RESEARCH METHODS FOR CEREAL/LEGUME INTERCROPPING

Proceedings of a Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa

Sponsored by CIMMYT, CIAT and the Government of Malawi
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Proceedings of a Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa
Held at Lilongwe, Malawi
23-27 January 1989

Edited by S.R. Waddington, A.F.E. Palmer and O.T. Edje

Sponsored by CIMMYT, CIAT and the Government of Malawi

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WORKSHOP ORGANIZERS
Opening of the Workshop on Research Methods for Cereal/Legume Intercropping

The Honourable E. C. Katola Phiri, M.P., Minister of Community Services, Government of Malawi

Mr Chairman,
Your Worship the Mayor,
Mr District Chairman of the Party,
Representatives of the International Maize and Wheat Improvement Center and the International Center for Tropical Agriculture,
Distinguished Participants,
Ladies and Gentlemen

I am honored and most privileged to have the opportunity to officiate at this important function.

I am privileged to do so for and on behalf of His Excellency The Life President, Ngwazi Dr. H. Kamuzu Banda who is also Minister of Agriculture. Allow me therefore, to pay tribute to His Excellency the Life President for appointing me to open this very important Workshop on His behalf.

I am thus afforded the opportunity to extend to each one of you a warm welcome. We feel most honored to be your host. Please feel at home and enjoy every moment of your stay in Malawi.

I now return to the theme and observe that this Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa provides a very important forum where guidelines on a range of research methods for intercropping can be formulated in order to address crop production problems faced by smallholder farmers.

In this region, as in the rest of Africa and the world as a whole, the function of agricultural research is to provide farmers with improved and appropriate technologies that help to raise their well being. For most of our farmers here in Malawi, intercropping, in its many forms, is a normal way of crop production, tried and tested over generations.

Depending on soil moisture conditions, it is not unusual to see maize/groundnut, maize/pigeonpea, maize/chickpea, maize/bean mixed cropping or maize/bean mixed in relay with a bean crop. It goes without saying, therefore, that for our farmers, cereal/legume intercropping is very important and provides the range of foods necessary for a sound nutritional base.

Clearly then a key way in which agricultural research can help to raise farmer productivity in Eastern and Southern Africa is by improving upon existing cereal/legume intercropping systems. In order to do this effectively, researchers must be able to develop and use appropriate research techniques and procedures. This is the theme of this important workshop. By its very nature, research on intercropping is multicommodity and multidisciplinary. This is reflected in the broad spectrum of participants here present. Accordingly, it is essential that researchers on intercropping have sufficient opportunities to exchange ideas and experiences.

During the week you will be discussing methods of improving research on intercropping to make it more relevant to the needs of smallholder farmers in Eastern and Southern Africa. We attach great importance to this.

I am particularly pleased to be informed that a main aim of the workshop is to develop guidelines on research into cereal/legume intercropping. It is expected that the guidelines will be widely used by researchers in the region to further improve the quality and relevance of their research.

I believe such improvements will be manifested eventually only if research efforts will result in the development of appropriate technologies that will facilitate the formulation of meaningful packages for intercropping so that crop quality and production levels are improved.

Always remember that smallholder farmers are also experimenters and practitioners of great common sense. So I urge you to plan, order your priorities and develop research strategies so that you are able to offer them improved agricultural technology and systems.

I have no doubt that your discussions will address practical problems often experienced by farmers, both large and small scale, and take full account of the economic and sociological constraints and opportunities which obtain in our societies.

Participation at workshops like this one is good but what is more important is that you as participants should play a constructive role to improve and encourage sound cereal and legume production in your respective countries.
It is the policy of this Government to increase production per unit area of land and to encourage the production of high quality cereal and legumes to meet the requirements of both the domestic and the export market.

Malawi therefore greatly appreciates the contribution the International Maize and Wheat Improvement Center and the International Center for Tropical Agriculture have made towards improving agricultural production through their programmes. These organizations have been successful in part because of collaboration with the national scientists of the region represented here this morning.

On behalf of the Government and the people of Malawi, I would like to extend our most sincere gratitude and appreciation to these organizations and also to USAID and CIDA for their financial support.

Distinguished delegates, I invite you to visit the surrounding countryside to see and appreciate the efforts Malawi is making in agriculture in general and in intercropping in particular.

Once again you are most welcome. Feel at home.

Mr Chairman, Distinguished participants, Ladies and Gentlemen, it is now my honor and privilege to declare this workshop officially open.

Thank you very much.
Need for the Workshop

While interacting with colleagues in National Agricultural Research (and Extension) Services (NARS) in the region, CIMMYT and CIAT staff have been asked on many occasions to give advice on how researchers might undertake more effective intercropping work relevant to the needs of smallholder farmers.

Why was there this need for guidance especially after the great deal of intercropping research that took place in Eastern and Southern Africa during the 1970s and early 1980s?

To explain this perhaps we have to look at the type of intercropping research being done or planned today, and the persons charged with doing that work.

Recently there has been a significant shift from station-based intercrop research looking just at technical or scientific aspects (such as competition between crops grown in association, and plant spatial arrangements) to more problem orientated research driven by the needs of smallholder farmers. This newer work involves diagnosing problems that farmers face with their current intercrops, development of promising intercrop technologies on-station and on-farm, testing of those technologies with farmers under their circumstances and management, and evaluating the benefit of making changes to current practices. Technical considerations are rarely enough in this type of work. Other aspects such as resource endowments, nutrition and farmer decisions are vital.

Along with this shift in emphasis has been a change in the personnel doing the work. Many of the persons involved in research on technical aspects of intercropping in the region during the 1970s and early 1980s have either left the region or moved out of active research. Most on-farm researchers involved with intercrops are rather new to research and are faced with a situation where many of the methods from more technical intercropping research, even when known, are in any case not very appropriate.

Nor can the International Agricultural Research Institutes be looked upon as able to supply ready answers to more than a few of the many research methodology problems that modern intercropping research throws up.

Aims of the Workshop

Accordingly the organizers felt it opportune to bring together agricultural scientists from the region and a few from outside, to share their experiences and thoughts on methods to use in improving research on intercropping and in particular on how to make it more effective at addressing the needs of smallholders.

Around 40 agronomists representing commodity and disciplinary research, or adaptive or farming systems research, by NARS in Eastern and Southern Africa were invited to take part. Plant breeders, entomologists, plant pathologists, nematologists, extension specialists and socio-economists from NARS were also invited. In addition several key researchers on intercropping from outside the region and staff from CIAT and CIMMYT were present. Not all participants could claim to be experts on intercropping but we provided a mix of biases, experiences and insight that allowed us to develop some excellent discussion.

A Special Session was devoted to presentations by NARS scientists on country experiences in intercropping research.

The Main Sessions covered:

Session 1. The future of intercropping research and implications for research methods

Session 2. Understanding current intercropping patterns and diagnosis of intercropping problems in farmers fields

Session 3. Development of an intercropping research program and component research
Session 4. Experimentation with intercrops

The purpose of presentations in these Sessions was to introduce and give an overview of the issues relevant to each topic. Persons with considerable experience on the topics were invited to make these presentations.

Session 5. Analysis and interpretation of intercrop research

During the presentations a small committee noted relevant points or issues raised by the presenters and by participants from the floor of the meeting. From these notes the committee developed a set of points on each Session to be used during the Group Discussions.

Session 6. Sustainability and intercrops

Group Discussion Sessions were held at three stages during the workshop to discuss issues from Sessions 1 and 2, Sessions 3 and 4, and Sessions 5 and 6. At each stage six groups of 10-12 persons were formed. It was during these discussions that further guidelines on methods were discussed and proposed. Findings were presented to three Plenary Sessions directly after the group discussions and are summarised on p. 231-239.

After the Workshop a summary of issues/guidelines on on-farm experimentation with intercrops was compiled from information presented and discussed at the Workshop. This is reproduced on p. 240-245.
Relevance of the Workshop to Farming in Eastern and Southern Africa

O. Todo Edje, Workshop Co-organizer, SADCC/CIAT Regional Bean Program, Arusha, Tanzania

About a decade ago, on March 9-14, 1980, a workshop on the 'Potential for Field Beans in Eastern Africa' was held in Lilongwe. The workshop was attended by participants from 17 countries and representatives from international research institutions and donor agencies. At the end of that workshop, the participants recommended that the East African Cereals Conference, in which the research results and sometimes proposals from member states were discussed annually, be revived. They went on to say that future conferences should include grain legume crops and should be called the East African Cereals and Grain Legumes Conference. That recommendation at the end of a workshop held about a decade ago emphasizes the importance of intercropping to farming in this region.

Intercropping, which in the context of this present workshop includes mixed row, ridge relay intercropping and all variants of multiple cropping, is the commonest and most popular cropping system in Africa, Asia and Latin America. On these continents, 80% or more of the smallholder farmers -- who grow the bulk of the food crops and some of the cash crop -- grow two or more crops in association. The number of crops in the mixture can vary from two to a dozen, especially near the homestead. Although there are many complex combinations of intercrops the predominant ones are simple and usually combine a cereal with a legume, grown for their nutritional complementarity. For example, according to a sample survey of agriculture conducted in Malawi, 77% of the grain legume crop, excluding groundnuts, was grown in association with maize. In the same survey, 94% of the cultivated hectarage in Malawi was planted to crops in association and only 6% in pure stand. While Malawi, Zambia, Mozambique, Ethiopia, parts of Tanzania and other countries have predominantly cereal/legume associations, the story is different in the Great Lakes Region (Rwanda, Burundi and parts of Zaire) and parts of Tanzania and Uganda, where banana/bean intercrops are commonest. Whatever the crop combinations, intercropping is an intensive and sustainable land use system which the farmer has evolved over the years through experimentation. Because of the current human population pressures on our fragile and deteriorating ecosystem and shrinking arable land, intercropping will become more important not only for the smallholder farmer but for the estate sector too.

As recently as 20 years or so ago, intercropping was regarded as primitive and backward because the complex mixtures involved seemed haphazard to those unfamiliar with the cropping system. The philosophy then was one farm one crop, the concept of cleanliness was next to godliness. That changed in the 1970s when researchers began learning from farmers, who have been researching on intercropping for centuries. Because of renewed interest, there has been a tremendous increase in intercropping research. According to Professor Charles Francis, 1986 papers were published on intercropping as of 1980. While only 60 papers were published prior to 1950, some 1000 were published between 1976-1980 alone. The number has increased tremendously since then.

A review of most of the published papers to date seems to suggest that earlier researchers adopted traditional research approaches. For example, the role of the smallholder farmer, our client whom we professed to assist, was barely recognized and so was never involved in what is known as participatory research. The involvement of the farmer in the definition of research agenda, the evaluation of research results and even in the dissemination of results was ignored. Technologies were developed exclusively on research stations and had poor adoption rates with smallholder farmers because they were not relevant. The extension worker was always blamed for being a poor salesman.

Experimental designs, analysis and interpretation of data were based on monoculture and analysed little more than yield. The role of the socio-economist and the anthropologist in research efforts were never dreamed of. But all that is changing. The use of traditional research methods for intercropping is becoming history, hence the relevance of this workshop.

I think that this workshop is an honourable gathering. It is a roll call of who is who in intercropping in the world. We hope that during this week we shall have a singular opportunity to learn various methods and techniques of conducting intercropping research as applied to, for example:

1. Diagnosis of smallholder farmer problems
2. Development of an intercropping research programme and its components
3. Integration of pest management so as to reduce the use of pesticides
4. Experimentation with intercrops, and
5. Analysis and interpretation of results, which until recently were based on seed yield but ignored other quantifiable and non-quantifiable but valuable aspects of intercropping.

That is the relevance of this workshop.
New Innovations in Intercropping Research

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Abstract

Current food crises in a number of countries demand attention from the agricultural research community. We need to carefully examine the research and extension agenda, as well as the specific methods available for developing and introducing new technology.

