05a	1.32a	1.19a	1.31a	1.41a
Treatment 2	0.84a	0.93b	0.85b	1.00b	0.75b
Treatment 3	0.81a	0.76b	0.70b	0.96b	0.67b
Treatment 4	0.99a	1.38a	1.14a	1.37a	1.54a
Treatment 5	0.94a	0.98b	0.70b	1.18c	0.95c
			Total Soil Nitrogen (%)		
Treatment 1	0.094a	0.119a	0.094a	0.124a	0.093a
Treatment 2	0.096a	0.112ab	0.081a	0.055b	0.073b
Treatment 3	0.081a	0.091b	0.072b	0.070b	0.056b
Treatment 4	0.094a	0.145c	0.083a	0.131a	0.098a
Treatment 5	0.095a	0.109a	0.080a	0.093c	0.078ab

Any two means within a column not marked with the same symbol are significantly different at p = 0.05 according to Tukey's range test.

Table 4. Microbial biomass C and N in the top 10 cm of miombo soil from the different treatments during the middle of the rain season over five years.

Plot treatment	Season 1 1991-92	Season 2 1992-93	Season 3 1993-94	Season 4 1994-95	Season 5 1995-96
			Microbial biomass C (μg biomass C g^{-1} soil)		
Treatment 1	624a	657a	722a	630a	812a
Treatment 2	614a	570b	365b	308b	414b
Treatment 3	589a	551b	373b	308b	393b
Treatment 4	623a	622c	727a	640a	804a
Treatment 5	609a	603c	649c	592c	775a
			Microbial Biomass N (μg biomass N g^{-1} soil)		
Treatment 1	62a	63a	67a	62a	72a
Treatment 2	61a	59a	42b	37b	40b
Treatment 3	60a	58a	32b	31b	37b
Treatment 4	61a	62a	68a	61a	72a
Treatment 5	62a	61a	62a	56a	66a

Any two means within a column not marked with the same symbol are significantly different at p = 0.05 according to Tukey's range test.

Soil Microbial Biomass C and N

SMB C responded to surface organic matter manipulations almost immediately (Table 4). Although differences in SMB C were noted in the top 10 cm during the first season, these were found not to be statistically significant ($p > 0.05$). SMB C and N after five seasons had the following trend: treatment 1 (control) = treatment 4 (tree inputs) > treatment 5 (grass inputs) > treatment 2 (SOM removal with soil disturbance via tillage) > treatment 3 (SOM removal with no soil disturbance).

Regression analysis showed that total SMB C was significantly correlated to SMB N ($R^2 = 0.933$; $p < 0.001$). It appeared that SMB N was slow to respond to land use changes. In the first and second seasons, there was no notable change between plot treatments (Table 4). Only in the third season were there significant differences in the top 10 cm of the soil. A general increase in microbial biomass N was noted in the control, tree input and grass input treatments. The introduction of other land management systems led to a decrease of the N present in the SMB. Tilling the soil affected the size of SMB C and N, starting in the third season. During the 1994-95 rain season, the SMB C in all the treatment plots dropped significantly ($p < 0.05$).

DISCUSSION

Soil Organic C and N

Land management strategies can affect the short-term dynamics of the active C and N pools of SOM. In addition, quantity and quality of litter inputs as well as environmental conditions (temperature, precipitation and soil moisture content) also play major roles in the labile organic matter pools. In this study, the soil lost considerable amounts of soil organic C and N following a disruption in the aboveground organic inputs. These results confirm the assumed decrease in soil organic C and N under simulated cultivation and tillage trials. Substantial declines in soil C and N due to cultivation have also been reported by other workers (Bauer and Black, 1981; Srivastava and Singh, 1989). King and Campbell (1994) reported a 10% loss of soil C from the top 50 cm of a miombo woodland soil after its conversion into an arable maize field and pine plantation. This depletion may be partly due to a reduced input of C into the soil while other biological processes such as decomposition and mineralization continue.

Low soil N contents observed in cleared plots particularly in the wetter seasons could be attributed to leaching. The importance of leaching was likely a result of high mineralization, no plants for uptake of available N and the low exchange capacity of the soil. Skujins (1981) considered soluble N compounds could be leached at the beginning of the wet season from litter accumulated during the dry season. The major part of miombo woodland soils is inherently low in N and its litter, being of low quality, is a poor source for mineral N (Mtambanengwe and Kirchmann, 1995). Thus, after disrupting the normal C and N cycles, the microorganisms appeared to mineralize C while N might be lost to immobilization and leaching.

Overall, organic matter removal reduced the levels of C, N contents as well as the microbial biomass pools after five years. The degree of C and N losses in this miombo woodland could be explained by soil texture. The soils in this woodland are sandy and thus may be less efficient in stabilizing and accumulating SOM (Ladd, Oades and Amato, 1981; van Veen, Ladd and Amato, 1985). Disruption of the soil aggregates through tillage practices and devegetation may have contributed to a more rapid mineralization through exposure of protected organic matter.

Soil Microbial Biomass C and N

SMB has frequently been proposed as an early indicator of changes in total soil C and SOM quality induced by land management practices (cultivation, settlement, pastures, mining and pollution). The study showed that the conversion of a natural ecosystem to other land management systems resulted in changes of the SMB C and N. Srivastava and Singh (1991) found that the conversion of forest into savanna resulted in 35% losses in microbial C and 42% losses in microbial N in just two years. These management techniques in this study probably caused several changes in the soil physical and chemical properties. The effects of complete removal of aboveground biomass on SMB C were apparent after one year and after two years with SMB N.

The plot simulating grazing (tree inputs treatment), registered an increase in SMB C and N and in some cases the concentrations were higher than those of the control plots. A possible reason is that any new grass shoots were promptly removed resulting in increased underground biomass because grasses have high root:shoot ratios (Frost, 1985). The death of roots and regrowth probably cause the most rapid change of the nutrient and energy situation in the soil. In addition, leaf litter in the woodland account for up to 70% of the litter standing crop (Campbell *et al.*, 1988) thus, the tree inputs plots had a different microclimate compared to other plots. These differences in microclimate among the treatments could be factors contributing to treatment differences in SOM and other measured parameters.

There was a slow but positive increase in microbial biomass C and N in the grass only plots. While previous studies have shown that SOM contents in grasslands are higher than any other land use systems (Voroney, van Veen and Paul, 1981; Oades, 1988), this was not so in this study. This was probably because the native organic matter in the treatment was that of a woodland type and five years may not have been long enough to show the effects of grass. Moreover, in the attempt to remove tree litter from the grass input plots in this closed miombo woodland (Campbell *et al.*, 1988), there was always severe disturbance to the grass plots, resulting in disruptions of the normal patterns.

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EFFECTS OF ORGANIC LEGUME RESIDUES AND INORGANIC FERTILIZER NITROGEN ON MAIZE YIELD IN MALAWI

JOHN D.T. KUMWENDA, ALEX R. SAKA, SIEGLINDE S. SNAPP, ROSAN P. GANUNGA, and TODD BENSON

Chitedze Agricultural Research Station, P.O. Box 158, Lilongwe, Malawi

SUMMARY

*The combination of inorganic fertilizers, and organic manures from cattle or legumes crops is recognised as one way to reduce the costs of inorganic fertilizers and to reduce the decline of soil fertility under smallholder cropping systems in Malawi. An experiment was conducted from the 1994/95 to the 1996/97 cropping seasons to determine the effects of organic legume residues and inorganic fertilizer nitrogen (N) on soil N and maize (*Zea mays*) yield. The experimental design was a split-plot in which seven cropping systems (legume residues from maize/legume intercrops, and from sole legume crops or sole maize were main plots and three N levels (0, 46, and 96 kg N ha*$^{-1}$*) were sub-plots. Results showed that the initial release of N was high from plots that received inorganic fertilizer without the addition of legume residues. The release of N from legume residues was retarded initially due to high [lignin + polyphenol]/N ratios. The combination of inorganic N and organic residues improved the release of N from plots with organic residues, suggesting that a starter N is required to reduce the immobilization capacity of legume residues. Nitrogen application resulted in significant yield increases over the no fertilizer application. The application of 48 kg N ha*$^{-1}$* gave the largest yield increments of 982 kg ha*$^{-1}$* in the 1995/96 cropping season and 1196 kg ha*$^{-1}$* in the 1995/96 and the 1996/97 cropping season. The highest grain yields of maize were obtained when maize was grown in rotation with legume crops [pigeon pea (*Cajanus cajan*) + maize, sunnhemp (*Crotalaria junacea*) + maize or mucuna (*Mucuna aterrima*)+ maize]. In the 1995/96 cropping season, grain yields of maize from these legume+maize rotation systems were 25 to 29% higher than maize yields from the continuous maize system (maize-maize) which yielded 4669 kg ha*$^{-1}$*. In the 1996/97 cropping season, the pigeon pea -maize-maize rotation gave the highest yield of 6616 kg ha*$^{-1}$* which was 1257 kg ha*$^{-1}$* higher than the yield from the three-year continuous maize system. Only the maize/sunnhemp intercropping system gave significantly higher maize yield than the continuous maize system. The combination of inorganic fertilizers and organic legume residues improved yields of maize, but the largest increments were obtained when maize was grown in the maize/legume intercropping systems.*

The agronomic results showed that sole legume crops when grown in rotation with maize can result in increased maize yields than when grown in intercropping systems, largely due to higher biomass production. An economic analysis, however, showed that sole continuous maize gave the highest net benefit. The best intercrop with fertilizer was pigeon pea at 96 kg N ha^{-1}* or sunnhemp at 48 kg N ha*$^{-1}$*. The maize+legume rotations (mucuna, sunnhemp or pigeon pea) had the lowest net benefits.*

INTRODUCTION

The combination of inorganic fertilizers and organic manures from cattle or legume crops is one way to reduce the costs of inorganic fertilizers and to reduce the decline in soil fertility of the smallholder cropping systems in Malawi (Kumwenda, Waddington, Snapp, Jones and Blackie 1997, 1996; Conroy and Kumwenda, 1995; MacColl, 1989, 1990; Zambezi, Kumwenda and Jones, 1994; Waddington and Heisey, 1997). At present there are few studies of these combinations. Even though crop rotation is recommended for soil fertility and crop yield improvement, most smallholders have very small land holdings (< 1 ha) (Conroy and Kumwenda, 1995) that make rotations difficult to practice. Alternative cropping systems to rotations need to be investigated for land-constrained smallholders.

This study was designed to test whether the intercropping or rotation of legumes with maize (*Zea mays* L.) can improve soil fertility and maize yields. Specific objectives were to determine (i) alternative sources of nitrogen (N) and organic matter (OM) for maize, (ii) long-term maize yield and soil fertility trends in a maize-legume based cropping system, and (iii) organic and inorganic fertilizer interactions in maize+legume based cropping systems.

MATERIALS AND METHODS

The trial was conducted at Chitedze Research Station near to Lilongwe in central Malawi. In the 1992/93 and 1993/94 cropping seasons the trial site was first planted to a sole crop of maize without fertiliser application in order to deplete soil nitrogen. The trial was started in the 1994/95 cropping season when seven cropping systems; maize+legume intercrops, sole legume crops and pure maize (see Table 1) were planted and arranged in a randomised complete block design with three replicates. The plot size of each cropping system was 12 rows x 0.9 m x 6.3 m. Pigeon pea (*Cajanus cajan*), and sunnhemp (*Crotalaria junacea*), in both intercropping or rotation systems were planted at the same time as maize, while mucuna (*Mucuna aterrima*) was planted four weeks after planting maize. In 1994/95 all cropping systems received no fertiliser. Legume residues (all above ground tops) of each legume source were incorporated in December 1995, two weeks before planting the maize.

Table 1. Experimental treatment arrangement and sequence from 1994/95 to 1996/97

1994/95 season	1995/96 season	1996/97 season
Maize+pigeon pea intercrop	Maize+pigeon pea	Maize+pigeon pea
Maize+mucuna intercrop	Maize+mucuna	Maize+mucuna
Maize+sunnhemp intercrop	Maize+sunnhemp	Maize+sunnhemp
Sole pigeon pea	Sole maize	Sole maize
Sole sunnhemp	Sole maize	Sole maize
Sole mucuna	Sole maize	Sole maize
Sole maize	Sole maize	Sole maize

In the 1995/96 and 1996/97 cropping seasons, the trial was arranged in a split-plot design with three replicates. Cropping systems were; legume residues from intercropping or rotation systems or the sole crop of maize on main-plots, and nitrogen rates (0, 46 and 92 kg N ha^{-1}) on sub-plots. Nitrogen was applied each year as urea. All plots, except plots that did not receive N, received a basal fertiliser rate of 21 kg P_2O_5 ha^{-1} from 23:21:0+4S. In the 1996/97 season, only legume residues from the maize+legume intercrops were incorporated two weeks before planting maize in December 1996.

The maize hybrid "MH17" was planted in all plots. In the 1995/96 and 1996/97 cropping seasons, maize+legume intercrops were planted in the same plots. Two crops of sole maize were grown after each sole legume crop (legume-maize-maize) to determine the residual effects of legume residues. The maize-maize-maize system was also planted in the same plots. Data included biomass of legume crops at harvest, biomass quality, and maize grain yield. Maize yield was determined by harvesting 5.4 m x 0.9 m of the two middle rows of each sub-plot. Yield was adjusted to 12.5% moisture content. The statistical analysis was done using the MSTAT package.

RESULTS AND DISCUSSION

Initial Soil Chemical and Physical Characteristics

The soil chemical and physical characteristics are shown in Table 2. The soil textural class at the experimental site is a sandy loam or sandy clay. The soil was medium acidic (pH 5.3-5.4), and the organic matter content was 4.15% from the 0-15 cm soil depth and 3.82% from the 15-30 cm soil depth. Soil nitrogen was 0.25% from a soil depth of 0-15 cm and 0.19% at 15-30 cm. Phosphorous was low in the upper soil (7.36 ppm) and medium at 15-30 cm.

Table 2. Initial soil chemical and physical characteristics at Chitedze Research Station, 1992/93 cropping season

Depth	Soil Class	pH	OM	N (%)	P (ppm)	K	Ca	Mg
0-15	sl/scl	5.3	4.15	0.25	7.36	0.39	8.06	1.17
15-30	scl	5.4	3.82	0.19	15.5	0.32	7.95	1.14

Rainfall

Monthly and yearly rainfall totals for 1994/95 to 1996/97 cropping season are shown in Table 3. The 1994/95 cropping season was very dry (478.5 mm) while the 1995/96 and 1996/97 cropping seasons were wet years (949.5 and 786.9 mm, respectively).

Maize Grain and Stover Yield in 1994/95

Maize grain and stover yields from 1994/95 cropping season are shown in Table 4. Maize yield from

Table 4. Maize grain and stover yield (kg ha^{-1}) as influenced by maize/legume intercropping at Chitedze Research Station, Malawi, 1994/95 season

Treatment	Maize stover	Maize yield
Maize/pigeon pea	10399	1171
Maize/mucuna	10946	1701
Maize/sunnhemp	11670	1833
Pure maize	13617	2978
Mean	11658	1921
CV (%)	15.9	51.5
SE	1071 NS	571*

Table 3. Monthly rainfall (mm) at Chitedze Research Station, Malawi

Site	Monthly Rainfall (mm)								Total
	October	November	December	January	February	March	April	May	
(1994/95)	36.4	18.0	142.0	151.0	118.0	10.4	2.1	0	478.5
1995/96	-	-	290.7	123.6	349.6	228.5	47.4	9.7	949.5
1996/97	-	10.3	188.3	257.1	139.5	60.2	131.5	-	786.9

the pure maize crop was significantly higher (2978 kg ha^{-1}) than from the maize+legume intercrops that gave yields ranging from 1171 to 1833 kg ha^{-1}. These yields were low because all treatments did not receive fertiliser (being the initial year), and also the season was dry (see Table 3).

Biomass Production and Quality in 1995/96 and 1996/97

Dry matter of legumes at harvest at Chitedze Research Station is shown in Table 5. Legume growth was reduced when grown in the intercropping system with maize compared to pure stands. Fresh pigeon pea leaves or leaves plus stems, and mucuna leaves had higher N concentrations than pigeon pea or mucuna litter (see Table 6). However, pigeon pea or mucuna litter had the highest calcium (Ca) concentration. These results are consistent with those reported by Constantinides and Fownes (1994) in Hawaii, USA. Lignin and polyphenoles were generally high for all samples, but pigeon pea or mucuna litter had higher lignin, polyphenoles, and (lignin + polyphenolics)/N ratios than fresh leaves (Table 6). The higher (L + PP)/N ratios suggest that pigeon pea or mucuna litter would decompose at a slower rate than fresh air-dried leaves (Fox, Meyers and Vallis, 1990).

Table 5. Dry matter yield (kg ha^{-1}) of legumes at harvest in a maize/legume intercropping system at Chitedze Research Station, Malawi, 1994/95 season

Treatment	Dry matter yield
Maize/pigeon pea	2489
Maize/sunnhemp	4741
Maize/mucuna	423
Pure pigeon pea	9033
Pure mucuna	3251
Pure sunnhemp	14699
Mean	5773
CV (%)	22.2
SE	741***

Table 6. Concentration of N, P, Ca, lignin and polyphenols in 12 month old pigeon pea and mucuna legume plants grown at Chitedze Research Station in Malawi

Sample	N (%)	P (%)	Ca (%)	Lignin (L) (%)	Polyphenolics (PP) (%)	(L + PP) /N
Pigeon pea fresh leaves and stems	4.24	0.23	0.57	14.60	2.90	4.13
Pigeon pea litter (dried)	1.67	0.07	1.49	19.10	3.10	13.29
Pigeon pea fresh leaves	4.96	0.26	0.43	15.30	2.50	3.59
Mucuna litter (dried)	1.97	0.07	1.90	11.1	3.20	7.26
Mucuna fresh leaves	4.10	0.26	0.83	8.60	0.50	2.22

Soil Nitrate

Effects of fertiliser application -- Soil nitrate increased with rate of N application (Figure 1), although differences among N rates were most marked early during maize growth. The similarity of soil nitrate levels later in the season could be due to higher N uptake by the larger plants at the high N rate. The addition of inorganic fertilizer N to incorporated legume residues increased soil nitrate when compared to soil nitrate obtained from plots without inorganic N (Table 7). This suggests that in the initial years or where initial soil N is low, some modest amount of inorganic N should be added to organic legume residues to enhance mineralisation and consequent supply of N to the following maize crop. Data in Table 7 also show that soil nitrate peaked at 60 and 75 DAP in plots in which legume residues were incorporated without N application. These values were much higher than those obtained from maize plots without fertilizer N application or without incorporation of legume residue.

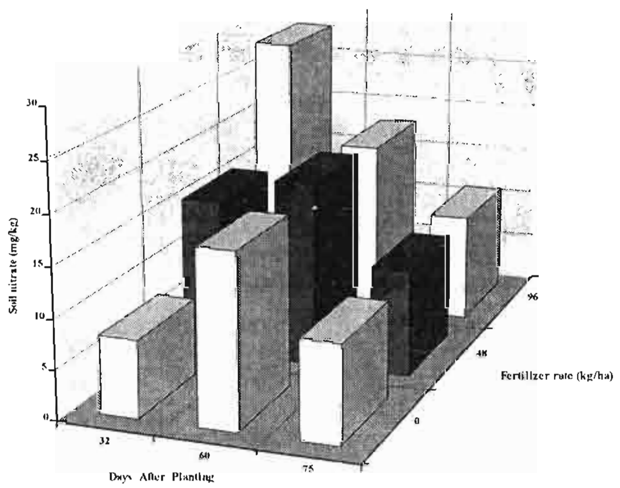

Figure 1. Soil nitrate (mg/kg) as influenced by inorganic fertilizer application at Chitedze research station, 1995/96

Table 7. Soil nitrate as influenced by fertilizer N application and legume residue incorporation at Chitedze Research Station, Malawi, 1995/96 season

Treatment	32 DAP	60 DAP	75 DAP
Legume residue incorporation without fertilizer N	7.5	18.0	18.0
Legume residue incorporation with fertilizer N*	20.7	16.8	11.0
Maize after maize without fertilizer N or legume residue incorporation	9.9	13.2	9.7
Maize after maize with fertilizer N* application alone	31.4	25.3	9.9

* Mean value from 48 and 96 kg N ha^{-1}

Effect of cropping systems -- Averaged over cropping systems the trend for soil nitrate at 32 and 60 DAP, was maize after maize > maize+legume rotation > maize+legume intercrop (Figure 2). In this study, immobilisation of soil N was not measured but is, in part, reflected in lower soil nitrate (Figure 2) at 32 and 60 DAP in maize plots in which legume residues were incorporated compared to those without incorporation of legume residue (Fox *et al.*, 1990; Giddens, 1985; Meyers *et al.*, 1994). Even with application of fertilizer N to legume residues immobilization could have occurred. Immobilisation of soil N could be the result of the high levels of lignin and polyphenoles and the (L + PP)/N ratios in these legumes (see Table 6). Palm and Sanchez (1991) reported that legumes with high polyphenolics such as pigeon pea, despite high N concentrations, can result in immobilisation and a delay in the subsequent release of N. Sakala, Cadisch and Giller (1996) also reported that pigeon pea residues showed a short N immobilisation period (21 days after incubation) followed by a steady net mineralization. The addition of starter fertilizer N should reduce the immobilisation period of legume residues with high (L + PP)/N ratios.

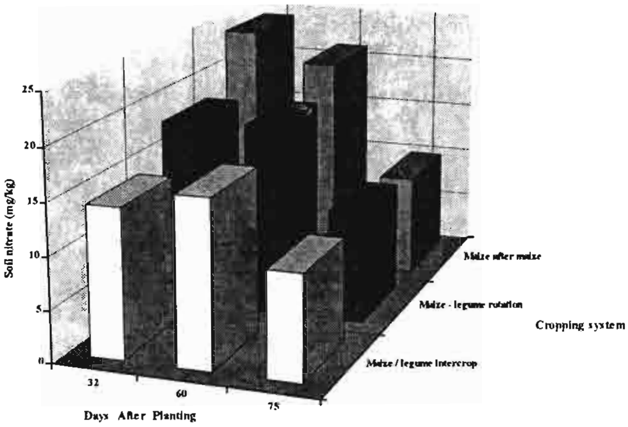

Figure 2. Soil nitrate as influenced by cropping system at Chitedze research station, 1995/96

Grain Yield in 1995/96 and 1996/97

Effects of nitrogen application -- Nitrogen application significantly ($P < 0.01$) increased maize yields in both years (Figs. 3 and 4). The application of the first 48 kg N ha^{-1} gave the largest yield increments; which were 982 kg ha^{-1} (22%) in the 1995/96 season (Figure 3) and 1196 kg ha^{-1} (28%) in the 1996/97 cropping season (Figure 4). The application of N up to 96 kg N ha^{-1} gave a significant yield increase (1072 kg ha^{-1}, 19%) only in the 1996/97 cropping season.

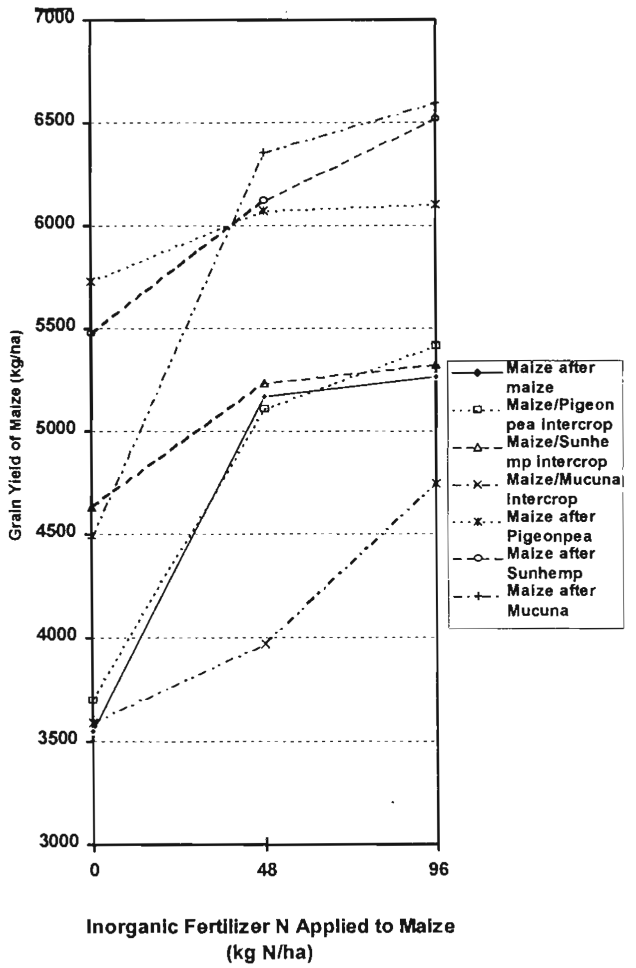

Figure 3. Grain yield of maize as influenced by incorporation of legume residues and inorganic N fertiiizer at Chitedze research station, 1995/96

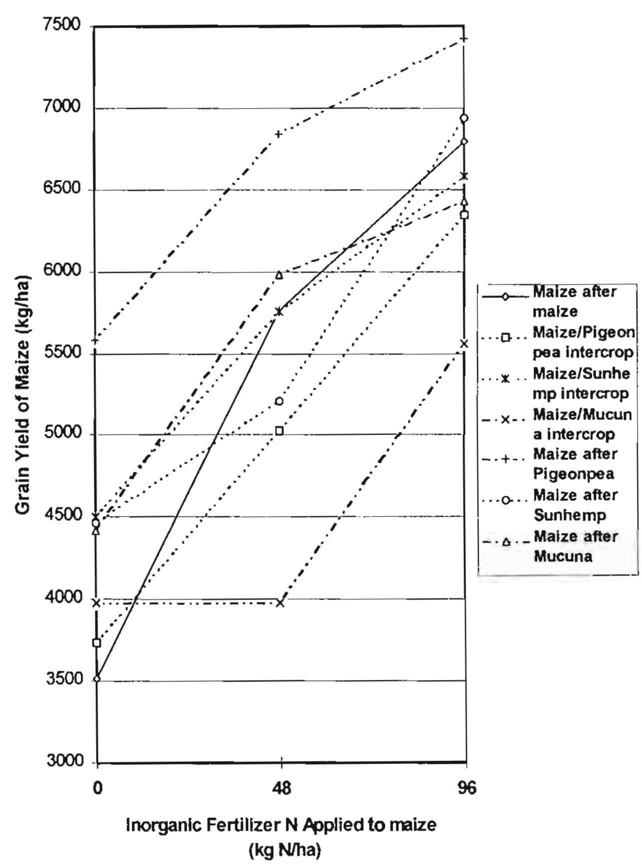

Figure 4. Grain yield of maize as influenced by incorporation of legume residues and inorganic N fertiiizer at Chitedze research station, 1996/97

Effects of cropping systems -- In both the 1995/96 and 1996/97 cropping seasons, the highest grain yields of maize were obtained when maize was grown in rotation with legume crops; pigeon pea, sunnhemp and mucuna (Figures 3 and 4). In the 1995/96 cropping season, grain yields of maize from the legume-maize rotation systems were 28, 29, 25%, respectively for these legumes; higher than maize yields from the continuous maize system (maize-maize) which averaged 4669 kg ha^{-1} (Figure 3).

In the 1996/97 cropping season the highest maize yield was obtained from the pigeon pea-maize-maize rotation (6616 kg ha^{-1}) which was 1257 kg ha^{-1} (23.4%) higher than the 3-year continuous maize system (Figure 4). This shows that pigeon pea had the largest residual effects which were still observed in the second year. The high maize yields from the legume-maize rotation are in part due to the high biomass produced from the sole legume crops (see Table 5).

Grain yields of maize from the maize+sunnhemp intercropping system were significantly higher than from the continuous maize system (Figures 3 and 4). The maize+mucuna intercropping system gave a lower maize yield than the continuous maize, most likely due to competition from mucuna.

Cropping system x nitrogen effects -- The analysis of variance of these results showed that the cropping system x nitrogen application interactions were not large enough to be significant. However, results clearly show that in 1995/96 (Figure 3) maize yields without fertiliser after pigeon pea, sunnhemp and mucuna without inorganic fertilizer were 2.1, 2.0, and 1.0 t ha^{-1} higher, respectively, than continuous maize without fertiliser N. Again maize yields obtained after legume crops when inorganic fertilizer N was not applied were equivalent to those from continuous maize receiving 48 kg N ha^{-1}, suggesting that legume residues alone were sufficient as a source of fertiliser.

Similarly, in the 1996/97 season, the legume-maize-maize rotation systems without fertiliser gave yields ranging from 4418 to 5582 kg ha^{-1} (Figure 4) that were much higher (by 25-62%) than the yield (3519 kg ha^{-1}) from the 3-year continuous maize without added fertiliser. Also maize yield from the pigeon pea-maize-maize rotation system was equivalent to that obtained from the maize-maize-maize system which received 48 kg N ha^{-1}. However, in the maize+legume intercropping systems, the addition of at least 48 kg N ha^{-1} resulted in yield increments of 1 to 1.5 t ha^{-1} in the maize+pigeon pea and maize+sunnhemp intercrops (Figure 3). The response to the addition of inorganic fertilisers in this system was because low biomass of legume residues were produced in the intercropping systems (Table 5).

PRELIMINARY ECONOMIC ANALYSIS

No economic analysis was done for the maize yield obtained in the 1994/95 cropping season (Table 4). This was because the sole maize yield was significantly higher than the yield from the intercropping treatments, and thus there was no need for an economic analysis. Maize yield used for the economic analysis for the 1995/96 and 1996/97 cropping seasons was discounted by 20% (Table 8). Averaged over the two seasons, the economic analysis showed that the continuous sole maize crop gave the highest net benefit while the maize-legume rotations gave the lowest net benefits (Table 8). The best net benefits from intercrops with fertiliser were maize+pigeon pea at 96 kg N ha^{-1} and maize+sunnhemp at 48 kg N ha^{-1}. For the unfertilised intercrop, the best net benefit was from the maize+sunnhemp intercrop. The maize+mucuna intercrop did not perform as well as the other intercrops.

CONCLUSION

These results show that large grain yields of maize (4400 to 5700 kg ha^{-1}) were obtained when grown in rotation with legume manures, even without the addition of inorganic fertilisers when compared to continuous maize which yielded 3500 kg ha^{-1} without inorganic fertiliser. In this study the largest yields were obtained when maize was grown after pigeon pea and sunnhemp, which also showed higher residual effects in the second year of rotation. The large yields obtained after sole legume crops were attributed to the high biomass that were produced from these plots. The sole continuous maize gave the highest net benefit while the maize+legume rotation systems gave the lowest net benefits. Net benefits from the maize+legume systems were intermediate.

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Table 8. Economic analysis of the maize-legume cropping systems in Malawi

				Maize price per kg: MK1.55								
Maize seed cost	**Legume seed cost**	**Discount rate**	**Cost of fertilizer**	**0**	**700**	**1400**	**Gross Benefits**			**Net benefits over two years (MK)**		
				0kgN/ha	48kgN/ha	96kgN/ha	0	48	96	0	48	96
			1995/96 season									
400			Maize after maize	3547	5167	5267	5497.85	8008.85	8163.85	9279	12483	11367
400	24		Maize/pigeonpea intercrop	3696	5108	5415	5728.8	7917.4	8393.25	9655	12267	11740
400	200		Maize/sunnhemp intercrop	4635	5233	5324	7184.25	8111.15	852.2	11971	12270	11129
400	200		Maize/mucuna intercrop	3588	3972	4745	5561.4	6156.6	7354.75	8996	8687	9484
400	32	1.2	Maize after pigeonpea	5729	6073	6104		9413.15	9461.2	6968	6712	6052
400	450	1.2	Maize after sunnhemp	5477	6121	6516	8489.35	9487.55	10099.8	6224	6356	6167
400	450	1.2	Maize after mucuna	4484	6357	6598	6950.2	9853.35	10226.9	4942	6661	6272
			1996/97 season									
400			Maize after maize	3519	5766	6791	5454.45	8937.3	10526.05	9200	14185	15698
400	24		Maize/pigeonpea intercrop	3733	5028	6346	5786.15	7793.4	9836.3	9760	12040	14385
400	200		Maize/sunnhemp intercrop	4499	5754	6581	6973.45	8919.7	10200.55	11585	13751	14701
400	200		Maize/mucuna intercrop	3980	3982	5558	6169	6172.1	8614.9	10110	8716	11794
400	32	1.2	Maize after pigeonpea	5582	6842	7442	8652.1	10605.1	11535.1	6778	7706	7781
400	450	1.2	Maize after sunnhemp	4461	5206	6936	6914.55	8069.3	10750.8	4912	5174	6709
400	450	1.2	Maize after mucuna	4418	5984	6431	6847.9	9275.2	9968.05	4857	6179	6057
			Mean of two seasons									
400			Maize after maize	3533	5467	6029	5476.15	8473.08	9344.95	9240	13334	13532
400	24		Maize/pigeonpea intercrop	3715	5068	5881	5757.48	7855.4	9114.78	9707	12154	13062
400	200		Maize sunnhemp intercrop	4567	5494	5953	7078.85	8514.93	9226.38	11778	13011	12915
400	200		Maize/mucuna intercrop	3784	3977	5152	5865.2	6164.35	7984.83	9553	8701	10639
400	32	1.2	Maize after pigeonpea	5656	6458	6773	8766.03	10009.13	10498.15	6873	7209	6916
400	450	1.2	Maize after sunnhemp	4969	5664	6726	7701.95	8778.43	10425.3	5568	5765	6438
400	450	1.2	Maize after mucuna	4451	6171	6515	6899.05	9564.28	10097.48	4899	6420	6165

A discount rate of 20% was applied to the net benefits of the 2nd year.

Seed costs are estimates.

1US$ = MK22.00

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BENEFICIATION OF DOROWA PHOSPHATE ROCK THROUGH COMPOSTING WITH CATTLE MANURE: RESIDUAL EFFECTS ON GROUNDNUT

DAVID K.C. DHLIWAYO

Soil Productivity Research Laboratory, Private Bag 3757, Marondera, Zimbabwe

SUMMARY

Composting Dorowa phosphate rock (DPR), gypsum, single superphosphate (SSP) and Compound fertilizer (CpD) with cattle manure in cattle kraals or curing heaps simultaneously enhanced the residual agronomic effectiveness of both DPR-based P fertilizer materials and cattle manure by an average of 82% (range, 72-99%) for groundnut kernels, and 96% (range, 73-116%) for stover yields, compared with the control (zero treatment). The residual agronomic effectiveness of SSP was found to be 37% for groundnut kernels and 38% for stover yields; compared with the control. CpD had a residual effectiveness of 32% for groundnut kernels and 34% for stover yields relative to the control.

Partial acidulation, pelletization and compaction of DPR are alternative low cost beneficiation processes that also enhance the residual agronomic effectiveness of DPR. Composting partially acidulated, pelletized and compacted DPR-based P fertilizer materials with cattle manure is a feasible technology that could be adopted by resource poor smallholder farmers who live around Dorowa Phosphate Mine in Zimbabwe.

INTRODUCTION

Most crop production in Zimbabwe is carried out on soils that are inherently deficient in N, P, S, Mg, Ca and micronutrients. Fertilizer inputs are required to supply and maintain soil fertility for crop and pasture production on these soils. However, the escalating cost of fertilizers has made it difficult for most communal area (CA) farmers in Zimbabwe to apply adequate fertilizer inputs to their depleted lands to achieve economic yields for their survival. Collett (1987) reported that fertilizer use by peasant farmers is declining because the farmers are failing to pay back expensive loans and less money is now available for fertilizer loans. There is therefore a need to develop alternative low cost fertilizer materials in Zimbabwe. Dorowa phosphate rock (DPR), which is the main mineral source of P in Zimbabwe, provides an opportunity to develop low cost P fertilizers. The direct use of DPR as a P fertilizer has been reported to be agronomically ineffective in both the greenhouse (Govere, Chien and Fox, 1995a; Dhliwayo and Mandiringana, 1994; Fernandes, Van Straaten, Dhliwayo, Fundire, Mandiringana, Mahlangu and Maponga, 1994; Fernandes, Van Straaten, Dhliwayo and Maponga, 1995) and the field (CSRI Annual Reports, 1984/85 to 1992/93; Fernandes *et al.*, 1995; Dhliwayo and Mukurumbira, 1996) due to its igneous nature (Khasawneh and Doll, 1978; Barber, 1989; Fernandes, 1989).

Beneficiation of DPR is needed to enhance its agronomic effectiveness. Partial acidulation of phosphate rock (PR) or pelletization/compaction of PR with soluble fertilizers such as single superphosphate (SSP), triple superphosphate (TSP) or urea is a simpler and cheaper alternative way to produce P fertilizers from an indigenous PR source that may otherwise be unsuitable for use as P fertilizer (Chien, Sale and Friesen, 1990; Menon, Chien and Gadalla, 1991; Kpomblekon, Chien, Henao and Hill, 1991; Govere *et al.*, 1995a). Composting of DPR-based P fertilizer materials with cattle manure proved to be effective in enhancing the agronomic effectiveness of both DPR and cattle manure (Dhliwayo and Mukurumbira, 1996).

While the agronomic effectiveness of composted DPR-based P fertilizer materials and cattle manure in the field is known (Dhliwayo and Mukurumbira, 1996), the residual effectiveness of these fertilizer materials is not known. Residual effects must be considered when evaluating the agronomic effectiveness of new fertilizer materials (Govere, Chien and Fox, 1995b) because, of all the nutrient elements, P is the most susceptible to immobilization by soil, so that plants usually recover less fertilizer P in the short-term than other nutrients (Holford and Crocker, 1991). Residual effectiveness of phosphate rock has been reported to be greater than (Khasawneh and Doll, 1978; Chien, Hammond and Leon, 1987), equal to (Bationo, Johnson, Kone, Mokwunye and Henao, 1991) or less than (Engelstad, Jugsujinda and DeDatta, 1974; Bolland and Bowden, 1984; Resseler and Werner, 1989) that of superphosphate. The residual effects of P fertilizer materials are part of the economic return expected from fertilizer investments. Hence it is very important with P fertilizer recommendations to account for residual effects since this will affect future fertilizer needs and future profits (Govere *et al.*, 1995b).

The objective of this study was therefore to determine the residual effects of DPR-based P fertilizer materials composted with cattle manure in cattle kraals (pens) or curing heaps and compare them to SSP or TSP. The null hypothesis was that the P fertilizer materials would have a lower residual effect and result in lower kernel and stover yields of groundnut (*Arachis hypogea* L.) cv. Spanish compared with composted materials.

MATERIALS AND METHODS

Dhliwayo and Mukurumbira (1996) began the beneficiation of DPR-based P fertilizer materials with cattle manure in 1995. Duplicate kraals were erected at three sites -- Svosve, Duri and Mugadza. Every two weeks 20 kg of phosphate rock (DPR) was added to one of the kraals until a total of 200 kg DPR was applied. At the end of July 1995 manure in both kraals was dug out and left to cure in heaps until the end of October 1995, before application on experimental plots. Manure was also mixed with DPR or gypsum and left to cure in heaps for two months (September - October, 1995) before field application in experimental plots. Nine manure/fertilizer treatments were compared in a randomized complete block design (RCBD) replicated thrice per site in the 1995/96 season using maize (*Zea mays* L.) hybrid R215 as the test crop.
These were:
1. 0 = Control (zero)
2. M = Manure (10 t/ha)
3. MDR = Manure + DPR composted in kraals (10 t/ha)
4. MDH = Manure + DPR composted in heaps (10 t/ha)
5. MGH = Manure + gypsum composted in heaps (10 t/ha)
6. MSP = Manure + SSP applied in the field (manure at 10 t/ha; SSP, 150 kg P_2O_5/ha)
7. MCD = Manure + Compound D applied in the field (manure at 10 t/ha; Compound D at 150 kg P_2O_5/ha)
8. SSP = Single Superphosphate (150 kg P_2O_5/ha)
9. CpD = Compound D (150 kg P_2O_5/ha).

Results from an analysis of the manure and manure + P fertilizer applied in 1995/96 season are shown in Table 1.

Table 1. Chemical and physical analysis of samples of manure composted in kraals (pens) or in heaps with phosphate materials or with gypsum

	N	P	K	Ca	pH	% Sand
	<------------	%	---------->			
SVOSVE						
M	0.63	0.05	1.02	0.85	9.36	62
M + DPR (K)	0.89	0.41	1.11	3.74	9.39	47
M + DPR (H)	0.67	0.48	0.77	6.03	8.87	57
M + GYPSUM (H)	0.80	0.03	1.11	3.53	8.05	58
MEAN	0.75	0.24	1.00	3.54	8.92	56
DURI						
M	0.44	0.01	1.10	1.36	9.24	79
M + DPR (K)	0.64	0.40	0.63	1.59	9.26	58
M + DPR (H)	0.59	0.37	0.76	4.88	8.72	64
M + GYPSUM (H)	0.53	0.01	0.81	3.19	8.00	64
MEAN	0.55	0.20	0.83	2.76	8.81	66
MUGADZA						
M	0.48	0.01	0.80	1.22	9.22	75
M + DPR (K)	0.67	0.12	0.77	2.62	9.32	63
M + DPR (H)	0.51	0.10	0.69	2.18	9.23	75
M + GYPSUM (H)	0.56	0.01	0.61	2.24	7.96	76
MEAN	0.55	0.06	0.72	2.07	8.93	72
CHAKANDIWANA						
M	0.54	0.05	0.87	1.13	8.93	72
M + DPR (H)	0.67	0.48	0.99	6.67	9.08	61
M + 25% PAPR (H)	0.55	0.48	0.72	2.23	7.99	64
M + 50% PAPR (H)	0.62	0.57	0.80	1.75	7.78	70
M + PPB 30/70 (H)	0.61	0.66	0.77	3.48	8.21	62
M + CPB 30/70 (H)	0.64	0.69	0.81	1.38	8.35	56
M + PPB 50/50 (H)	0.64	0.71	0.93	2.96	7.69	73
M + CPB 50/50 (H)	0.66	0.73	0.87	2.42	7.65	62
M + TSP (H)	0.68	0.75	0.86	1.80	7.25	70
MEAN	0.62	0.57	0.85	2.65	8.10	66

M = Manure, K = composted in kraals, H = composted in heaps
DPR = Dorowa Phosphate Rock, TSP = Triple Superphosphate
25% PAPR = 25% partially acidulated phosphate rock
50% PAPR = 50% partially acidulated phosphate rock
PPB 30/70 = 30/70 TSP/DPR pelletized phosphate blend (PPB)
CPB 30/70 = 30/70 TSP/DPR compacted phosphate blend (CPB)
PPB 50:50 = 50:50 TSP/DPR PPB, CPB 50:50 = 50:50 TSP/DPR CPB

At a fourth site (Chakandiwana), 600 kg manure was mixed with up to 30 kg of DPR, 25% PAPR, 50% PAPR, 30:70 TSP:DPR pelletized phosphate blend (PPB); 30:70 TSP:DPR compacted phosphate blend (CPB); 50:50 TSP:DPR PPB; 50:50 TSP:DPR CPB and triple superphosphate (TSP) and left to cure in heaps for two months (September-October 1995) before field application in experimental plots. Eighteen treatments were applied and compared at two rates (80 kg P_2O_5/ha or 5 t manure/ha and 160 kg P_2O_5/ha or 10 t manure/ha) in a RCBD replicated three times in the 1995/96 season using maize (*Zea mays* L.) hybrid R215 as the test crop.
These treatments were:
1. 0 = zero
2. D = DPR

3. 25P = 25% PAPR
4. 50P = 50% PAPR
5. P30 = PPB 30/70 TSP/DPR
6. C30 = CPB 30/70 TSP/DPR
7. P50 = PPB 50/50 TSP/DPR
8. C50 = CPB 50/50 TSP/DPR
9. TSP = Triple superphosphate
10. M = Manure
11. MD = Manure + DPR
12. M25 = Manure + 25% PAPR
13. M50 = Manure + 50% PAPR
14. MP30 = Manure + PPB 30/70 TSP/DPR
15. MC30 = Manure + CPB 30/70 TSP/DPR
16. MP50 = Manure + PPB 50/50 TSP/DPR
17. MC50 = Manure + CPB 50/50 TSP/DPR
18. MTP = Manure + TSP.

Analysis of the manure and manure + P fertilizer applied in 1995/96 season is shown in Table 1.

After the 1995/96 experiment, the same sites and plots (Table 2) were re-cropped with groundnut cv. Spanish in the following 1996/97 season on residual fertility with no fertilizer added. The groundnut plant spacing was 45 cm between rows and 7.5 cm within a row. The gross plot was 6 m x 5 m while the net plot was 2 m x 2 m. At harvest the groundnut kernel and stover yields were determined.

Table 2. Characteristics of the sites selected

PARAMETER	SITE			
	Svosve	Duri	Mugadza	Chakan-diwana
Natural Region (NR)	IIb	III	IV	IV
Distance from Dorowa mine (km)	200	20	0.5	40
pH (0.01M $CaCl_2$)	4.4	4.3	5.2	4.6
Olsen P ($\mu g P_2O_5/g$)	27.6	22.6	25.6	6.7
% Clay	4.8	2.3	2.8	2.3
% Silt	5.5	3.5	4.5	3.5
% Sand	89.7	94.2	92.7	94.2
Field capacity (%) at 1/10 bar	4.5	6.3	10.5	7.0

Analysis of variance was performed for groundnut kernel and stover yields.

RESULTS AND DISCUSSION

The null hypothesis was rejected because, for the specific conditions of the field tests, significant differences in groundnut kernel and stover yields were observed after cropping on residual P fertility.

Residual Effect of Beneficiated Dorowa Phosphate Rock At Svosve, Duri and Mugadza

Effect of site on groundnut kernel and stover yields after cropping on residual P fertility – Table 3 shows the kernel and stover yields of groundnut at three sites after cropping residually in the 1996/97 season. Groundnut kernel and stover yields at Mugadza were significantly ($P<0.05$) higher than at both Svosve and Duri. Svosve (NR IIb) and Duri (NR III) received a lot of rainfall during the 1996/97 season that resulted in waterlogging which in turn greatly reduced both the kernel and stover yields of groundnut. Mugadza (NR IV), received adequate rainfall without waterlogging, which did not interfere with the natural process of nitrogen fixation, and hence the high kernel and stover yields of groundnut at that site.

Table 3. Effect of site on groundnut kernel yield (kg/ha) and stover yield (kg/ha) after residual cropping in the 1996/97 season

Site	Kernel Yield [LSD (P<0.05) = 183]	Stover Yield [LSD (P<0.05) = 457]
Svosve	1071	3372
Duri	978	3646
Mugadza	2426	6469

Effect of residual manure/P fertilizer materials on groundnut kernel and stover yields – Table 4 shows the effect of residual manure and P fertilizer materials on the kernel and stover yields of groundnut across three sites (Svosve, Duri and Mugadza) in 1996/97. The percent increase in groundnut kernel yield over the control (zero treatment) was 74, 99, 73, 83, 90, 72, 38 and 37 for M, MDK, MDH, MGH, MSP, MCD, SSP and CpD, respectively. All these increases were significantly ($P<0.05$) greater than the control. However, the residual effects of manure and manure + fertilizer treatments (M, MDK, MDH, MGH, MSP and MCD) on groundnut kernel yield were not significantly different from each other, and

Table 4. Effect of residual manure and phosphate on groundnut kernel yield (kg/ha) and stover yield (kg/ha) in the 1996/97 season

Fertilizer Material	Kernel Yield [LSD (P<0.05) = 317]	Stover Yield [LSD (P<0.05) = 792]
O	915	2626
M	1592	5671
MDK	1823	5346
MDH	1586	4545
MGH	1670	5098
MSP	1739	5177
MCD	1577	5006
SSP	1271	3476
CpD	1253	3517

the residual effects of the two fertilizer treatments (SSP and CpD) were also not significantly different from each other (Table 4). The residual effect of manure and manure + fertilizer treatments on kernel yield was greater than that of the two fertilizers (SSP and CpD). Most of the SSP and CpD may have been used up in the previous 1995/96 season leaving little nutrients for the following 1996/97 groundnut crop. Whereas with the manure and manure + fertilizer materials which are effectively slow release fertilizers, some of the nutrients may have been retained and released in the following 1996/97 season, as also reported by Holford and Crocker (1991).

Increase in groundnut stover yield over the control (zero treatment) was 116, 104, 73, 94, 97, 91, 32 and 34 percent respectively for M, MDK, MDH, MGH, MSP, MCD, SSP and CpD. All these increases were significantly ($P<0.05$) greater than in the control. Again the residual effect of SSP and CpD was significantly ($P<0.05$) lower than that of manure and manure + fertilizer (Table 4). M and MDK had a significantly higher residual effect than MDH (Table 4). However, the residual effects of M, MDK, MGH, MSP and MCD; and MDH, MGH, MSP and MCD on groundnut stover yield were not significantly ($P<0.05$) different (Table 4). The slow release nature of the manure and manure + P fertilizer treatments meant that further mineralization of nutrients in the following (residual) 1996/97 season could have occurred. The significant ($P<0.05$) site x fertilizer material interaction on groundnut stover yield in the 1996/97 residual season (Table 5) shows the adverse effect of the high rainfall at the two sites (Svosve and Duri) as discussed earlier.

Table 5. Effect of site x fertilizer material interaction on groundnut stover yield (kg/ha) in the 1996/97 season [LSD ($P<0.05$) = 1371]

		Site	
Fertilizer Material	Svosve	Duri	Mugadza
O	1062	2455	4362
M	5053	5385	6575
MDK	4877	3831	7328
MDH	3219	3146	7272
MGH	4146	4404	6745
MSP	3495	4794	7242
MCD	4249	3703	7067
SSP	1531	2697	6202
CpD	2721	2397	5432

Residual Effect Of Beneficiated Dorowa Phosphate Rock At Chakandiwana

Effect of residual phosphate/manure rate on kernel and stover yields of groundnut -- Table 6 shows the effect of residual phosphate/manure rate on kernel and stover yields of groundnut at Chakandiwana in the 1996/97 season. Where rates of 80 kg P_2O_5/5 t manure and 160 kg P_2O_5/10 t manure had been applied in 1995/96, groundnut kernel yields were significantly ($P<0.05$) higher by 69 and 141% and stover yields by 40 and 81%, compared to the control.

Table 6. Effect of phosphate/manure rate on kernel and stover yields (kg/ha) of groundnut at Chakandiwana site applied in 1995/96 season and residually cropped in 1996/97 season

Phosphate/manure rate	Kernel yield	Stover yield
0	863 a	2 884 a
80 kg P_2O_5/ha; 5 t manure/ha	1455 b	4023 b
160 kg P_2O_5/ha; 10 t manure/ha	2078 c	5210 c
LSD ($P < 0.05$)	495	1100

a,b,c, Means with the same letters for each column are not significantly different ($P < 0.05$)

Effect of residual partially acidulated, pelletized, compacted and composted Dorowa phosphate rock based-P fertilizer materials on groundnut kernel and stover yields -- Partial acidulation, pelletization and compaction of DPR significantly ($P<0.05$) enhanced the residual agronomic effectiveness of the rock on groundnut kernel and stover yields at Chakandiwana in 1996/97 (Table 7). As the percent acidulation, or the TSP/DPR ratio increased, the residual agronomic effectiveness of the fertilizer materials in-

Table 7. Effect of residual manure and phosphate on groundnut kernel yield (kg/ha) and stover yield (kg/ha) in the 1996/97 season at Chakandiwana

Fertilizer Material	Kernel Yield [LSD ($P<0.05$) = 485]	Stover Yield LSD ($P<0.05$) = 1121]
O	863	2884
D	1191	3600
25P	1226	4131
50P	1838	4694
P30	1372	4504
C30	1714	4457
P50	1413	3928
C50	1878	5264
TSP	1629	4518
M	2178	5208
MD	1569	3736
M25	1618	4460
M50	2088	5019
MP3	1815	4529
MC3	1973	4658
MP5	2200	4652
MC5	2246	5768
MTP	2082	5365

creased, possibly due to increased *in situ* acidulation of the rock by TSP or the direct residual effect of increasing TSP, or both (Chien *et al.*, 1987). Composting manure with DPR, PAPR, PPB, CPB or TSP significantly ($P<0.05$) improved the residual agronomic effectiveness of manure on groundnut kernel and stover yields (Table 7). These results agree with the work reported by Grant (1970), Rodel, Hopley and Boultwood (1980), and Mugwira (1985) which indicated that supplementing manure with inorganic P or P + N enhanced the direct and/residual agronomic effectiveness of the manure. In my study it would appear that composting manure with DPR-based P fertilizer materials simultaneously improved the quality of manure and the solubility of PR which in turn could have enhanced the residual agronomic effectiveness of the fertilizer materials.

CONCLUSION

The residual agronomic effectiveness of Dorowa phosphate rock (DPR) and cattle manure can be greatly enhanced by composting DPR with manure in cattle kraals (pens). This technology is feasible, particularly with CA farmers around Dorowa Phosphate Mine in Buhera district, where transport costs would not offset the benefits of the technology.

Partial acidulation, pelletization and compaction of DPR are alternative low cost beneficiation processes that also enhance the residual agronomic effectiveness of DPR. Composting partially acidulated, pelletized and compacted DPR-based P fertilizer materials with cattle manure is an economic and feasible technology that can be adopted by resource poor smallholder farmers in Zimbabwe.

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AN EVALUATION OF THE AGRONOMIC EFFECTIVENESS OF LOW RATES OF CATTLE MANURE AND COMBINATIONS OF INORGANIC N IN ZIMBABWE

HERBERT K. MURWIRA[1], FANUEL TAGWIRA[2], REGIS CHIKOWO[2] and STEPHEN R. WADDINGTON[3]

[1]TSBF, c/o ACFD, Box A469, Avondale, Harare; [2]Africa University, Box 164, Mutare, and [3]CIMMYT, Box MP163, Mt Pleasant, Harare, Zimbabwe

SUMMARY

The paper presents the first year (1996/97) results of a multi-locational SoilFertNet trial established at Domboshava, Kodzwa, Muchinjike, Musami, Wedza and Sanhwa. The trial was designed to evaluate the agronomic effectiveness of modest amounts of cattle manure when combined with inorganic fertilizer nitrogen. The trial had a factorial design with three rates of inorganic N (0 kg N/ha, 40 kg N/ha and 80 kg N/ha) applied as ammonium nitrate and four levels of cattle manure (0 kg N/ha equivalent, 20 kg N/ha equivalent, 40 kg N/ha equivalent, and 60 kg N/ha equivalent). Fertilizer effects were significant with a linear trend at all sites except Muchinjike and Wedza where excessive rains waterlogged the trials. Manure effects were varied, and there was no interaction between manure and fertilizer at all the sites.

INTRODUCTION

Livestock-cropping systems are the predominant farming systems in Zimbabwe, particularly in the higher rainfall areas of Natural Regions 2 and 3. In these systems, cattle manure forms a significant soil fertility input for maize and other crops. The availability of cattle manure is limited with farmers not having enough quantities to apply to all of their arable lands. The situation is further compounded by the poor quality of manure in the communal areas. Many studies in Zimbabwe indicate that manure alone generally produced low crop yields and that it needed supplementation with inorganic fertilizers, particularly N, for optimum yields (Grant, 1981; Mugwira, 1985). It is necessary therefore, that research efforts be made to determine optimum combinations of manure and fertilizer. A factorial arrangement of treatments is one way to compare different rates of manure or fertilizer and the additive effects of combined manure and fertilizer treatments.

A multi-locational trial was established by members of SoilFertNet during the 1996/97 growing season to quantify the productivity and N-use gains by combining organic material from cattle manure with inorganic N fertilizer for maize at rates practicable for smallholder farmers in Zimbabwe. The trials were planned to run for three years (1996/97 to 1998/99).

MATERIALS AND METHODS

The experimental treatments were a factorial of three rates of inorganic N (0 kg N/ha, 40 kg N/ha and 80 kg N/ha) applied as ammonium nitrate and four levels of cattle manure (0 kg N/ha equivalent, 20 kg N/ha equivalent, 40 kg N/ha equivalent, and 60 kg N/ha equivalent). Manure from six different sites was used. The cattle manure was analyzed for total N prior to application on the field. Their total N contents were (Kodzwa (0.73%), Sunhwa (0.9%), Wedza (0.8%), Domboshava (1.94%), Musami (0.67%), and Muchinjike (0.54%). All the manure was applied at planting by banding it about 10cm away from the seed in opened furrows. N was split-applied with half of the inorganic N applied at planting or seven days after crop emergence and half when the crop reached "knee height". All trial sites had a randomized complete block design and were replicated three times. A short-medium maturity hybrid, R215, was planted at an inter-row spacing of 0.90m and within-row spacing of 0.30m. Plot sizes (minimum 5 rows x 6 m) were 6m x 4.5m.

Satellite plots were also established at all trial sites to assess manure from other sites. One plot of each manure source per replicate (i.e. three plots per source per site) was used.

All sites were characterized where possible for type of soil, agro-ecology, pH, NPK, Ca, Mg, trace elements and organic matter. Soil samples were collected prior to planting and after harvest. Measurements of grain yield, aboveground non-grain biomass, and N uptake by the maize crop were made after harvest.

RESULTS

Table 1 gives the soil analytical data for some of the sites. Some of the analytical data was not available at the time this paper was written. All the four sites whose data was available had low pH values and were deficient in phosphate (Table 1). The sites at

Table 1. Initial soil characteristics of some of the trial sites.

Site	Analysis								
	pH	P	K	Ca	Mg	Zn	C	N	N
	($CaCl_2$)		(µg/g)			(ppm)	(%)		(ppm)
Domboshava	4.1	47.3	36.0	-	24.0	0.70	0.44	0.05	16.1
Hwedza	4.8	14.7	47.7	-	18.7	0.20	0.23	0.03	6.4
Muchinjike	4.1	6.0	0.6	3.1	1.6	-	-	-	17.0
Musami	4.2	8.0	0.7	4.6	2.4	-	-	-	18.0

Musami and Muchinjike had medium grained sandy soils while the Domboshava and Hwedza sites were loamy sands.