Intercropping research to date has followed established patterns within our national and international public institutions. Choice of treatments and experimental units, use of traditional research designs, collection and analysis of data have employed the methods developed primarily for monoculture systems. The innovative part of this research has been a focus on entire cropping and even total farm systems rather than specific crops and practices. Implementing the farming systems methodology, research and extension specialists have sought more participatory approaches in the field in the design of trials, and collection and interpretation of results, as compared to traditional research with monocultures. Women’s roles have been identified explicitly in some programs, and these taken into account in the design of new technology.

Over the past two decades, there has been an accelerated interest in the entire range of component technology for intercropping: breeding new hybrids or varieties, determining fertility needs, assessing weed and other pest management strategies, and designing alternative systems. Most treatments have been evaluated using traditional measures of productivity -- grain yield per hectare, net income per hectare. However, it is likely that these are not the only nor perhaps the primary criteria used by limited resource farmers to evaluate their own success. Such priority questions as return to labour, risk of adopting new technology, stability and sustainability of production, nutritional and other food quality factors may in fact be more important to the farm family. Complex questions in farming systems may be more easily studied across a wide range of climatic conditions through simulation research. This would require credible baseline data, relevant measures of system productivity in terms or units which are meaningful to farmers, and careful consideration of the appropriate levels of inputs and resources. Interdisciplinary team approaches are essential to understanding the complexity of intercropping and how systems can be manipulated to increase productivity and sustainability.

This is an important moment in time because of the magnitude of the challenge of producing enough food, because of the current interest and support by funding agencies in intercropping research and total farm systems, and because of the overwhelming need to plan strategies for successful long-term conservation and use of natural resources. Intercropping will play an important role in long-term food production strategies in Africa.

Introduction

Agricultural production and food availability need to be near the top of each country’s development agenda for the twenty-first century. Although complete food self-sufficiency cannot be a feasible goal for every country, there is a vital need to produce as much food as possible and to generate foreign exchange in order to purchase the needed balance. Current capacity for food production -- based on soil and climatic conditions and levels of farm technology -- is shown in Figure 1 for African countries. According to the World Bank (1984) and this information reprinted from OTA (1984), there are fourteen countries in Africa which cannot produce enough food on a sustainable basis to support the population level in 1975. This assumes a continued subsistence level farming. The countries are shown in Figure 1 with the legend “less than 1.0”, the ratio of population-supporting capacity to actual population density. It is clear from this map that greater attention needs to be placed on food production and a rational choice of technologies to increase productivity.

Prior emphasis has focused on development of infrastructure and availability of fossil-fuel based production inputs such as fertilizers, pesticides, and irrigation to increase potential productivity; this follows the ‘Western’ or the ‘Asian’ model of development. It is becoming increasingly clear that this model has met with limited success in the African context for a number of complex reasons (OTA, 1984, 1988a, 1988b). What is emerging appears to be a development strategy uniquely designed by Africans for their own climatic, social, and political realities, but based on the agricultural and economic experiences on this continent and elsewhere. Intercropping is an important component of this new strategy.

Recognition of this importance of intercropping by scientists can be illustrated by the increase in number of journal articles appearing
intercropping have been prevalent over the past several decades (Francis, 1986). Table 1 shows an approximate doubling in number of published items each five years since 1950; current data would undoubtedly confirm that this trend continues. Workshops on intercropping have been prevalent over the past decade. Among these meetings were the conference in Knoxville, Tennessee in 1975 (Papendick et al., 1976), in Los Baños, Philippines in 1976 (IRRI, 1977), in Morogoro, Tanzania in 1976 (Monyo et al., 1976) and in 1980 (Keswani et al., 1982) and in Hyderabad, India in 1979 (Willey, 1981). Recent comprehensive books on intercropping were written or edited by Steiner (1982), Beets (1982), Gomez and Gomez (1983), and Francis (1986). The reviews by Willey (1979a, 1979b) and pioneering work at ICRISAT (see Rao, 1986) should be recognized as major contributions to our understanding of complex systems.

This trend and continuing interest can be seen in national, regional, and international conferences on cropping systems and the economics of farming systems. It is likely to be of increasing importance in the overall scientific research agenda for the coming decades.

**Strategies for Intercropping Research**

The first reaction of research specialists to a challenge of improving productivity of cropping systems often has been to recommend monoculture. Trained in the tradition of sole cropping technology and efficiency, such scientists are reacting in a predictable, though perhaps irrational, manner to a situation which they do not understand well. Assumptions that the limited resource farmer has access to necessary inputs, ready markets for excess production, and educational preparation to put this all together may not be realistic in many small farm situations. The farming systems research/extension methodology has helped put technical people into closer communication with farmers, a step toward solving this problem of always recommending monoculture.

A second logical approach by scientists trained in development of new technology has been to apply available hybrids and varieties, fertilizer recommendations, weed and insect control practices, and other component practices -- all developed in monoculture systems -- in the target intercropping systems. In some cases this has been successful, for example, if the new hybrid has resistance to an insect or has increased yield potential in both sole crop and prevailing intercrop systems. Biological principles are the same in all systems; however, the relative importance of different factors and increased number of interactions in an intercropping system make it risky to assume that available technology will always apply.

In variety development, for example, there have been numerous studies of genotype by cropping system interaction. Are the best hybrids or varieties for sole cropping the same for a more intensive intercropping system? Results of these studies have been summarized by Francis (1985) and Smith and Francis (1986). Over a large number of trials with upper story cereals and lower story legumes, for example, there is often not a system by genotype interaction for the upper story species while this interaction is significant for the lower story crop. Thus, a maize or sorghum variety or hybrid developed for intercropping would likely be useful in a broad range of systems; the lower story groundnut, cowpea, or bean varieties may have more specific adaptation to sole cropping or to intensive shading conditions found in an intercrop. There is enough data now on a range of crop species to predict this reaction to intercropping; the same is not necessarily true for fertility relationships and crop needs, for insect and weed control, or for design of complex mixtures.

Another approach sometimes taken by field research specialists who are somewhat familiar with a range of crops and systems in different climates is to introduce exotic systems and new crops in a sincere attempt to improve productivity. Although this strategy has been successful in a few unique locations, it has often been useful only to the researcher in getting publications into reports and international journals! This research recently was termed "agronomic trivial pursuit" (Youngquist et al., 1988), describing the basic approach to learning a great deal about "non-problems" in the field and to comparing intercrops with sole crops using indices which may not be meaningful to the farmer. There is certainly value in searching among the available systems and technologies for solutions to priority problems; there is neither time nor sufficient resources to research problems which are not really limiting production on the small farm.

What are some potential strategies that are efficient in resource use and carefully directed toward priority problems on the farm? First it is important to work on systems which are used by farmers and that have researchable problems susceptible to solution. In the following example, it is assumed that the maize/bean intercropping system has priority for farmers in the region of interest. The methods developed could be applied to any system.

One approach to sorting out the near-infinite potential research topics that could be explored in an intercropping system is to prioritize the factors limiting yields and the most likely interactions among those
factors. Expected two-way interactions between factors affecting productivity of maize/bean patterns are shown in Figure 2 (from Parkhurst and Francis, 1986). The factors are maize and bean varieties, maize and bean densities, relative planting dates, spatial organization or arrangement, fertilizer levels, and herbicide used to manage weeds. Only those factors considered most likely to interact are connected with arrows in the diagram. Assuming that it would be difficult to study these factors in all combinations, the next step is to quantify which of these are most important and most likely to interact. Table 2 shows the empirical probability of a significant interaction as well as a ranking (highest number = most important) of the importance of that interaction in affecting system productivity (above diagonal). These two estimates are based on results of field trials, on observations in farmers’ fields, and on prior knowledge of the two crops grown as sole crops. The product of these two numbers is called the ‘Priority index’ of each interaction (below diagonal in same table). These estimates of importance can be used to set up research priorities and to design trials.

Although it is more difficult to interpret the three-way and higher order interactions among factors, these certainly need to be taken into account. For example, genotypes of maize and bean not only influence each other but are affected differentially by their relative densities in the intercrop. Tables 3 and 4 indicate the same type of estimation of interaction probabilities, importance of interactions, and priority indices for three-way and four-way interactions among factors. Although these are estimates, the exercise in developing the priority indices helps a research team to assess what is known about a system and its components, what factors are important and likely to interact, and what should be taken into account in designing experiments to solve priority constraints in the system.

Study of these factors in a traditional experiment station manner would involve precise replicated trials under relatively controlled conditions. Three options for such trials are shown in Table 5. First, if all factors were combined in a complete factorial arrangement (4 x 3 x 3 x 6 x 8 x 4 x 3 treatments) and this set were replicated only two times with minimum plot size, the experiment would occupy about 68 hectares. Another option is to design a fractional replication of the same combinations; most important interactions as determined by the exercise above would lead to specific combinations to replicate, and the trial would occupy about 7 hectares. Finally, breaking the treatment combinations into eight smaller trials where concentration is on the most important interactions and two to four factors are included in each trial would allow study of main effects and interactions in a trial which takes up less than one hectare of land.

Practical experience in the field with the first and the third options suggest that the latter approach is more efficient in terms of getting practical results, making the analysis simple enough to perform: interpret, and providing some protection against losing a large amount of information if one part of the experimental area is lost. This experience in Colombia leads us to recommend a number of small experiments to focus on priority issues, rather than large factorial trials in the field. There are unresolved questions about how to conduct this type of trial efficiently on farmer’s fields. Hildebrand and Poey (1985) outline many of the challenges in conducting on-farm research, and Gomez and Gomez (1983) describe methodology for testing technologies in the Asian humid tropics. There is much work to be done in the design of efficient strategies for on-farm research and for integrating on-farm with on-station work on intercropping systems. Statistical analysis using bivariate distribution has been addressed (see Mead, 1986).

Component Versus Systems Research

Classical research approaches on the experiment stations have focused on one or a small number of factors in each trial. Maize varieties or hybrids, fertilizer levels of a limiting nutrient, or different tillage alternatives are examples of this approach. We have attempted to hold all other factors constant, in order to study the isolated effects of the varieties or fertilizer levels under study. Holding these constant has most often been interpreted as making them non-limiting, so that full expression of the hybrids or fertilizer added will be observed. Depending on the correspondence of on-station to on-farm conditions, the results may or may not be applicable to the real farm situation. If similar tests are conducted in farmers’ fields, there is greater probability that conditions will correspond to the real world -- yet the results may be applicable only to situations where the conditions are the same as on the testing farm. Thus, there is no guarantee that results from either location will be useful to extrapolate to a broader recommendation domain.

At the other end of the spectrum, the farming systems approach (Gilbert et al, 1980) leads us to carefully examine the systems being used by farmers in each domain, and to focus research on those elements considered by the farmer to be most limiting to yields. Although this is perceived as more “real world” by the research community, the design of specific
trials still boils down to choice of one or a few factors to test and a limited range of options (new hybrids, different levels of fertility) actually placed in the field. This is an equally reductionist approach to research, even though there is some confidence that we are focused on the right questions rather than something of only academic interest.

One alternative is to study or compare complete systems -- traditional crop culture versus complete production package versus some intermediate combinations of inputs, for example. With results in hand from this approach, whether the results come from the farm or from the station, we have difficulty in separating out the effects of each factor in the production system. Unless it is obvious that certain hybrids fall down and other stand until harvest, that nitrogen is a limiting factor in crop growth and productivity, or that some other specific problem is the factor limiting yield, it is difficult to make rational and least-cost recommendations about new systems from this type of research. We face this quandary in designing 'system research'; there are not good answers yet for our questions about how to efficiently study individual factors which may limit yields and at the same time assure that they will fit into the most important systems in a region.