Sunhwa

The main effect of manure was found to be non-significant (P=0.099). In contrast, the nitrogen effect was highly significant (P<0.001). Regression analysis showed a significant overall linear trend in the nitrogen means (P<0.001), with a perfect fit to the straight line (r=0.99). ANOVA also showed non-significant manure x linear interaction, (P=0.578). This indicates that when straight lines are fitted to the nitrogen means for each manure level separately, the slopes of these lines are not significantly different (at 0=0.024; 20=0.032; 40=0.033 and 60=0.028). Since interaction is not significant, overall N means can be compared using SED = 0.192 while overall manure means are to be compared using SED = 0.157, with a Residual Mean Square of 0.222. Figure 1 shows that increasing nitrogen levels produced significantly higher yields (P<0.01), and the data could be fitted to a linear regression equation: Y= 0.029X + 0.839 (R^2=0.73), where Y is the yield and X is the fertilizer N. Since the nitrogen levels are equally spaced (0, 40, 80), a unit increase in nitrogen will produce an extra 0.029 t/ha grain yield, i.e. 29 kg grain for every 1 kg N investment, (SE=0.0024).

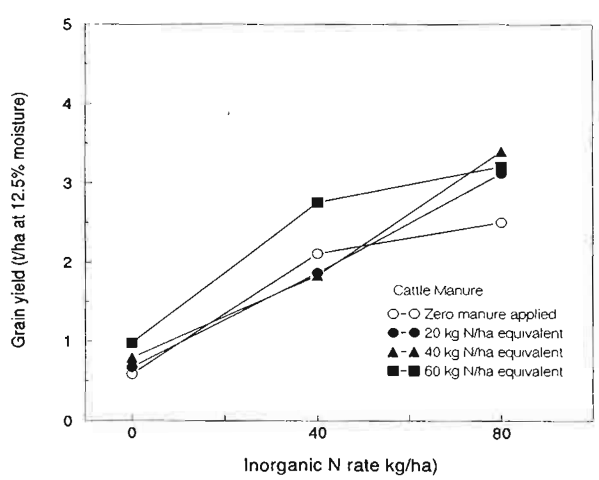

Figure 1. Maize grain yield response to inorganic N at three rates of cattle manure, Sunhwa, Zimbabwe, 1996/97.

Kodzwa

The analysis of variance (ANOVA) showed no significant interaction between manure and nitrogen (P=0.062). The main effect of manure was found to be significant at the 5% significant level, P=0.045. As for Sunhwa, the nitrogen effect was also highly significant (P<0.001). Increasing manure level (at zero nitrogen) increased yields, but there was a depression effect at high manure levels. Regression analysis showed a significant overall linear trend in the nitrogen means (P<0.001, Figure 2). The linear regression on N means gave the following equation: Y=0.0355X + 0.639 (R^2 = 0.71). A unit increase in nitrogen therefore produced a yield increase of 35.5 kg and at this site the inherent fertility could sustain a yield of 0.64 t/ha. The relatively high regression coefficient shows that most of the variation in the yield values is accounted for by the linear regression model.

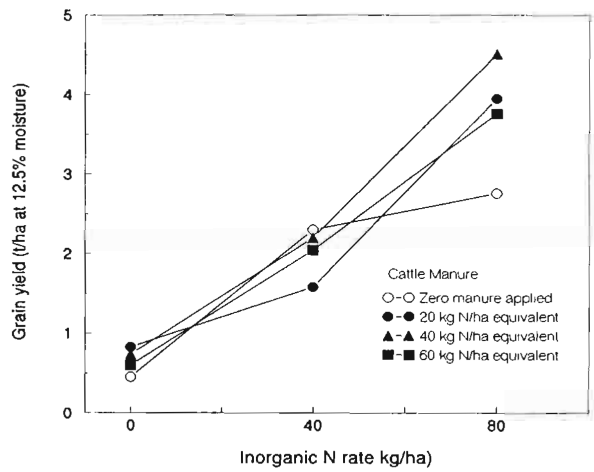

Figure 2. Maize grain yield response to inorganic N at three rates of cattle manure, Kodza, Zimbabwe, 1996/97.

Musami

The ANOVA indicated significant fertilizer effects at the 0.1% level. There was also a significant linear trend at P<0.001 (Figure 3). The regression equation was Y = 1.514 + 0.043X with a percentage variance accounted for of 42.2%. Manure effects were not significant, however, a quadratic function could be fitted to the data.

Muchinjike

There were no significant treatment effects at this site. Table 2 and Figure 4 gives the nitrogen and manure means for maize yields obtained at the Muchinjike site. Since interaction is not significant, overall N means are compared using SE =0.132, 5% LSD = 0.386 while overall manure means are to be compared using SE = 0.152 and LSD (5%) of 0.445. The regression equation for the nitrogen effect was Y = 1.507 - 0.001X, however the residual variance exceeded the

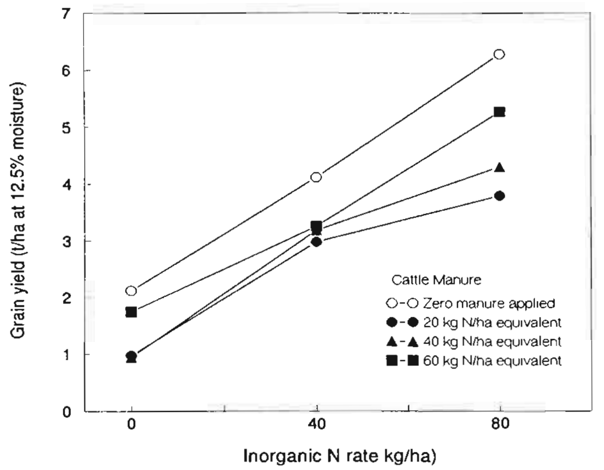

Figure 3. Maize grain yield response to inorganic N at three rates of cattle manure, Musami, Zimbabwe, 1996/97.

Table 2. Nitrogen x manure table of means for Muchinjike.

Nitrogen rate (kgN/ha)	Manure rate (kg N/ha equivalent)				Means
	0	20	40	60	
0	1.307	1.355	1.764	1.308	1.433
40	1.352	1.893	2.084	1.080	1.602
80	1.323	1.323	1.179	1.489	1.329
Means	1.328	1.524	1.676	1.293	

SE*manure* = 0.152, 5%LSD=0.445 SE*nitrogen* = 0.131, 5%LSD=0.386, SE*nitr x man*= 0.263, 5%LSD=0.771

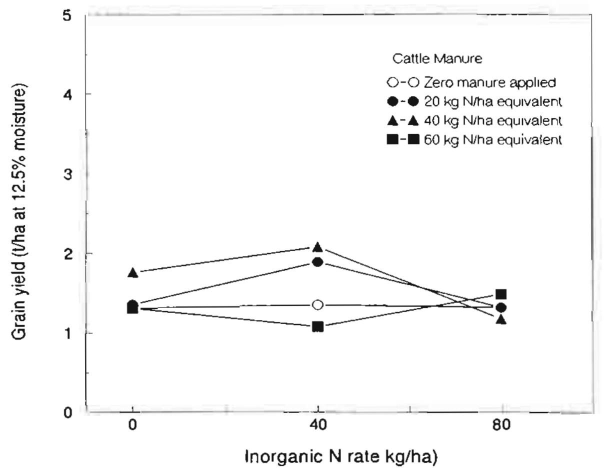

Figure 4. Maize grain yield response to inorganic N at three rates of cattle manure, Muchinjike, Zimbabwe, 1996/97.

variance of the Y variable.

Domboshava

Fertilizer effects were significant at the 0.1% level and they showed an overall linear trend (Figure 5). The regression equation for fertilizer effects obtained was Y = 2.784 + 0.015X (R^2 = 0.417).

Wedza

The ANOVA of the data from the Wedza site showed no significant treatment effects. The regression equation fitted was Y = 2.140 + 0.003X, however the residual variance exceeded the variance of the Y

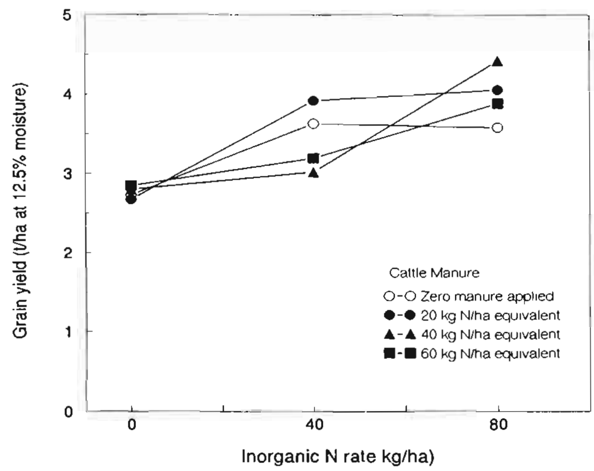

Figure 5. Maize grain yield response to inorganic N at three rates of cattle manure, Domboshava, Zimbabwe, 1996/97.

variate. Table 3 and Figure 6 give the means of the grain yield data for the site.

Cross-Site Comparisons

The analysis of variance (ANOVA) showed non-significant interaction between manure and nitrogen at all sites. These factors are therefore acting independently of each other. Fertilizer effects, and site x fertilizer interactions were significant (P<0.001) at all the sites.

Economics of N Fertilizer Use

In order to determine the profitability of using fertilizer, an economic analysis was carried out for all the

Table 3. Nitrogen x manure table of means for Wedza.

Nitrogen rate (kgN/ha)	Manure rate (kg N/ha equivalent)				Means
	0	20	40	60	
0	1.893	1.113	2.123	2.633	1.941
40	2.060	2.790	2.263	3.547	2.665
80	1.567	2.663	2.463	2.080	2.193
Means	1.840	2.189	2.283	2.753	

SE*manure* = 0.347, 5%LSD=1.016 SE*nitrogen* = 0.300, 5%LSD=0.880, SE*nitr x man*=.600, 5%LSD=1.76

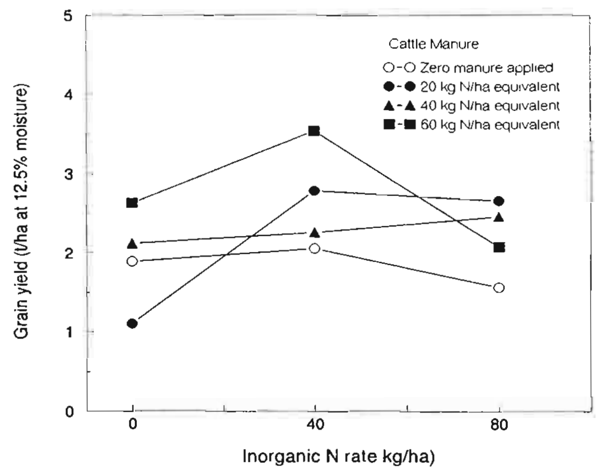

Figure 6. Maize grain yield response to inorganic N at three rates of cattle manure, Wedza, Zimbabwe, 1996/97.

sites. Fixed variables such as seed and labour were ignored since they apply to both the fertilized and unfertilized crop. The calculations were done as follows:

1996/97 AN (34.5%N) fertilizer price = $140.00 per 50 kg bag.

40 kg N = $ 325

80 kg N = $ 650

Unit cost of nitrogen = $ 8.13

Current maize producer price = $ 1200 / t

= $ 1.20/kg

For Sunhwa site: each kg N investment produced 29 kg grain, equivalent to $ 34.80

Returns per unit N fertilizer = $26.67.

Table 4 summarizes the results of the analyses.

Table 4. Economics of N fertilizer use at sites in natural regions 2 and 3.

Site	Grain yield (kg) per kg N investment	Returns per unit N fertilizer (ZW$)
Domboshava	15	9.87
Kodzwa	35.5	34.47
Muchinjike	1	-6.93
Musami	43	43.47
Wedza	3	-4.53
Sunhwa	29	34.80

NB. Muchinjike and Wedza sites did not have significant linear trends.

DISCUSSION

Inherent fertility at the sites, as indicated by yields from the controls, was very variable with the poorest sites being Kodza and Sunhwa which both had yields below 0.6t/ha. The most fertile site was Domboshava with mean yields in the control of 2.73t/ha, and Musami (2.118t/ha). Other sites could be described as medium fertility.

Response to application of fertilizer N was generally linear except for sites at Muchinjike and Wedza where no response to fertilizer was obtained. This is mainly because of excessive rains at these two sites, which resulted in waterlogged conditions for the greater part of the growing season.

Response to manure was varied. There was no response to application at sites such as Muchinjike, Wedza and Domboshava. At Musami, manure effects had a quadratic trend, whilst the trends were cubic at Sunhwa and linear at Kodzwa. The quadratic and cubic trends at some of the sites indicate that manure had a depressing effect at some levels of manure application. The depressed yields at these levels are likely due to active immobilization by the low quality manure. Other studies have also reported negative nitrogen effects in the short term after applying manure (Murwira and Kirchmann, 1993; Tanner and Mugwira, 1984). At the Sunhwa site, as nitrogen level got to 80 kg/ha, increasing manure applications produced increasingly higher yields. This may imply that the association between inorganic N and manure is beneficial only when the initial dose of inorganic N is high. The economic analysis shows that it is profitable to apply fertilizer at most of the sites. The long-term profitability of using fertilizer is not clear however, as the trials have only been conducted for one year.

CONCLUSIONS

The 1996/97 growing season was a favourable one with moisture not being a limiting factor; hence yields were unusually high for some of the unfertilized sites. However, the fact such yields are high belies a more fundamental question of 'to what extent soil fertility is a limiting constraint at these sites viz. the water unlimited yield potential?' Unfortunately, the available soil analytical data and the experimental design were insufficient to provide an answer to the question. For example, some of the sites had strongly acidic soils which could have affected crop response. It is necessary in future to have a standardized analysis done for all sites and ensure that sites chosen are indeed N limiting, with no other co-limiting factor.

The results obtained in the 1996/97 growing season are interesting by showing the profitability of using fertilizer in the high rainfall zones of the communal areas. It would be important in future to analyze the extent to which manure provides a subsidy to the cropping system.

Acknowledgements

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CATTLE MANURE MANAGEMENT OPTIONS FOR REDUCING NUTRIENT LOSSES: FARMER PERCEPTIONS AND SOLUTIONS IN MANGWENDE, ZIMBABWE

JEAN K NZUMA[1], HERBERT K MURWIRA[2] and SHEUNESU MPEPEREKI[3]

[1]Research Officer, Department of Research and Specialist Services, Chemistry and Soil Research Institute, Box CY 550, Causeway, Harare; [2]Post Doctoral Fellow, TSBF, c/o African Centre for Fertiliser Development, Box A469, Avondale, Harare; [3]Lecturer, Soil Science, University of Zimbabwe, P.O. Box MP 167, Mt. Pleasant, Harare, Zimbabwe

SUMMARY

One of the basic problems in communal area agriculture is low soil fertility. This can be improved by making use of locally available organic inputs supplemented where necessary by inorganic fertilisers. Communal farmers depend on cattle manure as a low cost fertility input, but its quality is often low due to imperfect storage and handling. The conditions under which the manure is stored allow for excessive aeration with high potential for ammonia losses. This suggests the need to develop manure management options that will minimise nutrient losses and enhance manure quality, and hence increase crop production. The search for management options to reduce nutrient losses from cattle manure requires community input and the integration of indigenous knowledge systems into scientific research.

This paper describes traditional practices that are followed by local people in Mangwende communal area in their storage and handling of cattle manure. The aim was to come up with an appraisal of local people's perceptions of the causes of nutrient losses from cattle manure and to determine strategies they use to counter the problem. These studies used a participatory methodology to evaluate the limitations with current storage systems, the possibilities for improving manure quality and designs for appropriate interventions.

INTRODUCTION

Soil fertility is the major constraint to crop production in the communal areas of Zimbabwe. The majority of communal farmers are located on sandy soils that are inherently infertile. Reasonable yields cannot be expected from sandy soils without regular application of fertility ameliorants. Communal farmers depend on manure to sustain soil fertility and to stabilise crop production. Manure applications to soil result in increases in waterholding capacity, pH, hydraulic conductivity, infiltration rates and decreases in bulk density (Grant, 1967; 1970).

Unfortunately quantities of manure available to the farmers are limited because of low livestock numbers per household. Average manure production per livestock unit is 1.2 t per year (Avila, 1987). The situation is made worse by poor quality of manure produced. This results from imperfect storage and handling conditions in the kraal. The low nutrient status of communal area manure has been reported to be the major factor that contributes to the low effectiveness of manure in improving crop growth and yields (Mugwira and Mukurumbira, 1986; Mugwira and Murwira, 1997). Local literature has reported soil contents in manure of 50 - 90%, total N of 0.5 - 1.2%; which is indicative of poor quality manure. One tonne of manure has been reported to be equivalent to 3 kg/ha of fertilizer nitrogen (Mugwira, 1987). Previous studies reported that the chemical composition of communal area manures is much lower than feedlot manure (Mugwira and Mukurumbira, 1984).

Communal area manure comes from cattle that graze the depleted veld. Manure nutrient status depends upon factors such as quality of feed, storage and handling conditions in the kraal, ambient temperature, moisture levels and length of exposure to the environment (Mugwira and Murwira, 1997). The conditions in the kraal under which communal area manure is produced allow for aeration and result in aerobically-dried and decomposed manure. The potential for nutrient losses particularly of N through ammonia volatilisation is high. Ammonia losses are of particular concern because they represent a large loss of potential fertiliser N. Losses of manure-N have been reported in Zimbabwe by Murwira (1995), for manure decomposing under storage conditions. The losses were low and amounted to 6% of the total N content in manure. Although losses might seem low, they are in fact high in the context of a low input cropping system. We note that the studies by Murwira did not measure N losses from urine which is a potential source of N.

The foregoing suggests that there is need to develop strategies that will improve the quality of manure by minimising nutrient losses, particularly N. To come up with a research agenda that is context sensitive, there is need to identify strategies that are being followed by farmers in the storage and handling of manure and to determine where the weaknesses lie in the system. Only then can helpful strategies for intervention be conceived. This paper reports the results of a survey that was conducted in Mangwende communal area to determine farmer practices in the storage and handling of cattle manure. It highlights weaknesses in the system and opportunities for improvement.

STUDY METHODS

A survey was conducted in Mangwende communal area using the farmer participatory rapid appraisal approach to determine farmer circumstances in the storage and handling of cattle manure. One hundred farmers were interviewed. In each case a questionnaire was administered. The interviewing team visited kraals and observed different manure management strategies in operation. Farmer priorities on the use of crop residues were determined. Cattle numbers per interviewed household and quantities of manure produced per annum were established together with the proportion of farmers that follow particular practices. A manure sample was collected from each kraal for analysis.

RESULTS

Use of Crop Residues by Farmers

Crop residue management practices were included in the survey to determine to what extent farmers recognise the use of crop residues as an essential tool in urine entrapment.

Our survey established that farmers managed crop residues in a holistic manner. Crop residues were used as cattle feed, bedding materials in kraals, for composting, ploughed into the soil as a soil fertility amendment or simply burned. Maize straw and groundnut haulms were commonly stored in raised platforms erected in or outside the kraal and at the homestead. These residues were fed to cattle at regular intervals, particularly in winter to supplement the veld grass. Some farmers kept the straw intact until the onset of rains during which time it was used as bedding for animals. Because of different management practices there was variation in the quantities of manure produced across households. For example, a herd of two animals could give a range of one to 16 carts of manure per year whilst a herd of 18 gave between 17 and 30 carts of manure per annum. This marked difference depended on how much residue was used in the kraals. In some cases cattle numbers were high but the resultant manure quantities were lower than expected (e.g. a situation where a herd of 22 cattle gave 16 carts of manure per annum in comparison with a herd of 10 producing up to 55 carts per annum).

Current Manure Management Techniques

Eight distinct practices were identified in the storage and handling of manure. These were:

1. selection of kraal site
2. addition of litter to the kraal, regarded as kraal feeding
3. digging out of manure from the kraal and subsequent heaping
4. manure is kept in the kraal under the animals until ready for application (deep stall)
5. trapping of seepages
6. placement of stones on elevated parts of the kraal
7. construction of walls around the kraal
8. rotation of kraals.

These practices were further divided into winter (dry season) and summer (rainy season) storage and handling strategies. The first two practices were regarded as winter practices (excluding kraal site) whilst the last three were summer practices. The deep stall practice was placed in both groups because it was done in both seasons. The farmers also distinguished kraal feeding as a handling practice with heaping and deep stall being classified as storage practices. The remainder were regarded as ameliorative strategies. The proportion of farmers following each practice at a particular time is presented in Tables 1 and 2.

Table 1. Winter storage and handling practices

Storage conditions	Length of composting	Percent sample farmers
Heaping	1 week to 6 months	82
Heaping plus fertilizer additives	2 to 3 months	4
Deep stall plus addition of litter	4 to 6 months	4
Deep stall without addition of litter	4 to 6 months	10

Selection of kraal site -- Some farmers argued that the location of a kraal had an influential role in either promoting or minimising losses; hence the kraal had to be constructed in such a manner and on a site that safeguarded nutrients from being evaporated or leached. Forty-six percent of farmers had their kraals on an unshielded flat surface, 14% of kraals were under shed trees on a flat ground, 10% were either on steep slopes or on an anthill, 6% of kraals were on pavement outcrops, 8% were in one corner of the field. The remaining kraals had depressions in the centre. Of particular interest were kraals that

Table 2. Summer storage and handling practices to counter run-off losses

	Storage and Handling System			
	Rotation of kraals	Trapping seepages into pits	Construction of a wall around the kraal	No ameliorative practices
Frequency amongst farmers (%)	8	28	52	12

were erected on anthills. The quality of manure from these kraals was perceived to be extremely high. The quality of the resultant manure was augmented by anthill soil since the latter was normally rich in nutrients. Some farmers pointed out that anthill soil had the ability to "capture" all leached liquids, hence most losses were recovered.

Addition of crop residues and litter to the kraal or kraal feeding -- Kraal feeding was regarded as a preliminary treatment in the handling chain. Ninety percent of farmers sampled followed this practice. However, there were differences in the time in which litter and crop residues were added to the kraal (40% of farmers fed kraals in the wet season only, 60% in both summer and winter seasons). Combinations of different waste materials from the threshing floor, fallen leaves collected from bushes and vegetable wastes from the garden were brought to the kraal along with grass and weeds.

Some farmers started adding residues to the kraal as early as March when groundnuts were being harvested. The use of groundnut haulms was usually extended to early June when they finally got exhausted. Those that did not store maize straw for use in summer stacked the straw as soon as harvesting of maize began in April. The use of maize straw for this purpose was often prolonged because quantities were high from large areas put to the crop. In summer when all crop residues were exhausted, farmers resorted to cutting grass, gathering leaf litter and weeds pulled up from the fields to keep the kraal dry.

In the investigation farmers were able to establish the advantages of kraal feeding. Manure that had been prepared with crop residues and or litter was believed to have more nutrients and power. According to some farmers, manure handled in this manner sustained the soil nutrients for two years. Others were of the opinion that pure manure without additives had a better nutrient supply. Kraal feeding minimised and prevented nutrients from being lost by liquid seepages, particularly during the wet season. This was the reason why some farmers provided bedding only in the wet summer. Farmers felt that losses were only prominent during this period. Kraal feeding was the only way they prevented dung and urine from falling directly on the earthen floor where it could accumulate sand. Manure with a high sand content was regarded as poor quality manure. The handling of the dung-urine mixture was also made easier once it had some residues in it.

Visual observation showed variations in quantities of litter used during the kraal feeding practice. Fifty-five percent of farmers interviewed felt that there was no need to limit quantities of litter that were added to the kraal. However, emphasis was put on the need to kraal the cattle at night. This would ensure continuous trampling and mixing up of dung, urine and straw. The straw should be incorporated whilst the rains were still available. The manure-straw-mixture would acquire the necessary moisture needed for decomposition. Some farmers said that there had to be a strong correlation between cattle numbers in a given kraal and amounts of litter that was added to the kraal. If the herd was small, use of large amounts of straw had to be avoided because cattle would not be able to soak up all litter with their excrement. Decomposition was prolonged in this case. In some cases farmers continued to feed the kraal until sufficient dung and urine had been dropped and until the depth of the trampled mass was high enough. Others continued stacking in litter until the end of the rainy season.

Digging out of manure and heaping -- Heaping was regarded as a storage practice. Eighty-six percent of farmers interviewed practiced this method. Manure was usually heaped or piled in or outside the kraal. The bedding material along with manure was transferred by a spade from one corner of the kraal to the other. The above-ground layer of the kraal was usually raw; so it was this layer that was turned down first followed by the partially decomposed innermost layers. If time was limiting, the raw litter was removed carefully and returned to the kraal. The sizes of heaps varied according to quantities of manure available.

The survey established that the heaping time stretched from February to November. The majority of farmers heaped between the months of August and October (i.e. 24% heaped in August, 21% in October, 19% in September). A handful of farmers heaped between February and May. These findings are presented in Table 3.

In the survey, farmers were able to establish the merits and demerits of some heaping times. Heaping in February/March allowed the heap to acquire moisture before the end of the rainy season. Farmers pointed out that it was the moisture that hastens decomposition. A greater proportion of farmers heaped in hot, dry and windy weather. Some views

Table 3. Month of heaping	
Month of heaping manure	**Frequency amongst farmers**
Between January and March	3
Between April and June	11
Between July and September	48
Between October and December	24

Note - 14 of farmers in the sample did not heap manure

were held that the hot, dry and windy conditions experienced during this period promoted nutrient losses by evaporation. Those that heaped during this period were of the opinion that the heap required radiation energy to facilitate the generation of heat needed by the heap to totally decompose. Heat generation was considered a sign that decomposition was progressing. Some farmers felt that if they were to heap manure as early as April, the quantities of manure produced by then would be too little.

Farmers felt that heaping ensured thorough mixing of all ingredients from the kraal. Heaping improved the quality of manure by thickening (kukora) the manure to a moulded (akaumbikana) and stable (akagadzikana) product. The heat generated by the pile destroyed weed seeds (e.g. sawi) that were often a menace in weeding. Some farmers heaped manure because of lack of transport to carry manure directly to the field after digging.

Three percent of farmers sprinkle single super phosphate or compound D onto the manure heap. No reasons were given for this practice other than to improve the availability of nutrients.

The heaping period stretched from one week to six months or more. This is reflected in Table 4. The length of heaping depended on the purpose for heaping. In some cases manure was left on the heap until November (due to lack of labour and transport to carry manure to the field) or until they were satisfied that the manure under the heap was ripe. Figure 1 gives a summary of indicators for manure maturity as perceived by farmers.

Table 4. Length of composting	
Length of composting	**Frequency amongst farmers**
1 to 3 weeks	15
1 to 2 months	27
3 to 4 months	27
5 to 6 months	8
> 6 months	9

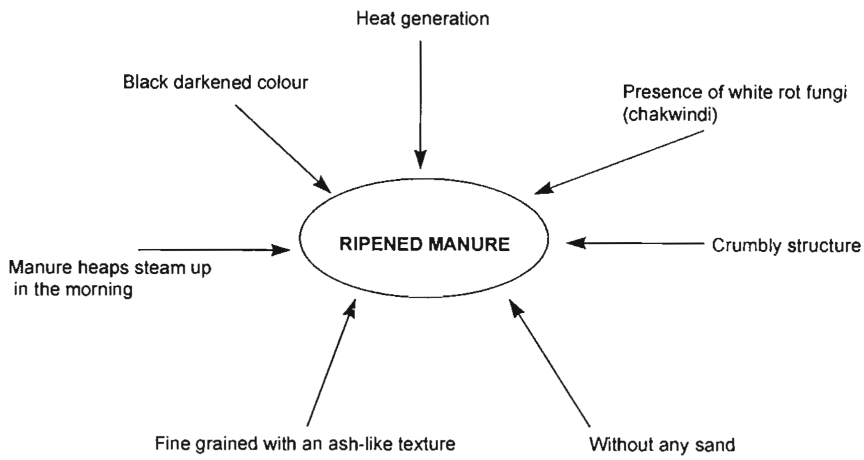

Figure 1. Farmer perceptions of indicators for maturity and good quality manure

The deep stall method -- In the deep stall method, manure was kept in the kraal until it was mature enough for application. Fourteen percent of farmers interviewed practiced this method. According to these farmers, this method is not labour intensive -- "you only need to scoop out into the wheelbarrow or cart and take manure to the field without making piles as in heaping". The recovery rate of the excrement was perceived as high. The bedding was continuously compacted and shielded from wind and excess heat. Manure remained under the stall until farmers were satisfied that it was mature enough to be applied to the soil or till October or early November.

Farmers also reported on factors that limit the use of the deep stall method of storage. They argued that manure remaining under stall for longer periods accumulated sand. The bottom and top layers of kraal contents presented differences in maturity; hence quality of the product was not uniform. The newly dropped manure was unearthed together with old manure. Farmers indicated that that this type of manure caused a scorching effect to the crops during early stages of growth.

Trapping of seepages -- The trapping of seepages from the kraal into pits or ridges was an ameliorative strategy that was used by 28% of farmers in the sample. It was only common during the rainy season. Whilst some farmers did not add any material to the pits, others used grass, leaf litter or crop residues to absorb liquids. The size of these pits varied and depended on the extent of liquid manure loss at a given time. After all the soup had percolated underground, the semi-solid part left was then returned back to the kraal using shovels or left to decompose in cases where residues and other materials were used.

Construction of walls around the kraal -- It was a common practice in the rainy season for some farmers to build a thick wall around the kraal to prevent seepages from the kraal. Thirty-six percent of farmers in the study area followed this practice.

Placement of stones uphill -- Sixteen percent of farmers placed stones aligned on upper slopes of the kraal. This was to divert masses of water from entering the kraal during the rainy season. A contour was sometimes constructed in this manner to drain water further away from the kraal.

Rotation of kraals -- Eight percent of farmers rotated kraals in summer. Some farmers followed this practice in winter. Farmers rotated kraals for two main reasons. Rotation of kraals prevented manure from spilling outside when it became full and gave ample time for one kraal to dry before animals could use it again.

It is interesting to note that a handful of farmers in the sample tied their animals outside the kraal once the wetness inside was too much.

Farmer Perceptions of Nutrient Losses from Cattle Manure under their Management Systems
Farmers defined nutrient losses in manure as "removal of soup (muto) from manure and the resultant accumulation of sand". This situation is induced by practices followed during handling and storage of manure or is a result of unfavourable weather conditions. The power of manure is perceived to be in the soup. Farmers believe that it is this soup that holds the manure to form a thickened and moulded characteristic. Thirty-nine percent of farmers interviewed had never heard of nutrient losses before, 40% were aware of the problem, whilst 21% had some idea about the issue. Farmers noted various opinions on causes of nutrient losses in manure. They argued that the amount of nutrients lost depended on the quantities of litter used in the kraal and during curing of manure. The larger the amounts used, the lower the seepages and losses. Others reported that heaping in hot, dry and windy weather triggered moisture losses by evaporation. In this dried state manure was subject to nutrient losses. Heaping in wet season equally caused nutrient losses through leaching. Curing manure under the heap for more than six months resulted in "overcooked" manure with a high sand content. It was established that this type of manure was of low nutrient benefit to crop growth and yields. Farmers also argued that kraals located on steep slopes or anthills tended to lose a lot of soup. This often required hard labour to undertake ameliorative measures. A summary of these causes is given in Figure 2.

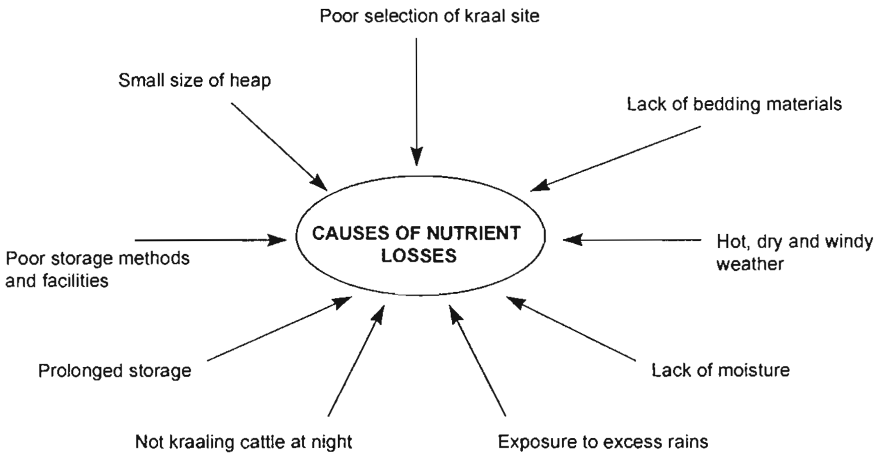

Figure 2. Farmer perceptions of causes of nutrient losses from manure

The strategies that the farmers used to counter losses included, construction of a wall around the kraal which was meant to prevent liquids from gushing out, trapping of seepages in pits, addition of litter to keep the kraal dry, rotation of kraals, reduction of length of composting and heaping before the end of the rainy period. These are summarised in Figure 3.

Current Nutrient Status of Communal Area Manure
The nutrient status of manure samples collected during the survey was generally low. Table 5 shows manure quality and frequency distribution amongst farmers. The manure samples were classified as deficient, marginal and adequate depending on their N, P and K contents. Seventy-six percent of manures analysed were deficient in N, 30% were marginal and only 3% were classified as adequate. This trend applied also to the rest of the nutrients.

DISCUSSION

Whilst combinations of different crop residues, grasses and leaf litter are used in the kraal, there is little attempt by farmers to conserve nutrients at the critical point of excretion. There were several cases in the study where farmers did not use crop residues at all during handling and storage of manure. Some farmers only increase their use of crop residues in the wet season. This indicates that crop residues are not being used efficiently. Several research findings in-

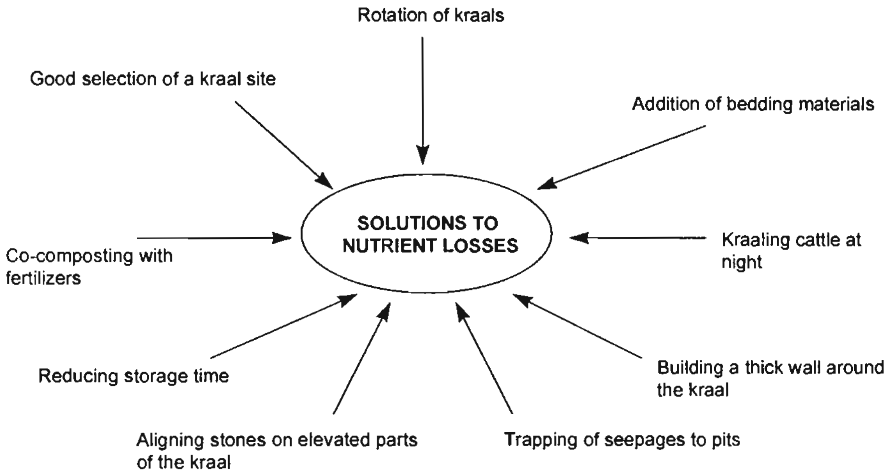

Figure 3. Farmer solutions to nutrient losses from manure

dicate that nutrients can be lost immediately after excretion, particularly nitrogen through ammonia volatilisation (Muck and Steenhuis, 1982; Muck and Richards, 1983; Murwira, 1995). These findings indicated that most losses occurred from urine which is the greatest potential source of N in manure. Fifty percent of total N content in manure is reported to be from urine. Furthermore, 90-95% of N compounds in urine can be converted to ammonia within a week (Luebs *et al.*, 1973).

The majority practice of heaping manure triggers aerobic conditions by allowing an influx of oxygen into the system which results in aerobically decomposed and dried manure. The quality of this manure is poor because of its unsatisfactory sources of N for increasing soil fertility and yields. Large amounts of nutrients, particularly organically-bound N cannot be released readily from aerobically decomposed manure (Mugwira and Murwira, 1997). Murwira (1993) reported a net immobilisation in the first eight weeks after applying aerobically decomposed manure. Anaerobically decomposed manure had a positive effect to the crops in the short term.

Table 5. Quality of manure and frequency distribution amongst farmers

Chemical composition of manure	Frequency distribution amongst farmers
N content	
* < 0.5 - 0.90	67
1.00 - 1.20	30
> 2.25	3
P content	
* < 0.15 - 0.20	51
0.25 - 0.30	43
> 3.0	6
K content	
* < 0.5 - 1.00	65
1.00 - 2.00	39
> 2.50	6

* deficient range

A majority of farmers set their heaps between August and September. Heat radiation and wind velocity are usually at their peak during these months. It has been reported that the physical environment in which the manure is stored (temperature and moisture levels) affect nutrient losses (Freney *et al.*, 1981). Due to exposure of heaps to the environment, moisture and nutrients are lost. Moisture is important because it facilitates decomposition. This suggests that there is need to determine the optimal month under which manure should be stored.

The trampling of manure in the kraal has been recognised as a vital tool in facilitating the mixing of kraal contents. However, it can result in exceptionally high sand content in manure through mixing of manure and soil (Mugwira, 1984). This scenario is common where kraals have earthen floors and where there is inefficient use of crop residues during handling. In a comparison of quality traits of manures from different kraal floors, Khombe *et al.* (1992) measured up to 41.3% of sand in manure from earth floors. Manure from concrete floors had less sand content.

The idea of trapping seepages in pits during the rainy season has beneficial effects in conserving nutrients, however, there is need to maximise its efficiency by adding crop residues and litter to the pit to absorb nutrients. Currently, very few farmers add residues to the pit. Pit-storage of manure has been reported to produce a manure of excellent quality by maintaining the soluble N fraction (Musa, 1975 and Kwayke, 1980).

In the current management system, there are variations in the length of the decomposition period. Prolonged storage has an effect on nutrient availability. Manure produced is dried and has a high sand content. This manure is of little fertilizer benefit to the crop. Kirchmann(1985) reported increases in N concentrations during the first six months of storage and a decline thereafter. A shortened decomposition period equally has some negative effects to crop growth because of net immobilisation during the early stages of crop growth. This suggests the need to determine the optimal length of composting.

CONCLUSION

Although the present management practices have reflected weaknesses in the system that need to be improved, there are some benefits that farmers get from their practices. The heaping practice is not labour intensive and produces manure in time for application. However, the quality of manure produced stands as a limiting factor to the efficient use of manure from this system. The addition of fertiliser to manure during decomposition, practiced by a minority of farmers, should be credited for improving quality of the resultant manure by increasing solubility of nutrients and their release. However, its sustainability is questionable. Although efficiency in trapping of seepages in pits needs to be improved, it remains an essential tool in conserving runoff losses.

The potential for improving quality of manure is there. Proper management in the kraal will minimise losses and sand content in the manure produced. The use of crop residues should be maximised to absorb nutrients from urine particularly at the critical point of excretion. The efficacy of residues also needs to be established.

Pit storage of manure combined with the use of crop residues in both summer and winter could be a promising technology that will reduce drying and leaching during hot and wet periods and so enhance quality of manure. It will be necessary to evaluate pit storage of manure compared with the conventional heaping practice. There is also need to cost the economics of each practice in relation to quality.

Treatment of the manure during storage can be improved by manipulating biological processes during decomposition of manure. It has been reported that anaerobic treatment results in better quality manure than does aerobic treatment. Therefore anaerobic treatment is a good technique that can be further tested both on-farm and in the laboratory. It will also be equally important to develop handling conditions for anaerobically treated manure.

In developing these technologies, farmers must be involved so that they remain with the farmers themselves.

ACKNOWLEDGEMENTS

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TITHONIA DIVERSIFOLIA: AN ORGANIC SOURCE OF NITROGEN AND PHOSPHORUS FOR MAIZE IN MALAWI

ROSAN GANUNGA[1], OLUSEGUN YEROKUN[2] and JOHN D.T. KUMWENDA[3]

[1]Maize Agronomist, Chitedze Research Station, Lilongwe, Malawi; [2]Lecturer (Soil Scientist), University of Zambia, Lusaka, and [3]Chief Agricultural Scientist, Chitedze Research Station, Lilongwe

SUMMARY

We conducted trials in Malawi to test the suitability of leaves from Tithonia diversifolia *as an organic source of nitrogen and phosphorus in Malawi. The application of Tithonia leaves gave maize grain yields that were significantly higher than from a no fertilizer treatment. The application of Tithonia leaves at 1.5 t ha^{-1} produced maize grain yields that were 39% over the control at Bembeke, 122% at Chitedze and 162% at Champhira. Tithonia leaves applied at 1.5 t ha^{-1} produced maize grain yields that were 12% higher than the standard fertilizer rate at Chitedze but were 24% lower at Bembeke and 30% lower at Champhira. Supplementation of TSP to Tithonia did not result in significant maize yield increases compared to the application of Tithonia leaves alone. There were no significant maize grain yield differences among the Tithonia treatments at Chitedze and Bembeke.*

INTRODUCTION

In Malawi, soil degradation and continuous cropping without the addition of external inputs have resulted in a decline in soil fertility and, consequently smallholder maize yields (Kumwenda, Waddington, Snapp, Jones and Blackie, 1996 and 1997; Zambezi, Kumwenda and Jones, 1993). These effects have to be reversed if Malawi is to maintain food self-sufficiency both at national and household levels. The decline in soil fertility in Malawi is due to several factors, among them: (a) the inability of most farmers to practice crop rotation due to land shortage, (b) reduced fertiliser use stemming from increased fertiliser prices following the removal of subsidies and the devaluation of the Malawi Kwacha.

Many studies have been conducted to address issues of declining soil fertility. These include the use of inorganic fertilisers (Bolton and Bennett, 1975), intercropping (Kumwenda *et al.*, 1996), the use of crop rotations (MacColl, 1989), agroforestry (Bunderson, Saka, Itimu, Mbekeani and Phombeya, 1991), green manuring (Kumwenda, 1996), and the use of compost or animal manure (Anonymous, 1985). Despite the positive fertility contributions by these technologies they are difficult for farmers to adopt. Consequently, agronomists in Malawi continue to explore other options for soil fertility improvement. One option is the use of *Tithonia diversifolia* biomass as a green manure.

Tithonia diversifolia is a naturally occurring bush in Malawi. It is available in over 75% of the districts in Malawi although a detailed quantitative survey of occurrence has not been conducted. It is highly vegetative and a perennial. It has a high nutrient composition and mineralises fast (Palm *et al.*, 1995). *Tithonia* is easily propagated by using cuttings just like cassava. In Kenya, Palm *et al.* (1995) reported that the application of *Tithonia* biomass at 5 t ha^{-1} to maize fields produced maize grain yields that were comparable to the application of 60 kg N of inorganic fertiliser.

In Malawi, the shrub is commonly used for construction work, as a hedge for vegetable gardens and for ornamental purposes. No work has been done to evaluate the potential of *Tithonia* for soil fertility improvement in Malawi. The objectives of the study were to: (a) assess the effect of *Tithonia diversifolia* on nutrient uptake and yield of maize when compared to inorganic fertiliser, and (b) measure the rates of mineralisation of *Tithonia* when compared to inorganic fertiliser.

MATERIALS AND METHODS

Researcher managed experiments were conducted in the 1996/97 cropping season. Field experiments were established at three sites in Dedza, Lilongwe district in central Malawi and Mzimba district in northern Malawi. All the sites are in the mid-altitude ecology of Malawi which lies between 600 and 1300 metres above sea level. These sites receive a unimodal type of rainfall. The following treatments were evaluated in a randomised complete block design experiment with three replicates: (1) No fertilizer (control), (2) 40 kg P_2O_5 ha^{-1} + 92 kg N ha^{-1} (standard recommendation), (3) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P), (4) *Tithonia diver-*

sifolia at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P), (5) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P), (6) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P) + 13.5 kg P from triple superphosphate (TSP), (7) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P) + 9.7 kg P from TSP and (8) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P) + 5.95 kg P from TSP.

Soil samples were collected from each experimental field before planting the field trials. Soil samples were collected from points diagonally in the field, and were analysed for nitrogen, phosphorus, calcium, magnesium and pH. The results of the analysis are presented in Table 1.

Table 1. Soil chemical properties for the experimental sites at the beginning of the season

Property	Bembeke	Chitedze	Champhira
pH	5.30	6.50	5.8
Nitrogen (g kg^{-1})	1.40	1.20	0.6
Phosphorus (mg kg^{-1})	7.38	3.07	2.33
Potassium (ppm)	17	21	11
Calcium (ppm)	3.05	2.97	2.33
Magnesium (ppm)	0.29	0.38	0.15
% Silt	14	14	10
% Clay	16	16	18
% Sand	70	70	72
Texture	SL	SL	SL

Initial *Tithonia* Analysis

To know the nutrient composition of the *Tithonia* biomass used in the study, leaves were obtained from natural bushes existing in Dedza district in July 1996. Dead and fresh leaves were collected separately. The fresh leaves were air dried before analysis. Leaves were analysed for nitrogen using the wet destruction method; phosphorus, potassium, calcium and magnesium using the Mehlich 3 method (Wendt, 1995). This was done at the beginning of the cropping season. The results of these analyses are shown in Table 2. The results of the analysis from the samples that were collected green were used to determine the quantities of *Tithonia* to be used in the *Tithonia* treatments.

Table 2. Nutrient composition of *Tithonia diversifolia*

Element	*Tithonia* leaves collected green and air dried (%)	*Tithonia* leaves collected already dry (%)
Nitrogen	2.94	1.45
Phosphorus	0.25	0.09
Potassium	3.25	2.34
Calcium	0.11	0.12
Magnesium	0.07	0.08

RESULTS AND DISCUSSION

Maize Grain Yield Response to Nutrient Application

At all sites, there were significant ($P<0.05$) maize yield differences among the treatments (Table 3). Application of *Tithonia* leaves at 1.5 t ha^{-1} gave maize yield increases of 39% (2692 kg ha^{-1}), 122% (4360 kg ha^{-1}) and 162% (769 kg ha^{-1}) over the control (1914, 1965 and 294 kg ha^{-1}) at Bembeke, Chitedze and Champhira, respectively. Similarly, the application of *Tithonia* leaves at 3.0 t and 4.5 t ha^{-1}, or the inorganic fertilizers, produced significant yield increases over the control (treatment 1) at all sites. At Chitedze maize yields of 2200 kg ha^{-1} have been reported from an alley cropping system with *Leucaena* leaves applied near the hedge and 1200 kg ha^{-1} when applied away from the hedge. This shows that similar maize yields were possible from *Tithonia* compared to *Leucaena leucocephala* which is one of the agroforestry species currently recommended for soil fertility improvement in Malawi.

Table 3. Effect of *Tithonia diversifolia* and inorganic fertilizer sources on maize grain yield (kg ha^{-1})

Treatment	SITES			
	Bembeke	Chitedze	Champhira	Mean
1	1914 c	1965 c	294 d	1400
2	3334 ab	3969 b	1000 bc	2734
3	2691 b	4360 ab	769 cd	2607
4	3262 ab	5808 a	1320 ab	3463
5	3841 a	5921 a	1430 ab	3731
6	2662 b	4540 ab	718 cd	2640
7	3275 ab	4470 ab	1366 ab	3037
8	3723 a	5598 a	1675 a	3665
Mean	3091	4566	1072	
F-Prob	0.001	0.0035	0.0007	
CV (%)	13.3	21.7	26.7	

Key to treatments

(1) No fertilizer, no *Tithonia* (control).

(2) 40 kg P2O5 ha^{-1} + 92 kg N ha^{-1} (standard recommendation).

(3) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P).

(4) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P).

(5) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P).

(6) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P)+ 13.5kg P from TSP.

(7) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P) + 9.7 kg P from TSP.

(8) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P) + 5.95 kg P from TSP.

Maize grain yields from the application of *Tithonia* leaves at 1.5 t ha^{-1} which supplied 44 kg N ha^{-1}, were not significantly different from the standard fertilizer rate (92:40, N:P_2O_5) at Bembeke and Chitedze (Table 3). One of the reasons for similar maize yields was probably because *Tithonia* supplied other nutrients such as potassium (48.8 kg ha^{-1}), magnesium (1.1 kg ha^{-1}) and calcium (1.7 kg ha^{-1}) (Table 2) which are not supplied in the standard fertilizer recommendation (N:P). Also the soil test values show that K, Ca and Mg were already very low in the soil (Table 1). Wendt (1995) reported that critical values for Malawi upland soils are 97 ppm for K, 50 ppm for Ca and data from North Carolina, USA indicated a Mg critical value of 75 ppm. These critical values are far above those reported in the initial soil analysis (Table 1). As such the contribution of these by *Tithonia* could have a positive impact on maize yields.

Among the *Tithonia* treatments, there were significant maize grain yield differences at Champhira and Bembeke but not at Chitedze. At Bembeke, the application of *Tithonia* biomass at 4.5 t ha^{-1} with and without supplementation with TSP produced maize yields of 3841 and 3723 kg ha^{-1} which were significantly higher than the application of 1.5 t ha^{-1} *Tithonia* with and without TSP supplementation (2691 and 2662 kg ha^{-1}, respectively). At Champhira, the application of *Tithonia* biomass at 4.5 t ha^{-1} with TSP supplementation gave maize yields of 1675 kg ha^{-1} and 1430 kg ha^{-1} without TSP. These were not significantly higher than the application of *Tithonia* at 3.0 t ha^{-1} which produced 1366 kg ha^{-1} with TSP supplementation and 1320 kg ha^{-1} without. At Chitedze, all the *Tithonia* treatments produced maize yields that ranged from 4360 to 5598 kg ha^{-1}. Mean maize yields across sites, show that maize yields were highest at Chitedze, followed by Bembeke and lowest at Champhira. This represents the variation in inherent fertility of the sites. It was interesting that the application of *Tithonia* biomass at 1.5 t ha^{-1} at Chitedze produced yields of 4360 kg ha^{-1} that were higher than the application of *Tithonia* at 4.5 t ha^{-1} at Champhira (which produced yields of 1675 kg ha^{-1}).

Visual field observations at Champhira revealed that when *Tithonia* was applied at 1.5 t ha^{-1}, the crop started to grow vigorously. However, towards tasselling, the vigour was lost and leaves began to turn yellow. This suggests the need for supplemental N application at the four leaf stage of maize when such low rates (1.5 t ha^{-1}) of *Tithonia* are used, especially in areas of low fertility. The maize yield results reported in this study are in line with those reported by Anonymous (1995a) in Kenya where the application of *Tithonia* leaves at 5 t ha^{-1}, supplemented with TSP, produced 3500 kg ha^{-1} maize grain yield. These were significantly higher than *Tithonia* alone and *Cassia spectabilis* supplemented with TSP, which gave maize grain yields of 2000 kg ha^{-1} each. In the same report, lowest maize grain yields were obtained from the control (no biomass, no fertiliser) and TSP alone which produced 0.8 t ha^{-1} each. Palm *et al.* (1995) reported highest maize grain yields of 2 t ha^{-1} from *Tithonia* only applied at 5 t ha^{-1} and half *Tithonia* + half diammonium phosphate (DAP) which supplied 15 kg P + 120 kg N. These were significantly higher than half *Tithonia* only which supplied 7 kg P + 90 kg N and the control treatments which produced 1350 and 850 kg ha^{-1}, respectively. The application of DAP and CAN at 60 kg N and 15 kg P per hectare produced a maize yield of 1500 kg ha^{-1} and this was not significantly different from the application of *Tithonia* only, at 5 t ha^{-1}.

In other studies carried out in Malawi with biomass from agroforestry species Kanyama-Phiri, Minae and Snapp (1997) observed that maize yields almost quadrupled two to three years later when intercropped with *Gliricidia sepium* in the absence of supplemental N. With *Gliricidia sepium*, maize produced 4700 kg ha^{-1} of grain compared to only 1100 kg ha^{-1} produced by a sole crop of maize. Because the application of 3.0 t ha^{-1} of *Tithonia* at Chitedze produced 5808 kg ha^{-1} of maize grain, it appears that the immediate benefit derived from *Tithonia* is an added advantage over the long term benefits derived from *Gliricidia sepium*.

At all sites, there was a general increase in maize yield as the rate of *Tithonia* biomass application was increased from 1.5 to 4.5 t ha^{-1}. The same trend was observed when the same *Tithonia* treatments received supplemental P; maize yields also increased remarkably (Table 3). At Bembeke and Champhira, these trends were much clearer than at Chitedze.

Effect of TSP Supplementation to *Tithonia* Leaf Application on Maize Grain Yield

Supplementation with TSP did not significantly increase maize yields at all the sites. With *Tithonia* only, average maize yields ranged from 2607 to 3731 kg ha^{-1}, while with TSP, the yields ranged from 2640 t to 3665 kg ha^{-1} (Table 3). These results agree with those reported by Gachengo (1996) in Kenya where *Tithonia* leaves applied at 5 t ha^{-1} and supplemented with 25 kg P_20_5 from TSP gave maize yields that were not significantly different from the application of *Tithonia* alone. The same report suggested that the high maize performance under *Tithonia* biomass was due to the other elements found in *Tithonia* leaves that improved the nutrient use efficiency of nitrogen and phosphorus.

In another study, Jama, Buresh, Palm, Smithson and Kinyangi (1997) reported significantly higher maize yields of 4000 and 3800 kg ha^{-1} when *Tithonia* was supplemented with rock phosphate or TSP. Urea supplemented with Minjingu Rock and TSP produced maize yields of 1700 and 2500 kg ha^{-1}, respectively. Urea alone gave the lowest yields of 800 kg ha^{-1}. The treatments were applied to supply 60 kg N and 250 kg P. These results by Anonymous (1995a), Jama *et al.* (1997) and from the current study indicate that *Tithonia* biomass can be used with or without inorganic phosphorus sources depending on the phosphorus levels in the soil.

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A REVIEW OF RESEARCH ON CATTLE MANURE AS A SOIL FERTILITY AMENDMENT IN ZIMBABWE: SOME PERSPECTIVES

LUKE M. MUGWIRA[1] and HERBERT K. MURWIRA[2]

[1]Chemistry and Soil Research Institute, Box CY 550, Causeway, Harare, Zimbabwe, and
[2]TSBF, c/o ACFD, Box A469, Avondale, Harare, Zimbabwe

SUMMARY

Research on the use of animal manure to improve soil fertility in Zimbabwe started around the turn of the century and has covered a wide range of topics related to soil productivity. The objectives of this paper were to review past and current research and attempt to identify future research needs on the use of cattle manure to improve soil fertility in Zimbabwe. Sixty articles dating back to 1913 were identified from literature and reviewed for objectives, experimental details and a brief on results. For convenience, the review was organized around selected topics to identify strategies and weaknesses of past and current research as pointers to future research needs on the use of cattle manure for soil fertility. The distribution of the research articles was as follows: quality and effectiveness, 13%; beneficiation, 1%; decomposition, mineralization, synchrony etc., 13%; supplementation with inorganic fertilizers, 22%; frequency and rate of application, 4%, method and rate of application, 1%; effects on soil organic matter and nutrient levels, 8%, use in crop rotations (direct and indirect effects), 8%; CA surveys or reviews, etc., 10%; and handling and nutrient losses or conservation 5%. These figures suggest that most of the focus of research on cattle manure in soil fertility has been placed on the supplementation of manure with inorganic fertilizers followed by studies on manure decomposition, quality and effectiveness of manure and least on beneficiation, and method and rate of application. The emphasis of the research, reviewed however, do not indicate or suggest a static situation since the research focus has been shifting towards more integrated use of the increasingly scarce manure, other organic plant nutrient sources, and diminishing soil nutrient reserves with inorganic fertilizers for resource-poor farmers. Some future research needs on the use of cattle manure for improving and maintaining soil fertility are listed.

INTRODUCTION

About 70 percent of Zimbabwe is covered with sandy soil derived mostly from coarse granite, but with some derived from gneiss (south) and there are also triassic sands and Kalahari sands (northwest). In common with other soil types in the country the sands are low in N, P and S but the sands are also low in nutrient reserves and exchange capacity due to low clay and organic matter. The sandy soils are also generally acidic. Reasonable yields cannot be expected from the sandy soils without regular input of fertility ameliorants because these soils are subject to rapid depletion in fertility. For this reason many croplands on granitic sandy soils in the communal areas (CAs) that have been cropped without regular applications of manure or inorganic fertilizers now show multiple nutrient deficiencies of N, P and S and sometimes Mg and K, as well as micronutrients such as Zn (Grant, 1970).

Traditionally manure has been the major fertility input used for stabilizing crop production in sedentary agriculture in the CAs of Zimbabwe, mainly on sandy soils. Manure is still a major fertilizer in the CAs.

The beneficial effects of rotations, particularly involving legumes, farmyard manure and the use of green manures, were appreciated early in the century and many experiments have been conducted between 1913 and 1975 in this country comparing different rotations and combinations of manure treatments. Much research into the benefits of green manures that was carried out at research stations from the early 1920s to the late 1950s also involved comparisons with manure used in rotations.

Although there is no documentation of similar work in the CAs during this period the Alvord rotation, recommended for cropping in these areas since the 1940s, was based on the application of about 37 t/ha manure to the first maize crop of a four-year rotation consisting of two consecutive maize crops, followed by a legume, and finally a small grain (Grant, 1987). However, much of the research conducted at the research stations indirectly contributed to the development of recommendations for crop production in the CAs, especially the work involving the use of manure in the maintenance of the fertility of granitic sands in the 1960s.

One of the most significant trials conducted at research stations was a medium-term experiment established to evaluate changes of sandveld soils under continuous cultivation of maize, a situation prevalent in the CAs. This trial was established by the Agronomy Section of Grasslands Experiment

Station on a granitic sand that was brought under cultivation in 1962. Nitrogen, lime and manure treatments were applied annually for continuous maize (Grant, 1967a,b). This trial was important because it related the general improvement in soil fertility due to manure, as assessed by crop yields, to changes in specific soil properties such as progressive increases in cation exchange capacity, exchangeable bases and soil pH.

In the 1960s experiments were also established on nutrient-depleted or fallowed sands in the CAs to investigate restoration and maintenance of soil productivity using manure and fertilizers. These included investigations on best combination of manure and N fertilizer in Chiweshe (Johnson, 1962); the use of lime, manure and fertilizer to restore productivity of depleted sands in Kwekwe, Manyame and Honde CAs (Grant, 1970), and the work on the restoration of productivity of depleted sands using manure and N and P fertilizers in Masvingo CAs (Grant, 1981). These studies indicated that manure alone generally produced low yields and needed supplementing with inorganic fertilizers, particularly N, for optimum yields.

The experiments conducted in the 1960s indicated a shift from the use of manure in rotations in comparison with green manures to the use of manure in conjunction with fertilizers. Considerable research on the value of manure as fertilizer has been done since then. Grant (1981) summarized the benefits of cattle manure based on previous research in Zimbabwe. These benefits derive primarily from the ability of manure to supply nutrients when applied to the soil. Manure application to granitic sands has been shown to overcome or prevent deficiencies of micronutrients including S, Mg, Zn and B and to enhance soil available N, P and K.