**Farming Systems Approach and Research Teams**

Much has been written about farming systems research and extension approaches over the past decade since the publication of a bulletin from Michigan State University (Gilbert et al., 1980). In spite of a number of successful applications of the many variants of this process, and the increased communication among researchers and extensionists and farmers, we are convinced that this approach is not a panacea. There are few easy answers to increasing productivity, especially where farmers have limited resources with which to work. There is interest at the moment in changing projects named "farming systems research" to a new catch phrase called "sustainable agricultural systems". Merely changing a name will not make a project more successful, nor more sustainable. Yet there are valuable steps in the FSR/E procedure which should be incorporated into many future projects, whatever the name of the approach. The communication with farmers, the participatory mode of identifying constraints and potential solutions, and the involvement of farmers in testing alternatives and evaluating results are important components which can be used in the study of intercropping systems. Recognition that women are important decision makers and implementers of cropping practices becomes a factor in the design of technological alternatives, and of the implementation of extension programs. Involvement of farmer groups that extend the research across a wider sub-set of farms in a recommendation domain would be especially valuable.

Organization and motivation of interdisciplinary teams have been important dimensions of the applied research agenda both in the international centers and in key national programs during the past two decades. The recognition that problems are complex, and that formal training in science prepares most of us to focus on small parts of the farming system, have encouraged the development of team approaches to research and extension. Although much remains to be done in designing efficient team research, to recognizing and rewarding individuals and teams, and to financing these efforts within our traditional departmental structures, this approach is a crucial one for progress in intercropping. We know that biological, economic, climatic, and social factors influence success of complex systems in the field -- it is important to take into account and even measure far more than just crop yield or net income from these systems. Interdisciplinary teams provide the technical expertise to accomplish these complex tasks.

**Potentials of Simulation Research**

There has been some speculation about the role of simulation in researching complex cropping systems (Barker and Francis, 1986). Computer simulation is possible when enough baseline data is available on the reaction of crops, both individually and in systems, to changes in the cropping environment. Modelling and simulation are complex processes, but their power is now available wherever a personal computer and relatively simple software can be found. This could be a time saving and resource efficient approach to testing large numbers of potential combinations of factors on the computer before committing time and energy in the field. This would be a way to evaluate new varieties, fertility levels, tillage or other practices under a wide range of climatic possibilities which are likely to occur in the field. From this, probabilities of success can be generated, and there can be validation of the best combinations in the field. Needless to say, the simulations will only be as good as the baseline data, the assumptions, and the creativity of those designing the new models or systems. This approach, and the related expert systems models, have found few applications to date in intercropping research and extension. This is one new direction for the future.
Conclusions

After several years of research on cropping systems and especially intercropping patterns, many of us are convinced that these systems hold one of the keys to increasing food productivity for limited resource farmers. There is difference in opinion on how to approach the critical research questions on components versus systems, on-farm versus on-station research, high-technology versus low-tech solutions, internal versus external resources, cash crops versus subsistence food crops. These questions are frequently confounded with decisions in research on intercropping systems. This is to be expected, since so many factors outside the biological world impact on the success of complex systems used by low-resource farmers. We do need to sort out these questions, to identify the important limiting constraints in each system and in each domain, and to decide which questions are researchable and capable of being resolved. It is important to think about setting research priorities, to seek efficient designs for field research, to consider extension and application of results before the actual field work is initiated, and to think creatively about approaches to improving intercropping systems. Agroecology and agroforestry (Altieri, 1983) are new areas which are receiving increased attention in research and extension. Biological interactions among crops, livestock, pest populations, and micro-organisms are becoming better understood. These are especially complex in an intercropping system, and biological principles can be used to better design new and more productive systems. More creative approaches to measuring system productivity are needed - ways to evaluate yield the same way that farmers evaluate success. This activity is not a simple one, and research on intercropping is likely to be one of the most challenging among the priority topics on our agenda for the next several decades.

Note of Acknowledgement:
The author wishes to thank these colleagues who sent reprints of recent papers or otherwise made suggestions about the topic of new innovations in research: Ray Weil (U Maryland), Louise Fortmann (U California Berkeley), Rattan Lal (Ohio State U), Matt Liebman (U Maine), Roger Mead (U Reading, U.K), Tom Scott (Cornell U), Kent Crookston (U Minnesota), Paula Bramel-Cox (Kansas State U), David Andrews (U Nebraska), Max Clegg (U Nebraska), John Sanders (Purdue U), Miguel Altieri (U California Berkeley), Eduardo Zaffaroni (U Federal da Paraiba, Brazil), Steve Gliessman (U California Santa Barbara), Fred Palmer (CIMMYT, Nairobi), Robert Cross (U Minnesota), Doug Carter (INTSORMIL, Gabarone, Botswana), Geoffrey Heinrich (ATIP, Francistown, Botswana), and others.

References


Table 1. Accelerating research on intercropping as illustrated by numbers of publications on 14 crops by 5-year period up to 1980 in ICRISAT resource lists (Francis, 1986).

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Cassava</td>
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<td>5</td>
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<td>1</td>
<td>4</td>
<td>25</td>
<td>44</td>
<td>84</td>
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<tr>
<td>Chickpea</td>
<td>1914</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>21</td>
<td>10</td>
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<td>23</td>
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<td>0</td>
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<td>14</td>
<td>28</td>
<td>38</td>
<td>133</td>
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<td>2</td>
<td>5</td>
<td>9</td>
<td>38</td>
<td>123</td>
<td>179</td>
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<td>Groundnut</td>
<td>1937</td>
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<td>17</td>
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<td>23</td>
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<td>1</td>
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<td>91</td>
<td>138</td>
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<td>1</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>34</td>
<td>35</td>
<td>86</td>
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<td>4</td>
<td>15</td>
<td>20</td>
<td>21</td>
<td>52</td>
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<td>1937</td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>31</td>
<td>20</td>
<td>53</td>
<td>108</td>
<td>227</td>
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<td>Sugarcane</td>
<td>1933</td>
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<td>7</td>
<td>6</td>
<td>18</td>
<td>16</td>
<td>53</td>
<td>40</td>
<td>142</td>
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<td>1929</td>
<td>9</td>
<td>4</td>
<td>11</td>
<td>50</td>
<td>22</td>
<td>30</td>
<td>43</td>
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<tr>
<td>Total</td>
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<td>42</td>
<td>85</td>
<td>196</td>
<td>163</td>
<td>440</td>
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</table>

Source: Dr. M.R. Rao, 1984 (unpublished)

Table 2. Probability of Two-Way Interactions, Importance of Interactions, and Priority Indices for Two-Way Interactions for Maize/Bean Intercrop Pattern in the Andean Zone (Parkhurst and Francis, 1986).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Bean variety</th>
<th>Maize variety</th>
<th>Fertiliser level</th>
<th>Herbicide mix</th>
<th>Spatial arrangement</th>
<th>Planting dates</th>
<th>Bean density</th>
<th>Bean density</th>
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<td>0.2</td>
<td>0.2</td>
<td>0.6</td>
<td>0.4</td>
<td>0.7</td>
<td>0.6</td>
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<td>Maize variety</td>
<td>7.2c</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Fertiliser level</td>
<td>0.6</td>
<td>1.8</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Herbicide mix</td>
<td>1.0</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.3</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Spatial arrangement</td>
<td>2.4</td>
<td>1.2</td>
<td>0.6</td>
<td>2.0</td>
<td>0.7</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Planting dates</td>
<td>3.2</td>
<td>1.8</td>
<td>0.2</td>
<td>1.8</td>
<td>4.9</td>
<td>0.6</td>
<td>0.7</td>
<td></td>
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<tr>
<td>Bean density</td>
<td>5.6</td>
<td>2.5</td>
<td>1.6</td>
<td>0.6</td>
<td>3.0</td>
<td>3.0</td>
<td>0.9</td>
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<tr>
<td>Maize density</td>
<td>5.4</td>
<td>4.8</td>
<td>2.4</td>
<td>1.2</td>
<td>2.4</td>
<td>2.1</td>
<td>5.4</td>
<td></td>
</tr>
</tbody>
</table>

* Probability that two-way interaction exists.

† Influence ranking: Importance of Interaction in intercrop success.

‡ Priority Indices for two-way interactions.

Source: Data from Parkhurst and Francis (1984b).

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
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<tr>
<td>Var B x Var M</td>
<td>0.2&lt;sup&gt;a&lt;/sup&gt;/0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.1/3</td>
<td>0.6/5</td>
<td>0.4/5</td>
<td>0.3/4</td>
<td>0.4/5</td>
</tr>
<tr>
<td>Var B x Fert</td>
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<td>0.1/1</td>
<td>0.2/2</td>
<td>0.1/3</td>
<td>0.2/2</td>
<td>0.2/2</td>
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<tr>
<td>Var B x Herb</td>
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<td>0.1</td>
<td>0.2/3</td>
<td>0.2/3</td>
<td>0.1/2</td>
<td>0.2/2</td>
</tr>
<tr>
<td>Var B x Spat</td>
<td>3.0</td>
<td>0.4</td>
<td>0.6</td>
<td>0.3/2</td>
<td>0.3/2</td>
<td>0.4/3</td>
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<tr>
<td>Var B x Pl. Dt.</td>
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<td>0.6</td>
<td>0.6</td>
<td>0.2/4</td>
<td>0.2/4</td>
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<td>0.2</td>
<td>0.6</td>
<td>0.8</td>
<td>0.3/3</td>
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<tr>
<td>Var B x Dns M</td>
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<td>0.4</td>
<td>0.4</td>
<td>1.2</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Var M x Fert</td>
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<td>0.1/3</td>
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<td>0.2/3</td>
<td>0.3/4</td>
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<tr>
<td>Var M x Herb</td>
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<td>0.2/3</td>
<td>0.3/3</td>
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<td></td>
</tr>
<tr>
<td>Var M x Spat</td>
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<td>0.9</td>
<td>0.2/3</td>
<td>0.3/3</td>
<td></td>
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<tr>
<td>Var M x Pl. Dt.</td>
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<td>0.2/3</td>
<td>0.3/3</td>
<td>0.3/3</td>
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</tr>
<tr>
<td>Var M x Dns B</td>
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<td>0.4</td>
<td>0.8</td>
<td>0.6</td>
<td>0.2/3</td>
<td></td>
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<tr>
<td>Var M x Dns M</td>
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<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
<td>0.6</td>
<td></td>
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<tr>
<td>Fert x Herb</td>
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<td>0.1/3</td>
<td>0.2/3</td>
<td>0.2/3</td>
<td>0.2/2</td>
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<tr>
<td>Fert x Spat</td>
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<td>0.6</td>
<td>0.3/2</td>
<td>0.3/3</td>
<td>0.3/3</td>
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</tr>
<tr>
<td>Fert x Pl. Dt.</td>
<td>0.4</td>
<td>0.4</td>
<td>0.9</td>
<td>0.4/4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fert x Dns B</td>
<td>0.4</td>
<td>0.4</td>
<td>0.9</td>
<td>1.6</td>
<td></td>
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</tr>
<tr>
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<td>0.4</td>
<td>0.9</td>
<td>1.6</td>
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<td></td>
</tr>
<tr>
<td>Herb x Spat</td>
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<td>0.3/3</td>
<td>0.2/2</td>
<td>0.2/2</td>
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<td></td>
</tr>
<tr>
<td>Herb x Pl. Dt.</td>
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<td>0.4</td>
<td>0.6</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herb x Dns B</td>
<td>0.4</td>
<td>0.6</td>
<td>0.2/3</td>
<td>0.3/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herb x Dns M</td>
<td>0.4</td>
<td>0.6</td>
<td>0.2/3</td>
<td>0.3/3</td>
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<td></td>
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<tr>
<td>Spat x Pl. Dt.</td>
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<td>0.3/3</td>
<td>0.2/3</td>
<td>0.3/3</td>
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<tr>
<td>Spat x Dns B</td>
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<td>Spat x Dns M</td>
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<tr>
<td>Pl.Dt. x Dns B</td>
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<tr>
<td>Pl.Dt. x Dns M</td>
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</table>

* Probability that three-way interaction exists.
* Influence ranking: Importance of interaction in intercrop success.
* Priority indices for three-way interactions.