The policy on fertilizer recommendation in Zimbabwe has been to take into account the potential yield according to the particular circumstances of the growers and whether manure would be used or not. The need for lime in the CAs remained minimal before independence in 1980 because only small amounts of acidifying N fertilizers had been used in the past and manure, which had been the main fertilizer, reduces soil acidity by releasing bases into the soil (Grant, 1981). However, the general decline in the amount of manure now available per household calls for a review of past and current research to assess future research needs for development of strategies to use the limited amounts of manure more efficiently and effectively.

METHODOLOGY

This paper is based on research done in Zimbabwe on the use of cattle manure to improve soil fertility since the early days of soil fertility research in this country. The sources of data include research articles published in journals, mainly *the Zimbabwe Agricultural Journal and Zimbabwe Journal of Agricultural Research*, Annual reports of the Department of Research and Specialist Services, the University of Zimbabwe and Africa University and work from private sector institutions.

Sixty-four articles of work dating back to 1913 were identified from literature and reviewed. The review was organised around related topics or themes to identify strengths and weaknesses of past and current research and as pointers to future research needs on cattle manure use for soil fertility.

The following topics were covered based on major themes of past and current research:

- Availability and use of manure in the communal areas: results from surveys and reviews.
- Effects of cattle manure on organic matter and nutrient levels in sandy soils.
- Cattle manure quality: concepts of manure quality; and quality and effectiveness of manure on plant growth and crop yield.
- Transformations and mineralisation during manure decomposition: decomposition of manure under storage; carbon and nitrogen mineralisation from manure in soil; gaseous manure-N losses before and after application to soil; and partitioning of manure nitrogen in soil.
- Improving the effectiveness of manure: supplementation with chemical fertilizers; beneficiation; rate and frequency of application; and method and rate of application.
- Rotations

RESEARCH TRENDS

This review indicated that research on the use of cattle manure for the improvement and maintenance of soil fertility in Zimbabwe has covered many aspects aimed at redressing the inherently low productivity of soils, particularly the sandy soils. However, like other research on crop production conducted in this country, the research on the use of cattle manure has shifted with changes of major stakeholders, i.e. from being primarily targeted to the needs of the large-scale commercial farmers particularly until the 1950s, to addressing principally the constraints and needs of the smallholder farmers in the last twenty years. Because of the more adverse production environment of more limited resources, degraded soils and generally drier climate in the smallholder sectors, research faced newer challenges.

The review shows that present investigations are directed towards increasing the use-efficiency and effectiveness of limited amounts of poor quality manure now available for most smallholder farmers, especially in the communal areas (CAs). Thus new efforts are directed towards beneficiation of the low-nutrient CA manure by co-composting with fertilizers before application in addition to increased research investigations on the supplementation of manure with inorganic fertilizers, and N synchronization. The paucity of manure is being addressed through investigations on the effects of frequency of application of varying rates (emphasizing on small rates) and methods of application designed to concentrate manure around the main rooting zones of crops.

RESEARCH NEEDS

In attempting to identify future research needs, we considered the constraints and practices of the present major stakeholders of research on the use of cattle manure for crop production and then decided if previous and current research has adequately focused on these aspects. It seems that the needs for future research on the use of cattle manure will be generally more on the relevant aspects that have been or are being addressed rather than on total technological gaps for the smallholder sectors. The most apparent of these needs are presented below.

Soils and Agro-Ecological Zones

The investigations contained in this review suggest that most of the research conducted on the use of cattle manure has been concentrated in NR II and little has been done in regions III, IV and V. However, the dependency of many CA farmers in NRs III, IV and V on manure to maintain soil fertility levels indicates a need to investigate crop responses to manure applications, both for quality and quantity. There is also a need to establish the reasons for responses that may be obtained.

There is need to investigate crop responses to manure application on vlei (hydromorphic) soils. These soils often play a major role in CA agriculture and yet very little research has been done to assess crop responses to manure application on these soils. Some research done in the CAs has indicated good crop responses to manure applied to wetlands (see Trounce *et al.*, 1985). Research results suggest that there may be significant benefits to be obtained from application of combinations of manure with fertilizers, particularly NP fertilizers. Both late dry season planted maize and dry season vegetables could be used as test crops to assess the economic value of manure on these soils.

Abandoned or nutrient depleted soils now occupy vast tracts of croplands in many CAs of Zimbabwe. Since the Agronomy Section of Grasslands, and Makoholi Experiment Station investigated the benefit of using manure for restoration and maintenance of productivity of depleted sands in the 1960s there has been very little research done on this aspect. Manure has been found to be a good substitute for P fertilizer in restoring productivity of these soils in Masvingo CAs (Grant, 1981) and for compound NPK fertilizer in Kwekwe, Manyame and Honde CAs (Grant, 1970). It is, therefore, important to investigate further the use of small amounts of manure in combinations with inorganic fertilizers for the restoration and maintenance of these soils on a wide scale.

Improvement of Manure Quality

Compared to feedlot manure, cattle manure from the CAs is low in nutrient content, particularly its P content (Mugwira and Mukurumbira, 1984). The low nutrient content of CA manure has been found to be a major factor that contributes to the low effectiveness of manure in improving plant growth and crop yield. Supplementation of manure with inorganic fertilizers applied separately, other than N fertilizer, has been generally ineffective in enhancing the effectiveness of CA manures (Mugwira, 1985). However, co-composting of the two types of nutrient sources in kraals seems to be more promising for beneficiating low-nutrient manure. There is, therefore, need to expand the work on beneficiating cattle manure by co-composting with P fertilizers (Dhliwayo and Mukurumbira, 1996) under different environmental conditions.

Several management options to improve quality are possible. Supplementing manure with inorganic P and K may be less economic and unsustainable, therefore solutions should rely on technologies and management of resources within reach of the farmer. The improvement of pastures by planting legumes can lead to better dung quality. Proper management of the manures in the kraal will enhance the quality of manures as it will reduce nutrient losses and the sand content of the manure. Greatest nutrient losses occur when dung is exposed to direct sunlight and rain. The potential to reduce losses is there. Stover can be used as a urine absorbent, though the efficacy of residues still needs to be established. Storage of manure in pits can also minimise drying and leaching during hot and rainy days. Another aspect that can be improved upon is treatment of the manure during composting. Anaerobic treatment of manure results in a better quality manure than aerobic treatment. Therefore anaerobic treatment is a good technique that can be adapted by farmers in Zimbabwe and other developing countries. Before the technique is adopted, however, handling techniques for the anaerobically treated manures need to be developed.

As a cautionary note, it has to be pointed out that manure is not the panacea to soil fertility maintenance for the resource poor communal farmer. The requirements of the 50 % or more farmers who do not own cattle (the source of manure) urgently need to be addressed by looking at other organic inputs or use of legumes. The way to go forward is to interact with the farmers to fully understand their problems and research needs for after all it is the farmers who have to live with the solutions.

Establishing Manure and Fertilizer Requirements

There is a need for research specifically aimed at the establishment of applied manure and fertilizer necessary to maintain soil productivity or soil fertility. In previous and current research, rates of manure and fertilizer have been selected rather too arbitrarily. As a consequence, crop responses to these inputs cannot be easily collated between trials. This calls for closer collaboration between researchers in the country to establish amounts of manure and fertilizer to be tested in trials. It will be necessary to take into account that manure is applied in soils primarily as a fertilizer and as such, it has a fertilizer replacement value.

The nutrient content of manures varies widely, hence there is no blanket recommendation that can be given. Before recommendations for quantities of manure to be applied can be given, it is essential to establish the initial soil fertility as a baseline for the amounts of nutrients to be supplied. The other factors that have to be taken into consideration are the quality (nutrient content) of manure, crop nutrient requirements, availability of manure and the expected yield. Therefore, research on the supplementation of manure with inorganic fertilizers also needs to assess the status of initial soil fertility, the nutrient content of manure applied and crop nutrient requirements so that crop responses obtained from different experiments can be collated more intelligibly, based on responses on actual nutrient inputs. Trying to match a manure application rate to the precise NPK needs of a crop is a difficult if not impossible task, therefore basing the application rate on the most critical element is more practical. In this light, the optimum application rate should be based on N content and especially the rate of release of N from manure. From the established rates of release, it could also be possible to make estimates of residual N availability in later seasons.

Though manure fertilisation is well established in Zimbabwe, a rational basis for its use has not been fully developed. Information on decomposition rates and tests on nutrient availability are required for proper recommendations. Mugwira and Mukurumbira (1986) indicate that the nutrient supplying power of manure has not been adequately evaluated in Zimbabwe. Despite the realisation that manure has a beneficial residual effect (Cackett, 1960; Mugwira, 1984; Mugwira and Mukurumbira, 1984) there is a critical lack of quantitative information on manure.

Research is also needed on the supplementation of CA manure with P fertilizers alone. This need arises from two factors. First the majority of CA soils are low or deficient in P but they usually do not respond to inorganic P fertilizers, and secondly CA manure appears to be a poor source of P (Tanner and Mugwira, 1984; Mugwira and Mukurumbira, 1984). The work started at SPRL on the supplementation of manure with various P fertilizers needs to be extended to depleted and abandoned sands in the CAs.

For the resource poor communal area farmers who lack the capital to buy substantial quantities of fertiliser, it is crucial to determine the minimum amount of inorganic N that needs to be added to obtain the optimum amount and timing of N release from manure. It has been shown that supplementing the manures with synthetic fertilisers improves the efficacy of the manure and fertiliser mixture (Mugwira, 1985; Rodel *et al.*, 1980). What is not certain, however, is whether nutrient release from manure is enhanced by fertiliser addition and if so, what the optimum quantity of fertiliser to add to manure is, as there is a need to correlate the nutrient contents in manure to plant growth.

The time of application of N fertilizer to fields that have received manure should be further investigated to synchronize N supply in the soil and N demand by the crop.

Improving Techniques for Manure Application and for Optimizing Crop Response

This review of literature indicated that there has been inadequate research conducted in Zimbabwe to determine the most efficient and effective ways of applying cattle manure for meeting crop nutrient requirements and producing optimum yields. This aspect is very important for the smallholder farmers who often have limited amounts of manure to apply at recommended rates to their croplands. Future research should emphasize the following aspects:

Assessment of method and rate of application of cattle manure, on crop yield. Farmers in the CAs normally try to stretch limited amounts of manure by spreading it thinly over the soil surface before ploughing the field for planting. Although this is the least labour demanding way to apply manure its effectiveness has not been assessed in comparison with that of other methods. However, results from a recent investigation that compared three methods of applying 4 t/ha and 8 t/ha manure on sandy soils showed that station placement of manure was superior in increasing maize yield to dribbling in the planting furrow, or broadcasting and ploughing in (Munguri *et al.*, 1996). These results point to a need for further research on comparisons of different methods of application of varying manure rates (emphasizing small rates) for optimising the efficiency and effectiveness of the limited amounts for the potential benefit of the resource-poor farmers on sandy soils.

The literature review also revealed little research comparing the benefits of applying small rates of manure more frequently, and those of larger rates applied at longer intervals. We found only one complete study in the literature on this. Arnold (1936, 1940) compared the effects of applying (1) 7 t/ha/year, (2) 14 t/ha every second year, and (3) 28 t/ha every fourth year manure on maize grown on a red clay. There were no differences in total yields obtained from these treatments after four years. There is apparently no similar work done on the sands in the smallholder sectors where such findings would create more flexibility for farmers in the application of the highly variable amounts available, particularly in the CAs.

The initial immobilisation of N obtained after manure application in both laboratory and field experiments means that it is beneficial to apply starter fertiliser N. Decomposition studies of communal area manures show that N release is low and spread over time, and that there is never a peak in mineralisation. Instead, the addition of fertiliser N to manure depresses mineralisation. Therefore fertiliser N should be considered as an addition to meet plant requirements, and not as a stimulant to increase N release from manure. As a management strategy application of inorganic N should be delayed to reduce N losses and increase synchrony of N availability and uptake by the crop. A simplified approach is to develop a relationship between total N content of manure, N mineralisation rate and minimum fertiliser N to be added.

There is limited research on the use of manure to fertilize rotations in the smallholder sector, and on responses of crops other than maize in all the farming sectors of Zimbabwe. The two aspects that need to be investigated are:

- Rationalization of nutrient use-efficiency in the common rotations currently practised in different areas of the country to improve these rotations and/or introducing more efficient crop sequences. The Alvord rotation which was widely advocated for the CAs since the 1940s could be rationalised on the basis of nutrient transfer from applied manure through the four-course crop sequence. Manure supplied all nutrients for the two maize crops; P, K and micronutrients for the legume; and the legume supplied N for the following small grain, a crop considered to have low nutrient demand. Such rationalization will be needed to establish the sustainability potential of current and future rotations.

- Maize has traditionally received manure because of its importance as a staple for the majority of Zimbabweans. However, other crops such as groundnut are important not only because of their food value but also due to their increasing commercial value as cash crops under the free market system. Grant (1981) reported that groundnut, for example, may respond markedly to manure and that even finger millet (*Eleusine coracana*) which is considered to have low requirement for nutrients also responded to manure. More recently, Chikowo (1996) found that groundnut responded more to manure than to fertilizer P. These examples show the need for manure research with other crops that small-scale farmers perceive to have niches in their food security and income generation.

Changes in Soil Fertility

In the majority of research trials conducted in Zimbabwe on the use of cattle manure for soil fertility the increase in crop yield has been the sole indicator of soil fertility improvement. Comparatively few trials have assessed the effects of manure on specific soil properties such as increases in pH, CEC and available P, as done by Grant (1967a, b). There is a need to assess the effects of CA manure on changes in soil fertility factors and other soil conditions that may indirectly affect soil fertility. These investigations include:

- assessment of changes in available soil P as affected by repeated application of manure and fertilizers in the CAs to establish if the application of CA manure helps to increase availability of P applied with fertilizers, and incipient soil P.

- establish critical evidence on the residual effects of manure that will be useful for assessing the value of manure as a liming and nutrient source when considering integrated nutrient management in the CAs.

- assessment of rates and frequency of application of CA manure which would help maize to withstand soil pests such as nematodes that adversely affect yield on sandy soils and limit fertilizer response, as found by application of heavy rates of manure at Grasslands by Grant (1987).

Further research is needed on the fate of manure nitrogen, and the residual effect of the manure on soil organic matter, and on nitrogen mineralisation in soil. The cumulative and interactive effect of manure addition on N mineralisation needs to be established to determine how it may affect synchrony with plant demand in later seasons.

Answers are needed on the more fundamental question of how manure influences the long term dynamics especially quantity, quality and stability of soil organic matter. Though N mineralisation from the communal area manures in the first season of application is low, it is probably advantageous in the long term. Organic N may accumulate in the soil and provide a reserve pool of nutrients which become available in the following seasons. This was the case with the results from the field study of Murwira and Kirchmann (1993b) which showed 46% mineralisation of N in the third season of manure application. In contrast, less than 10% of manure N was mineralised in laboratory incubations of five months or less.

Continued manuring affects the amount of organic matter in soil. In the tropics however, where decomposition rates are high, and manure application rates are low, build-up of organic matter may be less especially in the short term (Grant, 1967a). Therefore, the goal in any manure management approach should be to provide enough nutrients to sustain plant growth, rather than to apply optimum levels of manure for organic matter build-up. If there is any build-up of soil organic matter, it will be a secondary achievement rather than a primary goal. Besides, very few farmers have enough animals to supply the required quantities of manure. The alternative would be to apply smaller quantities every year. The limited amount of manure available could be supplemented with top dressings of nitrogen fertiliser.

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ARE THERE INTERACTIONS BETWEEN ORGANIC AND MINERAL N SOURCES? -- EVIDENCE FROM FIELD EXPERIMENTS IN MALAWI

OMMAR A. ITIMU[1,2], RICHARD B. JONES[3], GEORG CADISCH[1] and KEN E. GILLER[1]

[1]Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK; [2]Department of Agriculture, Chitedze Research Station, Lilongwe, Malawi; [3]The Rockefeller Foundation, PO Box 30721, Lilongwe 3, Malawi, and ICRISAT, P.O. Box 39063, Nairobi, Kenya

SUMMARY

An experiment was conducted on the Kasungu Plain, Malawi during the 1995/96 season to examine potential interactions between organic and mineral sources of N on fertilizer recovery by a maize crop. A 3^3 design was used with two replicates. In one of the replicates labelled ^{15}N fertilizer was applied. Available mineral N in the soil was monitored to 60 cm depth throughout the season. Only 50 % of the applied N was accounted for by the end of the season (4 months after application). Out of the 50 % that was accounted for, half was recovered in maize plants (20 to 26 % of the N applied) and the remainder was recovered in the soil. However, at the end of the season, applied N was found throughout the depth of the soil profile indicating that leaching may have been the major loss of the N that was not accounted for. To reduce N loss through leaching, split applications of mineral and/or organic N during the growing season following the recommended practice would be advisable.

No interactions between organic N (as legume tree leaves) and mineral N were observed on the availability of KCl extractable NO_3-N in the soil profile during the growing season. There were also no statistically significant interactions between organic and mineral N on final maize yield, N accumulation by maize, urea-N recovery by the maize or recovery of urea-N in the soil. Although a combination of both organic and mineral N sources resulted in a slight yield advantage, this appeared to be as a result of additivity of the main treatment effects, rather than interactive, synergistic effects. The organic and mineral resources are therefore complementary sources of N for maize and readily mineralizable organic N sources can be usefully substituted for mineral N fertilizers by farmers.

INTRODUCTION

Nitrogen deficiency is one of the major factors threatening agricultural sustainability in tropical Africa (Giller and Cadisch, 1995; Scholes, Swift, Heal, Sanchez, Ingram and Dalal, 1994; Smaling, Stoorvogel and Windmeijer, 1993). Therefore, there is an urgent need to find alternative sources of N (Giller and Cadisch, 1995) as well as improve the nitrogen use efficiency in these countries. Legume tree prunings have the potential of providing N for maize (Kang, Sipkens, Wilson and Nangju, 1981). The addition of small doses of mineral N together with prunings tends to improve crop yield (Danso and Morgan, 1993; Lehmann, Schroth and Zech, 1995; Xu, Saffinga, Myers and Chapman, 1993). Similar trends have also been observed in Malawi (Saka, Bunderson, Itimu, Mbekeani and Phombeya, 1991). It has also been suggested that N use efficiency may be improved by combining both organic and mineral sources of N (Ladd and Amato, 1985; Larbi, Jabbar, Atta-Krah and Cobbina, 1993; Snapp, 1995). However, the mechanism that brings about the yield advantage of a combination of organic and mineral source of N over organic or mineral alone has not been fully explained.

This experiment was designed to document N interactions between organic and mineral sources of N, with the following objectives:

1. To document how *G. sepium* and *S. spectabilis* prunings and urea N affect nitrogen availability in the rooting zone of a maize crop
2. To establish how *G. sepium* and *S. spectabilis* prunings and urea N affect seasonal nitrogen movement and recovery in the soil
3. To establish how *G. sepium* and *S. spectabilis* prunings and urea N affect N recovery by maize and final maize yield.

MATERIALS AND METHODS

This biomass transfer experiment was conducted at Lisasadzi Agricultural Extension Planning Area (EPA), Malawi during the 1995-96 cropping season. Soil and climatic features of the site have been described previously (Itimu, 1997). The experiment was a 3^3 factorial design with two replicates. The 54 plots were divided into six blocks of nine plots (in each block) by confounding the 3 way interactions. The treatments were: Urea -N (0, 30, and 60 kg N ha^{-1}); *Gliricidia sepium* (0, 1000, and 2000 kg dry leaf material ha^{-1}); and *Senna spectabilis* (0, 1000, and 2000 kg dry leaf material ha^{-1}). The amounts of prunings added were roughly similar in N content to the rates of mineral N fertilizer added, i.e. 0, 1000, and 2000 kg dry leaf material ha^{-1} were equivalent to 0, 30, and 60 kg N ha^{-1} respectively.

Main plots were 5 m wide (5 ridges spaced 1m apart) and 6 m long. Within each plot of one block, a microplot was marked using steel bars. The microplots were the middle 3 m of the central 3 ridges (36 plants per plot) and these received labelled fertilizers (urea or leaves). Malawi hybrid (MH 18) maize variety was planted on ridges on 16 December 1995. The maize was spaced at 25 cm within rows with two seeds per station. Soon after emergence the stations were thinned to one plant per planting station. The plots were hoe-weeded several times during the growing season.

Urea was applied as a split application (as a recommended practice); half ten days after planting, and the other half 28 days later. Labelled urea was applied in water. Plots receiving 30 kg urea N ha^{-1} received a higher enrichment (3.961 atom % ^{15}N excess), while the 60 kg urea N ha^{-1} plots received 1 atom % ^{15}N excess). A blanket application of 18 kg P ha^{-1} was applied using single super phosphate as the source of P, which was applied by banding along the ridge at the time of planting.

Coinciding with rains, soil sampling for available N using KCl was done at two week intervals starting two weeks after top dressing. At each sampling time, soil cores (using soil augers) were taken at 0-20, 20-40 and 40-60 cm depths on the centre of the ridge, and in the furrow in all plots. These samples were analysed separately. A pit was dug to a depth of 1.5 m across the net plot of micro plots. To do the sampling, the pit was dug in such a way that after smoothing the face there was a maize plant within 15 cm of the face. The face was then marked to depths of +20 (the ridge itself), 0-20, 20-60, 60-100 and 100-150 cm and, 0-20, 20-60, 60-100 and 100-150 cm for ridge and furrow, respectively for bulk density measurements and soil sampling to measure ^{15}N recovery.

At harvest, maize plants were cut where the last crown root emerges from the stem. All the material below this point was classified as roots. The percentage urea-N recovery in the soil (% FR) was calculated based on the amount of ^{15}N in each horizon as:

$$\% \text{ FR} = \sum_{\text{ridge}}^{150 \text{ cm}} (\text{N soil} \times \text{R soil}/\text{N fertilizer} \times \text{R fertilizer}) \times 100$$

where R = atom % ^{15}N excess

RESULTS

Mineral Nitrogen (KCl Extractable)

Little NH_4-N was observed during the experimental period. The ridge soil (+20 cm) had significantly more total KCl extractable NO_3-N than the other horizons especially during the first four weeks after urea application (top dressing) (Figure 1). Compared across soil horizons, extractable NO_3-N concentration decreased with soil depth up to the 20 cm depth (40 cm from top of the ridge) after which there were no differences in mineral N concentration with depth. While there was significantly higher extractable NO_3-N during the first two times of sampling in the top soils than the deeper soils (40 cm and below), there was more mineral N in samples at 40 cm and below taken from six weeks onwards, than the first four weeks. NO_3-N concentrations below the furrow were small throughout the season (data not shown). There were no significant interactions between urea-N and leaf-N application in NO_3-N concentration in the soil, and no detectable increase in NO_3-N concentrations in the plots where leaves had been applied (data not shown).

Recovery of Urea-N in the Soil

At the end of the season, there were also no significant interactions between urea and leaf N applications on the amount of the applied fertilizer (urea) N recovered from the soil, measured using ^{15}N. In terms of total N recovery in the soil, increasing rates of *S. spectabilis* resulted in an increase in N recovered in the soil significant only at the 10% level of probability (P = 0.08; Table 1).

Table 1. Recovery of urea fertilizer N in the soil and crop measured using 15N at Lisasadzi, Malawi, 1995/96 season.

Treatment	Urea-N recovery in maize (% of applied)	Urea-N recovery in soil (% of applied)	Total urea-N recovered (% of applied)	Urea-N lost (% of applied)
G. sepium (kg ha^{-1})				
0	22	24	46	54
1000	25	27	52	48
2000	26	23	49	51
S. spectabilis (kg ha^{-1})				
0	26	24	50	50
1000	21	27	48	52
2000	26	26	52	48
SED	5.8	4		

In the different soil horizons, there were no significant interactions between urea-fertilizer and leaf application in total soil N and in the recovery of urea fertilizer N. There were no differences between plots that received 1000 kg leaf material and 2000 kg of either leaf species in total N in the soil at the end of the season (data not shown). Recovery of urea-fertilizer N was not significantly affected by either leaf species (*G. sepium* or *S. spectabilis*) or rate of leaf application (0, 1000, and 2000 kg leaf material ha^{-1}).

Urea-N Recovery by Maize

There were no differences in ^{15}N enrichments between maize plants that had been treated with labelled leaves of both *G. sepium* and *S. spectabilis* and those treated with non-labelled leaves. Therefore, it was not possible to determine maize N recovery of the organic sources of N. In the plots that were treated with enriched urea N, recovery of urea-N was not affected by either of the leaf species (*G. sepium* and *S. spectabilis*) at any of the application rates (Table 1).

DISCUSSION

Soil Mineral (KCl Extractable) N During the Season

In agricultural systems N may be removed through crop uptake and harvest, soil erosion, nitrate leaching or gaseous losses. In the current experiment, higher concentrations of NO_3-N were found beneath the ridge than in the furrow soils up to 30 cm below the bottom of the ridge which indicates that there was more vertical than horizontal movement of N. Below the ridge soil however, NO_3-N concentrations were slightly greater at later sampling dates indicating vertical movement of N (leaching). At the end of the season, urea N was recovered at all depths in the soil profile up to the lateritic layer at 150 cm depth, indicating that leaching could have been a major route of loss of fertilizer N from the system. Since large applications of mineral N may easily leach in these soils, small doses of N split over time may be a more appropriate mineral N application procedure than large widely-spaced doses of N. Similar assessments were made by Piha (1993) who saw that flexible N applications that considered crop need in relation to water stress increased maize yield returns to applied N.

Application of 1000 and 2000 kg *G. sepium* leaf material ha^{-1} was equivalent to some 30 and 60 kg N ha^{-1}. Whilst 30 kg urea-N ha^{-1} resulted in a significant increase in availability of NO_3-N in the soil (Figure 1), there was no detectable increase above the control with *G. sepium* as a source of N at the time of sampling. When 30 kg *G. sepium*-N was applied, 75% (20 kg N ha^{-1}) was released from the leaves during the experimental period. The 20 kg N released over a 50 day period might have been too little to cause a significant effect on maize yield. When 2000 kg *G. sepium* leaf material was applied, some 40 kg N ha^{-1} might have been available in the soil, and this figure (40 kg N) was close to the 30 kg urea-N. Hence the two N sources (30 kg urea-N ha^{-1} and 2000 kg *G. sepium* ha^{-1}) had the same effect in terms of NO_3-N availability and maize yield.

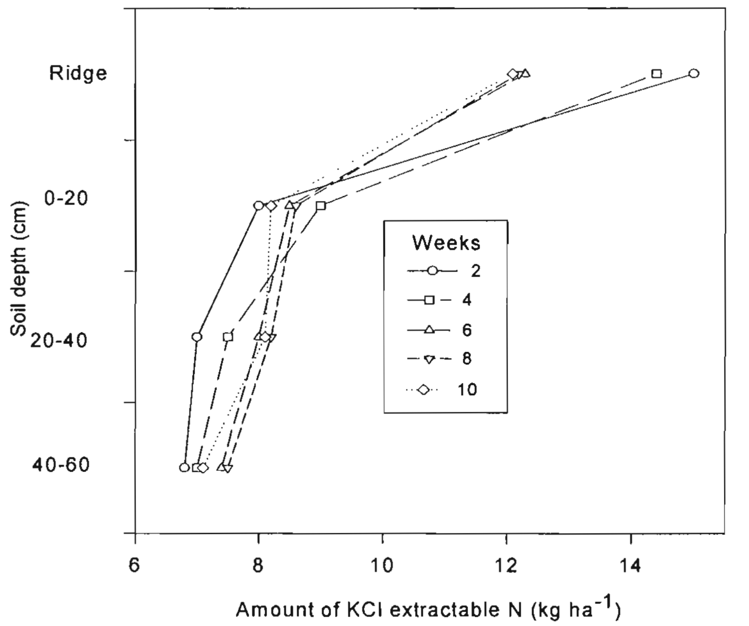

Figure 1. Changes in KCl extractable N in the soil profile with soil depth and time from application (averaged across all treatments) at Lisasadzi, Malawi; 1995/96 season in soil sampled below the ridge. Horizontal bars represents the SED

This indicates that there is a minimum amount of leaf material to be applied before the legume tree leaf application can make a significant impact on maize yields. This may explain why significant impacts of leaf application in alley cropping have not been observed at leaf application rates of less than 2000 kg ha^{-1} (Matthews, Lungu, Volk, Holden and Solberg, 1992; Saka *et al.*, 1991). Although none of the second order interactions were statistically significant, addition of urea N (30 kg ha^{-1}) had a higher response in maize grain weight when applied along with 2000 kg leaf material ha^{-1} compared with 1000 kg of leaf material ha^{-1} plus 30 kg N ha^{-1} (Figure 2). However, increasing the rate of urea application from 30 to 60 kg N ha^{-1} resulted in a reduction in the responsiveness of grain yield to added leaf material. In the case of *S. spectabilis*, up to 30 kg urea N ha^{-1}, there was a more positive interactive effect in maize grain yield at 2000 kg leaf material compared with 1000 kg ha^{-1}.

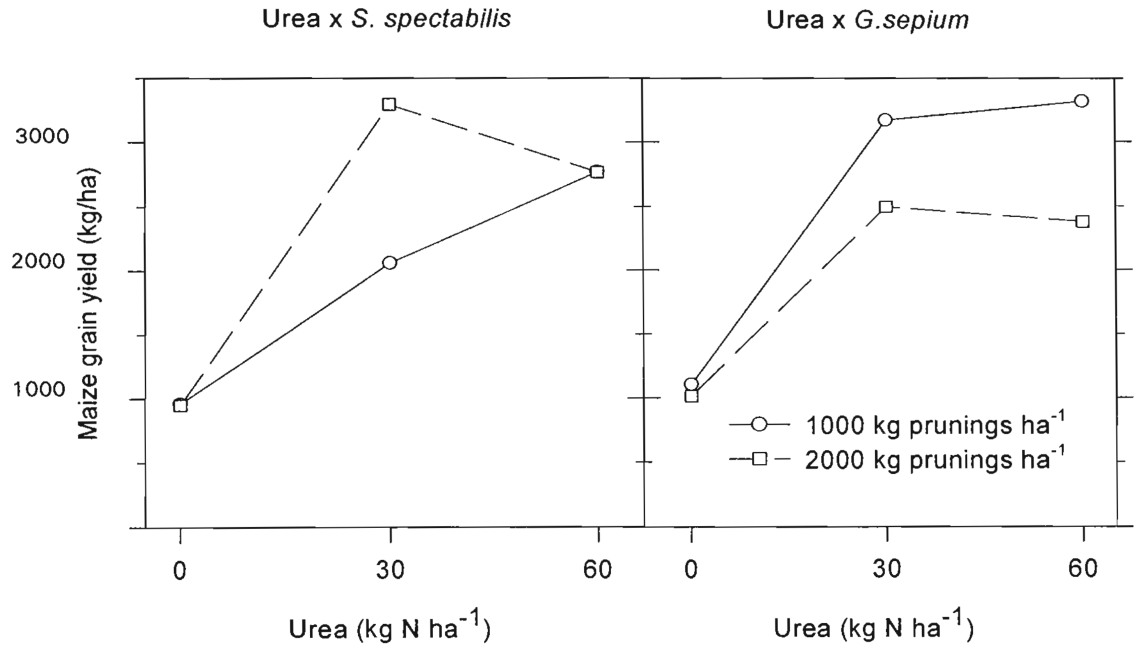

Figure 2. Second order interactions between organic (*G . sepium* or/and *S. spectabilis*) and mineral (urea N) sources of nitrogen on maize grain yield at Lisasadzi, Malawi, 1995/96 season. These interactions were not significant

Fertilizer N Recovery in the Soil

Almost 50 % of the applied fertilizer N was recovered either in the maize plant or in the soil (24 % in the plant and 25 % in the soil). Hence almost 50 % of the N was recovered and 50 % could have been lost through leaching, denitrification or volatilisation. However, as discussed earlier, leaching may have been the most important means of N loss in this experiment. At the end of the season, using the tracer technique, 25 % of the applied urea-N was recovered in the soil, of which half (13 % of applied N) was found in the ridge soil, and the other half was found in the deeper soil horizons below the ridge. Application of leaves had only a slight effect on urea N recovery in the soil, in that more was found when *Senna* leaves were applied. *Senna* leaves are known to cause an initial immobilisation early during decomposition (Palm and Sanchez, 1991) and this may have resulted in slightly more of the fertilizer-N being retained in the soil. These findings are in agreement with the results of Xu, Myers, Saffigna and Chapman (1993) who reported that 20 % of fertilizer N was recovered from the soil when applied with leucaena prunings, and half of the recovered fertilizer was found in the top soil. Christianson, Bationo, Henao and Vlek (1990) also observed that most of the fertilizer N recovered in soil was in the top 15 cm. As also observed by these authors, in the current experiment leaf application only slightly affected fertilizer N recovery (Table 1). Twenty-five percent of applied urea-N was recovered in the maize plant. These values are in line with what is reported in the literature (Christianson *et al.*, 1990; Giller and Cadisch, 1995; Xu *et al.*, 1993).

CONCLUSION

Ridging seemed to have the advantage of collecting the most fertile soils around the major rooting zone of the maize, reducing bulk density, and retarding leaching. Only 50 % of the applied fertilizer N was accounted for at the end of the season (4 months after application). Of the fertilizer N recovered, half was in maize plants (20 to 26 % of the N applied) and the remainder in the soil. However, at the end of the season fertilizer N was found at all depths in the soil profile indicating that leaching may have been the major loss of the N that was unaccounted for. To reduce N loss through leaching, split N applications during the growing season, as is the recommended practice, would be advisable.

There were no interactions between organic and mineral sources in the availability of KCl extractable NO_3-N during the growing season. There were also no statistically significant interactions between organic and mineral N in final maize yield, N accumulation by maize urea-N recovery by the maize or urea-N recovery in the soil. Although a combination of both organic and mineral N resulted in a slight yield advantage, the yield advantage appeared to be as a result of additivity of the main treatment effects, rather than interactive effects. Thus smallholder farmers can be advised to use high-quality organic manures, such as the legume leaves applied here, to supplement and substitute for fertilizer-N. Ridging is shown to be an effective method of protecting NO_3-N from leaching, as most water collects in the furrow and percolates vertically, whereas much of the soil rich in organic matter is mounded into the ridge which contains the largest amounts of NO_3-N.

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DISCUSSION: ORGANIC X INORGANIC INPUT COMBINATIONS

Comment on Giller papers from: Herbert Murwira
We seem to be doing all or at least most of the research suggested (except translating the results into a useable form), so what exactly is lacking? We need to define future thrusts that will give incremental and, eventually, large benefits.

Questions to Florence Mtambanengwe

From: Cheryl Palm
This is a very good study. There are eight similar trials around the tropics and these trials are helping us to understand the formation and loss of soil organic matter (SOM). There are some people that think SOM is a result of below-ground and incorporated materials, not above-ground, does your data support this?

Response:
Native OM in the top horizons is surely a result of above-ground inputs (the litter layer) and its decomposition through comminution and catabolism are major contributors to OM. I therefore still think any disruptions in above-ground C cycling result in SOM losses and that is shown by the Tillson and Killson treatments.

From: Danisile Hikwa
You measured N and microbial biomass only once at the peak of the rainy season in each year meaning the within season dynamics could not be captured. I thought part of the reason to measure the dynamics of N is to appreciate release and availability. Wouldn't three measurements be more appropriate, especially taking into account fluctuations in moisture at the beginning, middle and end of the season?

Response:
Most of the measurements were done three times a year at the beginning, mid and end of the rainy season. Light fraction and microbial biomass were done only in the middle of the season (because of analytical problems). But regression analysis showed that there was a positive relationship between these pools and soil C and N, so declines would also reflect other pools. As this is part of a thesis, other factors especially important to plant nutrient demands are addressed elsewhere (e.g. N mineralisation potentials).

From: Herbert Murwira
What are the soil microbial biomass amounts as a fraction of soil C levels in your treatments?

Response:
These were not addressed in this paper. Here are three quick calculations:

Control 0-10cm 4.8% biomass C as fraction of total C (1992)
Tillsom 0-10cm 3.4% biomass C as fraction of total C (1996)
Killsom 0-10cm 3.8% biomass C as fraction of total C (1996)
0-10cm of control has 13100 μgC g^{-1} soil and 624 μg biomass C g^{-1} soil
624/13100 % = 4.76%.

From: Ken Giller
1. In your data you found no difference between tilled (Tillsom) and untilled (Killsom) plots in the declines in soil organic C, and soil organic N declined more quickly in the untilled plots. Can you suggest why?
2. Which of the two early warning indicators (microbial biomass and light fraction) was the better indicator of change?

Response:
1. The duration of the experiment may not have been long enough to note any significant difference although the removal of organic matter did reduce the SOM. Moreover, the sandy soils showed little physical protection of aggregates (at least in the short-term).
2. Microbial biomass pool was a better indicator although the pool was not stable enough. Fluctuations were obvious. Declines in the Light Fraction pool are not immediate but gradual. Once the declines start to become clear we need to be concerned because it takes a long time to re-build the pool.

Comment from: Sheunesu Mpepereki
Disturbing (TILLSOM) sandy soils does not result in significant changes in organic matter levels because there is virtually no protected organic matter in those soils. Measurements of organic matter pools in sandy soils at Musana and Domboshava showed no detectable "protected" fraction. This explains why the TILLSOM treatment showed no decline in SOM as a result of tillage treatment.

Response:
The issue of OM protection needs to be quantified by soil type, native OM quality and quantity, and degree of soil disruption.

From: George Kanyama Phiri
1. Why did you choose to present recommendations rather than conclusions from your work?
2. What effect do you think drought episodes had on carbon and nitrogen over the five-year period of

study (especially on mineralization, microbial activity and N-flush)?

Response:
1. There was insufficient time to present all. The results were many and I thought obvious conclusions could be drawn from them. Also the objective was to provide management techniques to minimize soil degradation.
2. Mineralization and decomposition are moisture-dependent processes, so in years of low rainfall there were obvious reductions in total soil C and N.

Questions to **David Dhliwayo**

From: Melvyn Piha
Your data shows that 'manure-alone' is always as good as any of the 'manure + P' treatments. Thus there is no evidence of residual effects of added P fertilizer. If you are to claim a residual P effect it should be manure that has this effect.

Response:
The manure + P fertilizer material treatments had higher residual effects than P fertilizer material treatments alone. Hence co-composting of manure with P fertilizer materials could have improved the residual effects of the P fertilizer materials. In any case the high residual effect of manure alone was not significantly different from the P fertilizer materials co-composted with manure.

From: Luke Mugwira
What is the difference in residual effectiveness of manure plus rock phosphate treated in the kraal and on heaps?

Response:
There were no differences. However direct effects on maize were greater with kraal-composting (though these were not better economically).

From: Fanuel Tagwira
Did you try to check the calcium content of your soils since we know that the dissolution of rock phosphate is affected by the calcium content of soils -- the "Calcium sink theory".

Response:
The pH of the soils was generally low and the calcium levels were low.

Questions to **Herbert Murwira**

From: Luke Mugwira
Why are there no significant interactions between manure and fertilizer in the trials described?

Response:
No known answer at present.

From: Philip Mushayi
What do you think are the probable causes of declines in yield due to high manure applications? This is not the first time you have reported these effects.

Response:
Immobilisation of N.

From: Batson Zambezi
Could the low maize yields in the manure treatments be attributed to soil pests at the seedling stage, that could have come in with the manure, e.g. white grub?

Response:
There was little pest damage recorded and that was at one site only, Musami, where there was a small incidence of stalk borer.

From: Peter Jeranyama
You have presented response of grain yield only. What is happening to total above-ground biomass or at least some partitioning aspects with the manure?

Response:
These data are not yet analysed.

From: Ishmael Pompi
1. At what stage of manure maturity are you applying your manure?
2. How many cattle are needed to produce one tonne of manure?

Response:
1. The onset of rains dictates when manure is carted to fields. Usually farmers apply manure in October.

2. One animal produces 1.2 t of manure.

From: Roland Buresh
The experiment was designed to determine the N effect (benefit) of manure, hence other likely limiting nutrients were eliminated (e.g. with liming) in the trial. Manure can have many benefits (including buffering of soil pH) yet these other benefits can not be examined in this study. What is the longer-term research vision of these trials? Are you attempting to take N first and then look at other benefits in other studies? Do you believe that N is the primary benefit from manure? How will you unravel the complexity of multiple sources of manure? Economics should also consider costs of blanket-applied inputs, such as lime and P fertilizer.

Response:
Yes manure does have other benefits, particularly

the supply of bases, pH and moisture. However, the build-up of C is small at such low rates of application. We are looking at N first. Multiple benefits of manure are fairly well established but it is probably easier to isolate and study single factors on their own.

From: Todd Benson
Is there a theoretical explanation for why at some sites you found significant quadratic or cubic responses to manure? At the rates of N or manure applied one would expect a linear response.

Response:
We need to realise that the rainfall in 1996/97 was much higher than normal. We believed there was a lot of leaching that resulted in manured sites showing N deficiency. Also the manures used at the different sites could have been at different stages of composting.

Question to Jean Nzuma

From: Ishmael Pompi
At 1.2 t of manure per animal per year, who are your target farmers?

Response:
Farmers who have access to cattle. The aim here is to improve the quality of manure by minimising N losses from manure. We are improving the quality of manure which is available to farmers, irrespective of its quantity. So we are targeting farmers who have access to cattle. Farmers who have no cattle will be accommodated in a separate project looking at the composting of leaf litter and other available organic wastes. One could increase the quantity of manure by efficient use of crop residues and leaf litter. This will also increase the initial C/N ratio and reduce losses, but will have negative effects on the availability of nutrients (particularly N) during the first few weeks of crop establishment since it will slowly be released or immobilised.

Questions to Luke Mugwira

From: Batson Zambezi
Have you come across any work on manure from small animals such as goats, pigs and chickens? If so, how significant is the contribution of such manure to maize production in Zimbabwe?

Response:
There is no current work on manure from other animals. However, researchers routinely collect manure samples from goats and sheep from various places for analysis. Results from the analysis of various types of manure are available through the General Analysis Laboratory, DR&SS.

From: Ishmael Pompi
At what point or percentage of response can we say we have a good response?

Response:
Indicators of satisfactory crop response to fertilizer could be based on statistical assessment (probability), economic evaluation and level of quantitative response (e.g. increase in grain yield/kg fertilizer nitrogen applied). Researchers should address this point in assessing results.

Comment from: Antony van de Loo
There is a simple case of common sense from a farmers' point of view to combine both, combining thus the advantages and disadvantages of manure (cheap, bulky, good for soil structure) with those of fertilizer (expensive, easy to apply, short term effect).

Questions to Ken Giller

From: Cheryl Palm
The levels of N loss given (50%) seem extremely high. How representative might these figures be?

Response:
The 1995/96 season was extremely wet in Malawi and this may well have contributed to leaching losses. In other years we expect more N to remain in the soil.

From: Herbert Murwira
To what extent is nutrient retention in ridges compensated by losses in furrows or *vice versa*?

Response:
We have additional data which shows that mineral N content in the soil at the surface of the furrow was low whenever we measured it. As most of the organic-rich soil is in the ridge and the fertilizers and prunings were added in the ridge, then we think there was probably little leaching from the furrow.

From: Suzgo Kumwenda
Maximum release of N from the biomass should coincide with the maximum demand for N by the crop. It also means the time of application of the biomass is very critical.

Response:
You are certainly correct and this supports the recommendation of the Agroforestry Commodity Team in Malawi to add tree prunings at the time of first weeding when mineral fertilizers are also normally applied.

From: Rob Gilbert
What are the ramifications of the results of your N release/N uptake curves for leguminous interventions in which biomass additions are applied the previous season?

Response:
Given that soils are not completely dry when biomass is added at the end of the season it is likely that decomposition will continue and that there will be a lot of N release into mineral forms before the start of the next season. How much of this N is recovered or lost will depend on the intensity of the rains early in the next season.

NITROGEN USE EFFICIENCY OF SOME ZIMBABWEAN DWARF AND ZAMBIAN MAIZE HYBRIDS USING ^{15}N METHODS

MOSES MWALE[1], L.K. PHIRI[1], NORMAN M. MANYOWA[2], K. MUNYINDA[1] and ALFRED MAPIKI[3]

[1]Mount Makulu Central Research Station, P/B 7, Chilanga, Zambia, [2]ACFD, P. O. A 469 Avondale, Harare, Zimbabwe, [3]Misamfu Research Station, P.O. Box 410055 , Kasama, Zambia

SUMMARY

Field and green house experiments were conducted at Mt. Makulu and Magoye Research Stations in the 1995/96 and 1996/97 seasons. The objective of the study was to quantify the nitrogen use efficiency of some Zimbabwean dwarf hybrids and Zambian normal maize (Zea mays L.) hybrids by the ^{15}N methodology. In the first season, six Zimbabwean dwarf (ACFD951 - 956) and three Zambian (GV 408, 507 and 607) pre-released maize hybrids were evaluated. Four rates of urea-N were applied at 0, 40, 80, 120 kg N ha^{-1} with 1.83% atom excess ^{15}N applied only at Magoye at 80 kg N ha^{-1}. Subsequently a pot experiment with seven Zimbabwean dwarf hybrids (ACFD961 - 967) and two Zambian normal hybrids (GV 607 and 408) was planted. Two grammes ^{15}N was applied at 5% atom excess to 3 kg soil per pot. In 1996/97 season, five dwarf hybrids (ACFD 3351-261, 3351-225, 797725, 797754 and 21-244) and the same three Zambian hybrids were planted. Nitrogen was applied at 0, 50, 100 and 150 kg N ha^{-1} with 1.83% atom excess ^{15}N applied at 100 kg N ha^{-1} in both locations. Field experiments were harvested at physiological maturity while the pot study was harvested at 60 days after planting and analysed for total N and the isotope ratio. All the rates and hybrids tested were different within a location at the 5% level of significance in both seasons. The highest yield was obtained from ACFD956 with 9 t ha^{-1} at Mt. Makulu in 1995/96 season. The percent N derived from fertilizer (% Ndff) ranged from 21 - 56% and 73 - 84% in the field and pot experiments, respectively. This was probably due to greater mineralization-immobilization turnover in the field. Some N could also have been lost in the field due to leaching and denitrification. The fertilizer N utilisation ranged from 9 - 25% for the Zambian hybrids and 11 - 30 % for the Zimbabwean hybrids, although the differences were not significant (P=0.05) within location. These results show that in terms of yield and fertilizer use efficiency the dwarf hybrids compete well with the Zambian normal hybrids.

INTRODUCTION

Zimbabwean dwarf maize (*Zea mays* L.) hybrids are reportedly high yielding. The theory is that these hybrids are efficient in their utilisation of fertilizer and water, since they do not produce unnecessary biomass. The concept of fertilizer use efficiency implies not only the maximum uptake of the applied nutrient by the crop but also the availability of the applied nutrient under variable climatic, soil physical, chemical and biological conditions (Zapata, 1990). There is need to test these dwarf hybrids against Zambian normal hybrids to see if they can also be recommended to Zambian farmers. This evaluation should be conducted in all the agroclimatic zones of Zambia. Should the dwarf hybrids prove useful, especially in semi-arid regions (southern part of Zambia), it would enhance food production in that part of the country. It is vital that high yielding hybrids at low inputs (in terms of fertilizer and water) be identified because of the current high fertilizer costs, environmental concerns and unpredictable rainfall regimes. The objective of this experiment was to quantify the nitrogen use efficiency of some Zimbabwean dwarf and Zambian normal maize hybrids by ^{15}N methods.

MATERIALS AND METHODS

1995/96 Season

The field experiments were conducted at two locations, Mt. Makulu and Magoye in central and southern Zambia, respectively. The soil at Mt. Makulu is Makeni soil series, described as fine mixed isohyperthermic Udic Paleustoll, while that at Magoye is Nakambala soil series described as fine loamy mixed isohyperthermic Kandic Paleustalf (Soil Survey Staff, 1992). Selected chemical and physical properties of the soils at the two locations are given in Table 1. The design was a randomised complete block with three replicates. Six (ACFD951, 952, 953, 954, 955 and 956)

Table 1. Selected chemical and physical properties of the soils used in the experiment

			Soil parameter					Texture (percent)		
Location	Depth	pH§	C	P	K	Ca	Mg	Clay	Silt	Sand
	(cm)		(%)	(ppm)	--- (cmol$_c$ kg^{-1}) ---					
Mt Makulu	20	7.1	1.00	2.0	0.27	13.5	1.9	25	27	48 SCL
Magoye	20	4.7	0.53	4.0	1.00	1.7	0.7	14	12	74 LS

§pH was measured in $CaCl_2$

Zimbabwean dwarf hybrids and three (GV 408, 507 and 607) Zambian pre-released normal hybrids were planted at four rows per plot, 0.75 m apart with an intra-row spacing of 0.30 m. Four rates of N: 0, 40, 80 and 120 kg ha^{-1} were applied to all the hybrids. Due to inadequate ^{15}N, only the maize at Magoye had ^{15}N applied at a rate of 80 kg N ha^{-1} with 1.83% atom excess. The microplots were 3 m x 1 m within the main plots. The maize was harvested at physiological maturity and grain weight was determined. The grain isotope ratio was determined by the Kjeldahl - Rittenberg oxidation method (Axmann, *et. al.*, 1990) using the NOI-6PC Emission spectrometer.

A pot experiment was later planted with seven (ACFD961, 962, 963, 964, 965, 966 and 967) Zimbabwean dwarfs and two (GV 607 and 408) Zambian pre-released normal hybrids. Four seeds were sown in every pot and thinned to two after emergence. All pots were watered to maintain field capacity. Labelled 2 g 5% atom excess ^{15}N was applied to each pot containing 3 kg soil from Mt. Makulu. The experiment was replicated three times in a completely randomised design. The above ground parts were harvested after 60 days, dried, weighed and analysed for the isotope ratio (Axmann, *et al*, 1990).

1996/97 Season

The experiment was repeated in the same locations with some modifications. Nitrogen was applied at 0, 50 100 and 150 kg N ha^{-1}. The dwarf hybrids used were three-way cross hybrids ACFD 3351-261, 3351-225, 797725, 797754 and a single-cross hybrid ACFD 21-244. The same Zambian normal hybrids as in the previous season were used. Urea-^{15}N at 1.83% atom excess was applied at a rate of 100 kg N ha^{-1} at both locations. Phosphorus and K were applied according to prevailing recommendations for maize at 40 kg P ha^{-1} and 20 kg K ha^{-1}. The experiment was sprayed twice with endosulfan to protect the maize against stalk borer. The maize was harvested at physiological maturity. The grain was separated from the stover and weighed. Grain and stover from the ^{15}N microplots were dried at 60°C and ground to pass through a 2 mm sieve and analysed for 15N separately. Analysis of variance and mean separation were performed according to Gomez and Gomez (1984) using the Statistical Analyses System, SAS (Helwig and Council, 1979).

RESULTS AND DISCUSSION

1995/96 Season

The analysis of variance for yield of maize at the Mt. Makulu site showed that the N rates and genotypes tested were significantly different at the 5% level (ANOVA not shown). The linear model for the rates was also different though the quadratic and cubic models were not. There was no interaction between the rate and the genotypes tested. The highest yield was obtained from the dwarf hybrid ACFD 956 at a level of 120 kg N ha^{-1} giving a yield of 9 t ha^{-1} (Table 2), although the differences were not significant (p=0.05). ACFD 956 and 955 performed well at 0 kg N ha^{-1} giving yields of 8 and 6 t ha^{-1}, respectively, although again the differences were not significant (p=0.05).

Table 2. Maize mean yields at Mt. Makulu obtained in the 1995/96 season

	Zimbabwean (ACFD) dwarfs (kg ha^{-1})							Zambian (GV) (kg ha^{-1})			
N Rate (kg ha^{-1})	951	952	953	954	955	956	Mean	408	501	607	Mean
0	6370+	3278	4215	5267	6320	7848		4452	6207	5862	5507
40	7788	4996	4288	7037	5132	6769	6002	4663	6193	4685	5180
80	6210	6310	4534	7189	5574	6268	6014	6307	7895	6202	6801
120	7672	4600	4529	7614	5878	9078	6562	5425	6886	7808	6706
Mean	7010	4796	4392	6777	5726	7491		5212	6795	6139	
F(0.05)	ns	ns	ns	ns	ns	ns		*	ns	ns	
cv (%)	25	30	21	22	23	12		22	27	27	

+ Values are means of three reps, *Significant at 0.05, and ns Not significant at P=0.05

Generally, except for ACFD952, ACFD953 and GV408, all the genotypes gave high yields at Mt. Makulu (Table 2). Unfortunately the experiment at Magoye was planted late and the yields were very low (data not shown).

However, the isotope ratio analysis revealed that the highest percent nitrogen derived from the fertilizer (% Ndff) obtained in Magoye was only 36%, with statistics showing little differences between hybrids tested (Table 3).

Table 3. Percent N derived from the fertilizer (%Ndff) for the Magoye site, 1995/96 season

ACFD hybrids						GV hybrids		
953	951	954	955	952	956	607	501	408
35.9a*	33.0ab	30.6ab	29.5ab	28.1ab	27.3ab	28.2ab	27.1ab	21.2b**

* Values are means of three reps
**Means followed by the same letter are not significantly different at the 5 % level of significance.

As was to be expected GV607 gave a higher dry matter yield compared to most of the dwarf hybrids tested (Table 4). Table 5 shows that under optimum conditions, as much as 84 % Ndff would be obtained. This was probably because leaching is not a problem in the pots and denitrification was minimised.

1996/97 Season

Like in the previous season, rates and genotypes tested were different at the 5% level of significance (ANOVA not shown). The linear model for the rates was also different implying that, had the rate been increased, the yields could have been higher. There was also no interaction between the rate and the genotypes tested. Unfortunately there was too much rain in 1996/97 and as such the top dressing fertilization was delayed and yields were generally suppressed. This was particularly so at Mt. Makulu. The highest yield was obtained from the dwarf variety ACFD 799925 at a level of 100 kg N ha^{-1} giving a yield of 3.7 and 5.8 t ha^{-1} at Mt. Makulu and Magoye, respectively (Tables 6a and b), though the yield differences were not significant (p=0.05). The trial at Mt. Makulu was also attacked by leaf blight (*Helminthosporium turcicum*). Field observations revealed that hybrids ACFD 21-2443 and 797754 were the most susceptible.

Table 4. Dry matter yields (g pot^{-1}) from the pot experiment

ACFD hybrids							GV hybrids	
967	965	962	966	963	964	961	607	408
26.3ab*	25.0ab	20.0cde	22.3cde	19.3efg	18.3fg	16.3g	28.0a	24.7abc**

* Values are means of three reps, **Means followed by the same letter are not significantly different at the 5 % level of significance.

Table 5. Percent N derived from fertilizer (%Ndff) values for the pot experiment

ACFD hybrids							GV hybrids	
967	965	962	966	963	964	961	607	408
83.9a*	83.7a	82.4abc	79.1bcd	77.4bcd	76.4bcd	72.8d	81.3abc	79.8abc**

* Values are means of three reps, **Means followed by the same letter are not significantly different at the 5 % level of significance.

Table 6a. Grain yields of maize at Mt. Makulu for the 1996/97 season

	Zimbabwean (ACFD) dwarfs (kg ha^{-1})						Zambian (GV) (kg ha^{-1})			
N Rate (Kg ha^{-1})	1	2	3	4	5§	Mean	408	501	607	Mean
0	2567+	2394	1149	2884	2204	2240	1048	979	1115	1047
50	3198	2658	2441	3745	2796	2968	1855	2268	2022	2048
100	3677	3152	2348	3142	2244	2913	1900	2485	1380	1922
150	3576	2928	2822	2966	2153	2889	2510	3114	2163	2596
Mean	3254	2783	2190	3184	2349		1828	2211	1670	
F(0.05)	ns	ns	ns	*	ns		ns	ns	ns	
cv (%)	22	42	36	21	34		51	46	33	

§1, 2, 3, 4, and 5 designates ACFD hybrids 797725, 3351-225, 21-244, 3351-261 and 797754, resp.

+Values are means of three reps, *Significant at P=0.05

Table 6b . Grain yields of maize at Magoye for the 1996/97 season

	Zimbabwean (ACFD) dwarfs (kg ha^{-1})						Zambian (GV) (kg ha^{-1})			
N Rate (Kg ha^{-1})	1	2	3	4	5§	Mean	408	501	607	Mean
0	2458+	2017	1099	2146	2596	2063	1491	1107	1375	1324
50	4838	3902	2936	4731	5667	4414	2156	2508	3469	2711
100	5834	3851	4206	4378	5335	4720	4445	3955	2701	3700
150	4446	5602	3034	5030	5036	4630	4904	4729	4849	4827
Mean	4394	3843	2819	4071	4658		3249	3075	3099	
F(0.05)	ns	ns	ns	**	**		**	*	ns	
cv (%)	13	49	67	16	11		20	33	52	

§1, 2, 3, 4, and 5 designates ACFD hybrids 797725, 3351-225, 21-244, 3351-261 and 797754, resp.

+Values are means of three reps, *Significant at P=0.05, and **Significant at P=0.01

Table 7 shows the percent nitrogen derived from fertilizer (% Ndff), nitrogen grain yield and fertilizer nitrogen utilisation of the genotypes tested at Magoye and Mt. Makulu. Hybrid GV 607 took up 56% of its N from the fertilizer in Magoye. The rest of the hybrids took up lower but similar amounts of N. At Mt. Makulu ACFD 799925 and ACFD 3351-261 had lower % Ndff compared to the other hybrids. If the % Ndff values from the field (Tables 3 and 7) are compared with those from the pot experiment (Table 5), the field values are lower. This may be attributed to the mineralization-immobilization turnover (MIT) in the field. Some N could also have been lost in the field due to leaching and denitrification. Also the values obtained in the pot experiment are those analysed after 60 days of plant growth while field values are those from the grain analysis. Paul and Beauchamp (1995) reported similar results. The N yield, which is the total N multiplied by the grain yield indicated higher values for the Magoye location compared to Mt. Makulu. This was because yields at Magoye were higher (Table 7).

Within each location ACFD 799925 had the highest N yield which was 82 and 46 kg N ha^{-1} at Magoye and Mt. Makulu, respectively, although the values for Mt. Makulu were not significantly different (P=0.05). The fraction of the fertilizer nutrient taken up by the plant in relation to the rate of fertilizer nutrient applied is called the percent fertilizer utilisation (Zapata, 1990). For same genotypes, the % fertilizer N utilisation was about twice or more at Magoye compared to Mt. Makulu. Again this was because yields in Magoye were higher. However, within a given location, all genotypes had non significant % fertilizer N utilisation values.