<table>
<thead>
<tr>
<th>Interaction</th>
<th>Probability of occurrence</th>
<th>Influence ranking</th>
<th>Priority Index</th>
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<td>Var B x Var M x Dns B x Dns M</td>
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<td>5</td>
<td>1.5</td>
</tr>
<tr>
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<td>5</td>
<td>1.0</td>
</tr>
<tr>
<td>Var B x Var M x Spat Arr x Dns M</td>
<td>0.2</td>
<td>5</td>
<td>1.0</td>
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<tr>
<td>Var B x Spat Arr x Pl. Dt. x Dns B</td>
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<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>Var B x Spat Arr x Dns B x Dns M</td>
<td>0.4</td>
<td>3</td>
<td>1.2</td>
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<td>Spat Arr x Pl. Dt. x Dns B x Dns M</td>
<td>0.5</td>
<td>2</td>
<td>1.0</td>
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</table>
Table 5. Comparison of Three Designs for Several Levels of Eight Factors in Maize/Bean Intercrop Pattern (Parkhurst and Francis, 1986).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
<th>Factor</th>
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<tr>
<td>Bean varieties</td>
<td>4</td>
<td>Bean densities</td>
<td>6</td>
</tr>
<tr>
<td>Maize varieties</td>
<td>3</td>
<td>Maize densities</td>
<td>8</td>
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<tr>
<td>Fertility levels</td>
<td>3</td>
<td>Spatial arrangement</td>
<td>4</td>
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<td>Herbicide mixtures</td>
<td>3</td>
<td>Planting dates</td>
<td>3</td>
</tr>
</tbody>
</table>

**Option I:** Complete factorial \((4 \times 3 \times 3 \times 3 \times 6 \times 8 \times 4 \times 3)\)
- Treatment combinations: 62,208
- Size of experiment: 684,288 m\(^2\) or 68 ha

**Option II:** Fractional replication \((3^4)\) factorial \(1/3\) replicate
- Treatment combinations: 6561
- Size of experiment: 72,171 m\(^2\) or 7 ha

**Option III:** Eight small experiments
1. Maize (2) bean (2) varieties and maize (2) bean (2) densities split-plot with maize variety/density as whole plot treatment combinations and bean variety/density as subplots with whole plots in randomized complete blocks (2 replications), RCB.
   - Treatment combinations: 16
2. Bean varieties (2), spatial arrangement (4) and maize (2)/bean (2) densities. Factorial treatment design in RCB.
   - Treatment combinations: 32
3. Bean varieties (2), densities (3), spatial arrangements (4), and planting dates (3). Factorial treatment design in RCB.
   - Treatment combinations: 72
4. Maize varieties (2), spatial arrangements (4), and planting dates (3). Factorial treatment design in RCB.
   - Treatment combinations: 24
5. Maize (3)/bean (3) densities and fertility (3), split plot in RCB with fertilizer as whole plot, maize density as subplot.
   - Treatment combinations: 27
6. Variety trial for maize (8) and bean (6), split plot in RCB with maize variety as whole plot and bean variety as subplot.
   - Treatment combinations: 48
7. Spatial arrangement (4) and herbicides (3). Factorial treatment combinations in RCB.
   - Treatment combinations: 12
8. Maize density (3) and planting date (3). Factorial treatment combinations in RCB.
   - Treatment combinations: 9

Total treatment combinations: 240
- Size of experiments: 3120 m\(^2\) or \(1/3\) ha with 30 percent borders

Note: Minimum replications: 2. Minimum plot size is 5 m\(^2\) plus 10 percent borders; option III has 30 percent borders.

Source: Adapted from Parkhurst and Francis, 1984b.
Figure 1. Ratio of population-supporting capacity to actual population density, 1975.
Source: OTA (1984)

Figure 2. Expected interactions between pairs of factors in a two-crop pattern, maize (M) and bean (B).
Introduction

Malawi is divided into eight Agricultural Development Divisions (A.D.D.s) under the umbrella of the National Rural Development Programme (NRDP). The aims of NRDP are:

a) To increase the general level of Malawi smallholder agricultural production, and in particular the production of cash crops for export, the agro-industries and the production of food crops to sustain self-sufficiency and for feeding the growing urban population.

b) To provide the inputs and services necessary to allow smallholder production increases with particular emphasis on productivity per unit area.

c) To preserve natural resources.

The cropping pattern in Malawi is dominated by maize (the major staple food for the majority of Malawians) and maize mixtures. Other major smallholder crops include groundnuts, pulses, cassava, millet, tobacco and cotton.

Intercropping in Malawi

Intercropping is a common feature in Malawian agriculture and this takes different forms. Some farmers grow two or more crops simultaneously in rows while others grow intercrops without distinct row arrangements. The percentages of the common cropping mixtures found in Malawi are shown in Table 1.

Table 2 shows mean yields obtained from maize mixed with other crops. Maize yields are higher when maize is intercropped with pulses.

Intercropping has other advantages. In a survey conducted by Liwonde A.D.D. in 1984/85 the farmers interviewed gave the following reasons for intercropping:

a) Land scarcity or better utilization of land
b) Better utilization of land
Food security

Another advantage could be conservation of the soil. Certain crop mixtures conserve the soil better than sole cropping. In addition to this some intercropping systems may help to maintain or improve the fertility of the soil.

On the other hand some intercropping systems encourage competition between crops for nutrients, light etc., encourage soil erosion, reduce plant population and render cultivation practices difficult. There is therefore a need to carry out research to find suitable recommendations.

Intercropping Trends

For a very long time, the Ministry of Agriculture in Malawi has recommended the growing of crops in pure stands. As a result of this there has been some decline in the area planted to mixtures as shown in Table 3 below. This was especially so because of the introduction and adoption of improved varieties of maize such as hybrids and composites.

In spite of the above interventions many farmers still intercrop local maize with other crops, especially legumes. This is an indication that farmers make decisions on the practices they will use. Most of the practices they develop have been rationalized and therefore a careful study of their circumstances must be undertaken before new interventions are introduced.

The Ministry of Agriculture now encourages interplanting maize with legumes but there are no specific recommendations which the extension staff can take to the farmers with regard to crops to be intercropped, time of planting, spatial arrangement and fertilizer application. Demonstrations at farmer training centers and in the villages still carry pure stands of crops. Therefore there is a need for research leading to specific recommendations on intercropping.

Conclusions

The discussion above tells us that there is need to study and understand why a farmer carries out certain practices otherwise our recommendations may be of very little value to him. Failure to understand farmers' circumstances is the main cause of low or non-adoption.

We have also learned from the above that a lot of benefits can be derived from intercropping systems such as a maize/pulses mixture but at present we lack information regarding time of planting, what crop to inter-plant, spatial arrangement, varieties and fertilizer application. As a result the extension staff in Malawi have no specific messages on intercrops for the farmers. Research should therefore look into these issues and derive appropriate intercropping technologies. Extension staff should demonstrate intercropping at farmer training centers and in the villages.

In this way we should be able to meet some of the aims of the National Rural Development Programme.
References


Table 1. The percentages of the common cropping mixtures found in Malawi.

<table>
<thead>
<tr>
<th>Crop Mix</th>
<th>Malawi</th>
<th>Karonga</th>
<th>Mzuzu</th>
<th>Kasungu</th>
<th>Salima</th>
<th>Lilongwe</th>
<th>Liwonde</th>
<th>Blantyre</th>
<th>Ngabu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize/groundnuts</td>
<td>4.0</td>
<td>2.6</td>
<td>2.0</td>
<td>1.1</td>
<td>2.7</td>
<td>4.0</td>
<td>9.4</td>
<td>5.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Maize/pulses</td>
<td>7.8</td>
<td>9.2</td>
<td>10.0</td>
<td>3.8</td>
<td>0.2</td>
<td>11.2</td>
<td>5.0</td>
<td>15.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Maize/cassava</td>
<td>1.0</td>
<td>2.9</td>
<td>0.5</td>
<td>-</td>
<td>0.4</td>
<td>0.1</td>
<td>3.5</td>
<td>1.9</td>
<td>-</td>
</tr>
<tr>
<td>Maize/other</td>
<td>2.4</td>
<td>2.1</td>
<td>0.9</td>
<td>0.1</td>
<td>1.3</td>
<td>1.9</td>
<td>3.0</td>
<td>6.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Millet/sorghum</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>11.5</td>
</tr>
<tr>
<td>Other mixtures</td>
<td>0.6</td>
<td>1.4</td>
<td>0.5</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.6</td>
<td>1.7</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Source: National Sample Survey of Agriculture 1980/81
Government Printer, Zomba, Malawi

Table 2. Mean Yields By Crop Mixture (kg/ha).

<table>
<thead>
<tr>
<th>Crop Mixture</th>
<th>Malawi</th>
<th>Karonga</th>
<th>Mzuzu</th>
<th>Kasungu</th>
<th>Salima</th>
<th>Lilongwe</th>
<th>Liwonde</th>
<th>Blantyre</th>
<th>Ngabu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize mixed with:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundnuts</td>
<td>923</td>
<td>1375</td>
<td>676</td>
<td>581</td>
<td>1262</td>
<td>762</td>
<td>942</td>
<td>1033</td>
<td>-</td>
</tr>
<tr>
<td>Pulses</td>
<td>1202</td>
<td>1488</td>
<td>1301</td>
<td>1528</td>
<td>591</td>
<td>1347</td>
<td>904</td>
<td>1131</td>
<td>-</td>
</tr>
<tr>
<td>Cassava</td>
<td>855</td>
<td>793</td>
<td>912</td>
<td>-</td>
<td>530</td>
<td>-870</td>
<td>876</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>941</td>
<td>966</td>
<td>717</td>
<td>1233</td>
<td>894</td>
<td>1296</td>
<td>914</td>
<td>867</td>
<td>891</td>
</tr>
</tbody>
</table>

Source: National Sample Survey of Agriculture 1980/81
Government Printer, Zomba, Malawi

Table 3. Cropping pattern for maize and groundnuts.

<table>
<thead>
<tr>
<th>Crop</th>
<th>1968/69 ('000 ha)</th>
<th>1980/81 ('000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1068.0</td>
<td>969.6</td>
</tr>
<tr>
<td>Pure Stand</td>
<td>66.7</td>
<td>768.0</td>
</tr>
<tr>
<td>Mixed Stand</td>
<td>999.3</td>
<td>201.6</td>
</tr>
<tr>
<td>Groundnuts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>449.3</td>
<td>168.4</td>
</tr>
<tr>
<td>Pure Stand</td>
<td>43.5</td>
<td>135.5</td>
</tr>
<tr>
<td>Mixed Stand</td>
<td>405.8</td>
<td>52.9</td>
</tr>
</tbody>
</table>

The Role of Diagnosis

There are two main roles for a diagnosis:

1) To describe the cropping system.
   - Natural and economic circumstances
   - Cropping patterns
   - Farmer resource base

2) To understand management compromises and shortcomings in the light of circumstances, resources and objectives.

Methods/Tools for Diagnosis

The main methods are:
- Secondary data
- Informal survey
- Formal survey
- Monitoring
- Experimentation

Each of these methods has a place but as we go down the list:

a) The subject matter becomes more focused
b) The time or resource requirement increases

CIMMYT diagnostic methodology tends to focus quickly onto major production problem areas through informal surveying. The informal survey is the major method used to gain an initial holistic understanding of the system and then allow focusing. But the reason for focusing on the selected items is based on a holistic understanding of the system. Evaluation of the results is also based on a system-wide understanding.