Table 7. Percent nitrogen derived from fertilizer (% Ndff) nitrogen grain yield and fertilizer nitrogen utilisation of the hybrids tested in Magoye and Mt. Makulu

	NDFF(%)		NITROGEN YIELD (kg ha^{-1})		FERT N UTILISATION (%)	
VARIETY	MAGOYE	MT. MAKULU	MAGOYE	MT. MAKULU	MAGOYE	MT. MAKULU
ACFD 1§	37 b+	28 b++	82 a	46	30	13
ACFD 2	38 b	41 a	54 ab	44	21	18
ACFD 3	41 b	41 a	61 ab	27	25	11
ACFD 4	38 b	30 b	48 b	43	18	13
ACFD 5	38 b	40 a	57 ab	30	21	12
GV 408	40 b	43 a	62 ab	28	25	12
GV 501	40 b	47 a	57 ab	33	22	16
GV 607	56 a	42 a	41 b	20	23	9
LSD (0.05)	*	*	*	ns	ns	ns
CV (%)	18	11	28	46	33	50

+ Values are means of three replications, ++Means followed by the same letter within a column are not significantly different at the 5 % level, * Significantly different at 5 % level, and ns = Not significantly different.

§1, 2, 3, 4 and 5 designates ACFD hybrids 797725, 3351-225, 21-244, 3351-261 and 797754 resp.

FUTURE PLANS

The same dwarf hybrids and experimental areas used in the past season should be maintained in the next season as well. More data, such as 50% silking and 50% pollen shed, will be recorded in the next season, to help determine the maturity status of the hybrids tested, to have conclusive results.

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SOIL ACIDITY -- IS IT A PROBLEM IN MAIZE-BASED PRODUCTION SYSTEMS OF THE COMMUNAL AREAS OF ZIMBABWE?

DAVID K.C. DHLIWAYO, TRUST SITHOLE and HAPPYMORE NEMASASI

Soil Productivity Research Laboratory, P. Bag 3757, Marondera, Zimbabwe

SUMMARY

Most of the sandveld soils, on which the bulk of maize is produced in the communal areas, are acidic. The Al saturation percent exceeds 20% of the CEC. This level of Al is potentially toxic to maize plants.

Application of fertilizers to limed fields increases the fertilizer use efficiency by crops; hence the increase in both maize grain and stover yields. Yields increased by an average of 200% in Natural Region IIa/b, and an average of 150% in Regions III and IV. Lime application, particularly with manure, is very effective in increasing maize yields in the communal areas. The percent yield increases over the control were statistically significant (P < 0.05).

Lime recommendations based on pH measurements and Al saturation percent will enable communal farmers to apply only what is needed by their individual soils. The lime has to be applied and incorporated into the soil at least 4-6 months before planting. The residual effect of applied lime will be monitored in the 97/98 season.

INTRODUCTION

The sandveld soils most commonly found in the communal areas (CAs) of Zimbabwe are highly weathered, weakly buffered and acidic. Traditionally manure has been applied on these soils, producing a liming effect as demonstrated by Grant (1971). Surveys have shown that lime is routinely recommended by Agritex in many of the CAs without reference to existing soil acidity.

In reviewing soil acidity factors affecting maize yields in Zimbabwe, Tanner and Grant (1973) concluded that differences in response to lime were associated with Mg and Mo deficiencies and toxicities of Mn and Al. The same workers pointed out that reduction in yield when soils are strongly acid (i.e. pH 4.2 (0.01M $CaCl_2$) or less) should be ascribed to Al toxicity. Therefore, crop response to liming is associated with a decrease in the concentration of Al in the soil solution. In her studies Grant (1971) found that 32% of the light coloured soils from siliceous rock and 31% of the red soils derived from basic rocks had pH values of 4.2 or less. Grant found that maize yields are reduced by toxic levels of Al and Mn or by insufficient levels of Mg and possibly Ca. Informal surveys carried out by the Soil Productivity Research Laboratory (SPRL), in 1994 found that 21% of pale soils sampled from the CAs around Marondera had pH values which suggested potential Al toxicity. Current DRIS surveys of more than 900 communal area fields indicate that soil acidity is one of the biggest problems in realizing the full potential of crop productivity.

Phosphate and sulphate are also closely related to Al activity in the soil. Fertilization of lands with phosphate and sulphate is closely linked to available soil acidity and hence the need to look at the interactions between aluminium, phosphate and sulphate levels to ensure improved nutrient use efficiency. Soils and the crops in a given rotation must be considered in planning an efficient liming and fertilizer programme. For example, if maize is grown in rotation with grain legumes (bambara nut, soya bean, groundnuts), the soil should be maintained in a higher pH range than for maize alone. But maize may fail at high pH values because it is sensitive to trace element deficiencies induced in some soils by heavy liming.

JUSTIFICATION

Fertilizer use patterns in Zimbabwe lead to the development of soil acidity, particularly in depleted sands with weak buffering capacity where crop residues are continuously removed. Within the last 20 years there has been a big increase in the use of N fertilizers in CAs which has hastened acidification. An appropriate liming programme has to be developed to solve this soil fertility problem.

There has been no systematic investigation on the extent and degree of soil acidity in the CAs. Now, agricultural service organisations give blanket lime recommendations to apply 150 kg/ha and 250 kg/ha lime ($CaCO_3$) on sandy and clay soils respectively for every 0.1 pH difference below the optimum pH required. At best these recommendations should be viewed as a step in the right direction in trying to control the inhibiting effects of acidity on maize production. But as averages they inevitably result in under-liming or over-liming of most fields in different areas. There is a need for systematic surveys to determine the degree and extent of soil acidity in the different areas of Zimbabwe. Such surveys would help to establish more effective lime recommendations based on soil acidity, buffering capacity of the soil and crop response in relation to fertilizer inputs for particular crop rotations.

Although most current liming programmes aim to alleviate the effects of soil acidity, they do not take the negative effects of over-liming into consideration. Over-liming in Zimbabwe arises from two sources. First, lime in the CAs is applied routinely without measuring soil pH. Secondly, the lime is applied without accounting for the fertilizer inputs of previous years. A survey carried out in CAs showed that some innovative farmers reinforce manure with fertilizer and also lime fields that received manures in the previous one or two years. Liming such fields routinely may result in excessively high pH, which may induce micro-nutrient deficiencies and reduce yields.

In designing an appropriate fertilizer programme for use in CAs the efficiency of fertilizer use by crops depends on correct soil pH which controls both toxicities of Al and Mn and also on the availability of P and micro-nutrients that are chronically deficient in most of our soils.

MATERIALS AND METHODS

Soil Acidity Survey

Soil samples were taken from fields of Mhondoro, Zvimba, Murewa, Chihota, Svosve, Wedza, Serima, Buhera and Nharira CAs for pH determination. Soil chemical analysis data for the areas sampled was reviewed and incorporated into the present soil acidity survey. Fields and consequent regions were grouped according to the present Zimbabwe classification of soil pH as:

a) Extremely acid pH <4.2
b) Very strongly acid pH 4.2 - 4.5
c) Strongly acid pH 4.5 - 5.0
d) "High" pH >5.0 - 5.5

On this basis of grouping exchangeable Al, Al-saturation was determined for the first three groups. All samples were analyzed for P and exchangeable bases (Ca, Mg and K) in soil.

Fields were chosen in the following CAs: Mhondoro (NR IIa) - 5 sites, Chiota (NR IIb) - 4 sites, Nharira (NR III) - 4 sites, Buhera (NR IV) - 4 sites, Serima (NR IV) - 4 sites.

Treatments to those fields were:

A. LIME:
 A1. Control (No lime)
 A2. Lime rate from pH (0.01M $CaCl_2$) determination
 A3. Lime rate from Al titration
 A4. Manure, 25t/ha

B. INORGANIC FERTILIZER (Fertilizer rates for NR IIb aim at 5t/ha yield potential while those for NR III & IV aim at 3t/ha yield potential):
 B1. Control (No fertilizer)
 B2. (60 N, 40 P_2O_5, 20 K_2O) kg/ha NR IIa/b.
 (36N, 24 P_2O_5, 12 K_2O) kg/ha NR III & IV
 B3. (100 N, 80 P_2O_5, 40 K_2O) kg/ha NR IIa/b.
 (60N, 48 P_2O_5, 24 K_2O) kg/ha NR III and IV.

DESIGN: 3 x 4 factorial experiment arranged in randomised complete block design (RCBD) replicated three times (3 x 4 x 3 = 36 plots/site).

Parameters Measured

pH and P, K, Ca, Mg and Al in the soil were analyzed at the end of the season. Maize in rotation with groundnuts, small grain and bambara nuts will be harvested for grain and stover yields. N, P, K, Ca and Mg uptakes will be calculated and statistically analyzed.

RESULTS AND DISCUSSION

Soil Acidity Status in Communal Areas

Table 1 shows the soil acidity status in eight communal areas of Zimbabwe. The communal areas are Mhondoro (Mho), Chiota (Chi), Wedza (Wed), Zvimba (Zvi), Murewa (Mur), Buhera (Buh) and Serima (Ser). At least 70% of the soils are extremely acid to very strongly acid. This situation warrants the use of lime to eliminate soil acidity problems such as Al and Mn toxicity in these soils. These soils were also found to have an Al saturation of more than 20%. This level of Al is toxic to maize plants.

Table 1. Soil acidity status (percentage of sites) in eight communal areas in Zimbabwe.

Communal Area Locations	pH Range			
	4.15-4.19	4.25-4.50	4.57-4.84	5.01-5.61
Mhondoro	15	55	20	10
Chivhu	60	30	10	0
Wedza	33	0	33	34
Zvimba	12	48	28	12
Murehwa	80	0	0	20
Nharira	40	30	20	10
Buhera	50	10	40	0
Serima	40	50	10	0

Table 2. Effects of lime on maize grain yields (t/ha).

Farmer	Control	pH Lime	Al-titration Lime	25t/ha Manure	LSD (P<0.05)
Nyawo	2.43	2.44	2.69	3.27	0.49
Mahwehwe	1.35	1.81	1.56	2.33	0.61
Mufundikwa	0.73	1.00	0.90	1.35	0.32
Mugadza	0.81	1.35	1.02	1.65	ns

Table 3. Effects of lime on maize stover yields (t/ha).

Farmer	Control	pH Lime	Al-titration Lime	25t/ha Manure
Nyawo	2.08	2.14	2.18	2.75
Duri	0.56	0.94	0.84	1.32
Mahwehwe	2.44	2.94	3.24	3.35
Mufundikwa	1.68	1.62	1.33	2.11
Mugadza	1.49	1.98	1.65	2.90

Effect of Lime Application on Maize Grain and Stover Yields

For the 96/97 season, lime application alone had statistically no significant effect on maize yields in Mhondoro, Chiota and Buhera sites. However, in Nharira lime application showed a significant effect in increasing both grain and stover yields at two sites. Tables 2 and 3 show the effect at $P < 0.05$. In Serima two sites out of three showed positive responses to lime application. At Mufundikwa site, maize stover was influenced by lime application (Table 2). Increase in maize grain yield as influenced by lime alone was in the order of manure > pH lime > Al lime> zero lime (Table 2). Generally, lime recommendations from Al titrations gave lower yields that pH lime recommendations across the sites. This is probably due to over-liming effects because of high rates of lime application. Maize plants are affected by trace element deficiency, especially Zn and Mo, which become unavailable at high pH. High lime recommendations should be split such that half the recommendation is applied during the first year and half applied during next season. This is done to avoid upsetting the nutrient balance in the weakly buffered soils.

Application of 25 t/ha cattle manure gave the highest grain and stover yields across the sites despite the wide variation in manure nutrient content.

Effect of Fertilizer Rates on Maize Grain and Stover Yields

Application of fertilizers had a significant effect in increasing maize and stover yields compared to the control. Yields were highest with higher levels of fertilizer. Tables 4 to 7 show the effects. Within regions, the yield differences were brought about by different soil types and previous land management

Table 4. Effect of fertilizer rates on maize in Chiota, 1996/97 season.

Farmer	Control	$60N:40P_2O_5:20K_2O$	$100N:80P_2O_5:40K_2O$	LSD (P<0.05)
Grain yield (t/ha)				
Jaranganda	1.63	3.34	4.58	1.23
Munemo	1.32	2.65	3.30	0.69
Mutadzakupa	1.75	2.01	2.88	0.58
Stover yield (t/ha)				
Jaranganda	1.70	4.15	5.10	1.36
Munemo	0.90	2.46	3.09	0.68
Mutadzakupa	1.91	2.22	2.80	ns

Table 5. Effect of fertilizer rates on maize in Buhera, 1996/97 season.

Farmer	Control	$36N:24P_2O_5:12K_2O$	$60N:48P_2O_5:24K_2O$	LSD (P<0.05)
Grain yield (t/ha)				
Zvobgo	2.30	3.51	4.12	0.45
Fireyi	0.62	1.60	2.27	0.39
Makaure	0.65	1.75	2.60	0.90
Stover yield (t/ha)				
Zvobgo	2.45	3.49	3.63	0.68
Fireyi	1.33	2.35	2.85	0.89
Makaure	2.01	4.00	5.21	1.33

Table 6. Effect of fertilizer rates on maize in Nharira, 1996/97 season.

Farmer	Control	$36N:24P_2O_5:12K_2O$	$60N:48P_2O_5:24K_2O$	LSD (P<0.05)
Grain yield (t/ha)				
Nyawo	2.35	3.85	3.99	0.42
Duri	0.22	0.99	1.34	0.38
Marufu	0.22	0.31	0.81	0.28
Stover yield (t/ha)				
Nyawo	1.50	2.40	2.85	0.41
Duri	0.50	1.20	1.32	0.21
Marufu	0.35	0.90	1.60	0.33

Table 7. Effect of fertilizer rates on maize in Serima, 1996/97 season.

Farmer	Control	$36N:24P_2O_5:12K_2O$	$60N:48P_2O_5:24K_2O$	LSD (P<0.05)
Grain yield (t/ha)				
Mahwehwe	1.12	1.75	2.49	0.55
Mufuchikwa	0.61	1.14	1.48	0.28
Mugadza	0.60	1.20	1.42	0.44
Stover yield (t/ha)				
Mahwehwe	1.84	3.12	3.97	0.61
Mufuchikwa	1.52	1.79	2.15	0.46
Mugadza	1.54	1.64	1.72	ns

practices. In Mhondoro at Manomano site, the yields were as high as 7 t/ha grain and 7 t/ha stover. This site had received manure the previous three years and compound D the previous season. The sites with relatively low yields had no previous efforts to build soil fertility. There was no significant difference in yield between the lower fertilizer rate and the control at Manomano.

In Regions III and IV, the fertilizers applied seemed to have been low due to an abnormally wet 1996/97 season. The above normal rainfall received may have leached most of the fertilizer as some sites were waterlogged especially Duri site and Mahwehwe sites. There might be a need to adjust fertilizer recommendations for the regions in the next cropping season.

Effect of Lime x Fertilizer Interaction on Maize Grain and Stover Yields

These are in Tables 8-13. The combination of manure and high rate of fertilizer produced the highest grain and stover yields at almost all the sites. In Chiota, Jaranganda site lime recommendations based on Al titrations and high fertilizer combination gave the highest yields (Tables 11 and 12). Both fertilizer levels in combination with pH lime gave a yield similar to that from a combination of manure and high fertilizer rates. In Buhera at Zvobgo site there was no significant difference in yield between pH lime and Al lime in combination with high rates of fertilizer (Table 13). However at Jaranganda, Duri and Manomano sites the Al lime and high fertilizer combination significantly increased yields compared with the pH lime and high fertilizer combination. The increase in yield can probably be ascribed to elimination of potential Al toxicity problems. Yield gains were however not substantial. This is probably an indication of over-liming on the poorly buffered sands. For the same reason some sites showed no significant interaction between the applied lime and fertilizer input. Lime should be applied at least three to four months before planting, preferably at winter ploughing. This allows the correction of the acidity problem before the introduction of the crop. It is hoped that better interaction of lime and fertilizer will be observed during the 1997/98 season when residual work on limed fields will be conducted.

CONCLUSION

The sandveld soils in the communal areas are strongly acidic. Application of lime reduces soil acidity, improves fertilizer use efficiency and hence enhanced productivity.

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Table 8. Effect of lime x fertilizer interaction on maize stover yield (t/ha) at Duri, Nharira. LSD ($P<0.05$) = 0.43

	F1	F2	F3
L1	0.30	0.33	1.04
L2	0.51	1.00	1.30
L3	0.67	1.10	1.57
L4	0.59	1.47	2.04

Table 9. Effect of lime x fertilizer interaction on maize stover yield (t/ha) at Manomano, Mhondoro. LSD ($P<0.05$) = 2.11

	F1	F2	F3
L1	2.57	2.80	3.00
L2	2.65	6.61	7.20
L3	5.08	6.55	7.99
L4	3.00	6.21	7.80

Table 10. Effect of lime x fertilizer interaction on maize grain yield (t/ha) at Manomano, Mhondoro. LSD ($P<0.05$) = 1.80

	F1	F2	F3
L1	2.00	2.20	2.40
L2	2.90	4.74	5.51
L3	3.52	4.77	5.80
L4	3.52	4.96	7.01

Table 11. Effect of lime x fertilizer interaction on maize stover yield (t/ha) at Jaranganda, Chiota. LSD ($P<0.05$) = 1.84

	F1	F2	F3
L1	1.50	3.09	3.69
L2	2.23	4.03	6.08
L3	1.86	4.82	6.79
L4	1.46	2.61	4.48

Table 12. Effect of lime x fertilizer interaction on maize grain yield (t/ha) at Jaranganda, Chiota. LSD ($P<0.05$) = 1.18

	F1	F2	F3
L1	1.91	2.71	3.01
L2	1.74	4.21	4.51
L3	1.58	3.33	4.93
L4	1.29	3.09	4.52

Table 13. Effect of lime x fertilizer interaction on maize grain yield (t/ha) at Zvobgo, Buhera. LSD ($P<0.05$) = 0.99

	F1	F2	F3
L1	1.95	2.30	2.70
L2	2.31	3.63	4.12
L3	2.59	3.16	4.13
L4	2.32	3.98	4.36

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EVALUATION OF A FERTLIZER-BASED SOIL MANAGEMENT PACKAGE FOR VARIABLE RAINFALL IN COMMUNAL AREAS OF ZIMBABWE

MELVYN PIHA, JAMES MACHIKICHO and W. PANGENYAMA

Department of Soil Science and Agricultural Engineering, University of Zimbabwe, P.O. Box MP167, Harare, Zimbabwe

BACKGROUND

The 'optimum' crop yield for a given area usually occurs at slightly below the maximum attainable yield. Where fertilizers are available at reasonable prices and where crops can readily be sold, fertilizer application rates should be sufficient to obtain 'optimum' yields. At such rates, farmer profit should be maximised whilst production levels would be near to maximum. Also, from an environmental perspective, high yields per unit area may mean that more land is available for other purposes.

For various reasons, high input and high yield agriculture is generally not being adopted in sub-Saharan Africa. This is primarily because most African farmers cannot afford fertilizer inputs, and because the selling prices of crops are too low. In addition, because of highly variable rainfall patterns, optimum yield and optimum fertilizer requirements are difficult to predict, making fertilizer-use a risky investment.

Our long-term objective is to encourage 'optimum yield' agriculture by the small-scale farmers of Zimbabwe. For this to be possible, the limits to adoption, mentioned earlier, need to be removed. This will require research to determine optimum fertilizer management under variable rainfall conditions, the extension of methods and assistance with input purchases and marketing of products.

An 'optimum' fertilization strategy for the typical low soil fertility and variable-rainfall communal area conditions of Zimbabwe has already been formulated from theoretical principles (Piha, 1994) and compared with current recommendations in a series of on-farm researcher-managed trials. Over five seasons our 'optimum' approach gave 25-42% more yield and 21-41% more profit than did current recommendations, for three maize growing zones. Analysis of marginal returns indicated that these profits were attainable at an acceptable level of risk, particularly when used in combination with rainfall harvesting techniques such as post-emergence tied-ridging.

Our approach is based on supplying nutrients at rates that are equal to those removed by a crop of maximum yield under 'average' rainfall conditions. For nutrients which are stored in the soil (e.g., P, K, S) these fixed amounts are applied annually, with some reductions made for generalized soil contributions. Nitrogen fertilizer rates are however varied during the season through a series of topdressing applications. The rate of nitrogen used at each application is chosen on the basis of the expected yield declines that occur as a result of drought stress. A summary of this approach, together with actual recommended rates for typical communal areas is given in Table 1.

The main purpose of our current research programme is to verify whether the above approach to 'optimum' fertilization is a practical and viable op-

Table 1. Summary of the optimum fertilizer management approach and rates for Natural Regions II, III and IV.

1) Estimate 'optimum' yield of maize for a given area, based on maximum yield attainable in an 'average' rainy season. For sandy Zimbabwean soils optimum yield estimates are: NR II 5.3 t/ha; NR III 3.5 t/ha; NR IV 2.2 t/ha.

2) Estimate nutrient removal by the 'optimum' crop indicated above. Where residues are removed from fields, estimated nutrient removal per t of grain is: 20kg N; 18kg k; 4.5 kg P; 4.5 kg S; 4.5 kg S; 4.5kg Mg; 4.5 kg Ca.

3) Estimate generalized quantity of nutrients supplied by the soil. For inherently nutrient poor, low organic matter, sandy granite soils, which have been cropped continuously for many years, the estimated soil nutrient contributions are: negligible N, P, S,; sufficient K for 75% of crop needs; sufficient amounts of all other nutrients to meet crop needs.

4) Estimate nutrient addition required to attain optimum yields ie. amount required by crop minus amount supplied by soil (2 - 3). Calculated nutrient requirements (kg/ha) from above are:

NR II: 106 N, 24 P, 24 S, 24 P

NR III: 70 N, 16 P, 16 S, 16 P

NR IV: 44 N, 10 P, 10 S, 10 P

5) For nutrients which are 'stored efficiently' (i.e. P, K, S), these amounts are broadcast-incorporated annually as a pre-plant application. These rates can be approximated by use of Compound L fertilizer (5:18:10) at the following kg/ha rates: NR II 300; NR III 200; NR IV 135.

6) Nitrogen fertilizer rates are adjusted according to the rainfall pattern during the on-going season.

Ammonium nitrate is broadcast on three occasions during the growing season (i.e. 10 DAE; 30 DAE; tasselling). The amount applied at 10 DAE is fixed at 50 kg AN/ha. For the subsequent applications, the rate applied varied, depending on the degree of visible drought stress experienced since the previous application. No nitrogen is applied if there has been severe wilting; a high rate is applied if there has been no stress; intermediate rates are applied for moderate stress situations.

In practice, the optional kg/ha rates of ammonium nitrate are: 0, 50, 100, 150 - NR II; 0, 50, 100 - NRIII; 0, 33, 67 - NR IV. When used in combination with the small amount of N applied with Compound L (5%N) this results in the following total N rates: NR II 32 - 132 kg/ha; NR III 27 - 95 kg/ha; NR IV 24 - 67 kg/ha.

tion for improving crop production and farmer well-being in Zimbabwe. This requires implemention and farmer well-being in Zimbabwe. This requires implementation of the 'fertilization package' by farmers under realistic conditions. This should include extension of the technology to farmers under conditions where the real costs of inputs are paid for by the farmers.

Our aim is to help remove the barriers to 'optimum' production by small-scale Zimbabwean farmers. A promising technology for fertilizer use under variable rainfall conditions has already been developed for this purpose. Our intention is to extend this method while helping to remove barriers for input use through facilitatory financial arrangements. To be realistically sustainable an input loan package must involve real costs, and should be financially acceptable to potential lending agencies.

METHODOLOGY

Seven extension workers were selected and familiarized with the proposed soil management package (SMP). In addition to the fertilizer management practices indicated in Table 1, the package includes the promotion of post emergence tied-ridges established at approximately 30 days after planting. Seven smallholder farming areas were chosen, including one from NR II, four from NR III and two from NR IV.

The extension workers selected participating 'master farmers' from within their areas. Thirty-five such farmers were supplied with sufficient seed and fertilizer to plant 0.5 ha (NR II, NR III) or 0.75 ha (NR IV) of maize using the indicted package. Soil samples were analyzed for pH (0.01M calcium chloride) and available P, K, Ca, Mg, Zn and Mn (Mehlich 3).

The farmers received inputs on loan, and agreed to use them only as instructed. The farmers agreed to pay back the loan at the end of each season, when they were offered a new loan of inputs under the same arrangements. The loan repayment was to be in the form of maize grain, to be collected shortly after harvest. The value given to the maize was that offered by the Grain Marketing Board at the time of harvest. If a farmer was unable to repay the loan (i.e. due to drought), repayment or partial repayment was deferred until the following season. The 'realistic' value of the loan was calculated as the cost price of the inputs at Harare plus fifty-percent. This 50% charge includes approximately 5% for transport of inputs, 10% for transport of purchased grain, 25% inflation, plus 10% service.

It was intended that participating farmers would implement the soil management package (SMP) continuously with maize, without manure addition, on the same piece of land for three years (i.e. 1994/95, 95/96 and 96/97).

EVALUATION

Realistic evaluation of the proposed package includes production, financial viability, and acceptability of new technologies. There are three 'new' interventions in the SMP. These are:

i) Broadcast application of all fertilizers
ii) Selection of rainfall-varied nitrogen applications
iii) Establishment of tied-ridges 30 days after planting.

The evaluation of the package included an 'end of project' survey of participating farmers to assess farmer opinion of the above interventions. Results from this survey are not yet available.

Long-term evaluation (3-years minimum) was necessary to include season-to-season rainfall variation. Total production, profitability, and loan repayment rate by the participating farmers was evaluated at the end of the 3-year period. An attempt was made to compare the input costs, yields, and profits of participating farmers using the SMP against those for normal farmer practices. The participating farmers were thus asked to simultaneously plant a field of maize using their current management practices for comparative purposes. In addition, some neighbouring master farmers and non-master farmers were selected for comparative purposes, from a list held by an extension worker. Because the SMP intended to achieve relatively high production, early planting was recommended, and hence the 'priority' maize crop of the comparative controls farmers was selected for relative evaluation. For each extension area there were thus: five SMP farmers (Group 1), five other maize plots of these same participating farmers (Group 2), five neighbour master-farmer plots (Group 3), five non master-farmers' plots (Group 4).

The relative performance of participating SMP farmers (Group 1) compared with control farmers was likely to be highly variable, particularly because of the large variability in control farmer practices. In addition, because participating farmers were told not to use manure on their SMP plots, we envisaged that their comparative control plot (Group 2) would probably receive more inputs than was normally the case. Thus, for analytical purposes it was considered acceptable to compare the performance of each SMP farmer (Group 1) against the average performance of all the control farmers of the same extension area (i.e. mean of all Group 2, 3 and 4 farmers).

RESULTS

Seasonal Variation

During the three year experimental period there was a large variation in seasonal rainfall. This included one season of very low rainfall (45% - 65% of normal), one near-average season, and one season of relatively excessive rainfall (30% - 70% above normal). Thus, it was possible to compare the relative performance of the SMP under various rainfall conditions. Tables 2 and 3 indicate the average yields and profits of all SMP farmers combined, compared to the average for all control farmers for each of the above three seasons. For all three seasons, use of SMP gave greater average yields (54% to 101%) and greater average profits (62% to 109%) than the control.

Table 2. Average maize grain yields (kg/ha) of control farmers and SMP farmers for each of the three seasons.

	1994/95	1995/96	1996/97
Control	1235	1490	1822
SMP	1907	2989	3208
Increase (%)	54	101	76
Rainfall	Below average	Average	Above average

Table 3. Average profit (Z$/ha) and investment return (harvest value/input cost) of control farmers and SMP farmers for each of the three seasons.

	1994/95		1995/96		1996/97	
	Profit	Return	Profit	Return	Profit	Return
Control	570	2.20	1021	2.59	1022	2.24
SMP	922	1.98	2135	2.47	1811	2.11
Increase (%)	62		109		77	
Rainfall	Below average		Average		Above average	

Natural Region Variation

The performance of the SMP farmers (Group 1), averaged over the three year period, can be compared with that of the control group (average of Group 2 + 3 + 4) for each of the Natural Regions. Tables 4, 5 and 6 indicate the relative yields, input costs, profits and returns for investment of SMP and control farmers. On average, large increases in yields and profits were attained by SMP farmers despite the increased input costs. Profits and yields for SMP farmers were more than double that of control farmers for Natural Regions II and IV. These SMP profits were achieved with a return of Z$3.18 per dollar spent for NR II and Z$2.33 for NR IV. Average performance of the SMP farmers in NR III was relatively less superior than the control group. Average yield increases for NR III SMP farmers were only 55% higher than the control, whereas average profit increases were not significantly different. Average profits for the NR III SMP farmers were achieved at a relatively low return for investment (Z$1.70: 1).

Table 4. Average maize grain yields (kg/ha) of control farmers and SMP farmers for each of the three Natural Regions.

	NR IIb	NR III	NR IV
Control	2773	1417	1072
SMP	5583	2199	2266
Increase (%)	101	55	111

Table 5. Average input costs (Z$/ha) of control farmers and SMP farmers for each of the three Natural Regions.

	NR IIb	NR III	NR IV
Control	1204	760	569
SMP	2135	1515	1097
Increase (%)	77	99	93

Table 6. Average profit (Z$/ha) and investment return (harvest value/input cost) of control farmers and SMP farmers for each of the three Natural Regions.

	NR IIb		NR III		NR IV	
	Profit	Return	Profit	Return	Profit	Return
Control	1724	2.77	813	2.17	628	2.22
SMP	4199	3.18	1016	1.70	1549	2.33
Increase (%)	144		25		146	

Extension Area Variation

The relatively poor performance of NR III SMP farmers is further demonstrated by considering the average profits for each of the individual extension areas (Table 7). Whereas relatively large and significant profit increases were achieved by SMP farmers for all NR II and NR IV extension areas (i.e. +143%, +194%, +111%), only one out of four NR III extension areas performed similarly (i.e. +106%). For the remaining NR III sites, average SMP profits were not significantly different from the average of the control

Table 7. Average profit (Z$/ha) and investment return (harvest value/input cost) of control farmers and SMP farmers for each of the three Natural Regions.

	NR IIb A		NR III A		NR III B		NR III C		NR III D		NR IV A		NR IV B	
	Profit	Return	Profit	Return	Profit	Return	Profit	Return	Profit	Return	Profit	Return	Profit	Return
Control	1724	2.8	878	2.6	1073	2.5	887	2.0	413	1.7	537	2.3	721	2.2
SMP	4199	3.2	1800	2.2	1506	2.0	414	1.3	341	1.3	1576	2.4	1522	2.3
Increase (%)	143		105		40		-53		-17		194		111	

profits.

The yields and profits of each individual SMP farmer were compared with the control group average for each of the extension areas, averaged over the 3-year trial period. For all extension areas (except Manyene 1, NR III C) average SMP farmer yields were significantly greater than those for the control group. Out of a total of 35 participating farmers only three produced average yields that were below those of their respective control groups.

Because SMP input costs were generally double that of the control (Table 6), profit performance by individual SMP farmers was less satisfactory than that of yield. For four of the extension areas (Mhondoro-NR II, Nharira-NR III, Marange North-NR IV, Marange South-NR IV) average SMP profits were greater than control profits. For the remaining three extension areas (Manyene 1-NR III, Manyene 2-NR III, Dora-NR III) there were no significant differences in profits between control and SMP farmers. Out of a total of 35 participating farmers, 23 achieved profits that were greater than Z$1.5 per dollar spent.

Loan Repayments

Table 8 summaries loan repayment rates for each of the extension areas. Participating SMP farmers were expected to repay their loans at the end of each season. The value of the loan repayment was calculated to be the input cost, plus 50% to cover annual transport and interest costs. A total of Z$67609 worth of fertiliser and seed was purchased and loaned to the SMP farmers over the three year trial period, and a total of Z$101413 was therefore required to be collected to cover the 50% charge. At the end of the 3-year period the total amount collected was $94586, giving a loan repayment rate of 93%.

Extension area loan repayment rates were not directly related to average extension area profits, but were more dependent on the situation of the individual farmers. In some cases SMP farmers tried to avoid loan repayments despite profitable production, whereas in other cases farmers with low investment returns managed to repay loans from alternative sources. Loan repayment rates were above 95% for the remaining four areas.

Table 8. Loan disbursement and payment.

Communal area	NR	Loan given (Z$)	Repayment (Z$)	Recovery rate (%)
Mhondoro	II	21990	21990	100
Manyene 1	III	13565	12600	93
Manyene 2	III	13565	12402	91
Nharira	III	13565	11532	85
Dora	III	13565	10852	80
Marange N	IV	13165	13165	100
Marange S	IV	13165	12995	99
TOTAL		102580	95536	93

DISCUSSION

The soil management package was relatively most profitable when climatic conditions allowed for large yield increases to be obtained in response to input use. Thus the relative returns from investment with the SMP were greatest for the 'average' 95/96 season (Z$2.47), and were reduced slightly when yield potential was limited by flooding (Z$2.11 for the 96/97 season) or drought (Z$1.98 for the 94/95 season).

In theory, the overall profitability of the SMP was expected to be based on higher yields and profits in relatively wet years, whilst avoiding losses in dry years. Thus, the ability of the SMP to produce profits at acceptable returns even in a low rainfall season is an encouraging indicator of the flexibility of the approach. Similarly, the success of the SMP in both the drier marginal maize producing NR IV, as well as in the relatively wet NR II is further evidence of the resilience of the approach to climatic changes.

Almost all SMP farmers in the NR II and NR IV sites produced yields and profits that were more than double that of the control group. The three year average SMP maize yield for the NR II and NR IV sites were 5.58 t/ha and 2.26 t/ha respectively, compared to averages of 2.77 t/ha and 1.07 t/ha attained by the control group. These SMP yields compare remarkably well with the theorized SMP average yield potential targets of 5.3 t/ha and 2.2 t/ha respectively (see Table 1). When SMP farmer profits (Group 1) were compared with profits obtained by the same farmer for their control maize plots (Group 2), marginal returns analysis indicated that adoption of the SMP approach should be recommended for 100% of the NR II farmers and 87% of the NR IV farmers. The comparative success of the SMP maize against the farmer's own control is likely to be better in reality. This is because any cattle manure that was intended for use on the designated SMP field was deliberately excluded, and invariably resulted in higher manure use on the farmer's control plot.

For only one out of four NR III extension areas (i.e. Nharira) were relative yields and profits of the SMP treatment approximately double that of the control group. Although average yields for the remaining three extension areas were 11% to 61% greater than for the control, average profits were not significantly greater. This is because marginal yield increases were attained for approximately double the investment cost.

The poor average performance of the SMP at the NR III sites cannot simply be explained based on climate, given that more successful results were achieved in both wetter and drier extension areas. The three year average SMP maize yield for the combined NR III sites was 2.20 t/ha compared to an average of 1.42 t/ha for the control group. This SMP yield was however much lower than the theorized SMP target yield of 3.5 t/ha for NR III. The relatively poor performance of the NR III sites can partly be attributed to the location of some of the extension areas. Three out of the seven extension areas (Manyene 1, Manyene 2, Nharira) experienced a severe mid-season drought during the relatively high rainfall 95/96 season. All of these sites were in Natural Region III. Similarly, yield reductions due to flooding in the 96/97 season were most severe on the relatively shallow soils in the Manyene Communal Area of NR III. In addition to the above, there were extension problems in Manyene, resulting in numerous SMP farmers producing no yield during the dry 94/95 season.

Although average results indicate that the adoption of the SMP will result in an approximate doubling of national communal farmer yields and profits, it is the profit and returns on investments for each individual farmer that is more important when recommending adoption of a new technology. The proportion of SMP farmers that attained profits that were below that of the control group, or had investment returns of less than 1.5, were 0%, 50% and 20% for Natural Regions II, III and IV respectively. Based on the individual perfomance of the SMP farmers, our results indicate that the package can be confidently implemented in some extension areas, but would be too risky for other areas. On a national level the proposed package could only be recommended if those cases of failure can be explained, predicted and eliminated in future extension efforts.

The success of the SMP is dependent on a large response to applied fertilizers in good rainy seasons. If such responses cannot be attained because of other limiting factors, the SMP is expected to fail, and should not be implemented. To determine whether the poor performance by some SMP farmers was inherent in the proposed technology, or due to understandable and correctable factors, all individual results were ranked in order of success, based on returns for investment (see Table 9). Eleven out of 35 cases were identified where returns for investment by SMP farmers were less than 1.5. Those soils that had exceptionally low levels of essential nutrients not added as part of the SMP (i.e. Zn, Mg, Ca), or with exceptionally low pH (<4.3) were identified. Additionally, those sites where high yields could not be attained in good rainy seasons due to predictable

Table 9. Reasons fo soil management package failures.

				Predict						Manage	
NR	SMP	Site	Z$/$I	Zn	Mg	Ca	K	pH	F1	xsN	MGT
IV	B	Marange-N	3.67							-	
IV	D	Marange-S	2.60							-	
II	E	Mhondoro	3.33							-	
III	A	Nharira	3.30							-	
II	D	Mhondoro	3.18							-	
II	C	Mhondoro	3.04							-	
IV	A	Marange-S	2.93							-	
III	E	Nharira	2.74	*	*	*				-	
IV	B	Marange-S	2.72							-	
II	B	Mhondoro	2.71							-	
III	A	Manyene-2	2.70							-	
III	B	Dora	2.61							-	
III	C	Dora	2.61							-	
IV	A	Marange-N	2.40							-	
IV	D	Marange-N	2.33							-	
II	A	Mhondoro	2.16							-	
III	B	Nharira	1.92							-	
III	D	Dora	1.87							-	
IV	E	Marange-N	1.84							-	
III	C	Nharira	1.80	*	*	*	*	*		-	
III	B	Manyene-2	1.67					*		-	
III	A	Dora	1.61		*	*	*			-	
III	E	Dora	1.52							*	
IV	C	Marange-N	1.50							*	
III	A	Manyene-1	1.37							*	*
IV	E	Marange-S	1.33							*	*
III	D	Nharira	1.32							*	*
III	B	Manyene-1	1.29								
IV	E	Manyene-1	1.24					*	*	**	
IV	C	Marange-S	1.09	*	*	*				**	*
III	C	Manyene-1	0.98							*	
III	D	Manyene-1	0.93	*						**	*
III	C	Manyene-2	0.93					*		**	
III	D	Manyene-2	0.81							**	*
III	E	Manyene-2	0.60						*	**	*

Predict: Zn<0.5, Mg<0.1, Ca<0.3, K<0.1, pH<4.3, Flood (*)

Improve: Excess SMP N use <200% - >200% (*) >300% (**)

Reality: Management (*)

flooding were identified. Results shown in Table 9 indicate that such soil problems probably accounted for SMP failure in five out of the 11 cases.

It was also apparent that many cases of SMP failure were due to extension problems that could be reduced in the future. The correct selection of optional N fertilizer rates is an important aspect of the variable-rainfall fertilizer management package. It is possible that some participating SMP farmers attained reduced profits because they applied either too little or too much nitrogen. If this was the case, future SMP results could be improved by better extension. For each tonne of maize harvested, approximately 20kg of N are contained in the maize plant. Thus a comparison of N applied with estimated crop N uptake can be made, to evaluate N uptake efficiently. All sites where N fertilizer additions were more than double the nitrogen uptake were identified as being over-fertilized. In cases where N applications were more than triple crop uptake, overuse was classified as severe. Table 9 indicates those cases of overuse and severe overuse of N fertilizer. For all 24 cases where the SMP was successful (i.e. returns > 1.5) there was no evidence of N overuse. For the 11 cases of SMP failure (i.e. returns < 1.5), four were classified as having N overuse, and six were considered as having severe N overuse. Thus, in almost all cases low profits of SMP farmers could be attributed to N overuse.

It should be possible to improve the success rate of the soil management package by putting more effort into extension of N fertilizer selection rates. The current management package only calls for reduced N inputs in the case of expected yield reductions due to drought. The soil management package needs to be modified to include reduction of N inputs where low yields due to other causes are apparent. In many cases for the 96/97 season it was apparent that maize yields would be lowered due to flooding. Participating SMP farmers continued to use the highest N rates during this season, because the package only called for input reductions due to drought stress. Ideally, these farmers could have perceived that final yields were going to be low, and thus should have lowered their N inputs.

CONCLUSIONS

The adoption of the proposed soil management package by communal area farmers could result in a doubling of current yields and profits. For this to be possible however, arrangements for input loans need to be in place. Very high loan recovery rates are likely to be achieved, if repayment can be collected in the form of maize grain at harvest. Assistance with maize sales is likely to enhance the success given the current competitive marketing system.

It is important that extension of the soil management package be done carefully to ensure the success rate. In particular, the selection of nitrogen fertilizer rates in accordance with expected yield needs to be better understood and more clearly extended. The soil management package should not be extended to sites where high yields are unlikely to be attained in good rainy seasons. This is likely to occur where soil physical conditions or inadequate farmer management will limit production. Cases of additional limiting soil chemical problems (i.e. acidity, Mg, Zn) need to be identified and corrected before adoption of the management package.

The use of relatively high nitrogen fertilizer rates is likely to result in gradual soil acidification and hence potential reductions in SMP yields and profits. During the 3-year experimental period an average soil pH decline of 0.1 pH unit occurred in response to the addition of 80 kg of nitrogen, as ammonium nitrate. Given that numerous communal area soils are already marginally acid, and marginally limiting in Mg and Zn, the addition of some dolomitic limestone and Zn-containing fertilizers should be part of the soil management package.

The promising performance of the soil management package was achieved on nutrient poor soils that received no organic inputs, and which were cropped continuously with maize for three years. Further improvements are likely in reality, where the occasional use of manure and rotation with other crops is likely to occur. Farmer profits are likely to increase by using pre-plant SMP rates in combination with biological nitrogen fixation for the production of marketable grain legumes such as groundnuts and soybeans.

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MICRONUTRIENTS IN THE MAIZE-BASED SYSTEM OF THE COMMUNAL AREAS OF ZIMBABWE

LINUS MUKURUMBIRA and HAPPYMORE NEMASASI

Soil Productivity Research Laboratory, DR&SS, Private Bag 3757, Marondera, Zimbabwe

SUMMARY

Using the Diagnostic and Recommendation Integrated System (DRIS), complex nutrient ratios were computed for six communal areas. DRIS indices for these areas indicated widespread micronutrient deficiencies in the maize-based cropping system. Regular micronutrient applications are necessary where maize yields as high as 5 t/ha are targeted.

INTRODUCTION

A judicious integration of mineral fertilizers, organic mineral fertilizers and biological nitrogen fixation (BNF) with optimal soil and crop management practices can greatly contribute to sustainable agriculture. A decade of research by the Soil Productivity Research Laboratory ((SPRL) on legume -cereal rotations has shown that Zimbabwe's national maize yield could be increased from 1.5 t/ha to 4 t/ha in legume-cereal rotations. As crop yields increase, the demand for micronutrients by crops is raised. Zinc (Zn), boron (B), molybdenum (Mo) and Copper (Cu) have to be applied regularly on all lands along with medium to heavy NPK dressings if maize grain yields greater than 5 t/ha are to be sustained. Application of micronutrients as single-nutrient fertilizers leads to soil build-up of the micronutrient in question. However, the quickest method to correct deficiencies is by foliar applications.

In Zimbabwe, increased prevalence of Zn deficiency has been reported, especially on sandy soils (CSRI, 1987). The sandveld soils commonly found in the communal areas (CAs) of Zimbabwe are highly weathered, weakly buffered and acidic (Grant, 1970; DRIS, 1996). More than 60% of these soils are planted to continuous maize monoculture, with crop residues mostly removed to feed livestock. This may result in both macro- and micronutrient deficiencies in these sandy soils, when yield targets are greater than 3.5 t/ha.

In Natural Regions II and III, the majority of CA farmers use compound D fertilizer and ammonium nitrate (AN) in their maize fields. However, little attention has been given to using micronutrient fertilizer dressings to correct nutrient imbalances. Several factors have been reported to influence the availability of micronutrients to maize crops. Generally, pH and P application tend to interact with Zn uptake. Over-liming and high phosphate applications have been shown to reduce the availability of Zn to crops. In some areas, the change over from organic manures which may contain Zn to inorganic fertilizers has resulted in an increase in the deficiency problem (Tanner 1973). In the fersiallitic soils, which are moderately leached, Mo becomes unavailable at pH values below 4.8 [0.01M$CaCl_2$] (Tanner and Grant, 1974). In contrast, granite derived soils usually supply enough Mo for normal maize growth at these pH levels.

High levels of nitrogen and phosphorous may induce copper deficiency by optimisation of growth or interference with translocation in marginal deficiency situations (Tanner, Copper and Madziva, 1981).

Boron availability is decreased by liming and dry conditions and deficiency of this element is mainly by inadequate natural supplies in the parent rocks and by leaching in sandy soils.

METHODOLOGY

Soil fertility surveys of the communal areas of Zimbabwe were carried out. Areas included in this study were, Murewa, Chinamora, Chivhu/Nharira, Devedzo/Rusape, Mutoko and Mhondoro.

A total of 300, 534 and 493 farmers' fields were sampled during the 1994/95, 1995/96 and 1996/97 seasons respectively. Soil samples were collected from fields at an approximate distance of 1 km apart. The sampled areas covered 10 to 30 km^2 per extension worker. Olsen P was used as an indicator of soil fertility build-up. All the farmers received fertilizer recommendations for a maize yield target of 5 t/ha. The pH levels were raised to 5.2; the level assumed to be ideal for maize. Diagnostic and Recommendation Integrated System (DRIS) indices were computed for 1994/95 and 1995/96 based on foliar analysis.

RESULTS

Zn ranges of 22-37ppm and 17-23ppm in the whole plants and cobleaf respectively were found to be on the marginal to sufficient levels in the growing season. Cu concentration in the maize was found to be sufficient throughout the growing season (Tables 1 and 2).

Mn nutrition was sufficient to very high with values of 152 to 225 ppm and 99 to 299 ppm in whole plant and cobleaf respectively. There seemed to be no problem with Iron nutrition. Plants had values as high as 501 ppm during early stages of growth.

Zn levels were marginal to low with values of 18 to 32ppm in the whole plant and 16 to 22ppm in the cobleaf (Tables 3 and 4).

Cu was sufficient throughout the growing season. Mn nutrition was very high to excessive with values of 185 to 864 ppm in the whole plant and 97 to 177 in the cobleaf. Iron nutrition was sufficient to high with ranges of 64 to 186 ppm.

Zn and Cu were marginally sufficient to sufficient during the growing season (Tables 5 and 6). The manganese nutrition of the maize crop was sufficient to very high with values of 115 to 209 ppm in the whole plants and 124 to 158 ppm in the cobleaf. Fe ranges of 238 to 340 ppm were sufficient for the crops.

DRIS Indices

Tables 7 and 8 present indices for the 1994/95 maize crops. The most negative indices are for nitrogen. This indicates that nitrogen was the most limiting

Table 1. Murewa "Gororo" micronutrients in whole maize plants. Sample size 89.

GROUPS	ppm Zn	ppm Cu	ppm Mn	ppm Fe
1	26.33	9.00	163.33	424.67
2	27.00	10.67	151.67	459.00
3	27.83	9.67	162.00	343.67
4	29.50	11.67	173.67	368.00
5	29.83	11.00	198.00	501.00
6	22.00	8.67	186.67	668.67
7	36.67	10.00	225.00	257.67

Olsen P ranges: Group 1 = 0 – 18, 2 = 19 – 30, 3 = 31 – 42, 4 = 43 – 54, 5 = 55 – 66, 6 = 67 – 78, 7 = > 80 $\mu gP_2O_5/g$

Table 2. Murewa "Gororo" micronutrients in cobleaf. Sample size 89.

GROUPS	ppm Zn	ppm Cu	ppm Mn	ppm Fe
1	18.00	11.50	113.33	*
2	18.67	7.67	114.00	*
3	22.50	7.00	100.00	*
4	20.83	10.50	141.67	*
5	17.17	11.33	98.67	*
6	19.67	10.33	124.33	*
7	17.33	13.00	299.00	*

Olsen P ranges: Group 1 = 0 – 22.1, 2 = 22.2 - 34.2, 3 = 34.3 - 46.3, 4 = 46.4 - 58.4, 5 = 58.5 - 70.6, 6 = 70.7 - 82.6, 7 = > 82.7 $\mu gP_2O_5/g$

Table 3. Murewa "Chikukutu" micronutrients in whole maize plants. Sample size 76.

GROUPS	ppm Zn	ppm Cu	ppm Mn	ppm Fe
1	28.33	9.67	313.33	139.67
2	18.18	11.50	415.00	185.67
3	25.17	11.83	520.33	141.00
4	21.67	9.33	232.33	135.00
5	31.50	8.00	686.67	172.33
6	22.50	8.00	864.00	64.00
7	30.50	9.00	185.00	166.67

Olsen P ranges: Group 1 = 0 – 22.1, 2 = 22.2 - 34.2, 3 = 34.3 - 46.3, 4 = 46.4 - 58.4, 5 = 58.5 - 70.6, 6 = 70.7 - 82.6, 7 = > 82.7 $\mu gP_2O_5/g$

Table 4. Murewa "Chikukutu" micronutrients in cobleaf. Sample size 76.

GROUPS	ppm Zn	ppm Cu	ppm Mn	ppm Fe
1	18.17	11.17	158.00	*
2	15.67	11.00	132.33	*
3	19.33	12.17	137.00	*
4	20.17	10.17	121.67	*
5	19.33	8.83	124.33	*
6	21.50	8.50	96.67	*
7	17.50	14.00	177.00	*

Olsen P ranges: Group 1 = 0 – 18, 2 = 19 - 30, 3 = 31 - 42, 4 = 43 - 54, 5 = 55 - 66, 6 = 67 - 78, 7 = > 80 $\mu gP_2O_5/g$

Table 5. Chinamora "All" micronutrients in cobleaf. Sample size 117.

GROUPS	ppm Zn	ppm Cu	ppm Mn	ppm Fe
1	23.33	11.00	153.33	*
2	21.67	12.33	149.00	*
3	16.50	7.00	157.67	*
4	19.33	11.00	124.33	*
5	14.33	10.00	152.33	*

Olsen P ranges: Group 1 = 0 – 30, 2 = 31 - 60, 3 = 61 - 90, 4 = 91 - 120, 5 = > 121 $\mu gP_2O_5/g$

Table 6. Chinamora "All" micronutrients in whole plants. Sample size 117.

GROUPS	ppm Zn	ppm Cu	ppm Mn	ppm Fe
1	27.67	9.33	114.67	288.67
2	28.60	8.67	123.33	326.67
3	33.00	10.33	209.00	238.00
4	26.00	10.00	188.67	339.67
5	42.67	10.67	166.00	274.67

Olsen P ranges: Group 1 = 0 – 30, 2 = 31 - 60, 3 = 61 - 90, 4 = 91 - 120, 5 = > 121 $\mu gP_2O_5/g$

nutrient during the growing season. In Mrewa, Zn is very limiting as shown by the higher negative values. While in Chinamora Zn and occasionally Cu are limiting in maize production, even fields indicating reasonable P build-up by the Olsen test generated negative P-values. This seems to indicate a nutrient imbalance in the cultivated soils.

Tables 9 through to 12 present DRIS indices generated during the 1995/96 maize growing season. In Chivhu/Nharira district, plant nutrients limited growth in the following order: N > P > Cu > Zn = Fe = Mg.

Soil-available K remained at near optimal levels in the sampled fields (Table 9). In Devedzo district of Rusape, plant nutrients were most limiting in the following order: N > P > = Mg > Zn > Fe. Copper was not limiting.

A similar trend in limiting nutrients is apparent in Mhondoro (Table 11). Nutrients are limiting in the following order: N > P > Zn > K > Mg.

Table 7. DRIS nutrient indices in the cobleaf, 1994/95. Murewa extension worker Gororo 1994/95.

GROUPS	N	P	K	Ca	Mg	Mn	Zn	Cu
1	-27	-10	-4	-9	-19	33	-7	14
2	-17	-15	-4	-6	-9	31	-5	0
3	-17	-9	-6	-8	-11	26	1	-3
4	-22	-8	-5	-10	-27	43	-4	9
5	-27	-1	-3	-25	-3	27	-7	11
6	-19	-3	1	-12	-17	32	-6	4
7	-30	-9	-17	-26	-17	100	-23	8

Olsen P ranges Group 1 = 0 – 18, 2 = 19 - 30, 3 = 31 - 42, 4 = 43 - 54, 5 = 55 - 66, 6 = 67 - 78 7 = > 80 $\mu gP_2O_5/g$

In Mutoko, nitrogen was the most limiting and phosphorous the least limiting. Calcium and magnesium were in second place, followed by K, Zn and Fe (Table 12).

CONCLUSIONS

Micronutrients, especially Zn, play a very important role in the maize-based system of the CAs of Zimbabwe. Zn was found to be limiting where high rates of nitrogen and phosphorous fertilizers are used. Therefore, for the smallholder farmers to realize the full genetic potential of their maize and other crops, maintenance application of 3 kg Zn/ha should be applied every three to four years. Farmers should apply the correct amounts of fertilizers after soil analysis. This will avoid nutrient imbalances in the soil and luxury consumption of excess nutrients.

DRIS indices indicate wide areas of natural micronutrient deficiencies. Research and extension should give attention to the possibility that micronutrients might become critical, "minimum factors" as micro - and secondary nutrients are amended and yield levels are raised.

Table 8. DRIS nutrient indices, Chinamora, 1994/95.

GROUPS	N	P	K	Ca	Mg	Mn	Zn	Cu
1	-27	-19	-1	4	-3	36	-6	2
2	-29	-25	-3	6	1	38	-7	0
3	-9	-162	4	25	3	71	-6	2
4	-21	-22	-3	11	0	28	-11	0
5	-40	-15	1	6	-3	48	-21	0

Olsen P ranges: Group 1 = 0 – 30, 2 = 31 - 60, 3 = 61 - 90, 4 = 91 - 120, 5 = > 121 $\mu gP_2O_5/g$

Table 9. DRIS nutrient indices, Chivhu/Nharira cobleaf samples, 1995/96.

GROUPS	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
1	-31	-5	4	-3	3	10	-2	1	-1
2	-29	-6	1	-7	2	25	1	-2	-1
3	-43	-2	2	-4	0	27	6	0	-5
4	-42	3	3	-13	-2	34	1	-1	18

P ranges: Group 1 = < 8.0, 2 = 9.0 - 16.0, 3 = 17.0 - 24.0, 4 = > 24.0 ppm P_2O_5

Table 10. DRIS nutrient indices, Dewedzo/Rusape cobleaf samples, 1995/96.

GROUPS	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
1	-19	-15	-8	7	4	1	4	-5	6
2	-39	-15	-2	1	-4	25	-2	-2	13
3	-35	-12	-14	11	-14	39	-9	-1	12
4	-55	-13	12	6	0	16	2	-7	16

P ranges: Group 1 = < 24.45, 2 = 22.46 - 44.45, 3 = 44.46 - 64.45, 4 = > 64.46 ppm P_2O_5

Table 11. DRIS nutrient indices, Mhondoro cobleaf samples, 1995/96.

GROUPS	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
1	-26	-23	3	0	-13	21	3	-5	16
2	-51	-19	-14	6	-1	56	2	-16	6
3	-26	-17	-2	-1	-8	24	9	-5	5
4	-40	-15	1	-10	11	16	0	-4	18

P ranges: Group 1 = 0 - 18, 2 = 19 - 30, 3 = 31 - 42, 4 = 43 - 54 $\mu gP_2O_5/g$

Table 12. DRIS nutrient indices, Mutoko cobleaf samples, 1995/96.

GROUPS	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
1	-40	-1	3	-11	-11	24	4	0	6
2	-46	-1	-9	-6	-4	45	9	-9	5
3	-56	8	-9	-10	-11	34	11	-1	11
4	-36	3	-3	-3	-9	30	-7	-8	17

P ranges: Group 1 = < 16.25, 2 = 16.26 - 32.50, 3 = 32.51 - 48.75, 4 = 48.76 ppm P_2O_5

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DISCUSSION: INORGANIC FERTILIZER MANAGEMENT

Questions to Moses Mwale

From: Linus Mukurumbira
With other varieties we are getting the same N-use efficiencies that you report here, i.e. 20 - 38% NUE. There is virtually no difference. Please comment.

Response:
If the varieties are early maturing and high yielding, they should be grown, especially if they perform well with less water and N, because they do not produce unnecessary biomass.

From: Fannuel Tagwira
If the N use efficiency and yield of dwarfs is the same as that of other varieties in use, what advantage is there in using the dwarf varieties?

Response:
The dwarfs have probably a higher water use efficiency due to their size.

Questions to Happymore Nemasasi and David Dhliwayo

From: Bernard Kamanga
It has been shown that liming is advantageous and more-so if applied together with inorganic fertilizer. Farmers rarely purchase the fertilizers although they can buy lime. Are there ways we can help a farmer who has lime but no fertilizer?

Response:
In Zimbabwe most smallholder farmers are not aware of the important use of lime to reduce soil acidity. Those farmers who can afford fertilizers should commit a few extra dollars to buy lime so that they increase the fertilizer use efficiency by the crop. Farmer groups are being given fertilizer loans by various NGOs and other organizations. Their loans should also consider lime as an input.

From: Alfred Mapiki
To see whether soil acidity is caused mainly by Al^{3+} ions, it is recommended first you conduct a soil characterisation exercise. Lime recommendations could be based on the Kamprath formula: Lime Req = 1.65 x exchangeable aluminium. pH in Al affected soils is not a good approach to a liming program.

Response:
A full soil analysis has been carried out, including the quantities of Al^{3+} ions present on the exchange. The full characterization of sites will be carried out in the 1997/98 season. The suggestions will be considered in the project on the new sites and the results compared with the original sites.

From: Rebbie Phiri
The use of manure to alleviate acidity problems seems to be a viable option since the manure also improves the soil structure and adds N unlike lime. Is there any work that has been done on the use of manure to alleviate the acidity problem?

Response:
A lime effect produced by manure was reported by Grant in 1971. The liming project at SPRL is now taking care of this observation by including 25 t/ha of cattle manure as a lime treatment. pH changes will be determined in the manured plots and its potential effect in increasing pH and Al^{3+} ions will also be assessed.

Comment from: David Rohrbach
At liming levels of 2.7 t/ha, the cost of application would be roughly Z$1600/ha + transport + application costs of Z$1000/ha, or approximately Z$2600/ha. A farmer would have to harvest roughly 2.5t of additional maize to pay for the application. Future experiments with liming might consider this a threshold target to assure profitability.