In a diagnosis of intercropping, emphasis should be placed on the farmers’ objectives for intercropping. An informal survey is the best diagnostic tool to obtain the reasons behind farmers’ choices of plant mixtures, spatial arrangements, planting times etc. The content of most on-farm trial programmes in the region has been developed from informal survey findings. To date formal surveys or monitoring work have had relatively little influence on trial content or design.
Introduction

On-farm research is sometimes confused with research on multiple cropping. Although the two overlap, they are different. On-farm research usually works on stepwise modifications to existing farming systems, starting from an understanding of farmers' circumstances, practices, problems and objectives. The existing farming systems are often, but not always, multiple cropping systems. Multiple cropping research has often been conducted on experiment stations with the aim of proving or understanding the efficiency of multiple cropping systems, or of designing new systems on the basis of biological principles. More multiple cropping research should be conducted on-farm, and much should aim to offer farmers improvements of existing systems. Recent results on maize + beans intercrops show that experiment station trials may make poor predictions of the best varieties, fertilizer rates and application methods, population densities and, sometimes, disease control techniques (Woolley et al. 1989).

The link between diagnosis -- that is, understanding farmers' circumstances, practices, problems and objectives -- and planning research is perhaps the most important and the most difficult to achieve in on-farm research.

Farmers' objectives

A brief special mention is justified. Smallholder farmers of limited resources may have objectives other than maximum monetary return per hectare. Some combination of risk avoidance, obtaining several products from the farm and obtaining high returns is likely. Returns may be measured by the farmer per unit of labour, land, monetary investment or per kg of seed planted. In the particular case of farmers who grow intercrops, the objective may be maximum returns, counting all crops, or there may be a minimum necessary yield of one crop (especially, perhaps the main food crop) which the farmer will not sacrifice. Intermediate cases are possible in which one crop is more important, but yield might be sacrificed in return for valuable increases in the production of the other crops.

Diagnosis

General aspects of diagnosis in on-farm research are given by Low in these proceedings and in other publications (Byerlee and Collinson, 1980). In summary the aims of diagnosis are:

* To describe farmers' practices
* To identify farmers' problems
* To test hypotheses about the causes of problems
* To understand farmers' circumstances (resources, preferences, etc.) so as to evaluate possible solutions.

Initial diagnosis, before trials start, often includes an informal survey, followed by a formal survey to complement it (Table 1). Diagnosis continues while trials are run. It may use trials themselves, field sampling of plants or soil and interviews with farmers. Some examples of additional diagnosis are:

* Interviews with farmers to find out why they fertilize their maize at four weeks and not at planting.
* Interviews with farmers and middlemen about the quality and problems of stored grain, supplemented by inspections of storage structures and sampling of stored grain.

Planning On-Farm Research

Tripp and Woolley (1989) proposed six steps for the first part of the planning process. This part starts from a list of problems and produces lists of factors for on-farm experimentation and further diagnosis as well as suggestions for longer-term research and the institutional support needed (input availability, credit, special extension effort) if the proposed solutions are to have a chance of success. The steps pass through a sequence of problem-cause-solution (Fig. 1). Possible solutions should be identified according to the causes of a problem, not the problem itself. For example, in part of the state of Jalisco, Mexico, researchers at INIFAP, the national agricultural research institution, found a problem of patchy stand loss in bean fields. Many causes were hypothesized which were compatible with what was known about the area: poor soil preparation, insect damage, soil erosion, poor covering of the seeds, soil crusting, Fusarium root rots and blocking of the mechanical seeder. Each cause would have led to a different solution being investigated. Rotations to control root rots would have been an illogical solution if the patches were primarily caused by soil crusting. In this case, experimentation and observation was necessary to eliminate some of the hypothetical causes before experimenting with solutions.
Woolley (1987) has tentatively outlined the second part of the planning process through four further steps which group priority factors into on-farm trials (Table 2).

Examples of planning on-farm research in multiple cropping systems

I have chosen four examples which illustrate the connection of diagnostic information and planning in intercrops, relays and rotations. Because of the biases in my own experience, three deal with maize-bean systems in Latin America.

Early-maturing maize for a maize-bean relay in Mexico

In the La Fraylesca region of Chiapas state, Mexico, farmers plant bush beans in relay with maize when maize reaches physiological maturity. Because of the rainfall pattern, beans often receive insufficient water during flowering and pod-filling (Fig. 2). By interviewing farmers and through the researchers' local knowledge, an INIFAP on-farm research project identified the chain of causes behind this problem (Fig. 3). Some causes (e.g. the low water retention capacity of the soil) appeared costly to solve; others had possible solutions (Table 3). Woolley and Smith (1986) had shown in Costa Rica that by using less-leafy maize varieties, which did not shade beans so much, it was possible to obtain more bean yield under end-of-season drought by advancing bean planting 20 days before maize maturity (Table 4). The less-leafy maize varieties they used yielded less than the leafy ones. Fortunately, in Mexico, an early maize variety (V-424) was available which yielded similarly to farmers' maize (V-524, derived from "Tuxpeno"). Trials were therefore planted on three farms with the 2 maize varieties, 2 bean varieties (the farmers' and an earlier one) and 3 bean planting dates (the typical farmers' date and 10 and 20 days earlier). As hoped, V-424 permitted more bean yield than V-524 did in the earliest planting date and yielded as much maize. The earlier bean variety yielded a little more. The trials are being repeated, including an additional planting date 30 days earlier than farmers.

Increasing the population density of beans in a bean + maize mixed crop in Colombia

The next two examples come from an on-farm research project between ICA, the Colombian national agricultural research institute, and CIAT in the Ipiales district of southern Colombia. The area and the results up to 1986 are described in more detail by Woolley et al. (1988).

In Ipiales, an initial simple diagnosis with 45 farmers was conducted in 1982, and was repeated with 27 farmers during the first year of trials. One of the problems identified was that farmers could not plant densities above 2 plants/m² of their local climbing bean because it was very aggressive and caused maize lodging and also because its thick growth interfered with chemical spraying used by farmers to control anthracnose disease on the foliage. A proposed solution was to use a less-vigorous climbing bean, thus allowing higher densities. The less aggressive variety had several other desirable characteristics: higher yield potential, greater disease tolerance and apparent market acceptability. The first attempts at increasing bean density without increasing maize density made economic sense, but were rejected by farmers when verified in larger plots, because they feared increased maize lodging and anticipated difficulties in spraying (Table 5). Less drastic changes in spacing were proposed, verified and tested semi-commercially. Farmers do appear to be increasing bean densities, but curiously they are doing it by reducing between-row spacing, which researchers had thought would be hard to change.

Intensifying a bean + maize mixed crop in Colombia

Another of the problems identified by researchers in Ipiales was that the bean + maize crop occupied virtually the whole agricultural year (mean temperature is 11°C and the crops take 8-11 months to mature). It was proposed to seek a well-balanced combination of early climbing beans + early maize and to include a short season crop afterwards. It took four years to identify a properly balanced contribution (Table 6). Meanwhile, interviews with farmers indicated that barley or potatoes would be the preferred short season third crop. Some farmers indicated that being able to harvest maize + beans earlier was a benefit, and they would not necessarily expect to get a third crop. Although Ipiales specializes in growing climbing beans, rather than bush beans, farmers expressed interest in the earliness of bush beans which they had seen in other trials. These various possibilities were included in trials in the fifth year. Early beans + early maize-barley and bush beans-barley gave the same net benefit, but the latter was more costly, mainly because of the higher seed rates for bush beans (Table 7).

The interactions of teff and beans in Ethiopia

The staple crop teff is grown in separate fields from beans in many parts of Ethiopia. However, as Kirkby (1986) has discussed, the reason that bean yields are low is that labour is directed to weeding teff and beans are left unweeded (Fig. 4). Thus, a way to improve bean yields would be to find less labour-intensive methods of weeding teff (or to identify beans which compete well with weeds.)
Conclusion

The examples are intended to illustrate a number of points: the need to understand farmers' practices in order to identify causes and propose solutions; the need to look behind the obvious causes to the underlying causes of a problem, in order to find research opportunities; the use of additional diagnosis during farm trials; the way crops affect each other even when their periods of growth do not overlap, or when they are planted in different fields.

Acknowledgement

I am grateful to Ing. Bernardo Villar of INIFAP, Chiapas, Mexico, for sharing the details of his research.

References

Byerlee, D. and M. Collinson (1980). Planning technologies appropriate to farmers; concepts and procedures. CIMMYT, Mexico, D.F.


Table 1. Relationship between informal and formal surveys.

<table>
<thead>
<tr>
<th>Informal survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Confirm that the cropping system of interest is susceptible to change</td>
</tr>
<tr>
<td>* Identify tentative recommendation domains</td>
</tr>
<tr>
<td>* Initial list of problems and hypotheses about their causes</td>
</tr>
<tr>
<td>* Understand farmers' objectives</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Formal survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Confirm tentative domains</td>
</tr>
<tr>
<td>* Quantify practices</td>
</tr>
<tr>
<td>* Quantify problems</td>
</tr>
<tr>
<td>* Reject some hypotheses about causes</td>
</tr>
<tr>
<td>* Quantify farmers' objectives</td>
</tr>
</tbody>
</table>

Table 2. The planning process (second part) grouping factors in trials.

| * Identify the appropriate stage of research for priority factors and probable interactions with other factors |
| * Group factors in trials                                                      |
| * Adjust proposed activities (trials, additional diagnosis) to the available resources |
| * Define the experimental design, treatments and management of each trial     |
Table 3. Possible solutions to drought stress on beans. La Fraylesca, Mexico.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Possible solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers use long-season maize which yields more</td>
<td>Early maturing, high yield maize variety</td>
</tr>
<tr>
<td>Farmers’ maize overshadows beans</td>
<td>Use less-leafy maize and plant beans before</td>
</tr>
<tr>
<td></td>
<td>maize physiological maturity</td>
</tr>
<tr>
<td>Farmers use 75-day bean variety</td>
<td>Use earlier bean variety</td>
</tr>
</tbody>
</table>

Table 4. Advancing the planting date of beans with different maize plant types.

<table>
<thead>
<tr>
<th>Maize plant type</th>
<th>Yield of beans planted at maize maturity (t/ha)</th>
<th>Yield of beans planted 20 days before maize maturity (t/ha)</th>
<th>Maize yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leafy</td>
<td>1.01</td>
<td>0.96</td>
<td>3.29</td>
</tr>
<tr>
<td>Less leafy</td>
<td>1.09</td>
<td>1.31</td>
<td>2.67</td>
</tr>
<tr>
<td>No maize (bean sole crop)</td>
<td>0.90</td>
<td>1.42</td>
<td>_</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>0.11</td>
<td>0.11</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Mean of 2 years' data, Turrialba, Costa Rica, from Woolley & Smith, 1986.

Table 5. Increasing population density for beans in Ipiales, Colombia.

<table>
<thead>
<tr>
<th>Most common farmers' practice (surveys 1982 &amp; 1983)</th>
<th>4M2B at 1m x 1m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1982</td>
<td>2M2B at 1m x 0.5m successful in relay system elsewhere in Colombia</td>
</tr>
<tr>
<td>1982/83</td>
<td>2M2B at 1m x 0.5m increased maize yield, bean yield and net benefit (6 exploratory trials)</td>
</tr>
<tr>
<td>1983/84</td>
<td>Verified in 14 trials (worked for traditional variety as well as less aggressive one). Farmers liked until harvest but then rejected.</td>
</tr>
<tr>
<td>1984/85</td>
<td>Tested alternative spacings within row (0.5, 0.65, 0.8, 1.0m). Farmers regarded 0.8m as “not different from 1.0m”. 3M3B at 0.8m best economically (4 alternative trials).</td>
</tr>
<tr>
<td>1985/86</td>
<td>Verified in 15 trials.</td>
</tr>
<tr>
<td>1986/87</td>
<td>3M3B at 0.8m in 10 semi-commercial trials run by farmers. 3M4B at 0.8m discarded in verification.</td>
</tr>
<tr>
<td>1987/88</td>
<td>In group diagnosis, farmers say they are already reducing distances between rows.</td>
</tr>
</tbody>
</table>
Table 6. Intensifying the maize and bean system in Ipiiales.

<table>
<thead>
<tr>
<th>Previous information</th>
<th>Balance of vigor M + B associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informal and formal survey (52 farmers)</td>
<td>Long cycle of maize and beans identified by researchers as problem.</td>
</tr>
<tr>
<td>Planning: Year 1</td>
<td>Early, less vigorous beans known, but not suitable for early maize.</td>
</tr>
<tr>
<td>Trial: Year 1</td>
<td>Identified early maize, but beans unstable.</td>
</tr>
<tr>
<td>Trial: Year 2</td>
<td>New bean not early enough and too vigorous for maize.</td>
</tr>
<tr>
<td>Special study Year 2 (15 farmers)</td>
<td>Farmers interested in early M+B, for barley or potato 2nd crop or earlier harvest.</td>
</tr>
<tr>
<td>Trial: Year 3</td>
<td>New Bean &quot;L32983&quot; early enough but maize proved unstable in dry years. Bush bean-barley rotation tested.</td>
</tr>
<tr>
<td>Trial: Year 4</td>
<td>Trial of early maize from 3 countries identifies &quot;Pool 5&quot;.</td>
</tr>
<tr>
<td>Trial: Year 5</td>
<td>Trial of various combinations with active farmer evaluation.</td>
</tr>
</tbody>
</table>

Table 7. Intensification trial, Ipiiales 1986-87. Mean of four farmers.

<table>
<thead>
<tr>
<th>Maize cultivar</th>
<th>Bean cultivar</th>
<th>Barley Included</th>
<th>Yield (kg/ha)</th>
<th>Costs that Vary (thousand pesos/ha)</th>
<th>Net Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers'</td>
<td>Farmers'</td>
<td>No</td>
<td>1604 143</td>
<td>13.6</td>
<td>171</td>
</tr>
<tr>
<td>Farmers'</td>
<td>Frijolica 0-3.2</td>
<td>No</td>
<td>1558 471</td>
<td>16.6</td>
<td>216</td>
</tr>
<tr>
<td>Pool 7</td>
<td>TIB 30-42</td>
<td>No</td>
<td>1619 640</td>
<td>13.3</td>
<td>231</td>
</tr>
<tr>
<td>Pool 5</td>
<td>L 32983 after</td>
<td></td>
<td>2017 369 2986</td>
<td>59.5</td>
<td>355</td>
</tr>
<tr>
<td>None</td>
<td>Antioquia 8 after</td>
<td></td>
<td>999 4168</td>
<td>70.6</td>
<td>357</td>
</tr>
<tr>
<td>LSD(10%)</td>
<td></td>
<td></td>
<td>314 172</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Steps in the planning process

1. Identify problems
2. Rank problems
3. Identify causes
4. Analyze interrelations among problems and causes
5. Identify solutions
6. Evaluate solutions

- List A: Factors for experimentation
- List B: Other diagnostic activities
- List C: Longer term research
- List D: Institutional support

Further evidence required to identify or evaluate problems
Further evidence required to determine causes of problems
Figure 2. Crop cycle and mean monthly precipitation, La Fraylesca, Mexico.

Maize cannot be planted until it rains mid-May. Low water retention capacity of soil.

Bean planted mid-September.

Farmers use long-season maize which yields more.

Beans not planted until maize is mature and doubled.

Maize is main crop.

Farmers' maize overshadows beans unless doubled.

Figure 3. Causes of drought-stress on beans in a maize-bean relay, La Fraylesca, Mexico.
Figure 4. The Staple tef affects other crops in the Ethiopian highlands (adapted from Kirkby, 1986)
Elements of an Integrated Intercropping Research Program

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Introduction

This paper will focus on program development of intercropping research, at the level of the researchers who will actually conduct the experiments. Because of the authors' interests, examples will largely be drawn from situations where the cereal maize is intercropped with beans (Phaseolus vulgaris) and other legumes.

Maize-Bean cropping systems in eastern and southern Africa include simultaneous intercropping, relay intercropping and double cropping. In most cases maize is the dominant crop and yield of maize is expected to be little changed in the intercrop situation. Therefore in many situations the secondary crop is a bonus. However, in parts of Uganda farmers use very low maize densities in their maize-bean intercrops because the beans are of primary concern. Sole crop maize is most commonly grown in areas where high levels of inputs are utilized.

Maize-bean intercropping research in eastern and southern Africa has increased considerably in the last 15 years but often in the form of isolated experiments with limited objectives, within commodity programs and generally on-station. Awareness of intercropping research was promoted within this region by two workshops in Tanzania (Monyo et al. 1976; Keswani and Ndunguru, 1982). Also, the teaching manual by Davis and Smithson (1986) has provided valuable background information for researchers new to intercropping. In view of the persistence of intercropping systems in the region, improvement of the existing intercropping patterns should be an important strategy in the short and mid-term context. Most small farmers will be unable to make the jump to high input and more risky sole crop production in the foreseeable future.

The accepted advantages of intercropping (e.g. spreading risk, weed control, pest control, etc.) may not manifest themselves in all seasons, e.g. pest avoidance is not important in years when the pest is absent. So, the advantages of intercropping are not always evident as was described in Kenya by Fisher (1977).

The Various Levels of Research Program Formulation

The general aspects of program formulation are similar for all research activities including intercropping research. In a recent publication of ISNAR, Dagg and Haworth (1988) discuss three levels of program formulation in National Agricultural Research Systems (NARS) as follows:

Level 1 -- at the policy level: decisions on broad priorities and allocations of resources with respect to commodities, production factors, regions, etc.;

Level 2 -- at the research institution level: decisions on long-term research plans within a commodity or factor (and at the program leader level: choices concerning medium- to short-term programs);

Level 3 -- at the research station level: discussions on the choice of experiments and studies in the annual program of work for the coming year.

In their paper, Dagg and Haworth define "program" as the collection or aggregation of the individual experiments, studies and activities that researchers will carry out in order to obtain the information and materials that are required by clients. Rather than use the word program, they coin the acronym PRESA for "Program of Research Experiments, Studies and Activities". So, each national PRESA will be made up of institutional, station, departmental and sectional PRESAs. A few individuals in this workshop will operate at the institutional level but most of the group operate at the station or within-station levels.

In this workshop we are concerned with cereal and legume intercropping as a "commodity" if you wish. We shall assume that at the policy level it has been decided that the improvement of traditional cereal/legume intercropping systems has been identified as an important priority. It is then up to the researchers at the research station level to develop a PRESA for cereal/legume intercropping. To quote from Dagg and Haworth: "Whatever happens at higher levels of planning, the annual research PRESA that is implemented always consists of the aggregation of experiments and studies proposed by individual researchers and their team leaders, and duly approved by senior reviewing groups. It is important to recognize that in the final analysis, this growth of the program is a bottom-up process, and there will always be enough proposals to match the research resources available. Whether or not these proposals are the most relevant to national objectives depends critically on the top-down guidance given to researchers and team leaders on priority areas for research and criteria for choosing alternatives. These issues are extremely important in focusing choices with respect to highly relevant and sensitive experiments and studies, and it is unfortunate that such clear guidance from higher levels of management is often lacking. In such circumstances it is difficult to ensure that the various research proposals, taken together, constitute a package that is even reasonably relevant to national objectives, even if the experiments are technically of a high quality. Primary responsibility for assuring that the national research program
is relevant to national needs rests with higher levels of research management, not with the researcher. (However, the researcher must appreciate the relevance of his/her work to the solution of major problems of national development, and must be ready to make important technical advisory contributions to program planning and priority setting at higher levels).

In practical terms, however, national priorities are most likely to be communicated in terms of relative importance of various crops without specifying the systems within which they are grown by farmers. Information on the systems will come from the bottom-up process.

Special Considerations When Dealing With Intercropping Research

Organizational aspects
We are all familiar with national coordinated commodity research programs (for maize, beans, wheat, etc.). These can be quite complex to coordinate because a number of institutions may be involved, and within institutions several experiment stations, and within experiment stations several disciplinary groups e.g. breeding, agronomy, physiology, pathology, entomology, soils, economics etc. If we consider research into intercropping, we have all the above actors in the research program but related to the two or more crop components in the intercropping system in question.

The commodity-based organization of most National Agricultural Research Systems (NARS) may pose an institutional limitation to the effective implementation of intercropping research, and one that requires special institutional management. However, institutionalizing intercropping as a separate research program or department would often increase administrative costs without removing the need for some cross-program coordination. Simpler methods for achieving similar results through existing programs may well be preferable. The formation of across-program teams or informal working groups presents an intermediate solution. The composition of such working groups could vary with the range of the predominant systems being improved. Good inspiring leadership, important in all research programs, would be especially important in drawing together researchers of the various disciplines involved in intercropping research in a manner that proves compatible with the goals of the commodity programs and their leaders.

Setting research priorities
The research program should follow the well established sequence of activities including diagnosis, planning, experimentation, evaluation and replanning, and dissemination.

The diagnostic phase will have a survey component as well as an experimental component and is continuous. National and international agricultural production statistical reports frequently overlook or underestimate the importance of legumes hidden under a cereal canopy. Both commodity-specific surveys and even the FAO Yearbook often provide inadequate detail on associated crops. Hence diagnostic surveys in areas where intercropping is prevalent need to be conducted very carefully and timing may be important to verify the presence of the intercrop which may be of short duration. There may be little or no trace of it at harvest of the dominant crop.

Diagnostic surveys of the farming systems of an area normally require collaboration among commodity research programs. The surveys should be conducted in collaboration with a farming systems research program if it exists and should involve social scientists, but its execution should not be completely delegated by commodity programs to the FSR program.

Even the best surveys are likely to need follow-up exploratory research to capture all the reasons underlying farmers’ use of a particular intercropping pattern in an area. This is due to the complexity of the patterns and to their dynamics. In West Africa, farmers carefully manage the complex interaction among land types (dry upper slopes, moist lower slopes and wetter valley bottoms in a toposequence), cropping patterns and cultural practices (Stoop, 1986). While maize predominates on wetter valley bottom soils, sorghum/cowpea intercropping is most common on the slopes, with planting densities and other intercrop management practices varying with reduced soil moisture as one moves up the toposequence. Trials with newer varieties confirmed this effect of soil changes over a short distance within a farm.

Our understanding of many common systems is still limited by lack of adequate diagnosis. Many agronomists have emphasized comparisons of yields under sole cropped and intercropped conditions, rather than understanding other characteristics of an intercropping system which may explain its persistence and which may need to be preserved in an improved system. For example, replacing an open-headed sorghum by maize can increase pest damage in intercropped cotton by favouring the development of the bollworm, Heliothis armigera, populations.
Dagg and Haworth list the following broad groups of criteria for research priority setting:

i) Potential impact of research product on the national economy and society.

ii) Probability and cost of research success.

iii) Feasibility of using research product to increase productivity/production (i.e. likely adoption by farmers).

iv) Personal satisfaction of researcher (mainly applied at the station level of decision).

A step-by-step guide to the planning of on-farm research experimentation is given by Tripp and Woolley (1989). Parkhurst and Francis (1986) give a convenient method for assigning priorities among the list of problems identified within a selected intercropping system. This procedure involves weighting the relative importance of each limiting factor by the probability of finding a solution and by the probability of its adoption. A case study from a maize/bean intercropping pattern in the Andes is given, in which it was decided that the top priority should be given to resistance to Anthracnose in beans followed by manuring for maize.

**Experimentation**

Resources are always limited so it is vital that priorities for research are correctly assigned and resources allocated accordingly. At the research station level the detailed short-term (2-5 years) and annual PRESAs are formulated by the researchers and team leaders. This may or may not be coordinated into short-term or annual PRESAs by a national research coordinator or team leader. It is at this third level of PRESA formulation that most of us are involved, given certain policy and institutional PRESAs.