Questions to David Dhliwayo

From: Sheunesu Mpepereki
1. Is Al^{3+} the only or main source of acidity in sandy soils of Zimbabwe?
2. What proportion of soils tested had Al^{3+} saturation percentages in excess of 20%?

Response:
1. Low pH (i.e. high H^+ ion concentration) results in Al^{3+} ion activity. Al^{3+} ions then become toxic to plants at threshold levels. However, effects of Mn toxicity have not been quantified although there is a potential for Mn toxicity.
2. 70% - 80% of sampled fields had Al^{3+}saturation percentages in excess of 20%.

From: Ishmael Pompi
What should be the general baseline to response?

Response:
We should really have a compromise between statistical significance and economic significance. In our Dorowa phosphate rock work, although all the materials gave significant effects three were considered economic after a net benefit analysis.

Questions to Melvyn Piha

From: Cheryl Palm
You mentioned you will be adding manure in subsequent trials. Having seen the variable results from the Soil Fert Net (Herbert Murwira's) manure x N trials, how do you feel the manure might affect the results of your package?

Response:
We will consider any use of manure to be a supplement to our fertilizer. This would further boost production or build up the soil reserve. Unless someone can come up with a formula on how we can practically deduct for organic input use it is too complicated to deal with.

From: David Rohrbach
It would be useful to evaluate returns for each year rather than averaging returns across years. Farmers may be more concerned about the variability of returns and particularly about the possibility of losses in a poor year than as an average return.

Response:
I agree, but we know we will not get good responses in a drought year. We are counting on very good profits in high rainfall years to compensate for losses in dry years. Hence, our package is most interested in overall performance over numerous years. We do have the results for each year available.

From: Danisile Hikwa
The management package looks very good as long as it is handled by the researchers with a lot of control on the marketing strategy in particular. However is the marketing strategy sustainable beyond the life of the project? Even with the involvement of the Agricultural Finance Corporation, your farmers would not get the personalised service of delivery and collection of inputs and produce to sustain the credit scheme. With this background, can the strategy stand extrapolation to other similar environments? How much of an involvement of extension agents is there to ensure this? I do agree that synchronization of fertilizer application with moisture availability does increase yield. My reservation is on the credit scheme and marketing strategy.

Response:
I agree with your sentiments and am not sure that the system will work in the real world. But, because the potential is high we will put energy into trying to develop a loan system that is self-sustainable. Fertilizer companies may help, because they have most to gain.

From: Herbert Murwira
What is the figure used for baseline comparisons, i.e. the control normalised across all sites at 1?

Response:
For each communal area we take the average yield of our 15 control farmers and assign this a value equal to 1. Our farmer yields are compared to this value.

From: George Kanyama-Phiri
You have been very liberal in testing for levels of significance for results ($P = 0.1$). Any explanation?

Response:
The management and input levels of our control farmers are so variable that we felt we should be generous with our statistics. If we use $P=0.05$ we get the same results except for one of the sites.

From: George Kanyama-Phiri
What will happen, say at the end of the study, if you remove the simultaneous exchange between a bag of maize and a bag of fertilizer? Will the loan repayments be maintained?

Response:
The system will not self-sustain on its own. We need to come up with a self-sustaining loan package for our management approach to become successful in reality.

From: Todd Benson
How does the research project price of inputs to farmers reflect the 'free market' costs to farmers of that package? Sustainability issues arise if they are significantly different.

Response:
We use the Harare price (bulk purchase) + 50%. If someone were to have a rural fertilizer outlet they could have a similar 'free market' price. So our values are realistic. In practice it depends on where the farmer purchases the inputs. Some local stores charge more. Some groups do bulk purchases and can get inputs cheaper than we supplied.

From: Larry Harrington
Are Soil Fert Net sites geo-referenced?

Response by: Stephen Waddington
Many of our sites are now geo-referenced. Members in Malawi and Zimbabwe have access to a GPS and some are using it.

Questions to Linus Mkurumbira

From: Samson Maobe
On-farm labour constraint limits the split application of fertilizer. How widely is the split application of fertilizer done by smallholder farmer in Zimbabwe?

Response:
P, K, Ca, Mg and micronutrients, as well as lime, can be applied at winter ploughing, way before the rains come to avoid labour peaks.

From: Ishmael Pompi
Do blends from ZFC and Windmill address the problem of micronutrient levels in maize-based production systems of the communal areas of Zimbabwe?

Response:
ZFC makes special blends for large orders. Some of these blends may be used by communal farmers. But it is important to see what the commercial farmers are using, because that is where the money is.

From: Ernest Muzorewa
Given the limited additional resources available to communal farmers, what do you consider to be an optimum frequency of adding micronutrients to the sandy soils and heavy clays?

Response:
ZnO, $CuSO_4$, sodium borax apply 3 - 5kg with the basal PK fertilizer. Lime once every four years. You need as little as 100g of sodium molybdate once every four years. If you apply them as straights you have better control over the quantities to apply and can build up the levels.

From: Luke Mugwira
The way forward to increase productivity by incorporating proper nutrients levels in fertilizers should be easy since the fertilizer companies welcome such suggestions. It is up to DR&SS soil scientists and agronomists to articulate this need.

Response:
I agree totally. At present the fertilizer industry is 100% owned by Government. Liberalization of this should be reasonably easy.

From: Melvyn Piha
Are you suggesting that communal area farmers should automatically apply micronutrients to their fields, or should they base the application on soil analysis?

Response:
Farmer groups should buy micronutrient packets and weigh out amounts needed per ha.

DEVELOPING MORE PRACTICAL FERTILITY MANAGEMENT RECOMMENDATIONS

DAVID D. ROHRBACH

SADC/ICRISAT, Box 776, Bulawayo, Zimbabwe

Greater and more efficient use of chemical fertilizer can significantly improve crop yields in Zimbabwe. This includes grain yields in the 75% of the nation's farming areas situated in drought prone, semi-arid zones (Natural Regions IV and V). Yet less than 5% of these farmers purchase fertilizer (Rohrbach *et al.* 1990; Hedden-Dunkhorst 1993). Farmers openly acknowledge the value of this input (Ahmed *et al.* 1997) and application of chemical fertilizer is known to be profitable (Gono 1996; Ahmed and Rohrbach forthcoming). Yet the vast majority of small-scale farmers still fail to pursue this investment.

The payoff to further research and extension relating to fertility management in semi-arid areas depends on the diagnosis for this problem, and the associated prospects for implementing a solution. This paper reviews three key hypotheses explaining the limits to fertilizer use in Zimbabwe's semi-arid regions, and summarizes recent data about how farmers have used the fertilizer received free through Zimbabwe's drought relief programs. The paper then reviews a new strategy for the development of more practical sorts of fertility management advice. This involves the coordination of crop simulation modelling and farmer participatory research to develop a wider range of technology options suited to different sorts of farmers with varying risk preferences and resource levels. Rather than pursuing single optimal solutions suited to an agroecology, the approach aims to facilitate experimentation by small-scale farmers. The strategy targets smaller, but more consistent, improvements in each household's fertility management. The resulting technologies will not maximize yields or even farm profits. But these offer the prospect of practical improvements in yields and profits with a higher likelihood of adoption.

YIELD GAPS IN SORGHUM AND PEARL MILLET

During the drought affected 1993/94 cropping season, sorghum grain yields on the Matopos and Lucydale Research Stations in southern Zimbabwe ranged between 1.1 and 5.5 t ha^{-1} (ICRISAT 1995). The grain yields for pearl millet at Lucydale ranged between 1.3 and 1.9 t ha^{-1} (ICRISAT 1995). These crops were not irrigated. Yet even the lowest grain yields were more than three times the average yields achieved by small-scale farmers. According to national extension estimates, Zimbabwe's smallholder sorghum yields that year averaged only 350 kg ha^{-1} and pearl millet yields averaged 240 kg ha^{-1} (Crop Forecasting Committee 1994).

The yield gap between the experiment station and farmers' fields is almost entirely a function of crop management. Available data from on-farm trials indicates a change in sorghum seed alone (e.g. from a traditional, local variety to the improved variety SV 2) can improve grain yields by about 18%. In comparison, changes in seed plus management offer 80% yield gains (Table 1). Unexpectedly, the lowest yields achieved in these on-farm trials were almost 1 t ha^{-1}. This is already two to three times the average sorghum and pearl millet yields recorded for the country as a whole. These trials are partially described in Heinrich and Mangombe 1995.

Table 1. SV 2 yield advantages with and without fertilizer, in 1992/93 and1993/94 on-farm trials in Zimbabwe (kg/ha)

	Without Fertilizer		With Fertilizer	
	Farmer's Local	SV 2	Farmer's Local	SV 2
1992/93 Average	1.52	1.63	1.92	2.51
1993/94 Average	0.98	1.38	2.32	2.57
Overall Two Year Average	1.33	1.57	2.10	2.42
Percentage yield gain		18%	58%	82%

Source: SADC/ICRISAT SMIP

While fertilizer and manure application account for a large part of the gains being achieved in experimental trials, other components of crop management are also important. Both the on-farm and experiment station trials tend to be planted at a higher density than nearby fields, and receive more timely management. The quality of weeding may be better. These crops are probably better protected from losses to birds. Nonetheless, the magnitude of the yield gap, especially that evidenced in the on-farm trials remains cause for concern. The reasons for the persistence of this gap need to be identified.

HYPOTHESES ABOUT FERTILIZER INVESTMENT

Almost 50% of all small-scale farmers in the semi-arid regions of southern Zimbabwe have tried chemical fertilizer. However, recent ICRISAT surveys indicate that more than 95% of this experimentation has resulted from free fertilizer distribution associated with drought relief programs. Less than 5% of these farmers purchase any chemical fertilizer on their own. Unless otherwise indicated, the farm level data cited in this paper are derived from the Seed and Fertility Management Survey conducted by SADC/ICRISAT between May and June 1996. This survey covered 22 villages in 11 Communal Areas distributed across three agroecological zones in the south of the country. The Communal Areas were chosen at random from a listing of all Areas with at least 33% of their cereal grain area planted to sorghum and/or pearl millet. The villages were chosen at random within the Communal Areas. Ten households were chosen at random from each village.

These surveys have also revealed that more than 50% of cattle owners do not use manure on their field crops. This statistic was so unexpected that we did not collect an explanation for this failure. Further investigations are underway.

Continuing concerns about low levels of fertilizer and manure use, and stagnant sorghum and pearl millet yields, have stimulated the development of a collaborative research program with Zimbabwe's Department of Research and Specialist Services to assess how to improve these trends (Ahmed and Rohrbach 1996). Three major hypotheses have been proposed for low adoption rates for both the chemical and organic inputs. First, farmers may perceive fertilizer to be too risky. Farmers at the margins of subsistence cannot afford to accept even small risks of crop or financial losses. By inference, these farmers are more concerned about the possibility of an occasional loss than the average level of return. In order to be practical, fertility management technologies may first need to minimize the possibility of a given level of loss.

The second major hypothesis relates to the actual level of the return. Small-scale farmers may recognize that fertilizer offers a positive return. However, the average level of this return may not be high enough to attract scarce capital away from alternative expenditures - for example school fees. In this context, it is important to recognize that farmers do not make management decisions about a particular farm enterprise independently from their alternative investment opportunities across a wider range of farm and non-farm enterprises. When we conduct an economic analysis of a new technology, we commonly consider only the productivity gains of a particular enterprise with and without the technology. We mistakenly infer that if a technology is profitable, it will necessarily attract a capital and labour investment. In fact, the technology must be more profitable than alternative investment opportunities.

This trade-off may be worsened by inefficiencies in input or product markets. For example, chemical fertilizer may not be locally available. In addition, small-scale farmers in remoter rural areas face high transport costs getting their grain to the larger national market. If fertility management recommendations are to be practical, these must account for the high costs of fertilizer delivery and the low return on surplus grain production.

Finally, farmers are hypothesized to have incorrectly judged the relative returns to investment in chemical fertilizer. This is not surprising given the variability of rainfall across and within seasons in Zimbabwe's semi-arid areas. The complexity of estimating input responses is worsened by associated variability in weed growth and pest incidence.

Anecdotal evidence suggests farmers may also be confused by the difference between crop performance in years when fertilizer is applied versus the following years when the input is not available. Most acknowledge that fertilizer offers higher yields. But many small-scale farmers also state that 'soils are worsened by fertilizer'. When fertilizer is taken away, yields are perceived to drop below what they would have been if no fertilizer had ever been applied (Ahmed *et al.* 1997).

These hypotheses are not independent of one another. The answer to the fertilizer problem probably lies in a combination of explanations. The relative importance of each of these explanations also depends on the circumstances of the individual farmer. Households with more livestock may be more willing to accept the risks of cash losses in the occasional drought year. These farmers may find the market constraints most difficult. Farmers who face the severest food security constraints may view the risks associated with fertilizer use most problematic. Farmers with the least experience with fertilizer have the greatest difficulty estimating the relative payoff to these investments.

CURRENT EXPERIENCE WITH FERTILITY MANAGEMENT TECHNOLOGY

An initial step toward testing these hypotheses involves the assessment of current fertility management practices. The distribution of experience with the use of chemical fertilizer is highly skewed in favour of relatively higher rainfall zones (Table 2). In Zimbabwe's driest Natural Region V (low lying extensive farming areas with highly erratic rainfall averaging less than 650 mm per year), only 14% of households have ever tried chemical fertilizer, despite extensive fertilizer distribution programs associated with drought relief packages. In Natural Region IV (a semi-extensive upland farming system characterized by annual rainfall of 450-650 mm, periodic drought and mid-season dry spells), the proportion raises to 38% and in the border area of Natural Regions IV and III, almost 90% of households have tried this chemical input. Natural Region III is classified as a semi-intensive farming area with rainfall averaging between 650 and 800 mm. Much of this occurs in a few heavy falls and mid-season dry spells are common.

Table 2. Adoption of chemical fertilizer in southern Zimbabwe, 1991/92 to 1995/96 (% of farmers)

Rainfall Zone/ Natural region	1991/92	1992/93	1993/94	1994/95	1995/96	Ever Tried
Moderate Rainfall / NR III/IV [a/]	13.3	35.0	71.7	68.3	78.3	86.7
Low Rainfall / NR IV	7.5	13.8	18.8	15.0	18.8	37.5
Very Low Rainfall / NR V	1.3	2.5	2.5	5.0	8.8	13.8

a/ Border between Natural Regions III and IV.

Source: SADC/ICRISAT SMIP Seed and Fertility Management Survey, 1996.

The rise in chemical fertilizer use across time is closely related to the free distribution of this input in national drought relief programs. These were implemented every year of the reference period (1991/92 to 1995/96), though the quantities of fertilizer actually distributed varied each season.

Almost all of these households only use the chemical fertilizer freely obtained under the government drought relief programs. Despite the limited quantities of fertilizer being distributed by the government, in 1996/97, less than 3% of the fertilizer users purchased the input.

The government programs generally promised every farmer in the drought affected areas one 50 kg of bag of Compound D (8-14-7) and one 50 kg bag of AN (34.5-0-0). However, insufficient funding was available for this target delivery and actual distribution levels were consistently lower than these targets. Higher rainfall regions were favoured. Rumours circulated that farmers in drier regions did not want fertilizer or were simply selling this to commercial farmers. However, little evidence for this was found in the surveys. While fertilizer trade undoubtedly occurred, much of this was between neighbouring smallholder households; some traded one bag of fertilizer for another in order to obtain a preferred set of nutrients, while others traded fertilizer for labour.

Among farmers receiving the chemical input in 1995/96, the average level of application was 50 kg of Compound D and 65 kg of AN per farm (roughly 26 kg N and 7 kg P_2O_5). However, most small-scale farmers in the semi-arid regions never had access to the free input.

Almost all of the chemical fertilizer being applied by small-scale farmers in Zimbabwe's drought prone, semi-arid regions was used on maize (Table 3). This reflects farmer perceptions of the relative responsiveness of maize to this input, as well as their perception that this crop has a greater cash value in the national market. Maize has long been promoted as a national cash crop in this country. In contrast, the traditional staple foods of semi-arid Zimbabwe, sorghum and pearl millet, continue to be grown largely as subsistence crops.

The distribution of experience with the application of fertilizer corresponds with the distribution of perceptions of the input's usefulness. Almost all farmers with experience applying chemical fertilizer (in any previous year) believe this input is useful (Table 4). Over 90% of 'adopters' perceive fertilizer is useful for maize. In contrast, only one-third of households believe fertilizer is useful on sorghum or pearl millet.

Smallholder experimentation with chemical fertilizer has generally not been facilitated by extension support. Only one-third of small-scale farmers in Zimbabwe's 'medium' potential zones received extension advice relating to fertility management during the 1995/96 cropping season (Table 5). Only about 10% of small-scale farmers in the nations drier areas (both Natural Regions IV and V) received fertility management advice. The limited availability of fer-

Table 3. Allocation of fertilizer to alternative crops in southern Zimbabwe, 1991/92 to 1995/96 (% of fertilizer users; more than one crop could be cited)

Rainfall zone/ Natural region	maize	sorghum	pearl millet	other crops
Moderate Rainfall / NR III/IV [a/]	92.9	1.8	2.4	2.9
Low Rainfall / NR IV	69.6	17.7	12.7	0.0
Very Low Rainfall / NR V	68.2	13.6	13.6	4.5

a/ Border between Natural Regions III and IV.

Source: SADC/ICRISAT SMIP Seed and Fertility Management Survey, 1996.

Table 4. Perceptions of the usefulness of fertilizer on alternative crops in southern Zimbabwe, 1995/96 (% of farmers with experience using fertilizer; respondents could cite more than one crop)

Rainfall Zone/ Natural Region	maize	sorghum	pearl millet
Moderate Rainfall / NR III/IV [a/]	94.2	17.1	12.2
Low Rainfall / NR IV	93.8	31.0	40.0
Very Low Rainfall / NR V	100	33.3	0.0

[a/] Border between Natural Regions III and IV.

Source: SADC/ICRISAT SMIP Seed and Fertility Management Survey, 1996.

Table 5. Proportion of farmers receiving extension advice on crop fertility management, 1995/96 (% of farmers)

Rainfall Zone/ Natural Region	maize	sorghum or pearl millet	other crops
Moderate Rainfall / NR III/IV [a/]	36.7	10.0	15.0
Low Rainfall / NR IV	10.0	5.0	3.8
Very Low Rainfall / NR V	6.3	6.3	0.0

[a/] Border between Natural Regions III and IV.

Source: SADC/ICRISAT SMIP Seed and Fertility Management Survey, 1996.

tility management support is partly explained by the fact that only one-third of small-scale farmers see an extension worker each year. However, twice as many farmers received advice on seed and planting decisions as received assistance with fertility management.

One explanation for the limited advice received may be that the quantities of fertilizer being distributed in the drought relief packages were substantially smaller than the levels of application being proposed in formal extension recommendations (Table 6). While village field workers commonly adjust national recommendations to meet local contingencies, the levels farmers were applying were still far below what extension workers are taught to consider.

Farmers cite many reasons for not purchasing chemical fertilizer. In general these can be classified as justifications relating to the cost and returns of the input

Table 6. Difference between extension recommendations and actual rates of fertilizer. application in semi-arid regions of Zimbabwe

Crop	Official extension recommendation (kg ha^{-1}) [a/]	Average actual rate of application in 1995/96 *per farm* among fertilizer users for each crop [b/]
Maize	107-133 N 70-90 P_2O_5	24 N 7 P_2O_5
Sorghum	33-53 N 50-70 P_2O_5	7 N 7 P_2O_5

a/ recommendations for poor soils and marginal rainfall regions

b/ no information was collected on the area of land to which this fertilizer was applied

Sources: AGRITEX 1993; SADC/ICRISAT SMIP Seed and Fertility Management Survey 1996.

and justifications relating to the level of familiarity with the input. Farmers with more experience applying chemical fertilizer are more likely to cite problems of expense and availability (Table 7). The availability problem reflects both the difficulty of obtaining fertilizer as well as the high cost of transporting this from more distant retail shops. Farmers with less experience using fertilizer tend to believe this input is too risky. They recognize its value but are afraid of the possibility of losses when rains fail. Many also acknowledge their lack of familiarity with this input. Only a small proportion of farmers indicate they have no need for fertilizer. Most of these farm heavier soils near rivers.

While perceptions of the riskiness of fertilizer are positively correlated with the probability of drought, farmers with experience tend to change their view of these risks. The survey evidence suggests that farmers able to take advantage of the free fertilizer distribution programs are gaining a more accurate view of the risks and returns of application. However, questions remain about the relative profitability of this investment. Will these farmers start to purchase fertilizer after the free input distribution programs end? Are the returns high enough to attract scarce capital away from alternative farm and non-farm investments? The small proportion of farmers purchasing fertilizer raises doubts about the likelihood of this investment.

ICRISAT's continuing research, in collaboration with

Table 7. Reasons for not using chemical fertilizer, 1996 (% of farmers; respondents could cite up to three constraints)

Rainfall Zone/ Natural Region	too expensive	too risky	not locally available	not familiar with input	no need
Moderate Rainfall / NR III/IV [a/]	66.7	21.7	20.0	5.0	8.3
Low Rainfall / NR IV	65.0	41.3	17.5	36.3	13.8
Very Low Rainfall / NR V	23.8	85.0	18.8	58.8	17.5

[a/] Border between Natural Regions III and IV.

Source: SADC/ICRISAT SMIP Seed and Fertility Management Survey, 1996.

the Department of Research and Specialist Services, targets specialized assistance to small-scale farmers in estimating fertilizer (and manure) risks and returns. The underlying strategy is to apply crop systems simulation models to evaluate a wide range of technology options under the highly variable rainfall conditions characteristic of southern Zimbabwe. The technology options considered are those viewed as most practical to identifiable groups of farmers. These views are derived from an inventory of experimentation currently being pursued by small-scale farmers, as well as the perceptions of fertility management scientists about the prospects for productivity improvements in this risky environment. In addition, a component of the workplan targets direct assistance to farmers to help answer the questions they are raising about alternative management practices.

SIMULATION MODELS

Crop simulation models offer two major advantages to the scientist seeking to develop more practical sets of fertility management recommendations for small-scale farmers. These models allow the scientist to test a technology under the historical climatic conditions characterizing the zone toward which the technologies are being targeted. Rather than running 10 years of experimentation, a scientist can simulate a treatment response over a 50 year weather period within a day. In addition, the simulation models help the scientists assess the wider systemic effects of any given treatment. For example, the models can track the movement of nitrogen in the soil or assess how nitrogen application affects the breakdown of crop residues. Importantly, these linkages can be traced across seasons. While the models will not be 100% accurate, the levels of error are likely to be lower than the errors commonly associated with on-farm experimentation.

ICRISAT has been experimenting with the use of the EPIC [Environmental Policy Integrated Climate] simulation model to assess fertilizer risks and responses. This first involves a process of generic testing to assess the ability of the model to estimate yield responses with alternative fertilizer levels on the experiment station. These predictions have been fairly successful as indicated in Figure 1. This shows that the actual and model estimated yields of SV 2 sorghum at the Lucydale Research Station south of Matopos, Zimbabwe were consistently within 10-20% of one another.

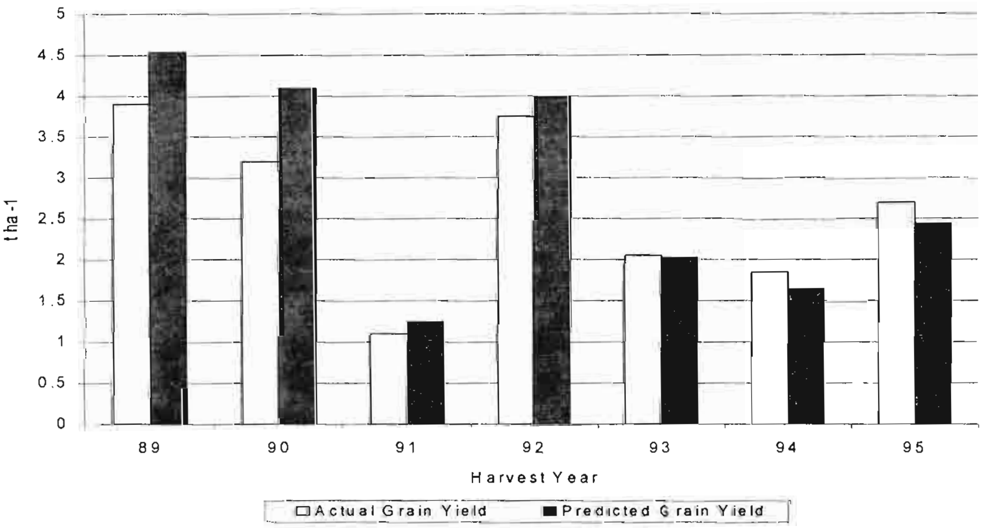

Figure 1. Actual versus EPIC predicted grain yields for the Zimbabwe sorghum variety SV 2 at Lucydale, Zimbabwe, 1989-1995.

Figure 2 displays the simulated variability of maize, sorghum

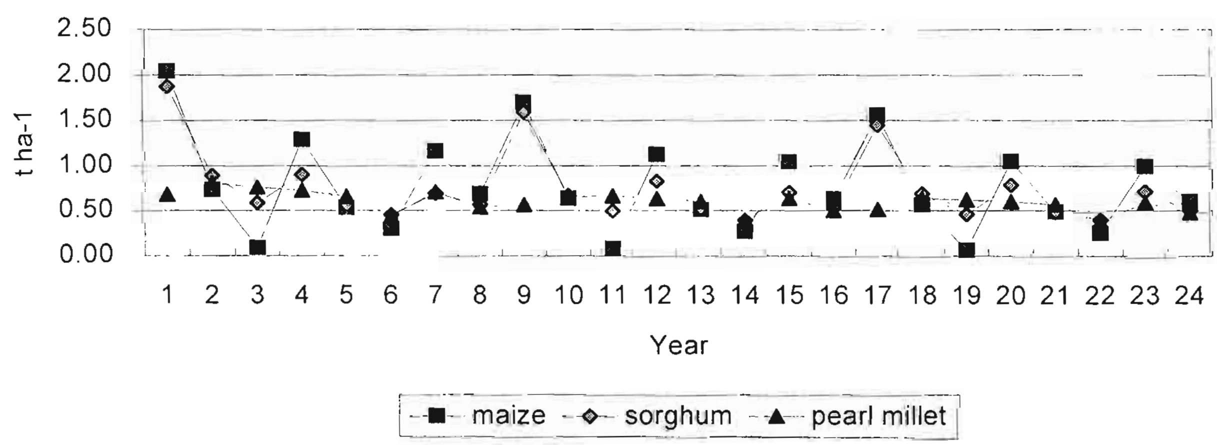

Figure 2. Simulated sorghum, pearl millet and maize grain yields for Lucydale, Zimbabwe over a 24 year period derived from eight years of actual rainfall data.

and pearl millet yields over a 24 year period of local rainfall constructed from an 8 year record. On the experiment station, under low fertility conditions, maize performs better than sorghum or pearl millet in all but the worst drought years. However, maize yields are also more variable than those for sorghum and pearl millet. Pearl millet, as we would expect in the southern Zimbabwe environment, offers the least variability in grain yields, but also the lowest average grain yields. Sorghum is in between. Further testing is still needed to assess these relationships under the management conditions more characteristic of small-scale farmers. However, these results seem to confirm the perceptions of farmers about the risks and returns associated with their main crops. Interest in maize reflects this crop's higher average yields, particularly when rains are favourable. But most households will also grow sorghum and or pearl millet to offset the risks of drought. They know well that in the worst drought years, the maize crop will fail. The sorghum and pearl millet will offer a basic level of subsistence.

This analysis can be extended with scenarios involving the application of different rates of chemical fertilizer. For example, Figure 3 shows a cumulative frequency distribution of the net returns to sorghum with varying rates of fertilizer application. These compare the relative returns to a zero fertilizer treatment with the 50 kg of Compound D and 50 kg of AN commonly distributed under the drought relief programs. The zero treatment approximates the level of sorghum yields actually being achieved by small-scale farmers in southern Zimbabwe - ranging from 325 kg ha^{-1} to just over 1000 kg ha^{-1}. Small-scale farmers face a 50% probability of earning more or less than about US$70 per hectare. If the drought relief fertilizer is used on one hectare of sorghum, this investment offers a 50% probability of a net return of at least US$80 per hectare. Farmers face a 25% probability of earning at least US$125 per hectare. But in years of severe drought (roughly one year in eight), net returns will be marginally higher without the fertilizer.

Again, further work is required to test models like EPIC under the low input circumstances common to small-scale farms. Additional calibration work is required for alternative varieties. However, the potential usefulness of such models for evaluating a wider range of crop management options in southern Zimbabwe is clear. ICRISAT and the Department of Research and Specialist Services are now gathering the data necessary to run a larger range of scenarios involving fertility management practices of more practical significance to farmers.

PRACTICAL EXPERIMENTATION

The practical value of alternative technology options needs to be defined in partnership with farmers. Rather than starting with the assumption that we as scientists know what technologies are appropriate, we need to work with farmers to answer their own questions. The wide distribution of free fertilizer under Zimbabwe's recent drought relief programs has provided a good basis for cataloguing both farmers perceptions of fertilizer, and the sorts of experimentation already underway. Further research, either on the experiment station, in the simulation modelling, or on farmers' fields can facilitate this experimentation. It can help farmers evaluate their own practices more quickly and accurately. Greater collaborative between scientists and farmers can speed up technology testing, and the associated process of technological change.

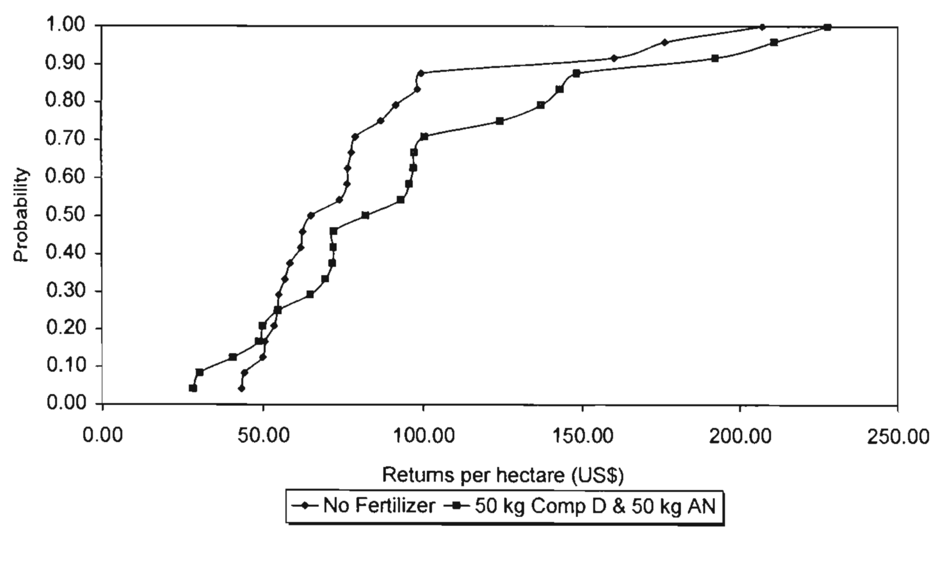

Figure 3. Simulated cumulative frequency distribution of gross returns per hectare of sorghum in southern Zimbabwe - with and without fertilizer

ICRISAT has initiated an inventory of experimentation with chemical fertilizer underway on small-scale farms in several representative semi-arid farming areas. A case study testing of this data collection method has highlighted the wide range of experimentation farmers are pursing (Table 8). Some farmers are particularly interested in testing basal applications of Compound D, while their neighbours prefer to test AN. Most small-scale farmers are targeting their limited fertilizer supplies

Table 8. Experimentation with chemical fertilizer by small-scale farmers in southern Zimbabwe, 1995/96

Experimentation by farmers with fertilizer	Information farmers seek from research	Likelihood of purchasing fertilizer in the future
- broadcast, banding or spot application of Compound D as a basal dressing with or without AN;	- methods of fertilizer application;	25% yes
- Compound D viewed as a substitute for manure;	- effects of continuous fertilizer use / how often can fertilizer be used in the same field	25% maybe
- spot application of AN only, especially to yellowed plants;	- fertilizer manure complementarity or tradeoffs;	50% no
- selective application of fertilizer depending on quality of rains	- options for application to sorghum & pearl millet;	

Source: SADC/ICRISAT SMIP Fertility Management Options Survey, 1997.

on parts of their fields with poorer performance the previous season (which may make judging the effects of the fertilizer difficult). Most farmers view chemical fertilizer and manure as substitutes, but many question the value of fertilizer - manure rotations.

This listing is not meant to be comprehensive. Rather it provides a simple indication of the variability of experimentation underway. More detailed information will be collected during the up-coming 1997/98 cropping season. However, it is already clear that options offering advice on the targeting of smaller quantities of fertilizer are likely to be more useful than blanket recommendations or even profit maximizing recommendations targeting an agroecological zone. Further work is also merited on the complementarities between fertilizer and organic nutrient sources.

NEXT STEPS

This research effort is only at an early stage. The main hypotheses about risk and relative returns to investment remain to be fully tested. Once the simulation models are validated, greater emphasis will be placed on farmer participatory experimentation. This will encompass the evaluation of best-bet fertility management options derived from our understanding of the simulation results and practical boundaries of household investment. A significant portion of the modelling and experimentation will simply target the construction of answers to specific questions about fertility management by identified groups of farmers.

Ultimately, this strategy seeks to offer farmers a range of options suited to their agro-climatic and biophysical systems, as well as their risk and investment preferences. These are expected to include such technologies for the better targeting of nutrients. Advice on the application of one 50 kg bag of fertilizer is expected to be more useful than advice on optimal rates of fertilizer application per hectare. The project is expected to consider the complementarity of chemical fertilizer and manure. Given the many questions about methods of application, future experimentation with farmers will likely evaluate the trade-offs between time of application and rainfall risks. And the project expects to consider the impacts of alternative crop rotation strategies including consideration of the relative contributions of grain legumes.

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'BEST BET' TECHNOLOGIES FOR INCREASING NUTRIENT SUPPLY FOR MAIZE ON SMALLHOLDER FARMS

STEPHEN R. WADDINGTON[1], ROB GILBERT[2] and KEN E. GILLER[3]

[1]CIMMYT-Zimbabwe, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe;
[2]The Rockefeller Foundation, P.O. Box 30721, Lilongwe 3, Malawi, and
[3]Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK

SUMMARY

The Soil Fertility Network (Soil Fert Net) has now been coordinating soil fertility research in southern Africa for four years and it is timely to review which of the approaches studied are the most promising for improving soil productivity and maize yields in smallholder agriculture. This paper highlights the technologies which are emerging as those most likely to have an impact. Two main criteria are suggested for selection of technologies for further investment of research effort and farmer evaluation: the intervention should make a significant impact on soil fertility and maize yield (with some beneficial effect in the short-term) and the technology should be applicable for a reasonably large number of farmers. As well as these, there are other promising technologies that Soil Fert Net members are working on to establish their benefits on farm, their profitability and farmer acceptance. Most of the technologies are the subject of research projects by individual members in direct receipt of grants from the Rockefeller Foundation. Some are being looked at collectively by groups of Soil Fert Net members in 'Network Trials' and are reported in these proceedings.

THE NEED FOR INCREASED NITROGEN (N) INPUTS

The review by Giller *et al.* (these proceedings) and several of the research reports clearly show that substantial amounts of N-rich organic matter are required to make a significant impact on crop yields. The changes to cropping systems which would lead to significant improvements in soil organic matter and soil N storage and in crop yields are those which produce significant quantities of biomass.

All methods for increasing soil organic matter depend on the allocation of land for production of organic matter or fodder, and the potential cost of loss of direct yield of food crops. Only where land is used either at a time when no crops could be grown, or on land that cannot be used for agricultural production is there no such cost. Where land is very scarce (southern Malawi) the intercropping of green manures and cereals may be the only feasible means for generating organic inputs. In this case the interplay between the reduction in cereal yield due to competition from the intercropped green manure and the residual benefit in yield due to the contribution of N returned to the soil in the green manure biomass is critical (Table 1). For a significant effect on cereal yields in a subsequent year the absolute minimum green manure biomass required would provide 40-60 kg N ha^{-1} (roughly 2 t ha^{-1} dry matter). As approximately 20% of the N from a high quality green manure residue is recovered by the first crop (Giller and Cadisch, 1995), this is likely to give a benefit in maize yield of less than 500 kg ha^{-1}. Given that the farmer has had to wait for a year to realize this extra yield, then the yield loss which can be tolerated in the first season is less than that returned in the following season. When the legume intercrop has other benefits (e.g. food from cowpea or firewood from pigeonpea) then these calculations can be relaxed (Table 1). A longer-term residual benefit from the

Table 1. Suggested criteria for selection of legumes for inclusion in farming systems in land-scarce regions. Examples from Malawi are given in parentheses.

a)	**Maize - grain legume intercrop (e.g. maize-pigeonpea)**
1.	Maize partial land equivalent ratio (LER) > 0.7 (i.e. farmers get > 70% of maize as sole crop)
2.	Total LER > 1.2 (> 20% land advantage to the intercrop)
3.	Total caloric output >= sole maize
4.	No net loss of soil N over time
5.	Grain legume acceptable to farmers for direct consumption
b)	**Grain legume rotation (e.g. Magoye soyabean)**
1.	Calorific output >= sole maize
2.	Net N additions from residue > 20 kg ha-1 yr^{-1}
3.	Net profit > maize production
c)	**Undersown green manure (e.g. *Tephrosia vogelii* at first weeding)**
1.	Maize partial LER > 0.8 in first season
2.	>2 tons ha^{-1} biomass produced (> 60 kg N ha added)
3.	Cost < equivalent N applied as fertlizer
4.	Maize yield increase subsequent seasons must be great enough to offset calories lost from reduced maize/grain legume output first season.
d)	**Improved fallow (e.g. *Mucuna pruriens*)**
1.	>5 tons ha^{-1} minimum biomass
2.	> 150 kg N ha^{-1} fixed
3.	Maize yield the second season must be more than double the control maize to make up for loss of production.

green manure may compensate for the initial competition with the main cereal crop, but as long-term benefits from addition of high quality organic materials tend to be small it is often hard to quantify such gains.

When similar calculations are applied to rotational systems although a two year fallow may give treble the yield of continuous maize in the same season, the cumulative maize yield over three years gives little advantage (Kwesiga and Coe, 1994). Unless land is abundant, such that farmers produce a maize surplus from their non-fallowed fields each year, the yield benefit after a green manure fallow must be substantially greater than that which could have been grown in three consecutive crops. Where land is not the most limiting resource, yield per ha is not the first evaluation criterion for the farmer.

BEST BETS FOR SOIL FERTILITY IMPROVEMENT

Over the last year Soil Fert Net has attempted to take stock of which soil fertility technologies offer the 'best bets' for improving the soil fertility of smallholder maize fields in Malawi and Zimbabwe in ways that are profitable and adoptable. The selection of 'best bets' has so far proved an uncertain task and is still evolving. Criteria used in the selection of 'best bet' technologies have included:

- Longer-term contribution to raising soil fertility
- Ability to raise crop yields and generate profit in the short term (1 to 2 years)
- Appropriate for many farmers across important agro-ecologies
- Small additional cash and/or additional labour requirements
- Only a small reduction in maize yields or substitution by production of other crop
- Where possible, little competition for arable land
- Resulting ease of adoption by farmers.

Clearly some of these criteria are more important than others in particular circumstances. For example, small cash and land requirements are fundamental for much of southern Malawi while minimizing additional labour demands is often vital in northern Zimbabwe.

Based on the above criteria, our identified 'best bets' for Malawi are:

1. Maize + pigeonpea intercropping
2. Magoye soybean rotations
3. Area-specific fertilizer recommendations for maize

Best bets for Zimbabwe are:

1. N fertilizer amounts conditional on rainfall for maize
2. Soybean for communal areas

Details on these technologies are given below.

Maize + Pigeonpea Intercropping in Malawi

(Maize Commodity Research Team of Department of Agricultural Research and Technical Services (DARTS) -- principally Webster Sakala and John DT Kumwenda)

Background -- In southern Malawi, where land is scarce and human population high, many farmers intercrop pigeonpea with maize primarily as a way to produce more food and only secondarily to maintain soil fertility. Late-maturing pigeonpea (ICP 9145) is especially promising since the growth and development of maize and pigeonpea complement each other temporally. Pigeonpea matures on residual moisture after maize is harvested, resulting in little competition with maize.

Results -- Maize + pigeonpea intercropping has been the subject of much research by the Maize Commodity Team. Optimal planting patterns and varieties have been worked out (Sakala, 1994). The best variety evaluated to date is ICP 9145 pigeonpea, a long-duration variety that is resistant to *Fusarium* wilt and higher yielding than local varieties. The planting arrangement places one pigeonpea station (with three seeds per hill) between maize stations (37, 000 plants ha^{-1}) within the ridge. Late maturing pigeonpea intercropped with maize can often produce a dry matter yield of 3 t ha^{-1} from leaf litter and flowers and, even if the seed is harvested for food, the leaf fall is sufficient to contribute N to the soil.

Current and future research needs -- Further work is underway on farm to look at ratooning to reduce seed costs and the extent that pigeonpea reduces the need for inorganic fertilizer. Studies over several years are required to examine the long-term benefits of this intercrop on soil fertility. It is hoped that experiments which were established by Webster Sakala as part of his PhD studies, and are currently in their third year, will be continued to address this.

A disadvantage of pigeonpea is that it is highly attractive to livestock, and therefore it has been considered that pigeonpea cannot be grown in the central plain or the north of Malawi where cattle are more abundant than in the south. As this is currently largely supposition a much wider survey and farmer testing is required to evaluate the potential for wider distribution of pigeonpea. As human population increases in Malawi, livestock will be less of a problem. This is also being addressed in trials that look at the effects of intercropping pigeonpea, mucuna, Crotalaria and maize during 1997/98.

Magoye Soybean Rotations in Malawi
(Maize Productivity Task Force -- principally DARTS and Bunda College of Agriculture)

Background -- Soybean is a grain legume that can produce more calories per unit of land than unfertilized maize in Malawi, besides providing large amounts of protein and fixing N from the atmosphere. However a major constraint to the use of soybean by smallholders has been the requirement for inoculation with rhizobium for N fixation and high yields to occur. Inoculants are not readily available for smallholder farmers in Malawi, and farmers are likely to be unable to afford them if available.

However, some naturally-nodulating or 'promiscuous' varieties of soybean are available that fix N with a wider range of rhizobia often found in smallholder fields. The best known of these is 'Magoye' which was developed in Zambia by Javaheri (1996). Naturally-nodulating soybean such as Magoye has a large above-ground biomass, a lower grain and N harvest index and a more indeterminate development pattern than most specifically-nodulating types. Initial results of experiments in Zimbabwe (see below) indicate that Magoye is a net contributor of N to the soil.

Results -- Magoye yields an average of 1.4-1.7 t grain ha^{-1} in monocuture and 0.86 t per ha when intercropped in Malawi (Kumwenda *et al.*, 1993). Many Malawian smallholders have planted soybean in the last two years and extensive demonstrations of soybean + maize rotations were mounted in 1996/97. A recent problem has been a collapse in the market price of soybean within Malawi.

Current and Future Research Needs -- A current project funded under the Rockefeller Forum is investigating N_2-fixation and the soil fertility benefits of Magoye soybean under smallholder conditions in southern Malawi (Mkandawire *et al.*, in progress). Although the general experience of NGO's with Magoye has indicated that this genotype nodulates widely on smallholder farms in southern Malawi, a wider survey is required to confirm the distribution of compatible rhizobia. Nothing is known of which species/types of rhizobia nodulate the promiscuous soybeans in Malawian soil.

Area-Specific and Economic Fertilizer Recommendations for Maize in Malawi
(Maize Commodity Research Team and Soils Team of DARTS and the Maize Productivity Task Force. Todd Benson has been the key player in the later parts of that effort looking at targeting through GIS and the economics of the new 'recommendations').

Background -- Malawi has had one blanket fertilizer recommendation for maize. Over the last 10 years area-specific fertilizer recommendations have been developed, through a major effort principally by the Maize Commodity Team. The maize grain yield response to N and P fertilizer on-farm was shown to be poor, often well below 20 kg of maize grain per kg of nutrient applied. This coupled with the high cost of fertilizer in Malawi meant that the current fertilizer recommendation of 96 kg N ha^{-1} was rarely economic.

Results -- Missing nutrient trials and widespread chemical analyses of soil showed regional deficiencies of Zn, S, B and K (Matabwa and Wendt, 1993; Wendt and Jones, 1993). In deficient regions, average yields improved by 40% over the existing N and P application when the deficiencies were satisfied. New basal fertilizer blends with these nutrients were developed with fertilizer suppliers. Several possible area-specific fertilizer recommendations were verified at 1670 on-farm sites throughout Malawi with the extension service and farmers (Benson, 1997). Through economic analysis, GIS maps and decision trees, economic area-specific fertilizer recommendations have been developed based on soil texture and farmer production goals. These have been accepted by extension in 1997 for promotion and their policy implications have been agreed with Government. Given the 1996 fertilizer and maize prices for market sale, the most economic fertilizer rate in most Extension Planning Areas was either 35 kg N ha^{-1} or no fertilizer at all.

Current and Future Research Needs -- Although current economic mineral fertilizer requirements of maize have been determined, it is widely acknowledged that few farmers will be able to use fertilizers given current prices. Attention is therefore also being focused on methods of increasing inputs of N from legumes. A collaborative research effort involving scientists from the Malawian Maize Commodity Team, Bunda College, ICRISAT and CIAT began in the 1997/98 season to evaluate several leguminous 'best bet' technologies together. The treatments include:

1. maize + pigeonpea intercrops
2. Magoye soybean rotations
3. area specific fertilizer rate applied to maize
4. unfertilized maize
5. maize + *Tephrosia vogelii* green manure intercrop
6. *Mucuna pruriens* rotation.

These treatments are being evaluated based on N added to the soil system, farmer assessments and economic comparisons.

Maize Yield Optimization Using Fertilizer Inputs Conditional on Rainfall in Zimbabwe *(Department of Soil Science and Agricultural Engineering, University of Zimbabwe -- Melvyn Piha)*

Background **--** The erratic and uneven distribution of rainfall makes fertilizer use by smallholder farmers highly risky. Farmers may be reluctant to use full rates of fertilizer in years with good rainfall because of the risk that the crop may fail, and they may apply more fertilizer than is justified in terms of the crop returns in drought years. This research has focused on developing practical methods of applying split doses of fertilizers dependent on the prevailing rainfall to optimize the economic efficiency of fertilizer use.

Results **--** The management of both the rates and timing of fertilizer applications in relation to rainfall for smallholder maize in Natural Regions II, III and IV of Zimbabwe has been examined over the last 10 years. The early work showed how, by adding P, K and S as a basal dressing and adjusting N fertilizer top-dressings to the evolving rainfall pattern in any one season, the profitability of fertilizer can be significantly increased. Trials over five years on farmers' fields gave 25 - 42 % more yield and 21 - 41 % more profit than did existing fertilizer recommendations (Piha, 1993). The project also showed that existing recommendations were too risky for lower rainfall areas and needed to be adjusted downwards to be profitable.

Current and Future Research Needs **--** This approach has been verified in recent years with more farmers, with comparisons made between farmers' current practice on adjacent fields and the conditional fertilizer package. Farmers have been supported through an input loan scheme as part of the project. In both sub-humid (NR II) and semi-arid (NR IV) areas the conditional fertilizer gave over 100% extra yield and profit in many cases along with a loan repayment rate above 90%. The next step is to build on the success of this package and expand to more farmer groups in collaboration with Agritex and the Zimbabwe Farmers Union. A major element of this activity involves financial management and marketing. Issues remain on better measures of spatial and temporal probabilities of profit.

Soybean for Communal Areas of Zimbabwe
(Department of Soil Science and Agricultural Engineering, University of Zimbabwe and AGRITEX -- Sheunesu Mpepereki and Ishmael Pompi)

Background **--** Some of the more widely used grain legumes in Zimbabwe, such as groundnut, are performing poorly on smallholder farms and this has prompted researchers and farmers to look for alternative grain legumes. One of these is naturally-nodulating soybean, such as the variety Magoye, mentioned earlier (Mpepereki, Makonese and Giller, 1996).

Results **--** Ongoing experiments on smallholder farms in Zimbabwe are confirming that naturally-nodulating types are better able to nodulate abundantly, while maintaining substantial yields (~1 t ha^{-1}) similar to specific-nodulating types at many on-farm sites. However, their larger biomass results in greater residual soil fertility benefits.

Current and Future Research Needs **--** This is now the subject of a major promotion drive in smallholder areas of Zimbabwe, involving AGRITEX, University of Zimbabwe, farmers' unions and the private sector. Work with 55 farmers in 1996/97 generated tremendous interest among smallholder farmers, with over 1000 requests for soybean demonstrations from the farmers themselves. For 1997/98 over 400 farmers are targeted within seven communal areas with a subsidised package of soybean inputs, including seed of Magoye. Farmer appraisal and extension will be the main goals and data on yield, soil pH and rainfall will be taken. Questions remain on the distribution of indigenous soybean rhizobia in communal areas and the ecological limits for soybean production.

OTHER PROMISING TECHNOLOGIES

Besides the Best Bet Technologies ('Best Bets'), Soil Fert Net is working on other technologies that show promise. For these technologies their soil fertility benefits on-farm, their profitability and farmer acceptance are less clear. Much further research and testing is needed and some of the priorities are listed by Giller *et al.* (these proceedings). Many of these technologies involve rotations and forms of intercropping, from which the benefits are highly variable depending on the rainfall in any season.

A major aim for the coming phase should be to evaluate how applicable different potential technologies are, and to target them to agroecologies and types of farmers that are most likely to benefit from them. A preliminary attempt at this, based on our current understanding, is presented in Table 2, which could be used as a tool for evaluating the relative importance of different technologies. We welcome contributions of information and suggestions to improve the accuracy of this analysis which is based largely on informed guesswork, as we believe this could be a very useful guide to assist decision making as to priorities for future research.

Table 2. The relative soil fertility benefit and applicability of potential interventions for improvement of soil fertility on smallholder farmers' fields in Malawi and Zimbabwe. This table was developed from discussions at Chitedze research station after a field tour in March 1997.

Technology	Wait period before effect	On-farm soil fertility benefit[1]		Farming system/Socioeconomic target		
	on cereal	Year 1	Longer term	Agro-ecology and farm	Adoption Potential	
					Ease	Number of Farmers
Malawi						
Legume fallows	+++	++++	+++	Larger arable holdings	+	100,000
New *Faidherbia* trees	++++	0	++++	Adaptation range	++	500,000
Grain legume rotation	++	++	+	Medium-large holdings	++	250,000
Sole green manure	++	+++	+	Medium-large holdings	+	250,000
Grain legume intercrop	+	+	0	Smaller holdings	++++	1,000,000
Green manure undersown or intercrop	+	+/++	0	Smaller holdings	+++	500,000
Mineral fertilizer to cereal	0	+++	0	Richer farmers	++	200,000?
Non-legume biomass transfer (*Tithonia*)	0	+++	+	Near to dambos where grown	++	40,000?
Hedgerow intercrop	++	++	++	Hilly areas?	+	80,000?
Zimbabwe						
Grain legume rotation Leg-Mz-Mz-Leg	++	++	+	Most holdings		
				NR2-3 Groundnut	+++	300,000
				NR3-4 Cowpea	++	1,000,000
Cattle manure	0	+++	++	Farmers with cattle	++++	400,000
Mineral fertilizer to cereal	0	+++	0	Richer farmers in wetter areas NR2-3	++	300,000
Sole green manure	++	++	+	Most holdings	+	600,000
Grain legume intercrop	+	+	0	Most holdings in NR2-4	+++	800,000
Tree leaf litter	0/+	+	+	Near to woods	++	80,000?
Termitaria	0	+/++	+	Most holdings	++	250,000?

0 = zero; + = low; ++ = moderate; +++ = high; ++++ = extremely high; NR = Natural Region

[1]As likely to be employed on farm (i.e. at a realistic rate and management)

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AN OVERVIEW OF THE SOIL MANAGEMENT PROJECT IN WESTERN KENYA

JOSEPH G. MUREITHI[1], E.N. OKOKO[2], E. NYAMBATI[3] and ELIZABETH DYCK[4]

[1]KARI - NARL, P.O. Box 14733 Nairobi, [2]KARI - Kisii, P.O. Box 523 Kisii, [3]KARI - Kitale, P.O. Box 450 Kitale, Kenya; [4]Rockefeller Foundation, New York, USA

SUMMARY

Low soil fertility is a major factor limiting smallholder farming in western Kenya. A soil management project began in 1994 to address the problem at two KARI Centres in the region; KARI - Kisii and KARI - Kitale. The project is supported by the Rockefeller Foundation both financially and technically. The approach adopted for implementation of the project activities involves Farmer Participatory Research. This approach enables farmers to have a greater influence on priorities and decisions of research to be undertaken because they are actively involved in the whole research process. Multidisciplinary teams involving several institutions participated in the implementation of the project.

Preliminary results indicate that the use of organic manures is more beneficial when combined with inorganic fertilizers. Combining stone lines and grass strips can be an effective method of controlling run-off, especially during the establishment of the grass strips. Suitable crop and forage varieties have been identified and the potential of mucuna and sunnhemp as green manure legumes has been confirmed.

INTRODUCTION

Farming in western Kenya is largely practised by smallholders and it is characterised by continuous cropping and little use of purchased inputs (Ensrinck, 1995; Njue, *et al* 1997). Land holdings are small with the majority of farmers having less than 2.5 ha. Population density is high (215 - 800 persons per km^2) especially in the districts closer to Lake Victoria. Maize is the staple food crop in the region and is usually intercropped with beans. Other food crops include sorghum, millet, sweet potatoes, cassava, groundnuts, vegetables and bananas. These food crops are grown in varying intercropping patterns such as maize/beans/bananas and/or maize/groundnuts. Cash crops include tea, coffee, sugar cane and pyrethrum. Types of livestock kept are cattle, goats, sheep and poultry. Livestock production practices include grazing on natural pastures mostly for indigenous cattle, goats and sheep, stall feeding for exotic dairy cattle and free range for poultry.

Soil fertility is generally low and few farmers use fertilizers to replenish soil nutrients (Jaetzold and Schmidt, 1982). However, the cost of commercial fertilizers is high and most farmers cannot afford them. As a result crop yields and animal performance are generally low. In response to this, a Soil Management Project (SMP) began in 1994 supported by the Rockefeller Foundation. The project was based at two Centres of Kenya Agricultural Research Institute (KARI) in Kisii and Kitale. The broad objective of the project was to develop, together with farmers, low-cost and sustainable methods of maintaining/improving soil fertility for increased crop and livestock production. This paper presents an overview of the project.

RESEARCH APPROACH

The adoption of agricultural technologies generated by the traditional technology development and transfer model has been low (Chambers *et al*, 1989), therefore the project adopted the Farmer Participatory Research (FPR) approach. In this approach, researchers, extensionists and farmers are partners in the research process and continuously collaborate in all stages of the research process. Thus, farmers participate actively in the development of the research agenda, conduct of the research, evaluation of results and dissemination of findings. Participation enhances relevance of the developed technologies, allows for tapping into farmers' local knowledge and is likely to lead to high adoption rates.

INITIATION OF THE PROJECT

The project began with formation of research teams that were multi-institutional (KARI researchers, extension staff and NGOs) and multidisciplinary (socio-economist, agronomist, soil scientists, agroforesters, livestock officers, horticulturists, pathologists, entomologists and biometricians). Because most members were not well versed with the FPR approach, they undertook a one-week training facilitated by experts from CIAT and local NGOs (CARE - Kenya and Permanent Presidential Commission for

Soil Conservation and Afforestation). This was followed by selection of project sites. The key criterion for site selection was declining soil fertility and extension staff played a leading role in this exercise. Four sites were selected for each Centre (Table 1).

Table 1. Soil Management Project study sites in western Kenya

KARI - Kisii				
Characteristics	**Bogetario**	**Nyamonyo**	**Kamingusa**	**Ontondo**
Soils	Deep, reddish well drained	mollic nitisols - Soil erosion	verto-luvic Phaeozems- moderately drained deep and dark brown	deep red generally well drained - soil erosion serious due to steep slopes
Rainfall (mm)	bimodal, 1800	bimodal, 1800 mm	bimodal, 800	bimodal, 1600 - 1800
Temperature (°C)	18 - 24	19 - 26	23 - 29	21 - 28
Farm sizes (ha)	0.2 - 0.8	0.4 - 1.2	0.8 - 4	2
Population Density (persons km^{-1})	800	800	230	316

Adapted from Njue *et al.* 1997

KARI - Kitale				
Characteristics	**Cheptuya**	**Anin**	**Matunda**	**Chbosta**
Soils	Cambisols and Acrisols, - shallow sandy loams, - severe soil erosion	orthic Luvisols and humic Nitosols	rhodic Ferralsols, - low fertility	mollic Gleysol, - poorly drained, - low fertility
Rainfall (mm)	bimodal, 800 - 1000	bimodal, 1000 - 1200	bimodal, 1200 - 1400	1000 -1200
Temperature (°C)	18 - 24	12 - 26	19-27	17 - 23
Farm sizes (ha)	8 - 40	0.2 - 2.4	0.8	1.0
Population Density (persons km^{-1})	13 - 45	65	124	89-

Adapted from Nyambati *et al.* 1997; Jaetzold and Schmidt 1982

PROBLEM DIAGNOSIS, CONSTRAINTS PRIORITISATION AND IDENTIFICATION OF POTENTIAL SOLUTIONS

The research teams conducted PRA exercises to identify major constraints to farming and the major causes of those constraints (Mwania *et al*, 1996). A checklist of key issues was developed to guide discussions during the exercises. The activities covered during the first three days of the exercise were transect walks, resource characterization and mapping, determination of cropping systems, cropping and labour calendars and problem identification. In addition, semi-structured interviews were held with key informants such as village elders and women leaders. During the fourth and fifth days the PRA teams met with the farmers to deliberate on the constraints identified. Farmers were guided through the process of problem prioritisation that started with farmers listing down all their problems. Then farmers went through the list and with a

Table 2. Site constraints identified and prioritised by farmers

Kitale SMP sites			
Cheptuya	**Anin**	**Matunda**	**Chobosta**
1. Inadequate domestic water supply 2. Low soil fertility 3. Soil erosion 4. Poor medical facilities 5. Inadequate extension services 6. Poor grazing pastures 7. Wildlife damage to crops 8. Prolonged droughts	1. Inadequate domestic water supply 2.Shortage of appropriate maize seed variety 3. High cost of fertilizer and other inputs (fencing) 4. Damage of crops by monkeys and porcupines 5. Lack of tick control facilities 6. Pests and diseases 7. Low market price for maize	1.Late planting of crops 2. Soil erosion 3. High cost of farm inputs 4. Lack of credit facilities 5. Lack of veterinary services 6. Low prices of farm produces	1. Inadequate domestic water supply 2. Shortage of health services 3. Poor veterinary services 4. Lack of credit facilities 5. Low soil fertility 6. Lack of extension services
Kisii SMP sites			
Bogetario	**Nyamonyo**	**Kamingusa**	**Otondo**
1. High cost of inputs 2. Soil erosion due to lack of extension advice 3. Pests (porcupine) 4. Low crop yields (e.g. maize) 5. Low soil fertility 6. Livestock diseases	1. Low crop yields 2. Low soil fertility 3. Bean diseases and pests 4. Livestock diseases 5. Lack of cash to purchase farm inputs 6. Lack of firewood 7. Poor artificial insemination services	1. Striga weed 2. Crop diseases (cotton, ground nuts, cassava) 3. Soil erosion 4. Delayed planting due to late land preparation 5. Low soil fertility 6. Livestock diseases 7. Lack of water	1. Low crop yields 2. Poor pastures and shortage of livestock feeds 3. Ticks and tick borne diseases 4. Lack of water for domestic use.

show of hands ranked the problems (Table 2). With the assistance from the PRA teams, they did a problem causal analysis and identified potential solutions. Based on the potential solutions, areas of intervention were identified. These included on-farm trials to test various technological options, demonstration of available proven technologies, organising farmer tours, video shows and workshops. The research interventions are summarised in Tables 3 and 4.