Once priority areas in intercropping research have been established, these have to be formulated into actual experiments, and executed. Intercropping is a technology most frequently found in use by small-scale farmers. Small-scale farmers often have several enterprises on their farm and the interactions between these enterprises are often important. Hence a farming systems perspective is necessary in any research on intercropping. To us, a farming systems perspective implies a farmer focus, i.e. tailoring the research program to farmer circumstances in a realistic manner in order to derive relevant production recommendations that can be adopted by the target group of farmers for which the research was initiated. Thus, we would expect to see a high proportion of on-farm research in any intercropping research program. In eastern and southern Africa, small-scale farmers have historically been the innovators in developing intercropping systems; researchers have usually got into the act later in trying to improve on the farmers' practices. This is especially true in relation to the plant population and spatial arrangements, of the intercrop components. In fact, probably too much effort has been expended in the area of plant population and spatial arrangements, to the detriment of other important variables such as fertilizer use, weed control and pest control, etc. Thus, on-farm intercropping research there is a need for a higher level of farmer involvement than in commodity research due to local agro-ecological adaptation and because of farmers' diverse multiple objectives in intercropping (Steiner, 1982).

One of the first questions in developing experiments on intercropping is whether the experiment should be conducted on-station or on-farm. In reality, the answer will depend on similar conditions to that for single commodity research. Thus, experiments on genotype selection, on elucidating biological relationships on competition and symbiosis, on water relationships, soil conservation, etc. would start normally with on-station research (OSR). Similarly, experiments aimed at developing production recommendations on variables such as varieties, planting dates, plant populations and spatial relationships, fertility, weed control, etc., should normally start with on-farm trials.

On-farm research (OFR) will include the well-known types of experiments: exploratory, determinative (levels) and verification trials, depending on the information presently available and the researchers' confidence in a potential solution to a production problem. In these respects, we do not feel that intercropping research is too much different from research on a single commodity. However, each crop combination as an intercrop needs to be treated as a "commodity" e.g. maize-beans, maize-cowpea, etc. All too frequently we see intercropping researchers developing ideas, treatments and recommendations for the components of the intercrop separately. Although previous experience and intuition may allow this to be done up to a point, researchers must evaluate the potential innovation within the intercropping context as a whole. A local example of the systematic testing for intercropping compatibility of technology under development on a research station was given by Ziegler (1986). Faced with non-adoption of an existing maize variety, the Burundi national maize program amended its genotype selection criteria on the station so as to favour the identification of earlier, less competitive varieties. This is followed by routinely evaluating
advanced materials in association with beans or peas before proceeding too far towards variety release.

Because of the complexity of intercropping systems, it is very important that researchers are aware of results obtained in neighbouring countries or further afield. Success or failure elsewhere can be helpful in planning experiments. Thus, information networks are useful.

Experimental designs for intercropping research may often be similar, we feel, to designs used for sole crops. Mead (this volume) has given the latest ideas on experimental designs for intercropping experiments. Similarly, aspects of field plot layout and field plot technique will be as for sole crops apart from any complexities introduced by the presence of two or more crops in the plots at the same time (e.g. plot size may need to be larger to adequately sample a crop with a low plant population and/or large individual plant size, to sample a shading interaction among crops, or plot sizes for different components of the intercrop may need to be different.

Treatment design, however, can be much more complex. This arises from the fact that several factors can be varied for each crop component, e.g. variety, population, spacing, fertilizer levels, pest control treatments, weed control methods, timing of planting, etc. Hence, for factorial treatment sets, the number of treatments can rapidly multiply up to very high levels. So, experiments have to be restricted to few variables and/or few levels of a variable or incomplete factorial treatment sets have to be used.

In designing experiments, the setting of levels of non-experimental variables is an important consideration often leading to confusion and conflict amongst researchers. In on-station research (OSR), non-experimental variables are frequently set at what are believed to be optimum or non-limiting levels because the aim is to determine biological responses and economics are largely ignored. However, maintenance at farmer level may be necessary if higher levels are expected to interact with design parameters. By contrast, in on-farm research with a farming systems perspective (OFR/FSP), non-experimental variables are generally set at the farmers' level though there are justifiable exceptions to that rule. Also, economic analysis of the data is an essential feature of the evaluation of OFR experiments. Of course, the form of evaluation (tabulation, analyses and interpretation) is a part of the planning process for an experiment, and yet it is often neglected.

Evaluation phase

When agronomists/physiologists approach the interpretation of intercropping experiments they often think of the Land Equivalent Ratio (LER). LER has proven useful in interpreting experiments from the viewpoint that intercropping is an approach to intensification of crop production i.e. intensification in use of land. So, the LER is often calculated and applied to the interpretation of certain on-station trials aimed at establishing biological relationships. However, farmers usually have other motivation, including maximization of profit at acceptable risk levels. LER may therefore be an inappropriate tool in many situations. Many small farmers, for instance, need a certain minimum quantity of one component of the intercrop to meet their food requirements.

Intercrops lead to multiple products, often having widely-differing values per unit weight. Therefore, statistical analysis of yields may be misleading. Attempts have been made to reduce yields of the various products to common units (e.g. calories, protein, etc.) but the most meaningful may be monetary value of the products on a hectare basis (Hildebrand, 1976; Sanchez, 1976). This idea is not universally accepted (Ofori and Stern, 1987). Again, this topic is developed more fully later in these proceedings (e.g. Ransom; Anandajayasekeram et al.). Using monetary values of products in the statistical analysis is still statistical analysis. This should be followed by economic analysis itself.

In eastern and southern Africa, labour rather than land is the most limiting production factor at periods of peak demand (e.g. planting and weeding). Thus, intercropping which suppresses weeds is attractive, but complex or precise planting patterns that increase labour requirement at planting and weeding are not attractive to farmers. The Kenyan experience described in these proceedings (Mwania et al.) with paired rows of beans between maize rows is an example having lessons for others.

Farmers may not be interested in anything approaching maximization of LER. Researchers should strive to understand the true motivation of the farmer and why he uses the intercrop system (or systems) he uses. Often farmers plant their intercrops in different patterns on different planting dates due to differing pressures or constraints, often related to labour. Four different planting patterns were used by a single farmer in a single field in Kenya. Therefore, intercropping research is very adaptive in nature. With the complexities of intercropping systems and the myriad opportunities for fine-tuning the system, strenuous efforts should be made to understand the farmers' criteria for evaluation of different systems. Many criteria may be of a socio-economic nature not strictly commodity oriented nor related to
agronomic performance per se. Therefore evaluation must include the farmers' criteria for evaluating technology. These are the same criteria used during the design of experiments.

Feedback to station and commodity researchers
As in all research with a farming systems perspective, feedback of results to guide commodity researchers on station is vital. This feedback from intercropping research needs to reach a wider audience because of the multi-commodity/disciplinary research teams involved. In this way, it is hoped that a station's overall research agenda can be made more relevant for farmers. In spite of the large amount of work done in intercropping research, Steiner (1982) noted that very few appropriate intercropping recommendations have emerged from that research.

This is a workshop on research methods. In this preliminary paper, we have tried to briefly mention some elements of intercropping research programs in NARS from the point of view of general concepts that we feel should be included. More details on methods to employ are covered later in the proceedings. NARS in eastern and southern Africa have many institutional structures. We have deliberately avoided trying to recommend any institutional structure for an intercropping research program even though it is obvious that informal collaboration (at least) is needed between the various commodity/disciplinary teams and dynamic leadership is important.

References


Intercropping Research in Mauritius - An Example of An Intercropping Research Program

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Introduction

The agriculture and economy of Mauritius are still dominated by the sugar industry in spite of major structural changes that have taken place in the economy during the past 10 years. Sugar cane occupies more than 90% of the area under cultivation and there are few prospects for developing more land for cropping. Sugar and cane by-products represent 90% of agricultural exports and 40% of total exports, but the food import bill absorbs a good part of the earnings from sugar.

Since the late 1960's efforts have been made to diversify agriculture in order to reduce the drain on foreign exchange and increase exports. However, because sugar cane is the crop that is most adapted to the soil and climate and because sugar benefits from remunerative prices and guaranteed markets, the policy is to diversify in addition to, rather than at the expense of, sugar production (Anon. 1983). This policy dictates that sugar cane should not be removed to make way for other crops. The present 3-pronged strategy of agricultural diversification, therefore, favours activities such as fisheries, meat, milk, egg production that do not require arable land. High value export crops such as flowers, fruits and off-season vegetables are also encouraged. The third prong of the strategy is the maximum development of crops that can be produced in association with sugar cane, either in rotation with, or as intercrops of sugar cane. Thus, intercropping of sugar cane is important in intensifying and diversifying agriculture.

Importance of Intercropping Sugar Cane

Farmers in Mauritius have been intercropping sugar cane with other crops for over a century, and the practice has been encouraged by the Chamber of Agriculture since 1866 (North-Coombes, 1953). The practice gained momentum during the Second World War when food supplies were disrupted. Soon afterwards the first intercropping trials were initiated but they were conducted for a few years only. For various reasons, intercropping did not become generalized.

Interest in intercropping was revived in the late 1960's when the present strategy of agricultural diversification was proposed, and when a Food Crop Agronomy Division was created at the Mauritius Sugar Industry Research Institute (MSIRI) and was entrusted with the research. Since then, much has been accomplished, and today, intercropping of sugar cane with food crops is widespread and accounts for an important part of the total production of field crops such as potato, maize and groundnut (Table 1).

Significant amounts of beans and vegetables, such as tomato are also produced in interrows of sugar cane.

Research Organization and Approach

The intercropping research is conducted at the MSIRI mainly by the Food Crop Agronomy Division. Other specialist divisions collaborate in research on food crops generally, and sometimes also in aspects of intercropping as they relate to their disciplines. For instance, the Sugar Cane Agronomy Division studies weed control not only in sugar cane but also in intercrops of sugar cane. This multidisciplinary approach is adopted for all food crops whose research has been entrusted to the Institute. The crops are maize, potato, groundnut and beans.

Because research resources are limited, it has been necessary to proceed step by step in the research and development of food crops. The first phase consists in desk work to establish the need for a crop, either because there are good export prospects or a large domestic market. Preliminary field trials are undertaken to ascertain that the crop grows reasonably well under local conditions and to appreciate the importance of pests, diseases and weeds. Only then, are the first intercropping trials laid down to establish that the intercrops have only minimal effects on sugar cane and to gain an insight into management problems. Further intercropping trials are laid down on stations and planters' lands to work out husbandry practices and estimate costs. A package is then prepared and tested in on-farm trials. Simultaneously, management problems are reviewed and possibilities of mechanization are studied. Depending on the crop and its importance and on the rate of adoption of production packages, the emphasis may be shifted from pure research to development.

The research at the MSIRI is development-oriented. For instance, not only does the institute breed new maize varieties for intercropping, but it also organizes and monitors maize hybrid seed production, advises seed producers and certifies the seeds. It conducts research on mechanization and also organizes training sessions.
Main Research Achievements and Research Needs

Potato
Potato is at present the most successful intercrop of sugar cane. A fairly complete package of technology has been developed and it has been widely adopted by all farmer groups; small growers and large estates each account for about half of the total production. This success is attributable in large measure to the fact that potato does not reduce the yield of intercropped sugar cane (Table 2) and conversely, sugar cane does not affect potato yields. It has been established that all commercial potato varieties can be intercropped with sugar cane. In relation to sugar cane harvest and planting dates, there are three potato intercropping systems. They are: intercropping with short-season plant cane (July to September plantation); intercropping with long-season plant cane (April to May plantation) and intercropping with ratoon cane (July to September plantation).

All the husbandry practices have been worked out (Govinden et al., 1986). Various planting patterns are possible. Chemical weed control is feasible with Sencor (metribuzin) or Linuron or Topogarde (terbutylazine + terbutryne) depending on weed species present and other conditions. Pest and disease control measures for intercropped potato are similar to those employed on the sole crop. To-date, there is no evidence that the incidence of pests and diseases and the effectiveness of the control measures are different in intercropped potato.