PROJECT IMPLEMENTATION AND RESULTS

Use of Organic Manures in Combination with Inorganic Fertilizers

Compost and farmyard manure were evaluated as alternatives or supplements to commercial inorganic fertilizers. Since farmers participating in this trial were required to provide compost and manure for the trial, they were first trained on methods of making compost using locally available materials. In Kitale, a local NGO (Manor house) together with researchers and extensionists facilitated the training.

Table 3. Soil management research activities at Kitale

Research activity	Research sites and treatments and/or test crops (per site)*			
	Cheptuya	**Anin**	**Matunda**	**Chobosta**
1. Demonstration of compost making and utilisation, FYM storage and utilisation (including educational tours)	boma manure composting and utilisation	-	making and storage	compost making
2. Evaluation of organic fertilizer as alternatives to inorganic commercial (compost and FYM) fertilizers	-	maize and bean	maize	maize
3. Demonstration and evaluation of low cost methods of soil conservation (including their maintenance)	grass strips, trash line, fanya juu terraces	-	-	strips and terraces
4.Evaluation of productivity of and utilization of improved forages	-	Napier grass and green leaf desmodium	-	-
5. Effect of land preparation on crop yields	-	-	maize and beans	-
6. Evaluation of crop varieties	millet, sorghum, sweet potatoes, cassava	five maize var.	millet, cassava, sweet potatoes and groundnuts	maize, sorghum, millet, napier grass
7.Screening of forages tolerance to water-logged conditions	-	-	-	grasses and nine legumes

* - hyphen indicates research was not conducted in that site

Table 4. Soil management research activities at Kisii

Research activity	Research sites and treatments and/or test crops (per site)*			
	Bogetario	**Nyamonyo**	**Kamingusa**	**Otondo**
1. Demonstration of compost making and utilisation.	-	-	compost making	-
2. Evaluation of organic fertilizer (FYM and compost) as alternatives to inorganic commercial fertilizers	maize, indigenous vegetables and napier grass	maize, kales and local vegetables	-	maize
3. Demonstration and evaluation of low cost methods of soil conservation (including their maintenance)	grass strips, trash line, fanya juu terraces	grass strip sweet potatoes, trash-line	grass strips, stones lines and a combination	establishment methods of sweet potatoes
4. Productivity and utilization of improved forages	-	Napier grass and green leaf desmodium	-	-
5. Evaluation of crop varieties	-	five bean var.	-	66 bean var. from CIAT
6. Demonstration of green manuring for soil improvement	mucuna, lablab bean, lana vetch, sunhemp	-	-	-
7. Striga management by crop rotation and application of organic and inorganic fertilizers	-	-	sorghum; sunhemp and simsim	inorganic fertilizer, compost and FYM

* hyphen indicates research was not conducted in that site

This was done early enough to ensure farmers had enough compost by the time the trial commenced.

The treatments evaluated varied from site to site, but they included the following;

a) control - no inputs
b) recommended inorganic fertilizer rates; 26 kg P and 60 kg N ha^{-1}
c) compost/farm yard manure (FYM) applied at recommended rates; 5 t ha^{-1}
d) compost/FYM + 50% recommended rate of inorganic fertilizers
e) compost/FYM + 25% recommended rate of inorganic fertilizers

Table 5. Effects of fertilizer and compost applied in combinations in Nyamonyo village (RRC-Kisii mid year report for 1996)

a) Maize grain yield*

Treatment	grain yield (t ha^{-1})
Control	3.3c
26 kg P** 60 kg N**	5.7c
5 t compost**	4.2bc
5 t compost + 13 kg P + 30 kg N	5.9a
5 t compost + 6.5 kg P + 15 kg N	5.2a
C.V. (%)	29.5

b) Fresh leaf yield* of Black night shade

Treatment	fresh leaf yield (t ha^{-1})
Control	2.0d
26 kg P + 60 kg N	3.8bcd
5 t compost	2.6a
5 t compost + 13 kg P + 30 kg N	5.7ab
5 t compost + 6.5 kg P + 15 kg N	7.2cd
C.V. (%)	32.9

* - yields are for long rainy season, 1996

** - application per ha

Means followed by the same letter are not statistically different (P<0.05)

Table 6. Effect of different fertilizer combinations on the dry matter yield of Napier grass (var. Bana) and intercropping with silver leaf desmodium (*Desmodium uncinatum*) in Nyamonyo village (Mbugua *et al.* 1997).

Treatment	Mean DM yield* (t ha^{-1})		
	Napier	Legume	Total
Control (no inputs)	7.9b	-	7.9b
26 kg P** + 60 kg N**	17.5a	-	17.5a
26 kg P + desmodium	13.0ab	2.0	15.0a
13 kg P + desmodium	9.7b	1.7	11.4b
13 kg P + desmodium + 5 t FYM**	8.4b	2.6	11.0b
10 t FYM	13.0ab	-	13.0ab
C.V. (%)	36.5		36.1

* - total of three cuts taken between August 1996 to January 1997

** - application per ha

Means followed by the same letter are not statistically different (P<0.05)

Preliminary results indicate that application of organic manures can improve crop and forage yields substantially. For example in Nyamonyo site, application of compost at the rate of 5 t ha^{-1} to maize and a local vegetable, black night shade (*Solanum nigram*) increased yields by 27 and 30% respectively, over the control (Table 5). Application of compost together with N and P fertilizers at half the recommended rate increased yield by 78 and 85%, respectively. In Bogetario establishing Napier grass (*Pennisetum purpureum*) intercropped with silver leaf desmodium (*Desmodium uncinatum*) with 5 t FYM supplemented with 13 kg P increased Napier dry matter yields by 6% and total dry matter yield by 40% (Table 6). Application of FYM increased napier dry matter by 64%. These results indicate that the use of organic manures is more beneficial when it is combined with inorganic fertilizers. The studies will run for another year before conclusive results are obtained.

Evaluation of Low Cost Methods of Soil Conservation

This activity also began with the training of farmers on how to lay out soil conservation structures and some of the participating farmers were taken on a tour to Machakos district where they were exposed to well conserved catchments. Treatments in these studies included grass strips, trash line, stone lines, combinations of grass strip and stone line and bare ground as a control. Due to poor rainfall in 1995, grass took rather long to establish and heavy gap filling was done in 1996. At Kamingusa, the effect of the treatments on run off were assessed and the stone lines and stones lines in combination with vetiver grass strips appeared most effective in reducing run-off (Table 7). Results that are more reliable will be collected this year because the grass strips are well established and the run-off collecting structures have been modified to eliminate leakage and over-

Table 7. Effects of different soil conservation methods on surface run-off in Kamingusa village (Nzabi *et al.*, 1997)

Treatment	cumulative weight of wet soil (kg)	cumulative vol. of water (litres)
Bare ground	0.29a	13.0b
Vetiver strip	0.34a	13.1b
Makarikari strip	0.24a	12.7b
Stone line	0.17a	7.4a
Makarikari strip + stone line	0.35a	7.1a
LSD 5%	0.18	4.60

Means followed by the same letter are not statistically different (P<0.05) flow.

Evaluation of the Productivity and Use of Improved Forages

This activity was implemented to encourage farmers to grow high quality forages for their livestock especially the dairy cows. In Kitale, the species evaluated included Napier grass var. Bana, Clone 13 and Pakistan hybrid, Rhodes grass (*Chloris guyana*) var. Boma and Pokot, lucerne (*Medicago sativa*), stylosanthes (*Stylosanthes guianesis*), vetch (*Vicia dyscarpa*) and green leaf desmodium (*Desmodium intortum*). The establishment of the forages was affected by poor rainfall in 1996, but growth this year (1997) is good. Preliminary results indicate Napier var. Bana is performing better than the other varieties. Under poor management desmodium persisted better than both lurcene and vetch. Large plots measuring about 0.1 ha of Rhodes grass/desmodium mixtures, Napier grass and desmodium have been established at Anin for feeding trials. Results so far have not indicated any discernible trend.

Evaluation of Crop Varieties

This activity was undertaken to expose farmers to more crop varieties, which are high yielding, drought tolerant and pest and disease tolerant. Five maize varieties were evaluated at Anin site in Kitale against an old variety H614. Preliminary results indicate that maize var. H625 and H626 performed significantly better than H614. At Matunda, three varieties of sorghum and millet were evaluated against the farmers' local varieties. Surprisingly, farmer varieties were superior to the introduced ones. About 66 bean varieties from CIAT were evaluated against infestation by bean fly at Otondo and Nyamonyo in Kisii. Preliminary observations showed a very low bean fly infestation in both sites. About nine varieties in Nyamonyo had below average damage and pest infestation. They were, P130, P53, P36, P16, P52, P52, P135, P101, and ZAA 12.

Demonstration of Green Manuring for Soil Improvement

Legume species for green manuring were demonstrated to farmers in Kisii at the Bogetaorio site. Legumes planted were mucuna (*Mucuna pruriens*), lablab bean (*Dolichos lablab*), lana vetch (*Vicia dsycarpa*) and sunnhemp (*Crotolaria ochreleuca*). The legumes were undersown in a maize crop about two weeks after planting maize. A farmers' field day was held to expose the legumes to farmers and to explain the role they play in improving soil fertility. The legumes were later harvested, incorporated into the soil and maize planted as the test crop. Table 8 shows the legume biomass incorporated and the effects it had on maize grain yield. Sunnhemp produced the highest amount of biomass. In the first farm the two green manures had a substantial effect on maize yield. The overall picture will be clearer once more data is available as the experiment is scheduled to continue for another two years.

Striga Management by Crop Rotation and Application of Organic and Inorganic Fertilizers

Striga weed is one of the major factors limiting cereal production in the Kisii region, particularly at Kamingusa and Otondo site. Improving soil fertility and rotating host with non-host crops is known to reduce striga infestation. In this study sorghum was the test crop and the treatments included; a) green manuring with Tanzanian sunnhemp, b) sorghum intercropped with sunnhemp c) rotation with simsim (sesame), d) rotation with pure stand groundnuts, d) sorghum + fertilizer and e) sorghum + compost. Results obtained so far indicate that there were no significant differences in striga counts across farms. However, difficulties in accurately assessing striga population and its effects on sorghum yield have been cited as some of the problems affecting the study. Collaboration with a CIMMYT supported project in the region has been sought to improve accuracy of data collection in this study.

Experience with FPR

A review of farmer involvement in the implementation of the SMP revealed that whereas the farmers participated actively in the stages of information gathering, problem identification and prioritisation, their participation in the identification of problem causes, identification of potential solutions and design of the trials was minimal. Farmer participation in monitoring and evaluation of the project was also low. In the three years of the project, the research teams have observed a decline of farmer interest in the research activities. This has been attributed mainly to low level of farmer participation in the subsequent stages of the research beyond the diagnostic and the planning stage. The research teams indicated that they lacked clear FPR methods to effectively involve farmers in these research stages. This supports reviews by Okali *et al.* (1994) who report that those methodologies are lacking or not well

Table 8. Legume green manure incorporated and effect on maize grain yield in Bogetaorio village during short rains 1996.

Legume species	fresh leaf biomass (kg ha^{-1})	maize grain (kg ha^{-1})
Mucuna	1120b	2825ab
Lablab bean	1000b	2298b
Lana vetch	-	2530b
Sunnhemp	2820a	3374a
No legume (farmers practice)	-	1294c
C.V. (%)	32	14

Means followed by the same letter are not statistically different (P<0.05) developed. The project plans to undertake new FPR activities to identify and test methods of involving farmers more in the research stages beyond diagnosis (Mureithi *et al* 1997).

CONCLUSION

The studies will have to continue for at least two more years in order to obtain conclusive results. However, combinations of organic manures and inorganic fertilizers appear promising in raising crop yields. The study on low-cost methods of soil conservation has shown that stone lines can be effective in checking run-off especially while grass strips are establishing. Promising crop and forage varieties have been identified for various sites and the potential of mucuna and sunnhemp bean as green manure legume species has been confirmed.

As the project continues, several activities are recommended to be undertaken and they include;
a) studies on economics of farmers' preferred treatments e.g. compost/FYM and fertilizer combinations.
b) more farmer training on the management of compost and FYM should be undertaken to ensure that compost and FYM are of good quality.
c) closer collaboration be sought from CIMMYT in continuation of the striga work.
d) test FPR methods to involve farmers in the research process beyond diagnosis.

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ASSESSMENT OF RESOURCE REQUIREMENT AND OUTPUT POTENTIAL OF SOIL MANAGEMENT TECHNOLOGIES IN ZOMBA, MALAWI

BERNARD C.G. KAMANGA[1], GEORGE Y. KANYAMA - PHIRI[2] and SUSAN MINAE[3]

[1 2] Bunda College of Agriculture, P.O Box 219, Lilongwe,
[3] European Union Microproject Programme, P.O. Box 30102, Capital City, Lilongwe 3, Malawi

SUMMARY

*A study was conducted in Zomba, Southern Malawi to assess the resource requirement and output potential of existing and introduced soil management technologies on smallholder food production. Sesbania (*Sesbania sesban*), Tephrosia (*Tephrosia vogelii*), and Pigeon peas (*Cajanus cajan*) were used as sources of green manure in improved fallow plots. Control plots used maize stover and natural weeds as sources of nitrogen. The amounts of time and labour involved in the management of each practice were monitored throughout the growing season. Results indicate that green manures are superior to maize and weeds commonly incorporated by smallholder farmers to improve yield. Management of green manure requires more labour and time than that of maize stover and weeds. Economic importance of the multipurpose tree species and maize in terms of nitrogen contribution to the soil and maize yields is discussed.*

INTRODUCTION

Agriculture is and will continue to be the backbone of Malawi's economy. Over the past ten years it has contributed 34 % to the gross domestic product (GDP) with smallholder agriculture contributing 25 % (Malawi Government, 1995). It has also contributed 85 % of the country's export earnings in the same period (Msukwa, 1994). More importantly, agriculture is a principal occupation for more than 80 % of Malawi's population (Kachule, 1994; Malawi Government, 1995).

Maize is the staple food in Malawi and has no competition from secondary staples such as cassava, rice and sorghum. Smallholder farmers equate maize to life and wealth (Peter and Herrera, 1989). However, smallholder agricultural production has remained consistently low and food insecurity is a chronic problem. For example, in Zomba, Southern Malawi, smallholder farmers are reported to be without food for more than five months after harvest (Kanyama-Phiri, Kamangira and Wellard, 1994).

One of the contributing factors to low crop production is the increase in human population that is estimated at 3.7 % per annum (Ng'ong'ola, Mtimuni, Kanyama-Phiri, Nothale and Wiyo, 1992). This has led to reduced land holding sizes, to deforestation, soil erosion and decreased soil fertility. Decline in soil fertility ranks high among the factors limiting food production. As human population continues to increase, more fragile land is brought into continuous use with little or no proper soil and water conservation practices. There is an increased need to develop more efficient agricultural production systems from limited and diminishing resources to maximize nutrient use efficiency and increase food production.

The most promising way to improve crop yields in smallholder agriculture has been by increasing inorganic fertilizer use (Malawi Government, 1995). Use of inorganic fertilizer has been the main focus for soil fertility improvement. Research has therefore tended to be concentrated on use and management of inorganic fertilizer.

Mainly the large-scale farmers have benefited from inorganic fertilizer use, leaving smallholder farmers with limited options for improving crop production. Although fertilizers may produce the best maize yields (Smale, 1991) this is no longer sustainable because current prices for that input are beyond the reach of resource poor farmers.

Farmers have helpful observations about their problems (Sikana, 1993). For example farmers in Malawi have commented that some inorganic fertilizers 'damage' the soil. They observed that once fertilizer has been applied, subsequent crops of unfertilized maize yield poorly (Blackie and Jones, 1993). Realizing the importance of soil fertility, farmers have traditionally maintained soil fertility through shifting cultivation. With land becoming more scarce and less productive, that system is no longer being widely used. Some farmers incorporate crop residues to improve soil fertility but the residues used are of low nitrogen content (Kanyama-Phiri *et al.*, 1994). Another system called "Fundikira" (incorporation of plant material in the soil) is also common. Dry grass is incorporated or burned on moulds where crops are subsequently grown. The system is common in areas where 'Irish' potatoes are commonly grown in Dedza, Nctheu and some parts of Zomba. However, these practices do not contribute much to soil fertility. Most research has incorporated this traditional knowledge in using organic fertilizers (Blackie and Jones, 1993). Jones, Snapp and Phombeya (1996) and Wendt (1996) reported that Leucaena prunings alone increased maize yield but when combined with inorganic nitrogen (N) the increase in yield was further enhanced. In another study, Onim, Mathuwa, Otieno and Fitzhugh (1990) found that the use of green manure increased maize yield. They found that 13603 kg dry matter of sesbania added 448 kg N/ha, 31.4 kg P/ha and 125.1 kg K/ha; 4806 kg dry matter of pigeon peas added 161 kg N/ha, 4.1 kg P/ha and 26.3 kg K/ha while 7793 kg dry matter of maize stover incorporated added 120 kg N/ha, 5.4 kg P/ha and 7.2 kg K/ha. Maize grain yield following these incorporations showed that Sesbania was superior (6667 kg/ha) to pigeon peas (6380 kg/ha) and maize stover (5156 kg/ha). Sesbania can fix 334 kg N/ha while pigeon pea can fix 69 - 70 kg N/ha (Dunbar, 1969).

Phombeya, Saka, Bunderson, Itimu and Mtupanyama (1989) found that *Tephrosia vogelii (cv Candida)* gave 2883 kg/ha of maize yield as compared to 2912 kg/ha of leucaena when incorporated in the soil. It was also shown that N content is substantial in sesbania and pigeon pea and if incorporated well and in time can improve crop growth and yield (Giller, 1991). However, incorporation of crop residues such as maize stover was shown to be of little importance for grain yield (MacColl, 1989) due to low N content (Kanyama-Phiri *et al.*, 1994).

High labour requirements of legumes may set back the adoption of technologies on a large scale. In agroforestry, labour is required for tree establishment, pruning and incorporation. For example between 40 and 85 man-hours/ha are required to prune hedgerows four metres apart (Young, 1987). Labour is often not available to manage the legume crop (Giller, 1991). This raises costs of production and their adoption in low intensity farms becomes difficult.

Because of the numerous constraints to smallholder agricultural production, it is vital that the available inputs such as labour are used economically and effectively. It is important, therefore, that the farmer knows how much labour is allocated to various farm activities and the magnitude of the return on the investment. It was against this background that research was conducted in Zomba, southern Malawi, to determine the impact of existing and introduced soil management technologies on smallholder food production. The objectives of the research were to:

1. describe and compare different soil management practices in the study area, and
2. assess the resource (input) requirements and output potential of agroforestry and existing soil management technologies and hence establish recommendation domains and adoption potential.

MATERIALS AND METHODS

The study was carried out in Songani Catchment area, Malosa Extension Planning Area (EPA) in Machinga Agricultural Development Division (ADD) with a latitude 15° 18.5' South and longitude 35° 23.5' East with an elevation of 785 metres above sea level.

Songani is relatively flat land with few fields on hill slopes greater than 12 percent, and its mean annual rainfall averages 1139 millimetres. Soils range from sandy-clay in low places to clay - sandy in high places with a pH (Calcium chloride) range of 5.3 to 6.5. Nitrate-N content in the soil ranges from 0.09 to 0.14 percent. The study area was chosen for the project because the catchment area is characteristically inhabited by resource poor farmers. Land holding per farm household is about 0.53 ha (Table 1). Farmers predominantly practise maize-based intercropping on a continuous cropping basis with little use of inorganic fertilizers, leading to low crop yields. Food insecurity is therefore a chronic problem plaguing the farmers in this area.

Table 1. Land area and average land holding capacity in Kanache and Mbelo sections of Songani, Malosa EPA.

Parameter	Kanache	Mbelo	Total
Total land Area (ha)	1403	1320	2723
Non - Arable Land Area	123	508	631
Arable Land Area (ha)	1280	812	2092
Farm Families (FF)	2007	1926	3933
Average Land Holding Capacity (ha/FF)	0.64	0.42	0.53

Source: (Kanyama-Phiri *et al.*, 1994)

Around one ha of land is required to produce enough food for a household of five people (World Bank, 1990). This shows the need for intensive cropping systems that would sustain land productivity on the diminishing farm sizes. Encouraging the use of legume tree species in this case would be one such improvement.

Transect sampling was used to characterize the cropping systems. Fifty farmers were selected at random from six transects spaced at 0.6 km apart from three slope categories (0 - 12 % dambo valley, 0 - 12 % uplands and > 12 % steep slopes). Each transect ran in an East/West direction originating from the Zomba - Lilongwe Road at the lowest elevation and terminating in the highest area of the catchment on the Zomba Mountain Forest Reserve Boundary. This was done to observe slope effects on soil fertility and effects of soil management on nutrient balance.

Each farmer had four plots measuring 15 metres by 15 metres planted with maize. These were undersown or planted with *Sesbania sesban, Tephrosia vogelii and Cajanus cajan* and pure stand maize as sources of organic nitrogen for the subsequent maize crop. Sesbania- and Tephrosia-based systems represented introduced technologies while pigeon peas and maize treatments represented the existing systems.

One-month-old seedlings of sesbania species were transplanted at first weeding in mid January at 75 cm apart for every other ridge and spaced 90 cm apart to give a plant population of 7,400 plants per hectare. Tephrosia and pigeon pea were sown directly using seeds at the same spacing as sesbania. The tree species were left in the field until October and incorporated into the soil at ridging (land preparation). Plant samples were collected from the tree species and maize was collected for analysis of N. Nitrogen analysis was done using a modified Kjeldahl Method (Wendt, 1993). In the following year, the procedure was repeated and MH18 maize was used as a test crop in all plots. Maize grain yield was determined at harvesting. Nitrogen contents in plants were compared with inorganic nitrogen to determine N equivalents contributed by the systems (Onim *et al.*, 1990).

Labour data was recorded for each farm activity in each plot. Data on planting and harvesting of multipurpose trees and maize was collected through direct observation while the remainder were based on recall by farmers for the activities. Recall data was collected immediately after the activity had been completed (Farrington, 1975; Poate and Daplyn, 1993). We used smaller plots than often recommended for estimating labour data on farm activities. This was because in this study area it was impossible to find larger fields because average land holdings are small (0.53 ha) per farm family (Table 1). Small landholding also made some farmers afraid of the technology since they were not sure of the benefits. This brought more problems to find land for the research. In two cases, farmers changed their minds when the technology had already been implemented in their fields and they destroyed the trees. However, this contributed to the results obtained.

RESULTS AND DISCUSSIONS

Table 2 shows the dominant cropping systems in Songani, Zomba. Out of 163 fields surveyed, 56.5 % (92 fields) had mixed intercrops of maize with pigeon peas, sorghum, cassava and other crops. Strip intercropping was observed in 32 % of the fields where cassava formed the main strips between maize and other crops. Eight percent of the fields were planted to one crop while 3.5 % of the fields were not clearly defined. The proportion of intercropped land probably indicates scarcity of land. It also indicates the potential for the inclusion of multipurpose tree species such as sesbania in the farms since farmers would be able to apply their indigenous knowledge to the technology.

Significantly high amounts of biomass was recorded from sesbania (1513 kg/ha), followed by maize which produced 1499 kg/ha (Table 3). Tephrosia and pigeon pea produced low biomass. For N recovered in the leaves, sesbania added 49.9 kg N/ha. Tephrosia and pigeon pea contributed 16.7 and 15.4 kg N/ha respectively. Maize stover added relatively more N than the last two legumes. Nitrogen from sesbania gave the highest returns of MK1105.3 compared to Tephrosia, pigeon pea and maize stover which gave MK369.9, MK341.1 and MK498.5 respectively. Considering the cost of production of N from the legumes, sesbania showed relatively higher costs than the other three systems. Lower values of N from Tephrosia and pigeon pea might have been due to the low biomass obtained.

Table 2. Cropping systems in Songani, Zomba.

	Mixed Intercropping	Strip intercropping	Monocropping	Undefined
Number of fields	92	52	13	8
Percentage of fields	56.5	32.0	8.0	3.5

Table 3. Plant biomass at time of incorporation and N equivalents by cropping system.

System	DM kg/ha)	N %	N (kg/ha)	N-Equivalency of CAN (kg/ha)	Value of N (MK/ha)	Production cost of N (MK/ha)	Difference (MK/ha)
Sesbania	1513	3.3	49.9	188.7	1105.3	725.6	379.7
Tephrosia	417	4.0	16.7	64.2	369.9	571.9	(202.9)
Pigeonpea	496	3.1	15.4	59.2	341.1	499.7	(158.6)
Maize	1499	1.5	22.5	86.6	498.5	578.4	(79.9)

Converting the nitrogen in plant biomass to a commercial N-containing fertilizer, Calcium Ammonium Nitrate (CAN), the various sources of biomass added to the soil contributed equivalents of 188.7 kg/ha of CAN from Sesbania, 64.2 from Tephrosia, 59.2 from pigeon pea and 86.6 kg/ha of CAN from maize. In monetary terms this would be a very substantial saving for smallholder farmers, who can barely purchase inorganic fertilizer like CAN. For example, the farmer would save MK1105.3 if sesbania systems were used in the field. Low nitrogen contents in the legume tree species might have resulted from the shedding of leaves. Harvesting was done at a time when some leaf biomass had been shed off. This may have reduced the dry matter and subsequently reducing N contribution, especially for pigeon pea and tephrosia. The N equivalents presented in Table 3 were calculated from above leaf biomass. Hence, nitrogen fixed in roots was not accounted for. This implies that more N might have been produced from the legume tree species. These results also show that legume tree species are capable of improving soil fertility.

Weeding across systems absorbs a larger share of labour (Table 4). The sesbania system requires 303 man-hours per hectare for weeding; the Tephrosia system requires 275 and the pigeon peas and maize systems require 263 and 265 man-hours respectively. Planting of maize in the systems takes less labour with an average of 35 man-hours per hectare. However, no significant differences were observed.

Table 4. Labour requirement (man-hours per ha) by small-scale farmers for several cropping systems in southern Malawi.

Activity	Cropping system			
	Sesbania	Tephrosia	Pigeonpea	Maize
Incorporating	275	189	145	156
Tree planting	196	144	122	-
Planting maize	39	35	30	34
Weeding	303	277	263	265
Harvesting	197	170	159	162

Tree planting and harvesting in the systems require relatively the same amount of labour. Incorporation ranks second in labour taken. More labour is required for incorporating sesbania into the soil than the other systems. Incorporating sesbania requires cutting the trees and chopping off all leaves and twigs from main stems. This is followed by laying the biomass in the furrow before incorporation. This process takes more time in the sesbania-based system than with the other two legumes because of the size of the plants, and it is no surprise that more labour was consumed. Maize stover incorporation showed a lower labour demand (Table 4). These results agree with those of Leach (1995) and Malawi Government (1994).

Based on an average of 3.1 workers per household and 20 working days in a month (Leach, 1995) a comparison was made between total labour supply and what the family actually used in the systems for five crucial months from October to February. Potential labour supply was 1314 man-hours per household with the mean landholding of 0.53 ha for all systems for five months (Table 5). The highest surplus labour is in the pigeon pea system followed by the maize system. Sesbania ranks last on labour surplus. Tree planting in sesbania system takes a longer time probably because of use of seedlings which requires more care than Tephrosia and pigeon pea where establishment was by seeding. The difference between the two systems (Tephrosia and pigeon pea) could be due to seed size. Tephrosia seed is smaller than that of pigeon pea. Planting of legume trees in relay systems is done almost at weeding. The results of Table 5 indicate that households would have no labour limitations if they planted the whole farm under these systems especially taking into account that the average farm size is 0.53 ha. Considering the critical months of January and February due to need for timely planting of maize, MPTs and weeding, households could experience labour shortage with Sesbania. Leach (1995) found similar results, however he pointed out that this leads to most people doing ganyu (wage employment). For example, labour required for planting of maize, weeding and planting of MPTs would be 369 man-hours for 0.53 ha. A household of 3.1 available labour has 526 man-hours with 157 man-hours remaining. This may result in conflicts in operations especially when ganyu is taken as a strategy for survival.

Table 5. Labour surplus or deficit by system.

System	Total labour used (Man-hours)	Labour surplus
Sesbania	1010	304
Tephrosia	815	499
Pigeonpea	717	597
Maize	617	697

NB. Available household labour was 1314 man-hours for five month period based on 0.53 ha.

In typical labour computations, man equivalents are obtained by using conversion coefficients of 1.0, 0.67 and 0.33 for men, female and children below fourteen years (Farrington, 1975). In this study such conversions were not used because plots used were small (225 m^2). Labour for planting and weeding was collected through farmer recall and other activities were timed directly. This too would have brought some variation in labour estimates.

Gross margins (Table 6) show more returns from a system with sesbania than for maize with and without inorganic fertilizers. There were negative returns from maize with inorganic fertilizer. This would have been contributed by the high prices of inputs such as CAN fertilizers. Returns per man-hour were also high in sesbania systems. This implies that if legume systems were successful, the yield benefit achievable would be enough to raise many currently food insecure households to a clear level of self sufficiency. It is also shown that sesbania would unlock some labour (man-hour) from the time the family would have been looking for fuelwood. The implicit values of sesbania wood have shown this advantage.

Table 6. Estimated income, variable cost and gross margins per hectare for the sesbania system, fertilized and non fertilized maize.

Item	Sesbania	With 12ON	Without N
Yield (kg/ha)			
Maize grain	1321.0	1697.0	691.0
Sesbania wood[1]	2045.0	-	-
Gross Income (MK/ha)			
Maize grain[2]	1651.3	2121.3	863.8
Sesbania wood[3]	613.5	2121.3	-
Subtotal	2290.4		863.8
Variable Cost (MK/ha)			
Maize seed[4]	237.5	237.5	237.5
Sesbania seedlings	370.0	-	-
Fertilizer	-	1728.0	-
Labour[5]	946.9	763.1	578.4
Total Variable Costs	1554.4	2728.6	815.9
Total labour (Manhrs/ha)	1010.0	814.0	616.0
Gross margin (MK/ha)	710.4	(607.3)	47.9
Returns to lab.(MK/man-hr)	0.7	(0.7)	0.5
Gross margin (MK/Var. cost)	0.5	(0.2)	0.4

1. Sesbania sesban seedlings were valued at MK 0.05/plant
2. Price of maize was valued at MK 1.25/kg and MK 0.30/kg for sesbania wood
3. Wood yield was calculated at density of 160 kg/m3 (Wenger, K.F 1984).
4. Maize seed/kg was priced at MK 9.50, 25 kg of seed were used.
5. Labour was valued at K7.50 per working day.

CONCLUSIONS

Based on the assessment of the systems, the sesbania-based system performed well although gross margins for the Tephrosia and pigeon pea systems are not shown. Sesbania gave reasonable yield for grain (1321 kg/ha) as compared to 691 kg/ha for maize without nitrogen. In addition, there was a wood yield of 2045 kg/ha. Wood would be used for fuel and this is a benefit that will unlock some labour resources for use in other farm activities. Looking at the gross margins, the sesbania system was superior to maize with and without fertilizer. Negative margins from fertilized maize would have come about because of the high prices of fertilizers. However, labour requirements for the legume-based systems imply that farmers with less available labour would have more conflicts between ganyu for survival and their own farm operations in critical months. However, in all the systems labour does not seem to be a limitation to crop production. This implies that agroforestry technologies pose no additional challenges to labour resources and can easily be undertaken. Although this is the conclusion from this study, it is important to look into more labour-saving ways of managing the legumes and such ways should consider farmer's immediate needs.

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OBSERVATIONS ON THE MALAWI MAIZE PRODUCTIVITY TASK FORCE

A. SUZGO KUMWENDA

Controller of Agricultural Extension and Technical Services, Ministry of Agriculture and Livestock Development, P.O. Box 30134, Lilongwe 3, Malawi

The author is responsible for the views expressed in this paper and they may not represent a consensus opinion in Malawi and not of the Ministry of Agriculture

SUMMARY

Maize contributes about 65% of the per capita food needs in Malawi. A recent food situation analysis has shown that from 1986/87 to 1994/95, there was adequate maize food only in three out of nine years. Food shortages have been recurrent for many years. An analysis of household food security is even more alarming. There was therefore an urgent need in 1995 to accelerate maize production and reduce the food deficits.

A major cause of the recurrent maize food deficits was soil fertility and poor adoption of improved and more productive technologies by the farmers. A Maize Productivity Task Force was therefore formed to address these two problems.

The Task Force formed four Action Groups. Action Group One was to develop area-specific fertilizer recommendations for maize and demonstrate any other related fertility improving technologies. Action Group Two had to multiply breeders and basic seed stocks of old and new varieties that were not being multiplied by the Commercial Seed Company, demonstrate them to farmers as extensively as possible and initiate a commercial seed multiplication programme by the smallholders for varieties of no commercial value to seed companies. The demonstrations by the three Action Groups permitted farmers to assess the technologies, and thus created a demand for them.

To date, area specific fertilizer recommendations for maize have been developed from 1920 verification trials. These recommendations show that maize can be grown at lower nitrogen and phosphorus levels than the blanket recommendation dictates. It is expected that these recommendations will increase the use of fertilizers on maize, increase its production in Malawi, and help attain food security. Very helpful comments have been made by the farmers on several technologies that were in demonstration plots. In some cases, farmers have requested such technologies.

The sustainability of a Commercial Smallholder Seed Multiplication Programme under a liberalized market economy, however, still remains questionable. Smallholder seed growers do not have infrastructure to process, store and sell the seed when the price is right, e.g. at the beginning of the growing season. It seems that the middleman role in the programme is unavoidable for it to be successful.

Despite the problem encountered in the seed multiplication programme, the MPTF has been recognised as a good mechanism for the verification and fine-tuning of technologies. Verified and fine-tuned technologies are expected to be easily adopted by farmers to enhance soil fertility improvement and food crop diversification. The taskforce has strengthened researcher/extension/farmer linkages; an important link in technology development and transfer.

INTRODUCTION

Malawi is an agricultural country with a population of about 11 million. The agricultural sector contributes about 35% of the Agricultural Gross Domestic Product and employs about 80% of the population. The sector is dualistic in nature. There is the smallholder sector which grows a wide range of crops, but dominantly maize, and the estate sector which grows tobacco and maize. In total, maize, being a staple, occupies about 70% of the arable land and supplies about 60% of the physical quantities of staples to meet per capita daily energy needs (Johnson 1996).

Estimates of recent annual food needs show that over a nine year period from 1986/87 to 1994/95, there was a surplus food production in just three out of nine years (Johnson, 1996). This trend of food under-supply is unacceptable for Malawi.

Considering that maize contributes about 65% of the per capita food needs, and that production of this staple has been stagnant from 1983/84 to 19994/95 (Table 1) a Maize Productivity Task Force (MPTF) was therefore formed to accelerate maize production

Table 1. Maize production estimates for Malawi

Year	Production kg	Area ha	Yield kg/ha	% area local	% area compost	% area hybrid
1984/85	1355205	1144853	1.18	91.58	1.88	6.55
1985/86	1294564	1193275	1.08	92.57	1.18	6.28
1986/87	1201757	1182415	1.02	95.7	1.17	3.14
1987/88	1423848	1215087	1.17	93.61	1.54	4.85
1988/89	1509513	1270822	1.89	91.28	1.97	6.74
1989/90	1342809	1343784	0.999	88.11	1.89	10.05
1990/91	1589377	1391878	1.14	85.76	1.36	12.89
1991/92	657000	1368093	0.48	83.17	0.98	15.85
1992/93	2033957	1327008	1.53	75.11	0.29	24.6
1993/94	818999	1129327	0.73	81.55	0.07	18.39
1994/95	1328495	1225580	1.08	70.10	0.19	29.71
1995/96	1701394	1242588	1.37	68.92	1.78	29.3
1996/97	1315461	1228640	1.07	74.16	1.65	24.19

Source: Ministry of Agriculture and Livestock Development Crop Production Estimates. 1984/85 - 1996/97

and close up the food gap (Malindi, 1995). It was clear to the MPTF that maize system productivity and soil fertility must be improved and that, in order to do so, nitrogen use efficiency must be increased and crop diversity enhanced.

Faced with this challenge, the Ministry of Agriculture and Livestock Development sought K25 million of financial assistance from the World Bank, Rockefeller Foundation and the European Union for the Task Force.

This paper presents a summary of general observations on the past and future of the Malawi Maize Productivity Task Force. While its activities have entered the third year and possibly will reach the fourth and fifth year, it is possible to comment on its results to date, draw lessons learned and project its future. The reader is referred to detailed reports of the Task Force.

METHODOLOGY AND OBSERVATIONS ON RESULTS

To achieve the goal of the Task Force four Action Groups were formed, each with a specific task and a necessary composition of members. Outputs from the groups were intended to have either an immediate or medium-term impact on maize production.

Action Group One

The task of this group, which comprised of agronomists and socio-economists, was to develop area specific maize crop fertilizer recommendations and increase the nitrogen use efficiency of maize. The group decided to choose this task because for many years maize was grown throughout the country using a single fertilizer regime of 92 kilograms of nitrogen and 40 kilograms of phosphate per hectare. Deficiency and or inappropriateness of this recommendation was observed in many agro-ecological zones of the country.

While the recommendation was generally appropriate for light sandy soils, it was inappropriate for fertile heavier textured and sandy clay loamy soils. Some farmers cultivating the fertile soils were unnecessarily applying excessive nitrogen; economically wasteful of the limited financial resource available to them. For the less fertile soils, farmers were applying inadequate nitrogen and phosphate. In both cases nitrogen use efficiency was not being achieved and area specific recommendations had to be developed.

Table 2. Fertilizer levels tested in the verification trial at 1920 locations in 1995/96.

Treatment	Element and rate of application (kg/ha)				
	Nitrogen	Phosphate	Sulphur	Fertilizer package	Provisional recommendation
1	96	40	0	DAP & Urea	Current recommendation
2	0	0	0	0	Lower Shire
3	35	0	0	Urea	Lakeshore
4	35	10	2	23:21:0 +4S & Urea	Lakeshore
5	65	21	4	23:21:0+4S & Urea	Medium textured soils in mid-altitude areas
6	92	21	4	23;21;4S & Urea	Light textured soils in mid-altitude areas

Source: The 1995/96 Fertilizer Verification Trial-Malawi. Economic analysis of results for policy discussion, Ministry of Agriculture and Livestock Development (MoALD), Lilongwe.

To develop such area specific recommendations, a total of 1920 fertilizer verification trials were conducted in 153 Extension Planning Areas (EPA) by extension staff, with the assistance of the researchers. The EPA being the lowest unit of an Agricultural Development Division (ADD) meant that extensive and diverse agro-ecological zones in Malawi were covered. The test treatments are listed in Table 2.

To assess the treatment effects, grain yield data was recorded, soil samples collected for analysis, and farmer comments recorded during the field days.

After successfully analyzing the enormous data sets obtained from over 90% of the 1920 verification fertilizer trials (Table 3) it was concluded that the blanket fertilizer recommendation on maize throughout the country was uneconomical at the current maize fertilizer price ratios. The zero fertilizer application treatment was the only economical fertilizer package for 86% of the 153 Extension Planning Areas and thus it was wasteful in nearly all the maize growing areas (Benson and Members of Action Group One, 1997). However, when a decision tree approach was used to determine the optimum rate of nitrogen on maize a set of recommendations, depending on soil texture and whether a farmer is growing maize for home consumption or for marketing, were determined (Benson, Kumwenda and Gilbert, 1997). These recommendations have been accepted by the extension staff and extension messages for the field assistants are being developed.

Table 3. MPTF activities in 1995/96 and 1996/97 seasons

	1995/96	1996/97
Action Group One		
Demonstration/Trial		
Verification trial	1920	X
Weeding x fertilizer	X	128
Fertilizer placement	X	440
Legume - Maize rotation	X	382
Action Group Two		
Variety Demonstration		
Maize	X	155
Sorghum	X	50
Pearl millet	X	49
Beans	X	118
Soya beans	X	146
Cow peas	X	144
Pigeon peas	X	124
Groundnuts	X	158
Seed Multiplication (ha)		
Maize	0.64	10.0 (10)
Beans	19.00	6.5 (15)
Soya beans	13.00	2.5 (7)
Pigeon peas	11.00	1.5 (3)
Cow peas	3.00	0.5 (1)
Groundnuts	1.50	15.0 (31)
Cassava	18.40	X
Action Group Four		
Organic Matter Technologies	X	464
Participatory Farmer Evaluation	7	
Compost Making	X	295
Crop Residue Management	X	277

Source: Quarterly Reports of Action Groups in 1995/96 and 1996/97, Ministry of Agriculture and Livestock Development, Lilongwe, Malawi

In addition to the development of the extension messages, training of the Field Assistants will be required and the fertilizer industry has to be informed about these new recommendations. It is important that the fertilizer industry make appropriate fertilizer packages for different recommendation domains.

The development of area specific recommendations, which generally show that maize can be economically grown at lower rates of nitrogen, is considered a direct response to the high prices of fertilizers. The recommendations should optimize returns from applied fertilizers. It is also possible that these new recommendations will contribute significantly to changing the concept of growing maize in Malawi, if farmers go through the decision making process to decide whether maize should be grown for cash or for consumption. In brief, the recommendations support the general policy of poverty alleviation of Malawi which encourages that farmers should get economic returns from investments in the agricultural sector (Ministry of Agriculture and Livestock Development, 1995).

While little can be said about the results of the 1996/97 demonstrations, farmer comments on the weed by nitrogen interaction effects indicate that they appreciate the benefits of weeding twice. There is need to find out whether they do appreciate the weeding frequency by nitrogen interaction effects on the productivity of their maize.

Regarding the fertilizer placement demonstration which compared the effect of three methods: broadcasting, banding and dollop (the current recommendation of fertilizer placement) farmers comments varied with location. In Lilongwe, farmers still prefer the current recommendation while in Kasungu some farmers preferred banding and others preferred the dollop method. Comments in Mzuzu ADD varied with sites.

Because research trials have shown that the dollop method of placement is more labour intensive than banding and yet grain yield differences are non-significantly different, the fertilizer placement demonstration should continue in the following year. It is also necessary to encourage the adoption of less labour demanding technologies because labour is becoming very expensive.

Action Group Two

The National Agricultural Research Systems in Malawi had over a 30-year period developed and selected a number of improved and more productive crop varieties than those grown by smallholders. Seed multiplication support programmes for these varieties either did not exist or were weak. For example there were no seed multiplication programme for crops such as sorghum, beans, pearl millet, soybean, groundnut, pigeonpea, cowpea and others. The only strong seed multiplication programmes, which supplied high quality seed of improved genetic stock, were for rice and cotton.

Absence of seed multiplication programmes limited the opportunities for several improved crop varieties from reaching farmers and so limited crop diversification and increased vulnerability of smallholders to chronic food insecurity. The existence of a National Seed Company of Malawi was of little help because the company multiplies and demonstrates only variety seed of commercial interest to them.

Action Group Two was therefore formed to:

a) Get on-the-shelf crop varieties and assist plant breeders in the multiplication of breeders and other seed for subsequent multiplication into basic and certified seed;

b) Demonstrate these varieties to create a demand for the improved crop seeds among farmers and develop and or initiate a sustainable system of multiplying and distributing crop seeds not normally multiplied and distributed by the Commercial Seed Companies.

Breeders seed had to be multiplied because there were inadequate start up quantities of this seed to run demonstration plots and start a seed multiplication programme.

To multiply adequate quantities of breeders seed, farmers were contracted and supervised by breeders in the supervision of the action group. To enable farmers to assess the crop varieties, on-farm demonstrations of these varieties were planted throughout the country (Table 3). In assessing the technologies, farmers indicated what they preferred. Demand for such varieties was created. Creation of demand for the selected varieties was essential because some of them were released several years ago.

To start a sustainable smallholder seed multiplication system for selected crop varieties, Action Group Two advertised through the radio and mass media calling on the farming community to invest in seed multiplication as a business. The response was encouraging. Sixty-six out of 200 applicant farmers registered and multiplied the basic seed in 1996/97 (Table 3) and 276 farmers have applied to multiply the certified seed in 1997/98. Members of the Action Group briefed the growers about seed multiplication businesses in the first year and have done the same this year.

Since the thrust of Action Group Two could not be immediate, results of its task so far should be considered to see if demand for the old and new crop varieties is being created and if a start on sustainable smallholder seed multiplication has been made. More importantly, what lessons have been learned from the two years of work?

For the first time a wide range of crop varieties have been widely demonstrated throughout the country, giving an opportunity to farmers to make their own assessment. Exposure of these varieties to many farmers increased chances of them being adopted.

As expected, preference for varieties varied with location thus suggesting location x variety interaction effects, reflecting both the differences in adaptability of the varieties to different locations and differences in farmers' preferences.

With 276 farmers interested in multiplying certified seed in 1997/98, there are fears that the programme could be too large for supervisors and seed inspectors to manage. Resources might not permit to implement such a large programme. If however, the 276 farmers can all be within areas where breeders seed was multiplied, all of them can be registered for the programme.

What lessons have been learnt about the involvement of individual farmers in the seed multiplication business? It has become very clear that in a liberalized market economy the question of who buys the seed crop from the farmers and who distributes to other farmers is very pertinent. If there was no government intervention in buying the basic seed from the farmers in 1996/97, it seemed likely that the seed growers would have sold it to any buyer and not necessarily to certified seed growers. The farmer needs money soon after harvesting his crop and he may not be prepared to keep a seed crop until near the planting season when he can sell it. He may not have infrastructure to store the seed viably for that long.

There are a number of questions therefore, which have not really been answered about the sustainability of the smallholder seed multiplication programme. These questions are:

- who buys the seed and sells and distributes it as seed in a liberalized market economy like that of Malawi?

- can the farmer retain the seed for 1-6 months after harvesting in April or May without being tempted to sell it to any one whether or not the buyer is buying it for seed, because the farmer needs money soon for his after harvest?
- and at what price should the farmer sell his seed crop?

It seems that there is need to link up the seed growers to some institutional set up that will buy the seed at a price acceptable to them so that their interest in this business is sustained. That institutional set up should buy and sell the crop as seed. The involvement of the private big established seed companies would be ideal. They have the infrastructure and are already in the seed business. Meanwhile it is expected that the smallholder seed growers who have shown interest in the seed business will make their own decision next year how they can continue their seed trade.

The task of Action Group Two can generally be considered as a good start towards setting a system, which will supply improved and more productive varieties to growers in Malawi. This conclusion is based on the spontaneous response by farmers in registering themselves for seed propagation. It definitely shows that some consider seriously investing in seed multiplication. To prove that this is the case, they have already set up themselves into two working committees to work out how they can organize themselves into a Seed Growers Association.

The enthusiasm farmers showed in assessing the selected crop varieties technology also showed that the objective of creating a demand for the varieties to enhance crop diversification has been fulfilled. It remains to be seen how this demand will be met.

Action Group Four

The stagnant maize production over the past ten years (Table 1) has been caused by a combination of factors amongst which were the unfavourable weather, declining soil fertility of the country and removal of subsidies on farm inputs. The devaluation of the MK in 1994 and the end of the Smallholder Agricultural Credit Assistance scheme made the situation worse. Farm input prices increased by almost four-fold. Afterwards poor resource farmers found fertilizer very expensive to purchase for their maize crop.

Thus soil fertility became a critical issue in maize production and Action Group Four was formed to develop and implement strategies that would address this problem. The task of this group was to enhance the integration and management of organic matter technologies into the maize-based cropping systems in Malawi and improve soil fertility. Improved soil fertility would subsequently reduce the reliance on inorganic fertilizers for increased maize production.

This was considered achievable through widespread demonstrations and trials of "best bet" organic matter technologies, showing their benefits to farmers. The technologies demonstrated included maize/grain legume rotations; maize/legume intercrops; compost and animal manure; crop residue management (compost making); improved fallows; green manure and forage legume under-sowing (Table 3). Participatory evaluation of the technologies in 1995/96 helped to choose the technologies to demonstrate in 1996/97.

By their nature, the impact of organic matter technologies can be long term and the thrust of the demonstrations by Action Group Four on maize production was intended to complement technologies demonstrated by Action Group One. Based on farmers' comments, the farmer participatory evaluation exercise of organic matter technologies in 1995/96 confirmed why intercropping is common in the Southern Region of Malawi where pressure on land is high. Farmers viewed intercropping as a source of two crop harvests, more than they considered it as a practice to improve soil fertility. A popular crop combination was maize/pigeon pea. Strip cropping with some of the agroforestry multipurpose trees was not as popular.

A major finding out of this work was that while farmers traditionally practice intercropping they lacked knowledge in management of the intercropped species, particularly the agroforestry species. To promote the integration of organic matter technologies, farmers need training to raise agroforestry seedlings and some of the traditional legumes.

Demonstrations of organic matter technologies showed that farmers and extension staff preferred the combination of organic matter and fertilizer. This treatment had a better stand of maize compared to the zero manure treatments and that some ADDs will encourage farmers to have demonstrations in their fields.

Compost making too was appreciated by most farmers. However, they observed that although the Chinese method of compost making was more resource demanding than the traditional method, it produced better quality compost.

While maize with legumes is a common practice across the country, especially in highly populated areas, farmers need to know the soil fertility improving function of this practice because they need to realise that the practice can reduce their reliance on inorganic fertilizer.

The government policy to promote the integration of more organic matter technologies into maize-based cropping systems needs to be promoted through campaigns. Action Group Four should emphasize this work.

FUTURE OF THE MALAWI MAIZE PRODUCTIVITY TASK FORCE

The MPTF can be viewed as a model to accelerate maize production and reduce the food deficit gap permanently and as a vehicle for technology development and transfer through improved research/extension/farmer linkages. This model can be applied to other crops in future. Indeed from the 1996/97 season the MPTF was more of a Food Productivity Task Force (FPTF) because the demonstrations and seed multiplication programme included several other food crops as well as maize.

However the MPTF could not have been implemented without donor funds. Therefore, any suggestions about its future direction must take into account the financial implications of such an expensive but very useful programme. If the limitation on financial resources can be overcome, the MoALD can use the lessons from the two years of MPTF activities in several ways.

Having produced the area specific recommendations for maize, the task force should now do the same for other food crops, including horticultural crops. This will enhance crop diversification and the attainment of food security. As indicated above, the main thrust of the area specific recommendations will be determined by the uptake of fertilizer by the smallholder farmers.

Will the uptake of fertilizer increase because of these recommendations? If so this will be reflected in the national maize production and the level of household food insecurity. Food (maize) should be reduced as maize becomes more economical to produce. Furthermore, the success of the area specific fertilizer recommendations will change the concept of growing maize. As more farmers think through in deciding whether to grow the crop either for marketing or home consumption, there could be more of them growing it for cash instead of home consumption. This concept can be applied to other food commodities, thus changing the whole concept of growing food crops in Malawi.

To what extent should the programme be controlled from Ministry Headquarters compared to from the ADDs themselves? It is becoming very clear after two years that the programme should be owned and managed by the extensionists and researchers at the ADD level; and be integrated into the mainstream of activities at this level. This will make it far much cheaper to implement.

Fears about the sustainability of the initiated seed multiplication programme are warranted considering the lessons from 1995/96 and 1996/97. In the first place, the seed multiplication programme is extensive, covering a wide range of crops. While this is good number of seed growers, it should match with the resources available to the Seed Quality Control Unit at Chitedze. Once again, if the numbers of seed growers increase there will be need to build capacity at the ADD to check on seed quality of the growers. This will be cheaper than the work being done from one central unit.

Having created a demand for the various crop seeds, the fear is that the market demand for the self pollinating crops will not last. Should this be the case, there will be frustrations among farmers who want to multiply seed as a business. There must therefore be another demand created for the selected crop varieties beyond the farm gate. Such a demand can be from either the consumers or the middlemen who can sustain the interest of seed growers in the seed multiplication business. There must be an institutional set up to guarantee seed growers that their crop can be sold at the time they want the money and that institution should further sell the seed. That way a system will have been put in place to supply improved and high yielding varieties on a sustainable basis.

Since it is a policy of the Government to increase the growth of agro-processing and add value to farm produce (MoALD, 1995) the private sector should be urged to invest in agro-processing. Other than the effect of this on maize, growth of the agro-processing industry will stimulate demand for some of the non-traditional food crops, and hence the seed by the growers. Furthermore, Government should facilitate the formation and management of seed growers' associations. This should not be viewed as counterproductive to the liberalization policy but as a way of enhancing it. If it is not done, farmers interest in seed trading may not be sustained.

Concerning the work of Action Group Four on organic matter technologies, most of which are already being practiced by some farmers, it is essential that there are more on-farm demonstrations by the farmers so that they appreciate the soil fertility function of intercropping. Extension staff have already considered some of the organic matter technologies for the demonstrations and the programme needs to be intensified.

In conclusion, the MPTF has strengthened the research, extension and farmer linkages. It is a model which researchers and extension can apply to other farmer problems, if resources permit. The MoALD feels strongly that the MPTF is a good model for technology transfer.

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ZIMBABWE SOYBEAN PROMOTION TASKFORCE: OBJECTIVES, ACHIEVEMENTS AND AGENDA FOR THE FUTURE

ISHMAEL POMPI[1], SHEUNESU MPEPEREKI[2] and EUSTONCE GWATA[3]

[1]Agritex, P.O. Box CY639, Causeway; [2]Soil Science Department, University Of Zimbabwe, P.O. Box MP167, Mount Pleasant; and [3]Department of Research and Specialist Services, P.O. Box CY530, Causeway, Harare, Zimbabwe

BACKGROUND

Soybean is largely grown by large-scale commercial farmers in Zimbabwe who produce over 90% of the crop, mainly in rotation with wheat. Smallholder farmers grow a small area, producing less than 10% of the crop.

Soybean has the capacity to fix nitrogen (N) in symbiosis with introduced or indigenous Rhizobia. Soybean varieties with relatively low harvest indices not only provide grain but also can improve soil fertility through residual N from incorporated plant residues. So they can contribute to sustainable cereal cropping, especially maize, the staple food of Zimbabwe.

The high protein (about 40%) and oil (about 20%) contents make soybean an excellent crop for supplementing protein-deficient maize-based staple diets.

Soybean residues are already being fed to dairy cows by smallholder farmers in Chikwaka -- Mashonaland East, Guruve -- Mashonaland Central, Mhondoro -- Mashonaland West and in Chikomba -- Mashonaland East.

Market prices, which previously were so low as to discourage small-scale producers, have recently firmed as demand has risen on both the domestic and export markets. Soybean prices have risen from Z$1600/tonne to about Z$3680/tonne compared to maize which has remained at Z$1200/tonne over the past two cropping seasons (1995/96 and 1996/97).

The advantages of introducing soybean to smallholder farmers is that they could raise cash for purchasing other inputs, improve nutritional diet, feed livestock and improve soil fertility.

A programme was born out of a workshop held in February 1996 at the University of Zimbabwe with the theme, "SOYBEAN GROWN UNDER NATURAL NODULATION -- POTENTIAL CONTRIBUTION TO SUSTAINABLE MAIZE BASED SMALLHOLDER CROPPING SYSTEMS IN ZIMBABWE".
The workshop recommended two major activities:

1. Research -- to characterize indigenous soybean rhizobia and quantify the residual soil fertility benefits for maize grown in rotation with soybean.

2. Extension -- Soybean promotion, production and utilization at home for nutritional purposes for humans and livestock, and to improve soil fertility to combat the rise in agricultural crop inputs.

A Taskforce was formed at the workshop to complement the Extension and Research activities. The taskforce is composed of the following organizations and individuals:

Ishmael Pompi -- Senior Extension Agronomist, Agritex (Convener)
Sheunesu Mpepereki -- Soil Scientist, University of Zimbabwe (National Coordinator)
Eustonce Gwata -- Soybean Breeder, DR & SS
George Hutchison — Chief Executive, Commercial Oilseeds Producer's Association
Silvester Tsikisayi — Chief Economist, Zimbabwe Farmers Union
Doreen Shumba-Mnyulwa — Extension Agronomist, ENDA-Zimbabwe
Fred Makonese -- Soil Microbiologist, University of Zimbabwe (Taskforce Secretary)
Trust Beta -- Food Scientist, Institute of Food Science, Nutrition and Family Sciences, University of Zimbabwe.

The Taskforce resolved to tackle the following problems that were thought to limit adoption of soybean by small-scale farmers:

- Seed unavailability.
- Inadequate training for extension personnel on soybean production and utilization technologies.
- Promiscuous soybean seed multiplication by smallholder farmers, with proper training on seed management and storage.
- Promotion of commercial production of both specific and promiscuous varieties.

PROJECT OBJECTIVES

The main objectives of the Taskforce's soybean promotion drive are:

1. To improve soybean adoption through provision of basic information and training in soybean agronomy, practical training in processing, home utilization and marketing for farmers and extension personnel.

2. To interact with and gain responses from farmers on their perceptions of soybean and its place in their production system.

3. To develop links between research, extension, farmers, commerce and industry, farmer organizations and NGO's in promoting soybean production and utilization.

4. To evaluate agronomic performance of specific and promiscuous nodulating soybean varieties and their contribution to soil fertility improvement.

AREAS TARGETED AND NUMBER OF FARMERS

High rainfall areas and areas already growing soybean were targeted as pilot project areas. These included:

Mashonaland Central Province
Guruve District - Kachuta 6 farmers
Mazowe District - Chiweshe 10 farmers

Mashonaland East Province
Mutoko District - Hoyuyu Resettlement 5 farmers
Chikomba District - Sadza 5 farmers
Goromonzi District - Chikwaka 5 farmers

Mashonaland West Province
Chegutu District - Mhondoro 5 farmers
Hurungwe East Dist. - Kazangarare 10 farmers

Manicaland Province
Makoni North District- Chinyika Ressettlement 5 farmers

ACHIEVEMENTS IN THE 1996/97 CROPPING SEASON

- Fifty-one farmers identified in eight sites from four provinces, and each grew 0.4 ha of soybeans.
- Soil samples were collected from all sites and analyzed for pH and nutrients.
- Sourced input donations from private and public agro-based organizations.
- Each farmer received seed for four cultivars of 10kg each to plant on 0.1ha per cultivar. Fertilizer, lime and chemicals were provided from the donations.
- Basic training on soybean agronomy conducted for AGRITEX field staff and farmers in pilot areas.
- Field visits undertaken during the season to monitor crop establishment and progress.
- Field days conducted in all project areas.
- General agronomic practices recommended.
- Conducted training on utilization and processing with over 160 mainly women farmers, including those not in the project.
- Held a meeting with ZFU President and his Directorate to discuss their input.
- Facilitation of marketing by farmers in the target areas.
- Mobilization of agro-based business, farmer organizations and NGOs through meetings and a review seminar.
- Managed to distribute inputs, train farmers and hold meetings without funding from October 1996 to January 1997.
- Received some funding from Rockefeller Foundation and APPROMA (a European Union supported commodity organization) early in 1997.

The following companies and organizations assisted with inputs:

ZFC and Windmill - Fertilizer
Seed Company - Seed
G & W Industrial Minerals,
Alaska Dolomite and Early Worm Mine - Lime
Rockefeller Foundation Grant to UZ - Seed, Chemicals and Transport

The following cultivars were given to farmers: Roan, Nyala, Gazell, Magoye (from Zambia) and Local, a variety from Hurungwe and Guruve.

LESSONS LEARNT

- Market information is lacking -- most are not aware of current commodity prices.
- Some farmers grow soybeans for soil fertility improvement.
- Grain Marketing Board grading system and pricing system discourages farmers from growing soybean as most get Grade D which is low-priced. In contrast, the open market is offering a minimum of Z$3000/tonne.
- Past soybean prices also discouraged farmers to grow the crop.

- Most farmers reduced the amounts they had intended to sell after home utilization and processing courses.
- Use of inoculant was well appreciated by farmers.
- Younger farmers were easier to work with and could follow written instructions.
- Face-to-face contacts, field visits and training proved the best strategies for encouraging farmer involvement.
- Yields from sandy soils were, surprisingly, higher than anticipated.

Inputs used were as follows: Inoculant, one packet (80-100g), 10 kg seed/cultivar, 125 kg Line/ha and 116 kg compound L/ha. Average soil acidity was between 4.0 - 4.8 pH. The average yields obtained from four varieties with those inputs are in Table 1.

Table 1. Grain yield (t/ha) of soybean with and without inputs.

	Fertilizer, Lime and Rhizobia	No Fertilizer, no Lime, no Rhizobia
Gazell	2.5	0.7
Roan	2.1	0.6
Magoye	1.8	0.5
Local	1.7	0.4
Nyala	2.0	0.7

AGENDA FOR THE FUTURE

- A seminar on soybean in the smallholder sector is planned for July 1997, generating interest in supporting soybean production by smallholders among stakeholders in the farming and agro-based industries.
- Plans are to increase the number of growers from 51 to about 1000 and source subsidized inputs for about 400 farmers.
- Greater involvement by the Zimbabwe Farmers' Union because the programme will be too large to handle. The ZFU president has agreed to support the promotion.
- Training of AGRITEX field staff on production and utilization.
- Sourcing of funds for field visits and training.
- Produce a booklet on soybean production and utilization.
- Encourage farmer organizations to establish an information network that reaches the farmers.
- Further develop interactions with research, extension, farmers, farmer organizations, agro-industry and NGOs.
- Run simple trials to establish optimum basal fertilizer levels for different natural regions (at present a blanket recommendation is used -- see inputs above).
- Continue evaluating agronomic performance of specific and promiscuous nodulating varieties and their contribution to soil fertility improvement.
- Encourage researchers to come up with specific agronomic practices and inputs for specific areas.
- Develop further marketing opportunities for soybean locally and abroad.
- Give selected farmers a full package of seed, lime, compound fertilizer and inoculant. Farmers will pay half cost of the package to encourage self-reliance and use of inputs.
- Contact CARE International for the rural trading scheme and may use it for inputs to farmers.

CONCLUSION

The Soybean Promotion Taskforce has managed in one season (1996/97), and with very limited resources, to demonstrate that:

1. Soybean can be successfully grown in small-scale (as well as in commercial) areas of Zimbabwe where rainfall is not limiting.

2. Farmers need proper training on the basic requirements for soybean, i.e. Rhizobia inoculant, basal fertilizer, and correct planting density.

DEVELOPING FLEXIBLE FERTILIZER RECOMMENDATIONS FOR SMALLHOLDER MAIZE PRODUCTION IN MALAWI

TODD D. BENSON

Maize Commodity Team, Chitedze Agricultural Research Station, P.O. Box 158, Lilongwe, Malawi

SUMMARY

The methodology used to develop flexible area-specific fertilizer recommendations for smallholders in Malawi that grow hybrid maize is presented. Agronomic and household economic conditions are incorporated into the recommendations through a two-level decision tree that uses information on the general soil texture of the maize field and the production goals of the farming household. Four fertilizer application rates, each appropriate for a particular combination of production aim and soil texture were derived. Simple suggestions and guidelines for additional modifications to the recommendations accompany them to enable the farmer to make as intelligent a decision as possible on the rate of fertilizer to apply to the maize crop within the particular economic constraints of the farming household.

The analysis revealed the degree to which national food security is threatened by maize producer prices that do not fully reflect the costs of fertilized maize production. While higher prices are required to enable farmers to produce sufficient maize with fertilizer to meet Malawi's food needs, these prices may cause malnutrition and suffering among the maize-deficit poor households of the country. The policy ramifications of this analysis are considerable, yet equitable policy solutions are difficult to conceive.

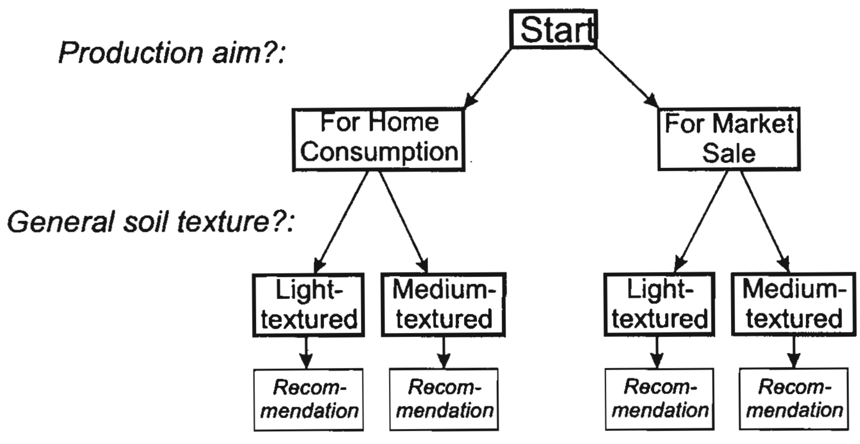
INTRODUCTION

In the late 1980s and early 1990s hybrid maize and fertilizer were widely adopted by smallholders in Malawi (Smale and Heisey, 1994). The technical foundation of the fertilizer use was based upon a nationwide blanket recommendation of 96 kgN and 40 kgP_2O_5 per hectare (GoM-MoALD, 1994, 48). For well over ten years, both agronomists and policymakers in Malawi have been calling for area-specific fertilizer recommendations to replace this blanket recommendation. As a country of extraordinary diversity in landscape and climate, area-specific recommendations are required on an agro-ecological basis alone. Moreover, the recent progression in Malawi towards agricultural markets under minimal government control has led to a situation where commercial production of fertilized maize is a financial gamble. Without a clearer understanding of how the local bio-physical conditions of production, the production aims of the farming household, and broader input and output prices interplay in determining appropriate fertilizer application rates, many farmers will make wrong decisions on the amount of fertilizer they apply to their maize. This complexity in decision making on fertilizer use requires that any area-specific recommendations incorporate a considerable degree of flexibility to respond to different production environments, household requirements and, in the longer term, changing economic conditions.

In early 1995, the Maize Productivity Task Force was set up by the Ministry of Agriculture and Livestock Development of the Government of Malawi to address in a dedicated fashion many of the constraints to increased maize production that smallholder farmers and the nation faced. Of the three Action Groups established to address specific production issues, Group One was given the task of developing area-specific fertilizer recommendations. The members of Action Group I during the 1995/96 season were J.D.T. Kumwenda (chairman), K.M. Chavula, A.C. Conroy, A. Gomez, R.B. Jones, the late E.E. Kanyenda, S.K. Mughogho, B.J. Sizilande, and T. Benson. While dissemination and extension efforts remain, the technical aspects of this work have now been completed with the presentation of recommendations to the Government in late June 1997.

As diagrammed in Figure 1, the recommendations are based upon a two-level decision tree that incorporates information on the production aim of the farmer - production for home consumption or for the market - and the general soil texture of the maize field - light-textured or medium-textured. For any site in the country, four recommendations are offered. Additionally, underlying the recommendations are guidelines for modifications to the stated decision tree fertilizer rates to account for local bio-physical or economic conditions not reflected in the recommendations applicable to that area. In this paper the process by which these recommendations were developed is sketched out, the nature of the recommendations and the means by which they can be fully implemented is discussed, and certain na-

Figure 1. Area-specific fertilizer recommendations decision tree.



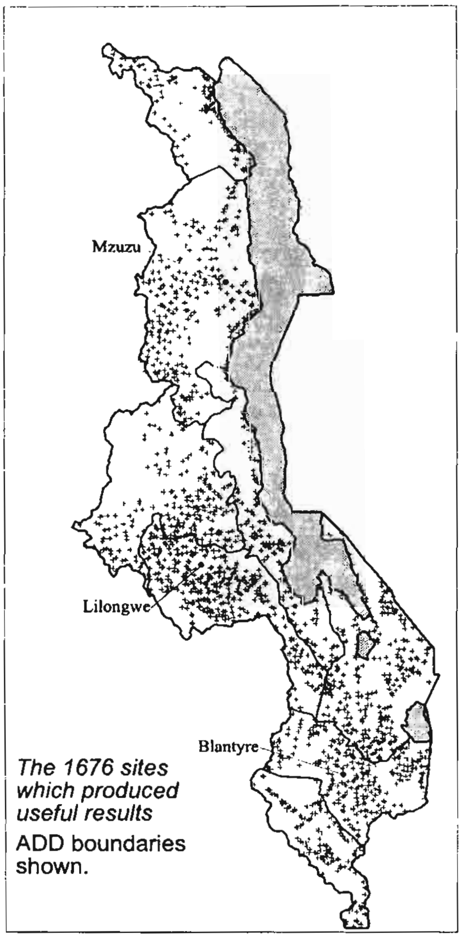


Figure 2. Trial locations for the maize fertilizer verification trial, 1995/96, Malawi.

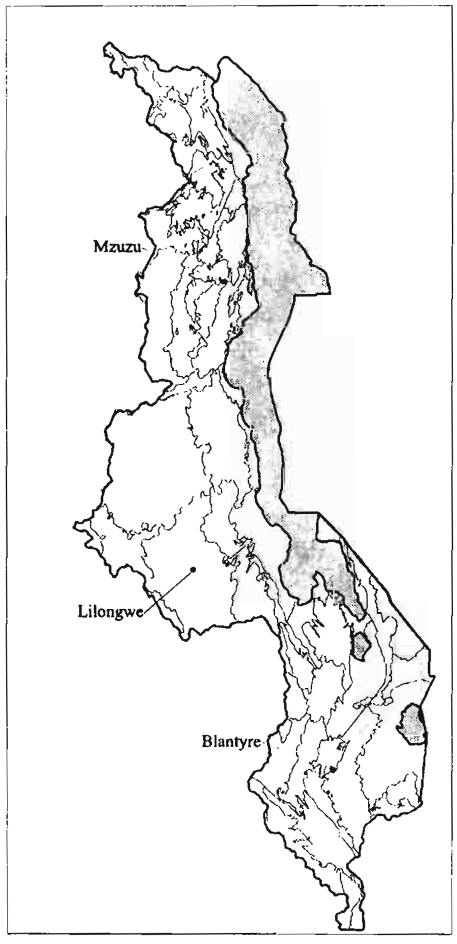


Figure 3. Boundaries of the fifty-five Natural Regions of Malawi.

tional food policy issues that emerged from the analysis underlying the recommendations are considered.

FERTILIZER VERIFICATION TRIAL - 1995/96

As a first step to develop area-specific fertilizer recommendations for maize, Action Group I produced provisional recommendations for the entire country using the results of past research on fertilizer response in maize. Under the Maize Productivity Task Force a nationwide verification trial was implemented in the 1995/96 rainy season to determine whether these recommendations were appropriate for farmers and to establish where recommendation-zone boundaries should be placed. Every Extension Field Assistant staffing a section in the country implemented one replicate of the trial design laid out in Table 1. The specific packages for the new recommendations were developed based upon the use of urea and 23:21:0+4S fertilizer. Trials were sited on farmer's fields at locations that had not received fertilizer in the previous two years. The farmer managed the trials, but his or her activities were closely supervised by the Field Assistant. Before the rains, all Field Assistants and their supervisors received training on the implementation of the trial and were provided with a simple, but detailed, forty-page trial manual to use as a reference. Hybrid maize MH17 was planted at upland sites with historically good rainfall conditions, while MH18 was supplied for trials in lowland areas and at those upland sites in rain-shadow areas. Soil samples were taken from each site.

Table 1. Plot treatments

Plot	kg N per ha	kg P_2O_5 per ha	kg S per ha	Fertilizer package *50 kg bags per ha*	Cost of fertilizer per ha (1996/97)[1]	Provisional recommendation zone
1	96	40	0	DAP: 12/3; urea: 3½	MK 1850	*(Malawi blanket recommendation)*
2	0	0	0	nil	nil	Lower Shire Valley
3	35	0	0	urea: 1½	MK 510	Lakeshore (N-only)
4	35	10	2	23:21:0+4S: 1; urea: 1	MK 690	Lakeshore
5	69	21	4	23:21:0+4S: 2; urea: 2	MK 1380	Medium-textured soils in Upland zone
6	92	21	4	23:21:0+4S: 2; urea: 3	MK 1730	Light-textured soils in Upland zone

[1] MK 15.20 = US$ 1.00.

Overall, the 1995/96 season was good for maize production. At the start of the 1995/96 season, 1919 trials were established. Of these, 1676 trials provided yield results of sufficient quality for economic analysis, for an 87 percent success rate. These sites are mapped in Figure 2.

ANALYSIS

Trial Site Grouping

The principal analysis used to establish the area-specific fertilizer recommendations is an economic analysis. The first step involved adjusting downwards by twenty percent the trial yield data to reflect more accurately the treatment yields we expect under farmer conditions. Once this was done, trial sites were grouped by natural region and by general soil texture. The mean adjusted treatment yields of sites grouped on these criteria were used in the economic analysis.

"A *natural region* is a part of the earth's surface within which the characteristics of the physical environment are relatively uniform (Young and Brown, 1962, 56)." The natural regions used were the fifty-five delineated by Young, Brown, and Stobbs for Malawi, the boundaries of which are shown in Figure 3 (*ibid.* Brown and Young, 1965; Stobbs, 1971). The cropped area of each Extension Planning Area (EPA) was assigned to a single natural region. Trial sites were grouped within thirty of the fifty-five natural regions.

While many EPAs have arable land within more than one natural region, a single natural region - the natural region of greatest agricultural significance - was assigned to an EPA. The rationale for this simplification lies with how the recommendations are to be put into practice. It was felt that an EPA should have no more than one set of the four recommendations. The complexity entailed by subdividing EPAs into more than one recommendation area would make the recommendations extremely difficult for the agricultural extension staff to use.

All trial sites within the same natural region were then disaggregated by general soil texture class. Two categories of general soil texture are distinguished. Medium-textured sites are those whose soil has more than a thirty percent clay content. Light-textured sites have a clay content less than or equal to 30% clay content. Simplifications of either of the two field methods described by Lafitte (1994, 106-109) are all that extension workers and farmers will have to use to determine general soil texture and make use of the decision tree to establish what level of fertilizer to apply. These methods involve the manipulation of moist soil into various shapes. The degree to which the soil can be shaped determines the texture. Although thirty natural regions were used to group trial sites, not all contained sufficient numbers of trial sites of both soil texture classes for analysis. The mean treatment yields of fifty-eight texture-by-natural-region trial site groupings were used in the analysis.

Economic Analysis

Prices and adjustments to prices -- Once the mean yields for each trial site group had been calculated, a marginal analysis was used to determine which fertilizer application rate of those tested in the trial was the optimum under specific economic conditions. For computational purposes the marginal analysis method used was the 'residual' method of CIMMYT (1988, 47-48). The method was slightly modified to make it directly comparable to marginal Value-Cost Ratio (VCR) analyses commonly used to evaluate the economic acceptability of agricultural technologies. The CIMMYT method does not explicitly include the opportunity cost of credit in the total costs that vary (TCV), but incorporates this cost in the minimum acceptable rate of return (MARR). In the analysis presented here these credit costs are included in the TCV. Consequently, at least for medium-textured soils, the minimum acceptable rate of return is adjusted downwards accordingly from the levels recommended by CIMMYT. The residual of a treatment is calculated as follows: *Residual = net benefits - ((total costs that vary) x (minimum acceptable rate of return))*. The treatment recommended as economically the optimum fertilizer application rate for a given texture-by-natural-region trial site grouping is the one whose mean yield provides the highest residual.

Two separate economic conditions were evaluated corresponding to the two principal production aims of a farmer growing fertilized hybrid maize: production for home consumption and production for market sale. The production for market sale analysis involved using the maize producer price, the full cost of credit, and appropriate crop transport and marketing charges, whereas the production for home consumption analysis used the maize consumer price and a nominal opportunity cost of credit. Table 2 presents the assumptions made to determine the optimal rates of fertilizer to apply under the two production aims.

The two production aims are significantly different in terms of their underlying economic conditions. Their foundations lie in the two maize prices: the consumer price of maize - that is, what it costs the household to buy maize at the market - and the producer price of maize - the price that the farmer receives when she sells part of the maize harvest at the market. The farmer places a different value on the maize depending on the intended use of the maize. If producing for the market, a reasonable value for the maize is the producer price the farmer will receive in the market. However, if the farmer is producing for home consumption and use, the significantly higher consumer maize price is the value which can be attached to the maize, as every kg of maize the farmer produces in his or her own field is one less that will have to be purchased in the market at the consumer maize price. As this price is considerably higher than the producer price, it makes economic sense for the farmer to apply higher rates of fertilizer to the maize when producing for home consumption. As will be seen, this is reflected in the recommendations.

Following the 1996 harvest, the prices which ADMARC, the smallholder agricultural produce marketing parastatal corporation, offered farmers for their maize was MK 1.55 per kg, while the consumer price was MK 2.50 per kg. With the mediocre maize harvest of 1997 - estimated to be 35 percent less than the previous year due to excessive rainfall and low levels of fertilizer and hybrid maize seed use - it is expected that supply constraints will boost maize prices in the coming months. In this analysis, maize prices are used which are 25 percent higher than those of 1996. Such a maize price rise would reduce the fertilizer to maize price-ratio by 20 percent.

Turning to the other components of the analysis, it is assumed that fertilizer prices will remain stable, as they reflect international prices plus transport and marketing costs. However, the opportunity cost of credit used in the production for market sale analysis is considerably lower than the cost prevalent in recent years. In the 1996/97 season, an annual interest rate of 36 percent was charged smallholders borrowing from the Malawi Rural Finance Corporation (MRFC). The interest rate MRFC charges are directly linked to the Reserve Bank of Malawi reference interest rate, which in turn is linked to the rate of inflation. Prior to the 1996/97 season, the annual rate of inflation in Malawi was above 50 percent. Since then it has dropped significantly. Currently it is estimated to be around 7 percent. Consequently, an 11 percent drop in the MRFC annual interest rate to 25 percent is assumed here.

At this point it is very important to note two points of practical significance that emerge from these analyses. First, if the farmer is producing maize using fertilizer acquired through commercial credit (MRFC or the like), then the 'for market sale' recommendations should be used. The analysis upon which these recommendations are based incorporate the full costs of this credit in determining the level of fertilizer to apply. The 'for home consumption' recommendations do not. There is a significant risk that the credit-using farmer will default on the loan if he or she uses higher rates of fertilizer than those indicated under the 'for market' production aim.

Table 2. Economic analysis – prices and adjustments

	Production for home consumption	Production for market sale	Notes
Maize price (MK/kg)	3.13	1.94	Twenty-five percent increase on 1996 ADMARC consumer and producer maize prices, respectively.
Maize price adjustment (proportion of maize price)	0.10	-0.10	Reflects transport and marketing costs, or these costs not incurred.
Urea (MK/50 kg bag)	342.00	342.00	ADMARC price in 1996/97
DAP (MK/50 kg bag)	375.00	375.00	Mean of Norsk Hydro and Optichem prices
23:21:0+4S (MK/50 kg bag)	350.00	350.00	ADMARC price
Fertilizer transport & application costs (proportion of fert cost)	0.10	0.10	Costs of transport of fertilizer from depot and labour to apply
Annual opportunity cost of capital (proportion of total fert cost)	0.10	0.25	Home consumption: passbook savings rate. Market sale: anticipated 1997/98 MRFC credit interest rate.
Credit repayment term in months	7	10	Seven months is period from fertilizer purchase to maize harvest. Ten months is the median length of time that MRFC maize loans are outstanding.

Secondly, if the aim of the farmer is to produce maize for home consumption, it is assumed that the funds necessary for purchasing the fertilizer came from a different source than credit. Essentially, the farmer is subsidizing fertilized maize production by another cash-producing activity of the household. This most commonly would be from tobacco production, but could also be from wage labour, cash gifts from family members working in urban areas, or some other source. The cash used for the fertilizer is not being treated as capital being invested to produce a profitable return. Rather, it is being consumed for household welfare, albeit in a roundabout fashion of delaying consumption for a growing season to derive some additional benefit by using it for fertilizer to acquire in the end considerably more maize than could be directly purchased with the cash.

Minimum acceptable rates of return (MARR) -- As noted above, a critical component of the method of economic analysis employed is the MARR. In the analysis here, the MARR principally incorporates the degree of risk that the use of the fertilizer entails for the farmer - specifically the risk that the farmer will derive negative returns from his or her use of fertilizer. As such it incorporates several not readily quantifiable factors that affect the efficiency with which the fertilizer is used - adverse soil conditions, poor rainfall, poor farmer management due to labour constraints, poor management due to lack of knowledge, and so on. With new technologies, socio-economists working with smallholder farmers have established that as a rule of thumb farmers require a MARR of 100 percent from the use of a technology before they will integrate it into their farming practices. That is, a farmer wants to receive net benefits from the use of the technology that are at least twice the costs incurred in using it. Algebraically, the MARR is the equivalent of a critical Value Cost Ratio - the VCR which the use of a technology must provide if it is to be economically acceptable to farmers. A critical value VCR of 2.0 is equivalent to a MARR of 100 percent, while a VCR of 1.75 is equivalent to a MARR of 75 percent.

Two different MARRs are used in the economic analyses here. Most Malawian smallholder farmers are familiar with the use of fertilizer. It is not a new technology to them. The benefits of its use on maize have been proven, at least under the economic conditions that prevailed several years ago. Consequently, a somewhat lower MARR is justified to evaluate the optimum rates of fertilizer that they should apply. However, fertilized maize production on light-textured soils is considerably more risky than on medium-textured soils. The greater nutrient and moisture holding capacity of medium-textured soils means that they are not as prone to the degree that light-textured soils are to drought under poor rainfall conditions and to nutrient leaching under excessive rainfall. Because of these considerations, the economic analysis of treatment yields from medium-textured sites were subjected to a 75 percent MARR, while the analysis of data from riskier light-textured sites incorporated a 100 percent MARR. In part as a result of this assumption, by and large the recommended fertilizer application rates for light-textured soils are lower than for medium-textured soils.

Sensitivity analysis and post-analysis adjustments -- After the initial economic analysis of the mean treatment yield data for all texture-by-natural-region groupings, a sensitivity analysis was done on the data using higher and lower fertilizer to maize price-ratios than that of the base economic conditions of the analysis. Where the base conditions had generated a relatively high optimum application rate that no longer was optimal under a slightly higher price ratio, the recommended application rate assigned to a texture-by-natural-region grouping was lowered appropriately.

Up to this point, all six fertilizer packages evaluated in the 1995/96 Fertilizer Verification Trial were considered in the analysis. Following the sensitivity analysis, two of the packages were dropped from consideration, so only four are used for the recommendations. One of the packages evaluated in the trial, the old blanket fertilizer recommendations of 96:40:0 was shown to be inferior to the other packages virtually everywhere in the country and under a wide range of economic conditions. The other fertilizer package excluded here, the straight nitrogen package of 35:0:0, performed exceptionally well from both an agronomic and an economic standpoint. However in developing the area specific recommendation zones it was decided on agronomic grounds to substitute 35:10:0+2S for 35:0:0 in those areas where the latter was shown to be the optimum recommendation. The long-term sustainability of maize production under a straight-N fertilization regime was seen as unlikely, hence the substitution of the more balanced fertilizer package.

Following the reduction to four fertilizer packages, the spatial pattern of the recommendations assigned to each EPA under the four separate production aims and general soil texture combinations were mapped and examined. Seventeen different sets of the four recommendations emerged across the country. The combinations applicable to each Agricultural Development Division and broad agro-ecological zones were examined to identify any areas where generalizations of the existing recommendation sets could be applied to simplify the overall pattern. This was done through an iterative process using both additional economic analysis and researcher knowledge.

of the agro-ecological conditions and fertilizer response patterns of the individual recommendation zones. Eight different combinations of the four recommendations resulted from this simplification process.

The recommendations so derived for each area were then evaluated using two sets of trial data - that of the individual trial sites of the 1995/96 Fertilizer Verification Trial upon which the analysis was based, and yield data from 780 nutrient response trials carried out in the past at 350 sites across Malawi over 15 seasons. With the first set of data, the trial sites of each EPA were examined in turn to determine under each production aim and soil texture combination the number of trial sites for which the proposed recommendation would have been the optimum, the number for which a lower rate of fertilizer would have been the optimum, and the number for which a higher rate would have been optimal. Several adjustments were made, resulting in the final seven sets of the four recommendations in the national recommendation pattern.

The use of the past trial data to evaluate the recommendations was particularly useful because the recommendations had been derived from one year of trial data. A linear interpolation procedure was used with the nitrogen response data from this set of trials to establish yield levels at the N-levels of the recommendations. Response to phosphorus or sulphur could not be considered in deriving calculated yields simply because of the nature of the response trial data. However, making the assumption that the effect of phosphorus is minor is not wholly without basis, as less than one-third of the nutrient response trial sites showed a positive response to phosphorus. As analysis of the Verification Trial Results has demonstrated, sulphur does provide a response. However, quantifying this response is problematic. In any case, it is considerably less than the response to nitrogen, and is often not expressed without nitrogen also being applied. These calculated yields at each site were subjected to the economic analysis to determine which of the four possible fertilizer application levels was economically the optimum. The results of this analysis were then examined for sites aggregated by recommendation zone to determine whether any of the proposed recommendations for a zone were consistently under or over the economic optimum applications rates as determined by the trial yield results. As expected, the variability in yield response was considerably higher than when the Verification Trial sites were used. However, no corrections were necessary as the proposed recommendations consistently fell in a median position of the range of optimum application levels for the individual trials for virtually all recommendation zones.

AREA-SPECIFIC FERTILIZER RECOMMENDATIONS

The resultant recommendations for the entire country that emerged from this analysis are shown in the four maps of Figure 4. As noted, light-textured soils under both production aims have lower rates recommended than is the case for medium-textured soils in the same area. The modal recommendation if producing for home consumption is 69:21:0+4S, while 35:10:0+2S is the modal recommendation when engaged in commercial production. However, note that light-textured soils are not appropriate for producing fertilized maize for the market.

When these four maps are combined into one coverage, seven separate sets of recommendations are required to cover all areas of the country, as is shown in Figure 5. The image is quite complex when examined at the national scale. However, when the scope of examination is brought to the level of the ADD or the even smaller Rural Development Project (RDP), the pattern is considerably simplified. Of the thirty RDPs in Malawi, only nine of them have been assigned more than one set of recommendations. Moreover, when one examines these few RDPs, their complexity in recommendation pattern usually reflects an underlying agro-ecological complexity - the RDPs cover two or more ecological zones. As the recommendations will be implemented by extension officers who operate at the more local scales of the RDP and EPA, the recommendation scheme is sufficiently simple for ease of use.

Components of the Extension Message Accompanying the Recommendations

These recommendations need to have a sufficient degree of flexibility to account for a wide range of production scenarios - scenarios which may vary due to ecological factors, mixed production aims, household purchasing power considerations, general or local shifts in the fertilizer to maize price ratio from that underlying the recommendations, and other factors. Information on how the recommendations can be appropriately modified to encompass these considerations will constitute part of the extension message that goes out with the recommendations. Several of these components are noted here.

Recommendations as maximum rates of application -- The Field Assistants of the extension service should clearly understand that these recommendations are <u>maximums</u>, rather than pure, all-or-nothing recommendations. Lower rates of fertilizer than those recommended <u>will</u> provide the farmer with good returns in maize yield or income. Application rates up to the levels indicated in all but the worst years will provide the farmer with an attractive

Figure 4:
Area-specific fertilizer recommendations for hybrid maize grown by Malawian smallholders
Disaggregated by production aim of farmer and by soil texture of maize field
EPA and ADD boundaries shown.

Based on the results of the Maize Fertilizer Verification Trial, 1995-96, aggregated by Natural Region & soil texture.
Unshaded areas are non-agricultural (lakes, urban, national parks, etc.).

Recommendation (kg/ha):

No fertilizer:
35 N, 10 phosphate, 2 S (50 kg 23:21:0+4S; 50 kg urea):
69 N, 21 phosphate, 4 S (100 kg 23:21:0+4S; 100 kg urea):
92 N, 21 phosphate, 4 S (100 kg 23:21:0+4S; 150 kg urea):

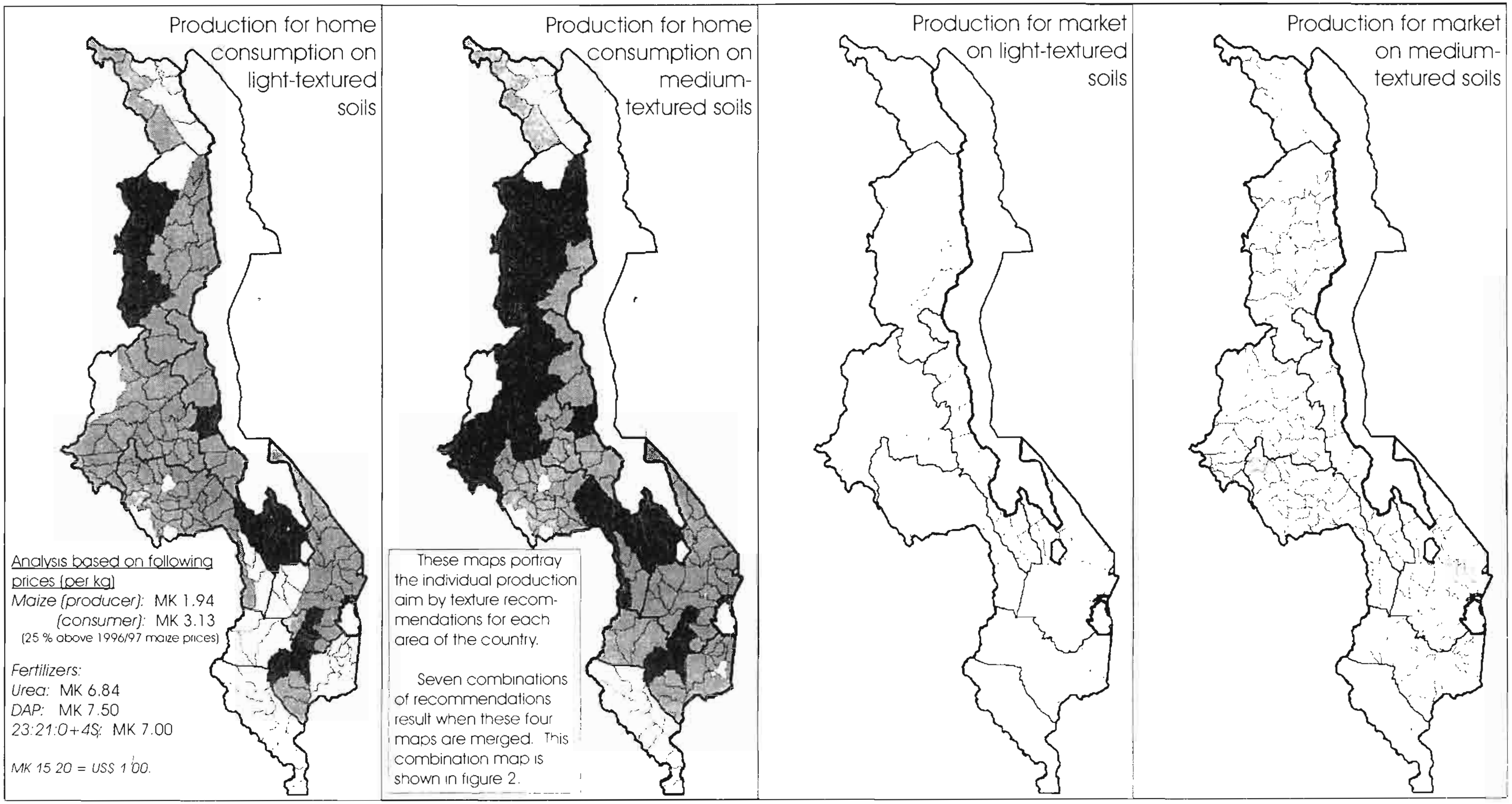
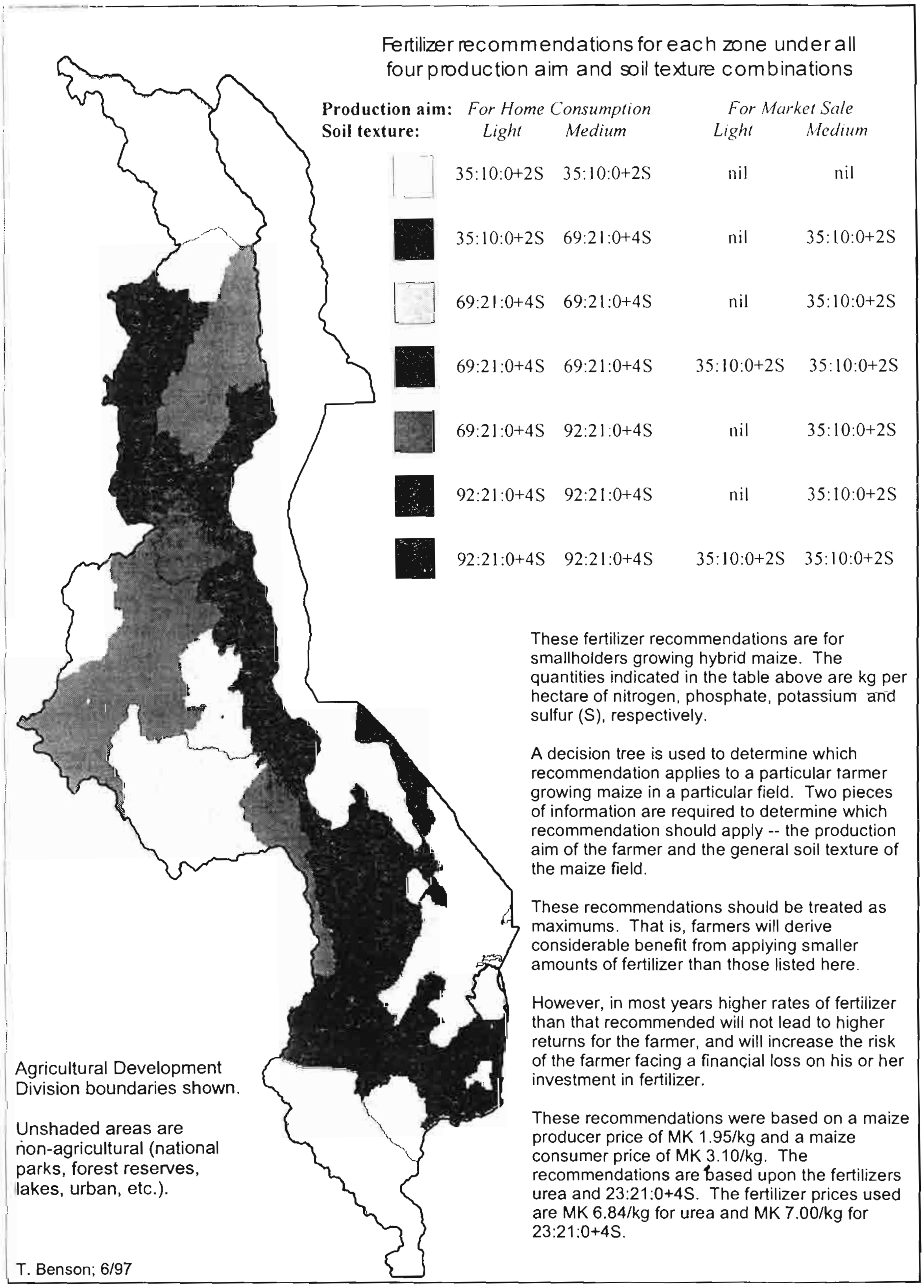


Figure 5. Hybrid maize fertilizer recommendation zones for Malawi.



return. Field Assistants should advise farmers, particularly when the farmers are producing for home consumption, that a little fertilizer is a worthwhile addition to the maize crop, even if not applied at levels near the maximums recommended.

However, higher rates of application than those indicated place the farmer at considerable risk of making a loss on the use of fertilizer, particularly when weather conditions are not favourable. In this light, the most interesting parts of the maps in Figure 4 are where lower rates of fertilizer are recommended, as these indicate where moderation in fertilizer use is the best strategy.

Micro agro-ecological variability -- As noted, a single set of recommendations was applied to each EPA. However, not all EPAs are homogeneous in their agro-ecological conditions and, hence, in the response of maize yield to fertilizer application. Modifications to the recommendations assigned to an EPA should be carried out for those areas of the EPA with different physical conditions to those underlying the recommendations. Among these areas are the EPAs in Mzuzu ADD which bridge two agro-ecological zones, Mvera EPA in Kasungu ADD that encompasses both the lakeshore plain and the highlands, and the upland areas rimming the Lower Shire Valley. The application rates recommended for comparable neighbouring areas should apply in these cases.

Mixed production aims -- Most farmers produce fertilizer maize both for market sale and for home consumption. The recommendations presented here represent the economically justifiable maximum fertilizer application rates when producing purely for one of the two aims. For production which is mixed for home consumption and market sale, some reasonable intermediate fertilizer level between the two recommendations for a particular soil texture should be used.

Use of less than the entire recommended package -- These recommendations are based upon fertilizer packages made up of urea (46% N) and 23:21:0+4S (% N:P:K+S) fertilizers. As such they provide the three most important soil nutrients for maize grown in Malawi - nitrogen, phosphorus, and sulphur. Of these three, however, nitrogen is the most important nutrient whose absence limits maize yields virtually everywhere in the country. Consequently it would be appropriate in the short term at least for the Field Assistant to recommend to farmers who cannot afford the full packages of urea and 23:21:0+4S that they simply apply urea to their maize. Although analysis is currently being undertaken to allow one to do so, at present it cannot be stated objectively what is the maximum level of nitrogen to apply for each zone. However, there are both economic and agronomic grounds to establish a rough rule of thumb of not using more nitrogen than a quarter to a third more than that indicated in the recommendation for a particular area, soil texture, and production aim. So, for example, if the recommendation is for 35:10:0+2S, the farmer could confidently apply 45 kgN/ha. If the recommendation is 92:21:0+4S, the farmer could apply up to120 kgN/ha, although this amount of nitrogen would have to be applied in two or three applications to minimize leaching losses.

However, applying nitrogen alone should be seen as a short term strategy for farmers. If the farmer applies nitrogen alone every year for an extended period, eventually sulphur and phosphorus deficiencies will begin to limit maize yields. As a rough guideline, farmers should apply 23:21:0+4S or another fertilizer containing phosphate and sulphur every two or three years if using nitrogen in other years at rates above 50 kgN/ha. If lower rates of N-application are used, it would be prudent to apply phosphate and sulphur at least once every three or four years.

Changes in the Fertilizer to Maize Price Ratio

Using urea as the source of nitrogen, the nitrogen to maize price ratios underlying the analysis is 4.8 for the consumer price and 7.7 for the producer price. Of more relevance to the extension worker and farmer is that these price ratios correspond to market situations where one can purchase either a 50 kg bag of urea or 2.2 bags of maize at the consumer price with the same amount of money, or one would have to sell 3.6 bags of maize at the producer price to purchase a bag of urea. These ratios, 2.2 and 3.6 correspond to the urea: maize price-ratio for the consumer and producer maize prices, respectively.

Price changes through space -- These recommendations assume pan-territorial prices for maize and fertilizer. While such an assumption was appropriate in the past, with agricultural market liberalization prices now vary from place to place to reflect marketing and transport costs. Including in the analysis price variation across space would have made the exercise extremely complex and any results tenuous. However, if farmers and extension staff are aware of the fertilizer to maize price ratios upon which these recommendations are based, they can make appropriate modifications to them to adapt them to the local price structure. If the expected price ratios that the farmer will face following the harvest will be significantly higher than the 2.2 or 3.6 ratios noted above, lower rates of fertilizer should be applied than is indicated in the recommendations. However, if the locally prevalent price ratios are lower than those used to develop the recommendations, higher rates can be used. In all probability, under normal to good rainfall conditions most rural areas of the country will face conditions of higher price ratios simply because it is expected that fertilizer costs will be somewhat greater given higher transport costs in rural districts and maize prices somewhat lower due to insufficient demand. However, in peri-urban and tobacco farming areas lower price ratios may prevail.

Price changes through time -- Just as fertilizer to maize price ratios are not constant across the country, so they should not be expected to be constant through time. The price ratio used in the analysis is not the one that currently prevails in July 1997 in

Malawi. It is anticipated that prices soon will approximate those underlying the analysis, but there is no guarantee that will happen. Moreover, even if those prices are realized, they will not stay there. For the recommendations to be very useful under a dynamic economic environment, information should be provided to the users on how the recommendations should be modified to reflect changed prices. Essentially the same modifications as noted in the paragraph immediately above should apply -- higher price-ratios call for lower fertilizer application rates, while lower price-ratios allow farmers to confidently apply more fertilizer than that recommended.

In this regard, given the variability in input and output prices in recent years, at what price-ratios will these recommendations no longer be valid? Sensitivity analyses indicate that overall these recommendations will still be appropriate with price-ratios up to 25 percent higher. They are quite insensitive to higher price-ratios. However, individual recommendations within certain zones, particularly those with relatively high recommendations under the production for home consumption aim, may require some downward adjustment in recommendations with smaller upward shifts in the price-ratio.

On the other hand, if lower price-ratios result from higher than expected maize prices or sharp drops in fertilizer prices, the recommendations for production for market sale will have to be revised upwards once the fertilizer to maize producer price-ratio drops by about 15 percent from the ratio underlying the analysis. The recommendations are quite sensitive to lower price-ratios. In most cases, this will simply involve raising the already low application rates to the next higher rate. One would expect that similar upward modifications would be required with the recommendations for home consumption. Since medium-textured soils in many areas of the country under this production aim already have assigned the highest rate evaluated, under the discrete economic analysis used here no assessment can be made of the recommendations applicable under lower price-ratios . If a continuous economic analysis is undertaken using estimated fertilizer response functions generated from the data, through extrapolation estimates could be made of higher optimal application levels than those levels evaluated in the trial.

Several other guidelines could be offered on how the area-specific fertilizer recommendations should be modified to make them more appropriate for particular economic situations of farming households and particular bio-physical condition of individual maize fields. As such, the recommendations should be seen as a starting point to the development of a fertilization strategy for an individual farmer. Building such flexibility into the recommendations constitutes a radical departure from the expectations underlying the blanket fertilizer recommendation of past years. Using simple information and guidelines on how fertilizer application rates should change with changing cropping and, most importantly, economic conditions, farmers are much more likely to find fertilizer use on their maize profitable.

POLICY CONSIDERATIONS

Fertilizer use on hybrid maize has been shown to be a worthwhile undertaking if the aim of production is to assure household consumption needs. However, production of fertilized maize for the market is a marginally viable economic activity. As is shown in the two maps at the right in Figure 4, profitable production of maize for the market only occurs on medium-textured soils at the lowest rate of fertilizer application. Moreover, acquiring the necessary capital to buy fertilizer and hybrid seed is problematic. In 1996/97, MRFC was unwilling in most circumstances to lend to maize producers who did not also produce a cash crop. When one considers the other economic activities in which the Malawian farmer could engage, particularly burley tobacco production, commercial maize production has few attractions for farmers.

At the scale of the farming household which is generally maize sufficient, such a situation poses no real threat. They will continue to produce maize to feed themselves. However, it is worth repeating an important caveat to the use of the recommendations for home production. That is that the fertilizer used on maize being grown for home consumption must be bought using the cash resources that the household has at its disposal, rather than with credit. Given that the rural cash economy of Malawi is not very vibrant, the proportion of the farming population that has readily available cash reserves to be able to apply the maximum rates of fertilizer for home consumption is certainly small. Nevertheless, most households who can afford to buy some fertilizer for application to their subsistence maize crop will find considerable benefit from whatever amounts they apply to their maize.

However, at the scale of the nation, that producing maize in quantities beyond the farming household's requirements is not worthwhile has serious implications for Malawi's overall food security. Many of the population of Malawi have to go to the market to purchase a portion of their staple food requirements. Besides the urban households, additionally somewhere between forty and sixty percent of rural households have to go to the market at some point during the year to buy their staple food. If there is no economic incentive for farmers to engage in commercial production of fertilized maize in Malawi, where will the necessary marketed maize surplus come from to feed these maize deficit households?

Maize is the staple food for most Malawians. National maize production currently only meets national requirements in those years with adequate and well-distributed rains. National maize yields will not keep up with the needs of Malawi's growing population without sustained increases in the use of fertilizer on maize, particularly on hybrid maize. An earlier report of Action Group I suggested that the fertilizer to producer maize price-ratio would have to come down by a third from the ratio prevailing in 1996/97 - and down by over 15 percent from the price ratio used in the analysis presented here - if the levels of commercial production of maize are to be sufficient to adequately meet the maize requirements of the population of Malawi (Action Group I 1997, 19). However reducing the price ratio necessarily will mean increases in maize prices for Malawi's poor, price rises which they likely cannot bear without considerable suffering. If this suffering is translated into political action, Malawi will quickly find itself in a state of economic and political crisis. Without the reintroduction of subsidized fertilizer or targeted maize price supports - retrogressive steps in the eyes of most agricultural policy analysts and, what is more important, in the eyes of most international donors supporting Malawi - equitable policy solutions to this potential food crisis are difficult to conceive.

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DISCUSSION: DELIVERY OF SOIL FERTILITY TECHNOLOGY

Question to David Rohrbach

From: Herbert Murwira
How do you explain why 40% of farmers in high rainfall areas who own cattle are not using their manure for improving soil fertility?

What would be the opportunity cost of labour for using manure in depleted lands?

Response:
We are not sure why so many farmers with cattle do not use the manure. We hypothesize that these farmers face a transport constraint in moving manure to their fields and the costs of hiring transport are too high. This implies also that they do not see a large yield response to manure.

The opportunity cost of labour most strictly could equal the rural wage rate.

Comments on: Best Bets

From: Robert Gilbert
Regarding impact of our technology, a table in the best bets paper shows for Malawi the potential number of farmers adopting grain legume intercrops at 1,000,000, with low soil fertility benefit. At the same time legumes with a high soil fertility benefit might interest at most 100,000 farmers. It is clear that farmers' interests lie in food security rather than soil fertility. However if maize +pigeon pea intercrops were adequate for soil fertility replenishment alone, we would not have the declining maize yields we have been experiencing.

There is a great need to compare different "best bet" technologies on-farm to get both farmer evaluation and quantification of the economic benefit. Then policy makers could be informed of consequences of their decisions on fertilizer subsidy, seed supply, etc. on long-term soil fertility issues. This would address some of the major concerns expressed at this meeting.

From: Cheryl Palm
The options suggested are basically what some good farmers are doing. The question then becomes how to get more farmers to do it? What is keeping them from doing it? We need to address seed supply and credit to farmers in the research agenda.

Questions to Joseph Mureithi

From: Cheryl Palm
You are using compost. Are you recording what goes into making the compost and what is the quality of the resulting compost?

Response:
We have collected samples but they are not yet analysed.

From: Luke Mugwira
How is farmyard manure managed in Kenya?

Response:
It used to be allowed to drain into pits but now it is composted with other materials that are locally available.

Questions to Benard Kamanga

Comments from: Roland Buresh
A very important consideration in agroforestry as shown in Bernard's presentation is the recognition of the value of products from agroforestry, such as sesbania wood.

To be economic, agroforestry systems will likely need to provide frequent benefits in addition to soil fertility improvement. The realistic valuation of these benefits is critical.

From: Todd Benson
You used a fertilized maize scenario of 120kg N per ha. What would the economic evaluation have looked like for sesbania vs. fertilized maize if less nutrient had been used, say 35 - 45 kg N per ha?

Response:
Definitely we would have different economic explanations to such a situation. The analysis was dependent on the N given. In this case 35 - 45 kg N would have a lower cost and could have shown more or less the same value with those of sesbania. We will need to look at these lower rates of N.

Questions to Suzgo Kumwenda

From: Batson Zambezi
During a recent visit to Malawi my colleague and I had an opportunity to visit two smallholder seed producers. They expressed concern about marketing of the seed after harvest. How soon will the Task Force establish processing and marketing of the seed?

Response:
This will be set up by the 1997/98 season. If the marketing problem is not sorted out the seed multiplication program will be futile.

From: Melvyn Piha
In a 'true' free market economy Malawians are supposed to die of starvation when they do not produce enough food. Apparently someone comes to their aid with food. Why cannot these people support farmers with fertilizer instead of giving food?

Response:
We are not talking of a 'true' free market. Policy reforms have been made but not on everything. A subsidy is part of that answer. What is important in the context of soil fertility is a challenge to scientists to come up with technologies that can benefit the farmers. We need to develop affordable technologies for farmers. The point is that even when subsidies were around what was the uptake of improved technologies by farmers? My experience is that they were often very low and food insecurity widespread.

From: Alfred Mapiki
The fertilizer recommendations for maize in Malawi should also look at other nutrients (secondary, micronutrients) and this could be achieved by soil tests and trials looking at the major limiting nutrient for a specific region. Also, fertilizer research for maize is extensively studied. It is more worthwhile to pay attention to crop diversification.

Response:
Crop diversification is central to the attainment of food security. The problem is addressed through the seed multiplication program under the Task Force.

Questions to Ishmael Pompi

From: Luke Mugwira
I have noticed miserable soybean crops in many fields in the communal areas of Zimbabwe, mostly on sandy soils. What do you think is the major constraint to soybean there?

Response:
From our experience it is likely to be soil pH. We had poorer yields from soils with pH 4.1 to 4.5 than from farms with soils of pH 5.0.

From: Danisile Hikwa
In your tests, you did not have fertilizer or rhizobia on their own. Instead these were combined. It is important to quantify the contribution of fertilizer vs. that of rhizobium inoculation to the yield increase in soybeans. The premise being that if rhizobia performs as well as fertilizer on its own, the farmers are most likely to go for the cheaper option, which is rhizobium. Do you intend to separate these options to support the subsequent extension messages?

Response:
There is a research component working on these, side-by-side with extension. Two MPhil students are working on the issues you raise.

Questions to Todd Benson

From: Robert Gilbert
Please comment on the lessons you learned from mounting a 1900-site trial for the Task Force? More specifically, as the Soil Fert Net moves towards the extension phase with its technologies, what are the challenges and opportunities of large-scale trials?

Response:
The planning, monitoring, and financial considerations of a nationwide trial are considerable, and clearly will limit the option to certain superior, simple, closely-defined technology packages. The design of the trial must be at a verification or demonstration stage and not basic research stage. Moreover, field days and farmer involvement are critical to success from the extension standpoint. I would add that the scale of the effort does not have to be nationwide. Communal-area-specific trial or demonstration programs are also of equal value. Of most importance is that you consider closely the message(s) you are interested in farmers taking away from the trial or demonstration.

From: Antony van de Loo
Is it clear how many farmers buy their maize for consumption from their neighbours, for a significantly lower price than the consumer price for maize, rather than in a shop?

If a majority of farmers do buy their maize for consumption from their neighbours, would this then mean that fertilizer recommendations should be lowered for maize grown for home consumption.

Response:
The end of the paper discussed how different maize prices would affect the recommendations. A relevant fertilizer to maize price-ratio could be calculated based on the neighbours' prices. Using that, appropriate adjustments would be made to the base recommendation. It is likely that the neighbours' price would be lower than the market consumer price. Consequently, the recommendations would be lower than the base recommendations made in the paper.

From: Moses Mwale
No potassium is recommended. Is it because the levels of K are high in Malawian soils? If so, can you please give us an idea of the levels?

Response:
The only areas in which K responses have been seen in maize in Malawi to date have been in high rainfall, intensively cropped areas. The soil parent material in Malawi tends to be richer in K than is the case for Zambia and Zimbabwe. However, monitoring of response to K must be done. At some point K responses may become apparent as soils continue to be mono-cropped year after year.

GENERAL DISCUSSION ON TECHNOLOGY DELIVERY

Comment from: Danisile Hikwa
The Malawians are doing a commendable job in developing and transferring fertilizer recommendations to the farmers. However, unless research and extension can influence fertilizer composition, the farmers will still be limited to what the fertilizer companies want to produce. Mechanisms should be put in place to ensure that the fertilizer companies respond to the needs of farmers.

Comment from: Monica Murata
For research to have significant impact it should be demand-driven. Let the farmers articulate their problems and then the researchers conduct work to come up with solutions to the farmers' problems.

Comment from: Danisile Hikwa
Do smallholder seed producers have to forego food production to meet the requirements of distances that minimize cross pollination especially since land holdings are less than 1ha per household? Seed production by smallholders is something that the NARS in Zimbabwe are currently debating. The Malawian experience is something we would like to draw on.

Question to the meeting from: Stephen Waddington
Based on the presentations on soil fertility in semi-arid zones, should Soil Fert Net be doing more work in semi-arid zones of Zimbabwe in cooperation with other institutions (such as ICRISAT)?
Should we be recommending to the Rockefeller Foundation to consider financing more work in semi-arid zones?

Comment from: Athanasius Mphuru
The semi-arid areas have not received top priority because very few people (researchers, extension officers, farmers, etc.) are prepared to take any risks. Because of uncertainty of rainfall, government tends to invest less in such areas.

Comment from: Ishmael Pompi
The AGRITEX contribution is limited by lack of resources to travel. The manpower is there. Arid areas are our target areas.

Comment from: Melvyn Piha
Soil Fert Net should definitely work in the drier areas, that is where most of the people are. In practice, our research group is Harare-based and the drier areas are a long distance from Harare.

Comment from: Herbert Dhliwayo
Soil fertility management is part of efforts such as:
- soil conservation, e.g. reduced tillage
- weed management, e.g. weeding frequency, weed control methods.

There is need for Soil Fert Net to consider collaborative work with organizations working in NRs III, IV and V e.g. Matopos/ICRISAT, DR & SS/Agronomy Institute, Chiredzi, AGRITEX/CONTILL.

General discussion from: David Rohrbach
What would be the impact of making research funding dependent on adoption patterns? Our experience suggests that such conditioning stimulates scientists to work with others (extension, input suppliers, etc) to resolve adoption constraints.

What would be the impact of asking farmers what questions they want resolved rather than simply offering demonstrations and asking for comment?

The periodic review of extension recommendations for the application of chemical fertilizer application may have a high payoff, particularly in circumstances of large changes in input:product price ratios. However, the review should also consider the practicality of these recommendations and adoption rates. Farmers may be less concerned about optimal rates of application and more concerned about targeting limited quantities of fertilizer in combination with manure (in Zimbabwe) or green manures or tree intercrops (in Malawi).

Comment from: Antony van de Loo
In relation to the discussion about the weak presence of AGRITEX related to available resources. This is the classical situation of most large-scale extension services in Africa. I believe it is not realistic to expect more resources from Government in the future. AGRITEX will have to experiment with cheaper models of extension, probably putting more emphasis on farmer participation in the knowledge and skill transfer process.

Comment from: George Kanyama-Phiri
The PAPPA demonstration plots of a pigeonpea and maize intercrop in Malawi, where the legume is planted in the furrow, is indeed a good example of how researchers run away from the farmers. We had a similar experience in Zomba where pigeonpea was planted in the furrow. The legume was choked by water collecting in the furrow, growth was retarded and farmers rejected the technology.

From: Ken Giller
To what extent should we as researchers try to influence policy to improve access to nutrients and other inputs?

Comment from: Antony van de Loo
Try to stimulate farmers to "change" the on-farm trial rather than instruct them how to treat the on-farm trial in detail so that it is executed according to the "protocol".

From : John Barnes
1. Groundnuts are not an effective crop rotation with maize on degraded granite sands, as virtually no nitrogen is fixed.

2. Pigeonpea intercropped with maize is a successful and important food security strategy in semi-arid eastern Kenya. Why not in Zimbabwe?

From: Ishmael Pompi
What do researchers have to offer for verification or demonstrations for extension?

How much are we considering indigenous knowledge in research and extension?

Can researchers carry out a diagnostic survey, rank farmer constraints and use them as a guideline for research priority setting and programmes to raise interest by farmers and extension in the results?

Comment from: Todd Benson
In transferring technologies to farmers, a critical aspect of my demonstration trials is the economic aspect. This can be incorporated into the trial or demonstration design. In Malawi, farmers have expressed considerable interest in evaluating the technologies demonstrated on an economic basis. Basic gross margin worksheets can be used at the harvest of the trial or demonstrations.

The information content of the trial or demonstrations should be examined to consider how much farmers will take away from it. Will the information they gain be of any use to them as they make crop management decisions later?

Comment from: Suzgo Kumwenda
Traditional knowledge is very important. The biggest challenge is therefore how to make these traditional practices as novel as possible so that farmers get excited about them. We need to think seriously about how to translate the information. How to practice it. That is a big challenge.

SOIL FERTILITY NETWORK ASSESSMENT PANEL REPORT

LARRY HARRINGTON, ROLAND BURESH and SUZGO KUMWENDA

Overall Comment

The Soil Fertility Network is an excellent forum for focusing research toward the needs of farmers, thus helping ensure relevance in research and in technology assessment. We commend the Network for its achievements in bringing together researchers. The sincerity and commitment of Network participants is very evident as they work together to identify, develop and promote relevant options for small-scale farmers.

The Network is evolving toward greater collaboration with farmers, and towards more systematic economic analysis (as well as farmer assessment) of experimental results. It appears, however, that the Network is not well represented by participants with disciplinary expertise in social science, or in farming systems or on-farm research.

Strengthening Practical Work with Farmers

The activities of the Network must continue to emphasize the development of practical technology options for resource-poor, small-scale farmers. Steps in the right direction include:

- diagnostic surveys to help guide subsequent research (by helping define problems and their causes);
- farmer consultations to uncover farmer-developed technologies that may have wider application;
- participatory experimentation with farmers to facilitate adaptation of prototype practices to defined farming systems;
- farmer panels and farmer-managed experiments for technology assessment; and
- the systematic use of economic analysis as a "reality check" with respect to the likely costs and benefits (including capital costs) of technical change.

We recommend that the steps listed above be continued and strengthened. More specifically, we suggest the following:

Recognize farmers' goals, especially income generation -- As a rule, farmers will find most attractive those technologies that produce near-term benefits as well as longer-term improvements in the resource base. Farmers often have several alternative uses for their limited labour and cash resources apart from investing them in soil management practices. It also is important to recognize that researchers and farmers may face a moving target. Market forces may influence the economic attractiveness of technologies, and practices that today are economically attractive may not be so tomorrow.

Give greater attention to farmers' practices and knowledge -- Researchers can benefit from the very considerable knowledge that farmers have relative to crops, production systems, soils, farmyard manure and green manures. We recommend greater utilization of farmers' knowledge in research design, implementation and assessment, including: problem definition, the search for possible solutions to important problems, the identification of potential best-bet technologies, the adaptation of prototype technologies to the circumstances of target areas, and technology assessment. We encourage diagnostic surveys or rapid appraisals as an important first step in the initiation of research programs. Indigenous knowledge on rotations, crop management and farmyard manure should be captured and utilized in the design of treatments and potential best-bet technologies. Farmers' rankings of farmyard manure quality, for example, should be correlated with chemical analyses of the manures. Such information should then be utilized in the design of research and identification of potential best-bet technologies for testing.

Conduct both farmer-managed and researcher-managed research -- The movement of research from research stations to farmers' fields is commendable. We suggest that, as much as possible, researcher-managed experiments be conducted in farmers' fields. This is especially true for experiments dealing with crop or system management, including intercrops and rotations.

We recommend that research programs feature, simultaneously, farmer-managed trials and researcher-managed trials. Researchers should not wait for a technology to be "perfect" before launching farmer-managed trials. We recommend taking advantage of existing knowledge on prototype technologies to go direct to farmer-managed trials in defined environments. Give farmers the opportunity to "experiment" with technologies and learn from them. We encourage researchers to link with extension workers in the research process.

Don't forget economic analysis -- We recommend that experimental programs be designed to enable the collection of information required for conducting economic analysis. This is most important for those experiments that aim to assess the attractiveness of new technologies for specific farmer groupings in defined environments. For these experiments, economic analysis should be conducted, with sensible estimates for labour inputs, transport and handling costs for products and inputs, and cost of capital, as well as for the direct costs of purchased inputs.

Formal quantitative economic analysis should be complemented by technology assessment by farmer panels, particularly when important inputs or products are difficult to value in monetary terms.

Obtain information on the policy environment -- The policy environment determines the "economic space" available for technical change. Policies that influence input and product pricing are supremely important in determining which technologies are profitable and which are not. Researchers should take an interest in policy and monitor changes in the policy environment that may affect the attractiveness to farmers of important technical options. In some instances, research findings can help inform the policy debate at the local, regional and even national levels. This possibility should not be overlooked.

Improve disciplinary coverage in Network activities -- Whereas the Network has members with considerable disciplinary expertise in soil science, agronomy and the biological sciences, it has few members with expertise in social science and on-farm research. Greater disciplinary strength is needed in these areas. This can be obtained from either (i) new members joining the Network, (ii) training of existing members and (iii) the formation of alliances with organizations, networks or scientists with the required disciplinary expertise.

Basic skills in the conduct of economic analysis (for example, partial budgeting) can be readily obtained by Network members from existing manuals and training of only one or two days. The conduct of more detailed analyses, such as the costing of labour, may require inputs from experts outside the existing Network.

We recommend the strengthening of Network links with extension, and the development of a partnership with extension workers as part of the research process with farmers. We further recommend that some funds within the Network be earmarked for encouraging and supporting work in areas with weak disciplinary coverage.

Selecting Best-Bet Technologies

In order to have relevant technologies for farmers, it is essential to understand (i) what constitutes a best-bet technology and (ii) where and to whom the technology should be targeted. We encourage periodic examination of Network results in order to identify best-bet technologies for specific target environments.

Focus on best-bet options -- Farmer production goals and resource endowments (as well as soil, rainfall and risk) can vary within short distances. Therefore, a "basket" of options should be encouraged within a targeted environment. Best-bet technologies should feature the basics of good agronomy in the seasonally wet-dry environments, e.g., early planting, utilization of soil N flush and effective weed management.

What, however, is meant by a "best-bet" technology? We suggest that such a technology have large potential positive benefits to farmers, that it offers something "new" to farmers, and that it be targeted to a defined area, environment, or category of farmers.

Determine potential impacts of options -- Potential impacts can be estimated from numbers of farmers or area likely to be affected; the per ha (or per farmer) improvement in near-term maize system productivity; and the expected time path of adoption. Where possible, analysis also should include longer-term productivity and sustainability consequences, e.g., changes in the productive capacity of the resource base from resource degradation or rehabilitation. Eventually, important off-site consequences of technical change also should be considered.

Target technologies to specific environments -- A given technology is not likely to work equally well in all locations. Technology targeting requires an understanding of the soil and climatic conditions suitable for the technology, and of the relevant characteristics of target farmers (for example, resource endowment). We recommend clearly defined criteria for targeting specific species, and crop and system management practices, to areas, environments, or farmer groups.

Develop and use shared databases and decision support systems -- We recommend the development of a shared database available to all Soil Fertility Network participants, featuring available geo-referenced climate, soils, crop distribution, system distribution, trial locations, and political boundaries. Later versions could also include major trial results. In principle, such a database could be distributed to all Soil Fertility Network scientists on regular intervals by mailing each member a single compact disk. These data should be used in research design, analysis, synthesis and assessment.

Link management and advanced germplasm -- We recommend that advanced germplasm, identified from other Networks and by other researchers, be considered for inclusion in research. Germplasm x management interactions can be assessed, and information useful to breeders can be forwarded.

Ensure that a technology has something new to offer farmers -- "Newness" refers to an improvement in the farmers' practice. Dimensions of "newness" include (i) species, (ii) varieties, (iii) geographic distribution, (iv) cropping system management (including improvements in farmers' own practices). Enthusiasm of the researchers/extension workers with a technology option is important to the generation of interest and enthusiasm on the part of farmers.

Assessing Alternatives

Learn from failures -- We encourage greater emphasis on examining and identifying factors leading to failures of species or technologies in specific experiments. For example, determine whether poor or no growth of a species is due to seed rate, seed quality, date of planting, waterlogging, poor establishment, weed competition, pests or diseases. Such information can be very helpful in refining future research and in delineating target environments for technologies.

Assess performance under unfavourable conditions of drought and risk -- A management practice that performs well under good conditions may cause farmers large economic losses in a bad season, e.g., too little or too much moisture. Researchers should check - through trials, farmer assessment, and/or modelling - the performance of technologies under unfavourable conditions.

Screen new organic options -- A focus on best-bet options does not preclude the continued screening of new organic-based options with potential to be useful.

Engage in practical work with farmers -- The suggestions in the first section on practical work with farmers are clearly relevant to issues of assessing technical alternatives.

Disseminating and Using Technologies

Disseminate relevant information -- Target groups for dissemination of information include extension, policy makers, farmers as well as the scientific community. Targeting farmer organizations, which are already popular in Zimbabwe and are being promoted in Malawi, can optimise the use of such information. We recommend greater emphasis and effort on packaging information for use by farmers and extension workers. Possible options include leaflets and simple decision trees.

Mainstream activities from the Network -- A useful question to remember is, "What happens after the Soil Fertility Network is phased out?" The benefits from the Network will be most durable and useful to the participating countries if they are mainstreamed into National Programmes.

We recommend that the testing of a few of the "best bet options" be absorbed by the National Programmes. The cost of this testing might be shared by the Extension and Research Departments, either through a task force activity or through farmer managed trials. This could be one way to sustain Network outputs, so that the effort of generating so much information through Network activities continues to be useful even after the Network as such is phased out.

Accelerate adoption of best-bet technologies -- Farmer managed trials, technology assessment by farmer panels, farmer field days, task forces, etc., are all tools to help accelerate technology adoption. The Network has reached a stage when "best bet" technologies are being identified. The "task force" approach, such as that used for soybean in Zimbabwe and maize in Malawi, can be used for best-bet practices for other commodities. We recommend that the Network pick out a few such technologies and use these approaches which have the potential to reach many more farmers, and help accelerate adoption.

Training -- We recommend refresher training for subject matter specialists to assist in getting relevant information to front-line field staff.

Improving the Quality of Research Implementation

Obtain and use relevant research results and methods from outside the Network -- We commend the efforts of the Network in commissioning bibliographies on key topics, in preparing working papers and in preparing workshop proceedings. We note that recent research findings from outside the Network have not been utilized in Network research. We recommend improved Network member access to relevant outside information. Examples include (i) the work in West Africa on the role of integrating organic materials with inorganic fertilizers in yield stabilization and (ii) soil fertility management and the effects of manures on soil fertility in semi-arid regions of Australia.

Relevant research results and methods from outside the Network do not necessarily have to come from outside the region. Network scientists should also take advantage of best-bet options emerging from National Programs in participating countries. These can be tested alongside Network best-bet practices in Network trials. Understandably, this requires an even closer collaboration between Network and non-Network National Program research activities, building on the close collaboration that already exists.

Use clearly defined hypotheses to guide the selection of research sites -- Before initiating Network trials, hypotheses should be formulated on the key factors (for example, soil pH, soil texture and rainfall) affecting the performance of treatments. The experimental sites should then be selected to represent either a contrasting level of the factor, or a range of the factor. The selection of sites with an appropriate representation or distribution of the factor is essential to enable suitable data analysis (for example, correlation or regression analysis) to identify likely target areas for a technology.

Characterize research sites before initiating experimentation -- We recommend soil analyses before starting experiments to ensure suitability of a site for research (for example, a site for testing the performance of P sources must have suitable soil P levels). As a rule, researcher-managed field trials should not be initiated before completion of a basic set of soil analyses for the experimental site.

We encourage common methods for soil characterization, using standardized analytical techniques to ensure that soil properties can guide technology dissemination and targeting. This may require conducting soil analyses for all sites in the Network trial at one laboratory, followed by subsequent cross calibration among laboratories.

Include realistic controls of either farmers' practices or recommended management -- We encourage the inclusion of treatments with the farmers' practice and recommended practices in experiments as "controls" against which other treatments can be compared. The rates of nutrient inputs in these "controls" should be at economic realistic levels. This is particularly important for trials that aim to assess the attractiveness of different practices.

We encourage a meeting of a small group of Network scientists before the start of a cropping season with the objective of discussing experimental protocols and addressing concerns on the appropriateness of experimental designs and "control" treatments of farmers' practices and recommended practices.

Maintain disciplinary excellence and collaborate in multidisciplinary teams -- With the increasing Network emphasis on economic analysis and participatory research, Network participants trained in the biophysical sciences may increasingly recognize their lack of expertise in the social sciences. Biophysical scientists must become familiar with the basic principles of simple economic analysis and of working with farmers, but they must also maintain disciplinary excellence in their areas of expertise by staying up-to-date with recent research findings and methodologies in their discipline, and by appropriate dissemination of their research findings. Biophysical scientists will need to increasingly collaborate in teams with social scientists in order to ensure essential expertise outside their discipline.

Utilize field visits for information exchange, maintaining scientific rigour and refining research hypotheses -- The importance of field visits in exchanging information, examining research activities and refining research hypotheses and approaches was highlighted by several participants. We recommend the continuation of field visits by participants of the Network.

Balance nutrient inputs in trials with organic and inorganic inputs -- When comparing the soil fertility benefits of organic materials relative to inorganic sources (or combinations of inorganic and organic sources), it is essential to recognize that organic materials supply a number of nutrients which can influence plant growth. Experiments designed with the objective of comparing the nutrient supply from organics and inorganics or their combinations should either (i) include treatments with inorganic fertilizers added at the same total rate of N, P, K and S as in the treatments with organic materials or (ii) examine only one nutrient at similar rates between organic and inorganic treatments and add a blanket application of a sufficient amount of other nutrients to ensure that they are non-limiting in both organic and inorganic treatments. To add organic materials at comparable nutrient rates as inorganic sources, it is essential to analyze the organic materials beforehand for total nutrient content.

Addressing Other Issues

Revisit the governance of Network activities, and Network links to NARS -- In fact, it might be appropriate for all Network activities to be peer reviewed by national scientists. The Departments of Research of both countries, Zimbabwe and Malawi, should be acquainted with Network activities. This has the advantage of fostering the mainstreaming of research results once the Network phases out. We recommend therefore that Departments of Research should have part ownership of the activities of the Network. After all the Network is using the same critical mass of scientists who are involved in other Departmental Work.

Improve clarity in problem definition -- In a few of the presentations, the major problem of concern was not clearly expressed. Sometimes, research appeared to focus on soil degradation and possibilities for reversing it. At other times, research appeared to emphasize the management of soils with inherently low fertility - with no suggestion that degradation as such was an issue. Note that intervention strategies might well differ in the two situations. In those instances where degradation was thought to be important, a clear understanding of the underlying processes was not always evident. Has depletion of soil fertility led to declines in maize system productivity? If so, through what means? If soil fertility is declining, is this a result of reduced levels of soil organic matter or does it stem from other processes, e.g., greater soil acidity and nutrient imbalances, resulting from intensive cropping and expanded use of inorganic fertilizers? What are the processes at work, and where are these processes important?

Take fuller account of the possible beneficial effects of organics -- Much of the research that was presented focused on the benefits of organics as substitutes for macronutrients. The Network trial on farmyard manure, for example, focused on the N benefit from farmyard manures. Such approaches will miss other potential benefits (for example, soil buffering, added micronutrients, improved soil physical properties, and increased soil biological activities).

Identify potential niches for legumes -- It is important to identify the potential niches for fitting legumes into cropping systems (relay, intercropping, rotation) and farms (boundaries, abandoned lands, fields) and then assess the relative importance of each by target environment. It would also be helpful for the assessment of the potential of legume technologies to assess the potential production and impact of legumes if available niches were fully utilized.

Reassessing Research Foundations

We are pleased to see that research on soil fertility in the region in recent years has shifted from a sole emphasis on inorganic fertilizers to include an examination of organic inputs/options and integrated use of organics and inorganics. We believe that it is now appropriate to realistically examine the likely roles and importance of inorganic and organic nutrient sources for maize production in the short to medium term in the Network target areas.

Continue with a foundation based on use of inorganic fertilizers -- Inorganic fertilizers undoubtedly will be essential to maintain and increase crop production in Malawi and the communal areas of Zimbabwe. A high priority, therefore, is maximizing the payoffs from inorganic fertilizers through site-specific management.

We recommend pushing ahead with the development and dissemination of risk-sensitive inorganic fertilizer management packages in Zimbabwe and improved inorganic fertilizer recommendations in Malawi.

Supplement and enhance inorganic fertilizers with organic-based systems -- The production of organic inputs and their potential in soil fertility maintenance and improvement will undoubtedly vary among areas covered by the Network. Because of the variability in (i) production of organic materials, (ii) competing uses for organic materials, (iii) crop production objectives of farmers and (iv) availability of inorganic fertilizers, a "basket" of options will likely be required for targeted environments.

We recommend that high priority be given to the evaluation of organic-based systems that provide income in addition to a soil fertility benefit. We particularly recommend moving forward with "promiscuous" soybean in the communal areas of Zimbabwe and maize-pigeonpea intercropping in Malawi. We encourage the testing of soybean in Malawi and the continued testing of maize-sesbania systems (intercrop and rotation) in Malawi. A condition for any swift "move forward" of course, is positive appraisal of these practices by farmer panels, and a reasonably positive economic analysis.

Uncertainties remain on the potential production of biomass of organic materials in available niches outside fields (boundaries and abandoned lands) and in fields (intercropped and in rotation). Therefore, the potential of organic materials relative to inorganic fertilizers for soil fertility maintenance and replenishment appears to be unclear. We encourage ex ante analyses on the (i) potential production and availability of organic materials for application to soils, the (ii) potential inorganic fertilizer equivalency of the available organic materials, and iii) the likely economic benefits to farmers in the context of current farming systems.

Improve researchers' understanding of benefits from organic-based systems -- Much of the research on organic-based systems (e.g., legumes and manures) has focused on the N and P contributions of organic materials. Organic-based systems, however, might have many other benefits such as (i) income generation (e.g., seed, fodder, wood), (ii) weed control, (iii) soil buffering and supply of micronutrients and (iv) breaking pest and disease cycles present with monoculture maize.

We recommend research on the identification, quantification and development of predictive ability of benefits from organics in addition to sources of N and P. We propose the following working hypothesis: "In order to be attractive to farmers, organic-based systems must provide a benefit(s) other than solely substitution of N and P fertilizer." Research to test this hypothesis should be conducted for several years after application of organic materials in order to identify and quantify both the short and longer-term effects.

Conduct multilocational trials with best-bet technologies -- We recommend the testing of best-bet technologies relative to "controls" of farmers' practices and realistic recommendations of inorganic fertilizers. The proposed research should provide evidence that site selection is based on knowledge of either (i) the representativeness of the site to a target area or (ii) characteristics of the site (e.g., soil properties) that enable the testing of hypotheses on the conditions under which technologies will work. Sites selection should not be based simply on the geographic location of the researchers. Some multilocational trials should be used as springboards for farmer assessment of the technologies.

We recommend in Malawi that the most promising agroforestry technologies with maize and sesbania be compared with the best-bet maize-pigeonpea system.

Way Forward for Soil Fert Net

- The Network has made a noteworthy contribution in bringing researchers together in a professional, sincere, and productive forum. We commend the Network and its Coordinator and strongly recommend continued support for the Network.
- Funding of activities in the Network should be contingent on likelihood of impact with farmers. Need to identify what will have impact. Move forward with a few best bets.
- Move away from agronomic research in research stations toward relevant research-managed trials in farmers' fields and increased participatory research with farmers.
- Strengthen links with extension in the research process and place greater emphasis on dissemination of information to extension workers and farmers.
- Funds within the Network could be earmarked for encouraging and supporting work in areas with weak disciplinary coverage.

PLANNING GROUP 1: REHABILITATION STRATEGY FOR DEPLETED FIELDS

From FANUEL TAGWIRA

Land availability has declined in both Zimbabwe and Malawi in the last few years. This has been mainly the result of human population increase. To meet increasing food demand requires that we increase production on the land already under cultivation rather than put more marginal land into production. Improving the fertility of the lands already unable to sustain crop production is the solution for sustainability.

The group defined depleted land as:

Land whose fertility and productivity has declined to an uneconomic level or to a level where the farmer attaches little value to the piece of land, or the land is below the level of sustainability.

Broad Characteristics of Depleted Lands

1. Very low organic matter status.
2. Low pH.
3. Very low levels of plant nutrients for growing crops.
4. Low levels of micro- and macro fauna populations.
5. Low ability to produce meaningful levels of biomass.
6. Farmer spends less time and energy on the land – lowest priority given.
7. Soil structure may also have been lost.

Causes of Depletion

The following are some of the factors that were thought to cause depletion:

1. Nutrient mining, i.e. extractive crop production methods. Nutrients are taken out but are not returned to the soil.
2. Leaching. Most of the soils that are more prone to leaching tend to get depleted faster than those that do not leach fast.
3. Erosion. This leads to loss of top soil, soil organic matter and nutrients.
4. Poor farming practices, e.g. repeated ploughing.

Occurrence

The problem is believed to be very widespread in both Zimbabwe and Malawi but there is need to quantify the size of the problem.

Strategies for Rehabilitation

We need to think of a basket of solutions to solve the problems depending on the level of degradation that has taken place. The following are the solutions that were proposed:

1. Nutrient recapitalisation through organic and inorganic inputs
   a) organic interventions
      ⇒ manure
      ⇒ green manures
      ⇒ agroforestry
      ⇒ use of abandoned termite mounds
   b) inorganic interventions
      ⇒ fertilizer use
      ⇒ liming
      ⇒ termite mounds
2. Crop management practices
   ⇒ rotation
   ⇒ alley cropping
   ⇒ intercropping
   ⇒ relay cropping
3. Soil conservation practices
   ⇒ reduced tillage
   ⇒ contour ridging
   ⇒ crop residue management
4. Socio-economic factors
   ⇒ sensitising farmers
   ⇒ resource availability, e.g. capital

SoilFertNet is already aware of the problems of nutrient depletion hence the current research targeted at improving the fertility of the lands. The following research work is being carried out by some of the Network members:

⇒ Risk management
⇒ Soyabeans and pigeonpeas
⇒ Rotation of cereals and legumes
⇒ pH
⇒ Use of legume green manures and improved fallows

Gaps in the Work Carried Out

1. A need for screening work to establish the most appropriate legumes for different areas.
2. The levels of nutrient depletion need to be quantified in both Zimbabwe and Malawi.
3. There is need for long term strategies, e.g. working with the same farmers for longer periods. It was agreed that current methods are short term interventions.
4. The levels previously adopted in the manure + inorganic trials are too low to have impact in depleted lands. There is need for higher treatment levels and special focus on depleted lands.
5. Lack of systematic transfer of technology to farmers.
6. Need to raise the availability of green manure seed.

Future Plan

The group felt that the current network trials should be kept but the methodology needed to be improved.

1. In the Zimbabwean Network trial it was felt that there was need to remove *Tephrosia* and add pigeonpea or cowpea instead.
2. More screening of legume green manure species is needed.
3. The levels of organic and inorganic fertilizers used in the other Network trial needed to be increased for the depleted lands.
4. Work very closely with farmers and extension staff.

Measurements

⇒ amount of biomass
⇒ quality of biomass
⇒ decomposition and nutrient release
⇒ soil analysis to follow soil fertility changes
⇒ rainfall
⇒ yield of test crop

Target Areas

These will depend on the quantitative survey of the depleted lands, showing where most are located.

PLANNING GROUP 2: ORGANIC X INORGANIC INPUT MANAGEMENT

From REBBIE H. PHIRI

Current Knowledge of Organics and Inorganics

The group agreed that there is a good understanding of inorganic fertilizers in the SoilFertNet countries and now fertilizer recommendations exist for agro-ecoregions. Most smallholder farmers know the importance of the use of the inorganic fertilizer. Farmers normally apply fertilizer in split applications so that nutrients are supplied when there is maximum uptake by the plant. This shows that farmers understand the issue of nutrient supply and demand. However, most smallholder farmers do not use inorganic fertilizers because they are very expensive. This is a common problem to both Malawi and Zimbabwe. Thus the current farming systems are predominantly organically-based, supplemented in some areas by inorganic sources.

The use of organics is common practice in SoilFertNet countries. For instance, in Malawi farmers incorporate crop residues, intercrop maize with pigeonpeas and, to a lesser extent, with *Sesbania sesban*. Zimbabwe farmers mostly use cattle manure as an organic nutrient. Some farmers use both organic and inorganic sources to improve crop production. The group concluded that this is already a positive move towards the improvement of soil productivity. Generally though there are sufficient quantities of organic materials on and around the farm, most of the materials have a low nutrient supplying capacity. The challenge is to get more higher quality organic materials onto the farms.

Where are the Gaps?

The group identified our continued difficulty in understanding the use of the two nutrient sources together. To make recommendations for combined nutrient use, information on the fertilizer equivalency of organics is needed. We lack knowledge on how much of the different quality organics to apply to get yields equivalent to those obtained from inorganic fertilizers. That is to say, there is little understanding on the equivalent amount of nitrogen (N) that can be supplied by organic sources.

How to Fill the Gaps?

Ways of filling the gaps were identified as:

1. first conduct research on fertilizer N equivalence of organic materials, then
2. combine organic and inorganic sources based on results from fertilizer equivalency values.

The first phase experiment would test the hypothesis that N supplied by an organic source is recovered at half the efficiency of that from inorganic fertilizer. This hypothesis is illustrated in Table 1.

The objective of the experiment will be to determine fertilizer equivalency values for organic materials of different quality in different climate and soil environments.

Table 1. Percent recovery of N from inorganic and organic sources

Inorganic	Organic
50	25
20	10

The quality of different organic sources will be characterized. For example, plant residues will have their N, lignin and polyphenol content analyzed. Cattle manure will be analyzed for N, ash, lignin and visual characteristics. Different organic sources will be applied at an amount of N predicted by the hypothesis to give a yield equivalent to that of N from inorganics. For example, 120kg N within an organic source would be required to give the same yield as 60kg N from inorganic fertilizer. If the yields are different from that predicted as shown by Q1, Q2 and Q3 in Figure 1, then attempts will be made to relate this difference to organic quality.

The timing of organic application would be used to try to synchronize nutrient supply and demand. This experiment will be done in the immediate (1 - 2 years) term.

The second phase of the research will carry out an experiment to determine whether the combination effect of inorganics and organics is additive or inter-

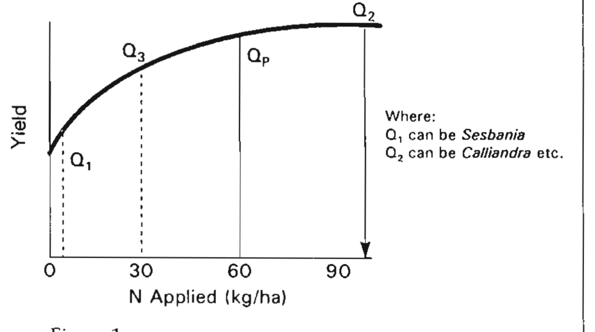

Figure 1.

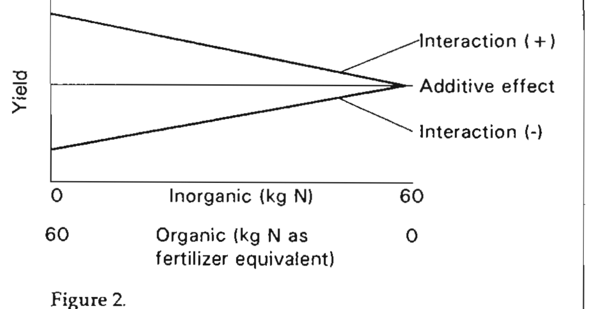

Figure 2.

active. This is illustrated in Figure 2.

In this experiment the 60kg N fertilizer equivalency of an organic material is compared to that of the inorganic fertilizer. The two nutrient sources are then substituted for each other in varying proportions. This objective can be achieved in the medium (2-5 years) term.

The persons in Table 2 volunteered to install the experiments if some funds are available. Other members not present in the planning group are also likely to be interested. The next meeting to discuss the planned activities will tentatively be early in October 1997.

Table 2. Interested Participants

Name	Organic Source	Location
Rebbie H. Phiri	Sesbania, Gliricidia	Chitedze and Makoka, Malawi
Jean Nzuma /Luke Mugwira	Cattle manure	Domboshava, Zimbabwe
Generose Nzigukuba	Gliricidia, Calliandra	Maseno, Kenya
Regis Chikowo	Cattle manure	Eastern Zimbabwe

PLANNING GROUP 3: 'BEST BET' TECHNOLOGIES AND LEGUME SCREENING

From ROBERT GILBERT

1. Best Bet Technologies

The group decided immediately that SoilFertNet should promote as "best bets" only those technologies that farmers would be extremely likely to profit from. Out of the papers presented at the Mutare conference the following interventions seemed likely to be the most profitable for farmers:

For Malawi these are:
1. Maize + pigeonpea intercropping
2. Magoye soybean rotations
3. Area-specific fertilizer recommendations

For Zimbabwe these are:
1. Yield optimization fertilizer package
2. Soybean for communal areas

Malawi

For Malawi, the consensus was that the "best bet" technologies should be demonstrated at as many on-farm sites as possible. There would be five plots located on a given farm:

1. Maize + pigeonpea intercrop
2. Magoye soybean + maize rotation (two plots: one soybean, one maize)
3. Area-specific fertilizer rate applied to maize
4. Farmer practice (control)

The maize + pigeonpea intercrop would use ICP 9145 pigeonpea, a long-duration variety that is resistant to *Fusarium* wilt and higher yielding than local varieties. The planting arrangement would place one pigeonpea station with three seeds/hill between maize stations (37,000 plants ha^{-1}). The variety and density are the "new" aspects of this technology (along with a greater geographical distribution because it is extended to central and northern Malawi). Possible problems associated with this intervention are seed availability, insect pests and attack from livestock.

Magoye soybean would be planted in double-rows in a ridge to get the optimum plant density. Magoye, a promiscuous variety from Zambia, has shown very good grain yield and biomass production in Zimbabwe and Malawi. It is one of the few grain legumes able to produce a caloric output equal to maize, and its low harvest index implies a N benefit to the succeeding crop. Two plots are required to examine this, one planted to soybean and the other to maize in 1996/97, then switched in 1997/98 to get every phase of the rotation each year.

The area-specific fertilizer recommendations should also be included, both to aid in their extension and for farmers to compare to the leguminous interventions. During the discussion, the comment was raised that after all the effort by the Maize Productivity Task Force (MPTF) on establishing these recommendations, wasn't including it here likely to confuse extension agents into thinking that we were testing them again? The response was that our Group hoped the inclusion of these recommendations would help in their adoption, and provide a valuable benchmark against which to judge the other treatments.

The farmer practice-control would be the customary practice of the farmer on his land. Thus if the farmer intercropped with local pigeonpea, or applied fertilizer, these would be included in the control. There was a proposal to produce good-quality leaflets on the demonstration technologies (e.g. on optimum agronomic management for intercropped pigeonpea) for the extension service and farmers.

Each site would be one replicate, and each plot 10 x 10 m.

The primary objective of this exercise is farmer appraisal and demonstration, not research *per se*. However, soil samples, crop yield and farmer rankings will be recorded for each site. It is envisaged that this would take place on <50 sites the first year, and if successful be scaled up in succeeding years. Clearly, funding of this effort is a major concern. The SoilFertNet coordinator will need to see if sufficient support can be available from the Network grant and, if not, contact the Rockefeller Foundation regarding the possibility of extra funding. Also, coordination with existing research projects, the MPTF and extension service is extremely important. If this activity is to take place, then a decision needs to be made quickly. Rob Gilbert, George Kanyama-Phiri and Todd Benson volunteered to help in this effort, but only if timely funding sources and collaborators to implement the trials are found.

Other side-research in Malawi should include: a) long-term effects of maize/pigeonpea intercrops (Webster Sakala), b) detailed N balance and economics of the "best bet" technologies (Rob Gilbert), c) detailed studies of intercropped green manures/multi-purpose shrubs (George Kanyama-

Phiri and Rob Gilbert), d) evaluation of short-duration pigeonpeas (possibly Sieglinde Snapp), and e) legume screening (see next page).

Zimbabwe
For Zimbabwe, there are two existing projects that are being funded to evaluate the two "best-bet" technologies identified. These are:

1. Yield optimization fertilizer package (Melvyn Piha)
2. Soyabean for communal areas (Sheunesu Mpepereki and Ishmael Pompi))

The research planned for these areas is outlined below:

1. *Yield optimization fertilizer package*

The paper by Melvyn Piha at Mutare outlined the fertilizer application strategy to employ in variable-rainfall areas of Zimbabwe. The next step is to build on the success of this package and expand to more farmer groups. The farmer groups will be chosen only in areas where inputs and loans are available, in collaboration with Agritex and the Zimbabwe Farmers Union. The plan is to work with four groups of ten farmers in areas where the farmers are already familiar with the application strategy. In these areas 1.5 ha would be used, with 1.0 ha planted to maize and 0.5 ha to a legume in any one year (the legume rotation aspect could be combined with the soybean rotations mentioned below).

In new areas, three groups of 15 farmers would be chosen, and the area under demonstration expanded gradually from 0.375 ha in year one to 1.5 ha in year three. Thus, this would be a three year project of expansion (to average out good and bad years), with part of the grant from the Rockefeller Foundation being used to cover any loans that the farmers could not pay back after three years. Natural regions II, III and IV will be targeted for this work.

Corollary research questions on this topic (which the SoilFertNet might want to address) include 1) which legume should be used in rotation?, 2) is broadcasting the most efficient fertilizer application method?, and 3) should lime, Zn or Mg be added? In discussion the need to get farmer appraisals and review the literature on fertilizer placement methods was mentioned. Also, other members of SoilFertNet besides Melvyn Piha might want to tackle some of the corollary research issues.

2. *Soyabean for communal areas*

Last season, Sheunesu Mpepereki worked with 55 farmers. This year there have been requests for over 1000 soyabean demonstrations from the farmers themselves, demonstrating the popularity of the technology.

For the 1997/98 season, 400 farmers will be targeted within seven communal areas. The package they will receive (for 0.1 ha) will include:
⇒ 10 kg seed
⇒ 2 varieties (including the promiscuous Magoye)
⇒ 25 kg compound L
⇒ 50 kg lime
⇒ 1 packet innoculant

The cost of the package will be subsidized in part, but not free. It is estimated that it will cost from Z$100 - 150. While farmer appraisal and extension will be the main goals, data on yield, and soil pH and rainfall will be taken.

Questions remaining for SoilFertNet to tackle include 1) what should be the basal fertilizer and liming rate?, 2) besides Magoye, what other promising varieties exist?, 3) what are the ecological limits for soybean production in communal areas?

2. Legume Screening

The group decided that subgroups from Malawi (Rob Gilbert, George Kanyama-Phiri, John D.T. Kumwenda) and Zimbabwe (to be decided, but likely to include Danisile Hikwa, Monica Murata, Fanuel Tagwira and Stephen Waddington) should meet later to discuss this issue. In the early stages of legume screening, the following trial design will be followed:

⇒ Large number of species (>50). Ken Giller will help to identify species through literature reviews and help locate germplasm from ILCA, CIAT and ILRI. During discussion it was noted that local leguminous species should not be ignored.
⇒ Small plots.
⇒ Score three times per season for growth, and harvest final biomass.
⇒ Three agroecologies, perhaps on-station to start.

The funding for this effort has not yet been established, so this would be a priority issue for SoilFertNet. Several SoilFertNet members will continue their research on management of promising species such as *Mucuna pruriens*, *Tephrosia vogelii* and *Sesbania sesban*. As other species emerge from this screening work, the issues of economics and intercropping with maize will be researched.

PLANNING GROUP 4: WORKING WITH FARMERS

From TODD BENSON

Underlying our discussion was the realization that the essence of farmer involvement in research is the question of the ownership of the research. For this to happen, farmers need to be part of the technology generation and information dissemination process. Our work affects their lives. They benefit if we do it right. We can't do it right without our hearing their voices. For that to happen, they must recognize our research as having a bearing on their own lives and, so, they must take on part ownership of our work. Our attitudes to the way we do our work must change if this is to happen.

Several questions were considered by the group. What sorts of research questions should involve farmers actively? At what stage do farmers come into the research? Does this happen at the beginning or after the process research is done? Furthermore, even if we do a good job in bringing the farmer into the mechanics of conducting research, how willing are we to listen to them? What input from the farmer and what aspects of their farming system do we incorporate into our research? A free-ranging discussion ensued.

Data Concerns

Areas of scientific concern in conducting research with farmers were highlighted. First, a distinction must be made between quantitative information and qualitative information or feedback from farmers. Quantitative information requires some significant degree of researcher participation. Qualitative information can readily be generated by farmer-managed trials — the data involved is principally farmer assessment of the technologies. Researchers require quantitative information to generate new technologies. Extension can play an important role in soliciting qualitative information from farmers and seeing that researchers bring it to bear on their research. However qualitative information, while necessary, is not sufficient for developing new technologies.

Continuing on this theme, the value of farmer assessment panels to review the trials was highlighted. Farmers often are very perceptive in looking at non-yield characteristics and are well able to judge what is the target environment for a technology. This sort of assessment can work at both the pre-formal research stage and at the dissemination of research technology stage. The farmer assessment can readily complement the quantitative data collected.

While recognizing the problems with collecting quantitative data from farmers, some such data can be acquired. By providing simple datasheets and notebooks for literate farmers together with simple guidelines on how the data should be collected, useful and timely information can be gained. Where more complex measurements must be done, the extension service could be brought in to assist. However, caution was urged for those contemplating laying out strongly qualitative data-type trials on-farm with farmers. In the effort to capture quantitative data, such farmer-run trials risk losing sight of arguably the most important information that can be gained — that of the farmer's evaluation of what is going on with the technology under examination.

Design of Research

Participatory Rural Appraisal (PRA) methods were seen as being of considerable value. Diagnostic research in PRA starts on a broad range of issues. The benefit of this wider survey is that it allows the researchers to capture a stronger sense of the context of the particular problems that the researchers have the capacity to work on — soil fertility issues. More importantly, PRA methods allow for a better understanding of the causes underlying the soil fertility issues which could be addressed by the researchers. It was noted that in most PRA exercises which SoilFert-Net members have conducted, soil fertility always came through as a problem, but in many cases not as highly ranked as the researchers would have expected (or may have desired). We noted with approval that several of the presentations of results at the Mutare conference incorporated the findings of PRA exercises to actually identify research needs and evaluation of trial results, but more could be done along these lines.

We highlighted that traditional research procedures usually need to be modified when working with farmers on their fields. The requirement that treatments be replicated is a difficult concept to convey to farmers. Ideally the stage of research on the technology when it is brought on-farm will not require as rigorous attention to statistical protocols as the research which preceded it. By the same token, plot sizes on farm should be larger than researcher's typically use. Yields from small plots exaggerate field yields, so larger plots are of more value for farmer demonstration. Single large plots for each treatment being evaluated and compared is usually the most appropriate trial layout for on-farm work where farmer assessment of the technology is sought.

In working on farm to verify or validate technologies, the provision of commercial inputs to farmers must be clearly thought through. Biometricians advising Agritex have suggested that to really assess a technology under farmer's conditions, one should only supply the inputs of interest, allowing the farmer to handle the rest, within his or her particular resource constraints. By providing nothing more than the specific inputs, a close approximation of how the technology performs under farmers' conditions is arrived at. However, the group noted that the riskiness of the new technology must be borne in mind. If the risks are great due to some unproved aspects of the technology, the researcher must be prepared to bear those risks, particularly those which arise from the use of purchased inputs, and compensate the farmer for any losses.

There was considerable discussion on the degree to which farmers should be involved with research on their farms. While it was acknowledged that in most cases the more farmers are involved the better, the level of farmer involvement should be conditioned by the nature of the trial. For example, data from replicated trials will sometimes be difficult for farmers to use, so the results of the analysis of such trials should be presented to the farmers for their comments, rather than the complex raw data. Also researchers should recognize that farmers have other things to do. There will be crucial moments for farmer participation in the trial. At other times, it is better to let him or her get on with their own work, while the researchers handle the details of the research on the farm.

Consequently, the participation of farmers frequently will be passive. This may be unavoidable at certain stages of the research. However, farmer input is critical to problem identification, crop management considerations, and the evaluation of technologies. That role for the farmer should not be lost sight of as the research goes on. Too often it is.

The incentives for farmers to participate with us in on-farm research were considered. Group members noted that farmers drop out from on-farm trial programs all too often. But the reasons are clear — trials that are too long in providing any benefits, trials which take too much land, or trials without clear benefits to the farmer. Moreover, we must recognize that the inappropriateness of a technology and the lack of continued interest by farmers in it may not be due to technical considerations. Local marketing or other constraints may result in farmers having no access to the necessary inputs involved in the new technology. In such cases, creating the necessary incentives for use do not lie with the researcher, but with policy makers.

Technology Transfer

On-farm research provides an important avenue for technology transfer. Consequently, it is necessary that the farmer who is working on the trial with researchers be able to explain to others what is going on in the trial and how it is important knowledge, if proven to be valid, for farmers in the area to use in their practices. If the farmer can't explain to a neighbour the purpose of trial, particularly at the verification and demonstration stages of research, then there is a gap that must be filled.

There needs to be an explicit inclusion of the wider farming community in training and discussion on the technology being researched. The farming community as a whole is the focus and context of the research being conducted. The community members must be involved in or at least made aware of the work, rather than simply the farmers upon whose land the research is being conducted. Often only the implementing farmer receives information.

However, farmers are heterogeneous in their socioeconomic conditions. It is naive to assume that all agricultural technologies researched on-farm will be appropriate for all farmers in the area. Some targeting of farmer groups should be done. A clear understanding of which farmers could adopt and benefit from a technology should be one of the goals of any research planning. Moreover, in targeting farmers attention should be paid to identifying which farmer groups could best foster effective farmer-to-farmer extension of the technology.

Practical steps to encourage SoilFertNet members to work with farmers

The group agreed that there is a need to provide researchers with guidelines on how to work with farmers in research and demonstration trials in order to be as effective as possible in getting what is required out of the on-farm work. Those aims particularly center on:

- diagnostic survey techniques
- fostering valid evaluations from the trials which would be of use as input into technology development or technology targeting.
- priming the farmer-to-farmer technology transfer process for good technologies.

It was felt that a SoilFertNet methods paper on Participatory Rural Appraisal would be of value to the network members. Such a paper should be focused on the special needs of conducting soil fertility research on-farm. As such it should be primarily oriented towards providing guidelines on specific aspects of on-farm research. Not all PRA methods will be particularly appropriate for all sorts of soil fertility research, but all research on-farm will be able to benefit from some of the guidelines offered. The aim is not necessarily to expect that researchers will conduct a full PRA investigation in their work. Rather, their research would benefit from employing several of the tools used in PRA work. Providing them with the knowledge on how to implement these tools – whether used all together or in a piece-meal fashion – would provide considerable returns in developing effective technologies.

However, the point was raised that many researchers will not realize the full value of the methods until they use them. The SoilFertNet should continue to encourage researchers to consider how they might incorporate into their on-farm research the techniques of PRA in order to capture the farmer context to the agricultural production constraints or the value of the technology being investigated. Among the means by which this could be fostered is for the Network to:

- adopt the policy that the results of farmer assessment should be part of data presentation on any SoilFertNet research. At the Mutare conference, some economic analysis was expected in the presentation of research results. At future conferences, the results of farmer assessment of the technology should also be expected to be part of any presentation.

- field tour site visits should be handled by farmers as much as possible.

- expect that farmers will do some of the technical operations of on-farm trials and the collection of data from these trials so that they can do a better job of assessing the trials and the technology. So far as possible, data collection by farmers should not be limited only to the qualitative.

Moreover, an added benefit of the farmer doing the technical operations is that this allows for timely trial field operations.

- approach the extension services and the Zimbabwe Farmers' Union (ZFU) to support the preparation of soil fertility management extension material. Mechanisms need to be developed to enable farmers to hear about our results and to provide feedback of use for the refinement of the technologies emerging from our work. The dissemination of information is a key aspect of this. Network scientists should take the lead in developing radio messages, brochures, and leaflets to provide information to farmers in an appropriate fashion. For example, the ZFU has a training section which will assist us prepare these. Our use of such a facility, and others like it elsewhere, must be part of our efforts in developing technologies of proven benefit to farmers.

LIST OF PARTICIPANTS AND CONTACT INFORMATION

England

1.
Prof. Ken Giller
Professor of Soil Microbiology
Wye College, University of London
Wye, Ashford
KENT
TN25 5AH
Phone: 44-1233-812401
Fax: 44-1233-813140
Email : k.giller@wye.ac.uk

Kenya

2.
Dr. Roland Buresh
Soil Scientist
ICRAF
P.O. Box 30677
Nairobi
KENYA
Phone: 254-2-521450
Fax: 254-2-521001
Email: R.Buresh@cgnet.com

3.
Ms. Lizbeth Levey
Director
Project for Information & Connectivity
P.O. Box 41081
Nairobi
KENYA
Phone: 254-2 251756
Email: l.levey@Frdfound.org

4.
Mr. Samson Nyangau Maobe
Research Scientist
Kenya Agricultural Research Institute
Kisii Regional Research Centre
P.O. Box 523
Kisii
KENYA
Phone: 254-0381-31803
Fax: 254-0381-31567
Email: Kisiirrc @Arcc.or.Ke.

5.
Dr. Joseph Mureithi
Forage Agronomist
Kenya Agricultural Research Institute (KARI-NARL)
Rockefeller Foundation
P.O. Box 14733
Nairobi
KENYA
Phone: 254-2-449810
Fax: 254-2-449810
Email: EDYCK@KEN.HEALTHNET.ORG

6.
Dr. Cheryl Palm
Scientific Officer
TSBF
P.O. Box 30592
Nairobi
Kenya
Phone: 254-2-622584
Fax: 254-2-521159
Email: cheryl.Palm@sbf.unon.org

Malawi

7.
Dr. Todd Benson
Geographer-Socio-Economist
Maize Commodity Team
Chitedze Agricultural Research Station
P.O. Box 158
Lilongwe
MALAWI
Phone: 265-767222
Fax: 265-782835
Email: TBenson@Malawi.net

8.
Dr. Robert A. Gilbert
Research Fellow
Rockefeller Foundation
P.O. Box 30721
Lilongwe 3
MALAWI
Phone: 265-781182
Fax: 265-782835
Email: RGilbert@Malawi.net

9.
Mr. Rosan Ganunga
Department of Agricultral Research (DAR)
Chitedze Research Station
P.O. Box 158
Lilongwe
MALAWI
Phone: 265-767222

10.

Dr. George Yobe Kanyama-Phiri
Senior Lecturer/Dean
University of Malawi
Bunda College of Agriculture
P.O. Box 219
Lilongwe
MALAWI
Phone: 265-277222
Fax: 265-277364

11.
Mr. Bernard C.G. Kamanga
Msc Student
University of Malawi
Bunda College of Agriculture
P.O. Box 219
Lilongwe
MALAWI
Phone: 265-277222
Fax: 265-277364

12.
Dr. Austin Suzgo Kumwenda
Controller of Agric. Extn. & Technical Services
Ministry of Agriculture & Livestock
Development
P.O. Box 30134
Lilongwe 3
MALAWI
Phone: 265-783446/784299
Fax: 265-783450

13.
Dr. J.T.D. Kumwenda
Senior Maize Agronomist
Department of Agricultral Research (DAR)
Chitedze Research Station
P.O. Box 158
Lilongwe
MALAWI
Phone: 265-767222

14.
Dr. Alfred P. Mtukuso
Deputy Director of Agricultural Research &
Technical Services
Ministry of Agriculture
P.O. Box 30134
Lilongwe
MALAWI
Phone: 265-784299
Fax: 265-784184

15.
Mr. Aaron D. K. Phiri
Msc Student (Agroforestry)
University of Malawi
Bunda College
P.O. Box 219
Lilongwe
MALAWI
Phone: 265-277 222
Fax : 265-277364

16.
Miss Rebbie Phiri
Student of Agroforestry
University of Malawi
Bunda College
Box 219
MALAWI
Phone: 265-277 222
Fax: 265-277 364

Mexico

17.
Dr. Larry Harrington
Director (NRG)
CIMMYT-Mexico
Lisboa 27, Apdo. Postal 6-641
06600 Mexico D.F.
MEXICO
Phone : 525-726-7532
Fax: 525-726-7558/9
Email: LHarrington1@compuserve.com

Mozambique

18.
Mr. Antony Christiaan van de Loo
Extension and Training Advisor
Prov. Agric. Services,
(DANIDA)
P.O. Box 293
Tete
MOZAMBIQUE
Phone: +258-52-22587/23227
Fax: +258-52-2340
Email:vandeloo@masunga.uem.mz (home)
danida@danidpa.uem.mz

USA

19.
Mr. Peter Jeranyama
Student
Michigan State University
Dept. of Crop & Soil Sciences
East Lansing, M1 48823
USA
Phone: (517) 355-3205

Fax: (517) 353-5174
Email: Jeranyama@pilot.msu.edu

Zambia

20.
Mr. Charles Kawimbe
Agronomist
Ministry of Agriculture Food and Fisheries
Mochipapa Research Centre
Farming Systems Research Team
P.O. Box 630090
Choma
ZAMBIA
Phone: 26032-20466/21504
Fax: 260-32-20467
Email: fsrt@zamnet.zw

21.
Dr. Alfred Mapiki
Soil Scientist/Chief Agricultural Research Officer
Dept. of Research and Specialist Services
Misamfu Regional Research Centre
P.O. Box 410055
Kasama
ZAMBIA
Phone: 260-4221215
Fax : 260-422 1135
Email: misamfu@zamnet.zm

22.
Mr. Moses Mwale
Agricultural Research Officer
Ministry of Agricultural Food & Fisheries
Mt. Makulu Research Station
P/B 7, Chilanga
ZAMBIA
Phone: 260-1-278429/278141
Fax: 260-1-278141/278130/278390
Email: Genetics@Zamnet.zm

Zimbabwe

23.
Mr. John Rupert Barnes
Department of Soil Science
University of Zimbabwe
c/o Dr. S.M. Mpepereki
P.O. Box MP 167
Mt. Pleasant
Harare
ZIMBABWE
Phone: 303211
Fax: 333407
Email: rbarnes@zimbix.uz.zw

24.
Mrs. Chinaniso Chibudu
Agronomist
Department of Research & Specialist Services
P.O. Box CY530
Causeway
Harare
ZIMBABWE
Phone: 704531

25.
Mr. Samuel Chikura
Research Officer
Department of Research & Specialist Services
P.O. Box CY530
Causeway
Harare
ZIMBABWE
Phone: 704531

26.
Mr. Regis Chikowo
Student
Africa University
P.O. Box 1320
Mutare
ZIMBABWE
Phone: 120-60075
Fax: 120-61785

27.
Mrs. Chipo Chivaura-Mususa
Dphil Student, University of Zimbabwe
Institute of Environmental Studies
P.O. Box MP 167
Mt. Pleasant
Harare
ZIMBABWE
Phone: 303211 Ext. 1406/1481
Fax: 333407
Email: Mususa@Biosci.uz.zw

28.
Mr. David K.C. Dhliwayo
Principal Research Officer
Soil Productivity Research Laboratory
P.O. Box 3757
Marondera
ZIMBABWE
Phone : 179-23621

29.
Mr. Herbert Dhliwayo
Agronomist
Department of Research & Specialist Services
Makoholi Research Station
P/Bag 9182
Masvingo
ZIMBABWE

Phone: 139-63255

30.
Mrs. D. Hikwa
Head
Agronomy Insititute
Department of Research & Specialist Services
P.O. Box CY530
Causeway
Harare
ZIMBABWE
Phone: 704531
Fax: 728317
Email: DRSS@MANGO

31.
Dr. Alois Hungwe
Soils Incorporated Pvt. Ltd.
PTA House
19 Union Avenue
Harare
ZIMBABWE
Phone: 749972

32.
Dr. David C. Jewell
Team Leader
CIMMYT-Zimbabwe
P.O. Box MP 163
Mt. Pleasant
Harare
ZIMBABWE
Phone: 301807/301945
Fax: 301327
Email: D.Jewell@cgnet.com

33.
Mr. Johannes Karigwindi
Research Assistant
CIMMYT-Zimbabwe
P.O. Box MP 163
Mt. Pleasant
Harare
ZIMBABWE
Phone: 301807/301945
Fax: 301327

34.
Mr. Patrick Kasasa
Student
University of Zimbabwe
Department of Soil Science
P.O. Box MP 167
Mt. Pleasant
Harare
ZIMBABWE
Phone: 303211 EXT. 1519
Fax: 333407

35.
Mr. Paul Mapfumo
Student
Soil Science University of Zimbabwe
Department of Soil Science
P.O. Box MP167
Mt. Pleasant
Harare
ZIMBABWE
Phone: 303211 Ext. 1481

36.
Dr. Sheunesu Mpepereki
Lecturer
Department of Soil Science,
University of Zimbabwe
P.O. Box MP167
Mt. Pleasant
Harare
ZIMBABWE
Phone: 303211
Fax: 333407
Email: Smpepe@Zimbix.uz.zw

37.
Prof. Athanasius Mphuru
Dean
Faculty of Agriculture & Natural Resources
P.O. Box 1320
Mutare
ZIMBABWE
Phone: 120-60026
Fax: 120-61785
Email: Dean@mre.zol.co.zw

38.
Mrs. Florence Mtambanengwe
Mphil Student/Research Technician
Department of Biological Sciences
P.O. Box MP 167
Mt. Pleasant
Harare
ZIMBABWE
Phone: 303211 Ext. 1406
Fax: 333407
Email: fmtamba@biosci.uz.zw

39.
Dr. Luke M. Mugwira
Chief Research Officer
Department of Research & Specialist Services
P.O. Box CY530
Causeway
Harare
ZIMBABWE
Phone: 704531
Fax: 728317

40.
Mr. Linus Mukurumbira
Soil Productivity Research Laboratory
P.O. Box 3757
Marondera
ZIMBABWE
Phone : 179-23621

41.
Ms. Monica Murata
Principal Agronomist
Department of Research & Specialist Services
P.O. Box CY530
Causeway
Harare
ZIMBABWE
Phone: 704531
Fax: 728317

42.
Dr. Herbert K. Murwira
Fellow
TSBF
c/o ACFD
P.O. Box A469
Avondale
Harare
ZIMBABWE
Phone: 860421/2
Fax: 86042
Email : Hmurwira@zambezi.net

43.
Mr. Philip T. Mushayi
Post Graduate Student
Crop Science Department
University of Zimbabwe
P.O. Box MP 167
Mount Pleasant
Harare
ZIMBABWE
Phone: 303211

44.
Mr. Ernest Irimayi Muzorewa
Senior Lecturer- Director of Practical Training
Africa University
P.O. BOX 1320
Mutare
ZIMBABWE
Phone: 120-60026/75/61611/18
Fax: 120-61785
Email: Dean@mre.zol.co.zw

45.
Mr. Zephirin Ndikumana
Laboratory Technician
Africa University
Faculty of Agriculture and Natural Resources,
Box 1320
Mutare
ZIMBABWE
Phone: 120-60026/75/61611/18
Fax :120-61785
Email : Dean@mre.zol.co.zw

46.
Mr. Happymore Nemasasi
Research Officer
Department of Research & Specialist Services,
P. Bag 3757
Marondera,
ZIMBABWE
Phone: 179-23621

47.
Mr. Nhamo Nhamo
Research Assistant
TSBF/ ACFD
P.O. Box A469
Avondale
Harare
ZIMBABWE
Phone: 860421/2
Fax: 860423
Email : Hmurwira@zambezi.net

48.
Mr. Chris Nyakanda
Research Fellow
Crop Science Department
University of Zimbabwe
P.O. Box MP 167,
Mount Pleasant,
Harare
ZIMBABWE
Phone: 303211 Ext. 1571
Fax : 333407
Email:Nyakanda@cropsci.uz.zw

49.
Miss Jean Nzuma
Research Officer
Chemistry and Soil Institute
Department of Research & Specialist Services
Box CY 550
Causeway
Harare
ZIMBABWE
Phone: 704531
Fax: 728317

50.
Dr. Melvyn Piha
Lecturer
University of Zimbabwe
Department of Soil Science and Agricultural

Engineering,
P.O. Box MP 167
Mount Pleasant
Harare
ZIMBABWE
Phone: 303211 Ext. 1721

51.
Mr. Ishmael Pompi
Senior Agronomist
AGRITEX
Box CY 639
Causeway
Harare
ZIMBABWE
Phone: 794601-6 or 707311
Fax: 730525

52.
Dr. David D Rohrbach
Principal Scientist (Economics)
ICRISAT
P.O. Box 776
Bulawayo
ZIMBABWE
Phone: 183-8311/2/3
Fax: 183-8253
Email: D.Rohrbach@CGNET.COM

53.
Mrs. Rudo Shongedza
Secretary
CIMMYT-Zimbabwe
P.O. Box MP 163
Mt. Pleasant
Harare
ZIMBABWE
Phone: 301807/301945
Fax: 301327
Email: R.Shongedza@cgnet.com

54.
Dr. Fanuel Tagwira
Senior Lecturer
Africa University
P.O. Box 1320
Mutare
ZIMBABWE
Phone: 120-60026/75/61611/18
Fax: 120-61785
Email: Ftagwira@mre.zol.co.zw

55.
Mr. . Gideon Tsododo
Deputy Director (Field)
AGRITEX
Box CY 639
Causeway
Harare
ZIMBABWE
Phone: 707311

56.
Dr. Stephen Waddington
Agronomist
CIMMYT
Box MP 163
Mount Pleasant
Harare
ZIMBABWE
Phone:/301807/301945
Fax: 3013275/301945
Email: S.Waddington@cgnet.com

57.
Dr. Batson Thomson Zambezi
Maize Breeder
CIMMYT
Box MP 163
Mount Pleasant
Harare
ZIMBABWE
Phone: 301945/301807
Fax: 301945/301327
Email: B.Zambezi@cgnet.com