Most of the cultural practices are or can be easily mechanized. Some improvement is required on mechanical hilling-up which must be done at planting. Spraying is done with motor blowers, but tractor-mounted sprayer booms may also be used. Harvesting is partially mechanized; tubers are lifted mechanically and have to be hand-picked.

At present potato and sugar cane are fertilized separately. Optimum fertilizer rates for cane are used, and the rates for potato were derived from the requirements of sole potato. It is now necessary to check whether the rates for the mixtures are not less than the sum of the rates for the component crops.

Another area that needs clarification is the water requirement, especially under drip irrigation where different water rates can be given to the two crops.

Maize
Like potato, maize has been the subject of many intercropping studies. Unlike potato, maize has been shown to exert competitive effects on cane, especially plant sugar cane. The adverse effect was found to be due essentially to competition for light, the maize shading the cane (Govinden, 1986). The magnitude of the competitive effect depends on maize varietal characteristics (height, maturity, leafiness), maize density and planting pattern and cane growth conditions.

Most husbandry practices have been worked out, tested and published (Govinden et al., 1984). The most common planting pattern consists of one row of maize in alternate interrows of plant or ratoon cane. Pests and diseases are controlled through the use of resistant varieties. To-date, no evidence has been found to indicate an increase or a decrease in disease or pest incidence in intercropped fields. This is surprising in view of the numerous pests and diseases that maize and sugar cane have in common. Admittedly, the worst ones do not exist in Mauritius.

Weeds are controlled by pre-emergence applications of atrazine alone or in mixture with metolachlor and post-emergence applications of 2,4-D amine.

As for potato, fertilization of intercropped maize is based on the response of sole crop maize. This point is being re-examined. Likewise, the water requirements of intercropped maize may differ from those of sole maize, and for this reason, this aspect is being looked into.

Planting is easily mechanized but mechanical harvesting is still a problem. The corn-picker developed for this purpose does not work well and should be modified.

Groundnut
As for the other two crops, a package of technology has also been worked out for groundnut grown in interrows of sugar cane. Groundnut resembles potato in that it does not adversely affect cane yields and it differs from potato in that its fertilizer requirements on cane lands are very low; so low, that most growers do not use any fertilizers. Work is now in progress to determine to what extent nitrogen fixed by groundnut becomes available to sugar cane sooner or later.

Bean
The Institute has only recently started working with beans and much remains to be done. It has been established that beans do not reduce the yield of intercropped cane, and various planting patterns are being examined. Recent results indicate that it may be feasible to grow beans in the interrows left free when maize is intercropped with plant sugar cane (Anon, 1988a).
Problems in Field Experimentation

Intercropping trials require more land for two reasons. Firstly, for such crops as maize that shade cane, many guard rows are required. Secondly, in many trials there is a need for multiple controls in order to fully meet the multiple objectives of the trials.

One problem specific to research on intercropping of sugar cane is the need to follow the cane crop until harvest. Most food crops are harvested in 4 to 6 months. It happens in many instances that the final cane yield obtained in a trial depends not so much on the original intercropping treatments as on the conditions that prevail after the food crop has been harvested. If the researcher does not manage the trials properly, the risks of drought or fire affecting the cane increase.

Perhaps the most important problem concerns the need for fairly sophisticated equipment and techniques in order to fully understand what goes on in many intercropping situations. In Mauritius, work on optimum irrigation and fertilization of mixed crops has started only recently because the equipment was not available previously.

Problems in Analysis and Interpretation of Results

More important than problems in experimentation are problems related to the analysis and interpretation of results. Mauritius is fortunate in having a clearly defined agricultural policy and in having a consensus around the strategy to be adopted in agricultural diversification. The main objectives of intercropping trials are usually clear, but often, the researcher also has subsidiary objectives. It is not at all clear which designs and analyses are best.

The measurement of total productivity of mixtures of sugar cane and other crops is important even in circumstances where the main objective of the trial is to determine whether the subsidiary crop has adverse effects on the cane. For mixtures of sugar cane and maize and also of sugar cane and potato, use has been made of total edible energy, sugar cane being the energy crop par excellence and maize and potato being essentially grown for energy. This calculation is obviously not acceptable in the case of mixtures of sugar cane and beans or groundnut where the protein production of the subsidiary crop is of critical importance.

There are also problems in the measurement of yield advantages of mixtures of sugar cane and other crops. Firstly, there is the large difference in the duration of the crops, 12 to 18 months for sugar cane compared to 4 to 6 for most intercrops. This makes such ratios as LER unacceptable even to those who discount statistical objections to the use of LER.

To avoid the problems mentioned above and also to complement the agronomic analyses, it is necessary to resort to some form of economic analysis. In the long run, economic merits determine the adoption and success of intercropping. In Mauritius, partial budget analyses have been used (Govinden, 1988), but there are problems here, too. Prices of sugar are artificial in the sense that most of our sugar is sold to the European Economic Community at preferential prices, and prices of some commodities such as potato and maize are fixed by the Agricultural Marketing Board. Financial analysis using such prices are therefore of value for the short term only. For Mauritius specifically, there are complicating factors such as the existence of numerous sugar taxes depending on the size of holdings.

On-Farm Trials and Adoption of Technology

Because the country is small and the communications media are well developed, there are usually few problems in the transfer of technology. At MSIRI, well before the recent re-discovery of on-farm trials, research has been conducted on farmers' fields. Conventional researcher-managed trials are laid on stations as well as on collaborating farmers' fields. These trials are complemented by large-scale, semi-commercial trials that are managed by farmers under the close supervision of the researchers. This is the first occasion to appreciate management problems. Finally, regular on-farm trials managed by the farmers themselves are also laid down more and more regularly.

In contrast to what is commonly observed in most other countries, in Mauritius, intercropping of sugar cane with food crops is much more popular with the corporate sector (sugar estates) than with smallholders. Most of the maize, potato and groundnut is produced on land belonging to sugar estates either by the estates themselves or by planters who rent the cane interrows for a few months. There is a large number of small planters who own about 45% of the total area under cane and who produce almost no intercrops. Recent surveys (Anon, 1987; 1988b) have indicated that this is mainly because many small planters are part-timers and do not have time to invest in the production of very small amounts of food crops. There was no evidence that they were not aware of the technological options or that these options were not adapted to their conditions. There is no doubt,
however, that the profit margins in most of the field crops are not attractive enough; the corporate sector benefits from economies of scale.

To-date, it has been very difficult to obtain certain important socio-economic parameters of intercropping. For instance, it is claimed that certain food crops are complementary to sugar cane in labour use. Idle or semi-idle labour exist on sugar estates and can be redeployed for intercropping. It has not been possible to determine how far this is true, and in financial calculations, the labour cost is computed as if extra labour was always employed for the food crops. As labour is becoming a constraint, it is necessary to investigate its importance in intercropping bearing in mind that scarcity of labour is one of the main causes of non-adoption of intercropping.

**Conclusions**

Mauritius has developed a unique approach to the intensification and diversification of agriculture, that of intercropping sugar cane, its main crop, with food crops. After two decades of research, the practice of intercropping is now well established.

Most of the husbandry practices have been worked out although some refinements are needed. The mechanization of production has been shown to be possible and it must be developed further, especially since there are already signs that labour may become scarce in future.

Some problems have been encountered, not so much with field experimentation, as with the analysis and interpretation of results. They arise partly because of the difference in durations of the component crops, and partly because one of the component crops, sugar cane is the main crop.

**References**


Table 1. Importance of intercropping of sugar cane

<table>
<thead>
<tr>
<th>Crop</th>
<th>Share of production (%)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Sole cropped</td>
<td>Intercropped</td>
</tr>
<tr>
<td>Potato</td>
<td></td>
<td>23</td>
<td>77</td>
</tr>
<tr>
<td>Groundnut</td>
<td></td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td>50</td>
<td>50</td>
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</table>

Table 2. Effect of potato planting pattern and density on the yield of potato and of intercropped plant sugar cane

<table>
<thead>
<tr>
<th>Potato planting pattern</th>
<th>Potato density (plants/ha)</th>
<th>Potato yield* (t/ha)</th>
<th>Sugar yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole cane</td>
<td>-</td>
<td>-</td>
<td>9.95</td>
</tr>
<tr>
<td>One row potato/cane Interox</td>
<td>7,580</td>
<td>3.36</td>
<td>10.35</td>
</tr>
<tr>
<td>One row potato/cane Interox</td>
<td>15,160</td>
<td>6.87</td>
<td>9.97</td>
</tr>
<tr>
<td>Two rows potato/alternate cane Interox</td>
<td>11,370</td>
<td>5.39</td>
<td>10.13</td>
</tr>
<tr>
<td>Two rows potato/alternate cane Interox</td>
<td>22,740</td>
<td>10.76</td>
<td>10.05</td>
</tr>
</tbody>
</table>

Pooled standard error: 0.11 0.19

* Mean of 8 trials
Beans in eastern and southern Africa are mostly grown by small farmers who commonly use multiple cropping systems. In some areas, for example Rwanda and Burundi, land is increasingly scarce, so that improving the land productivity is more important than labour productivity. In addition, the many stresses to which crops are subjected cause farmers to diversify by planting more than one crop species together, and/or by using variety mixtures. Both these strategies reduce the risk of failure.

For a crop like beans, it is essential to take into account the social environment in which the new varieties will need to perform. Their acceptance or rejection will depend on how well they fit into the social as well as the physical environments. Since breeding takes time, it is necessary to predict how the social environment will change. As farmers move from subsistence agriculture to marketing a larger proportion of their produce, so they tend to move away from intercropping and to the use of more uniform varieties. This trend can already be seen in some areas with access to urban markets, for example northern Kivu in Zaire. However, the advantages of intercropping in terms of increased land productivity and reduced risk are not to be given up lightly, and sustainable improvements in productivity could be more readily achieved if new varieties were bred which were adapted to existing cropping systems.

A problem here is that the existing cropping systems are rather varied. Of course, the cropping system is not the only factor which varies significantly, since the environment is often not subject to much control by the small farmer. Breeding programmes typically generate a great deal of material, which is gradually reduced until one or very few varieties are finally released. These varieties need to be widely adapted if large scale seed production is to be worthwhile. Beans are rarely a promising subject for large scale seed production. An alternative is to develop seed production in cooperatives of small farmers at a local level, and such small scale seed production would obviate the need for widely adapted varieties. Farmers could then become involved at an earlier stage in the process of selecting among the large genetic diversity in the breeding program, and varieties could be selected which are more specifically adapted to their conditions, including their cropping systems.

In this paper I consider some methodologies, with examples, for developing bean varieties specifically adapted to intercropping with maize.

Genotype x Cropping Systems Interactions and Heritability

Every breeding program has to contend with genotype x environment interactions, and decisions have to be made on the locations for breeding nurseries and on the conditions of soil fertility and disease and pest control. The objective is to achieve the right balance between conditions which are representative of those found on farm, and at the same time uniform enough to allow reasonably reliable selection. The latter is a precondition for achieving a satisfactory heritability for the traits under selection. The cropping system is just another variable like the others mentioned above, and the question is whether variety selection is enhanced by including it or not. If there is a strong genotype x cropping system interaction for yield, there are two ways of dealing with this. One is to endeavor to explain the interaction in terms of other traits related to plant type, maturity, disease resistance etc., and then group the material under selection accordingly. This may reduce the interaction to a level at which selection can proceed in sole cropping. The other possibility is to select under intercropping. This is probably only worthwhile when the intercrop actually improves the efficiency of breeding, as in the case of climbing beans, where the maize provides cheap stakes and the heritability of yield is at least as high in the intercrop situation as in the sole crop (Perez, 1982; Hopmans, 1983; Davis, Perez and Hopmans, 1983; Zimmerman et al., 1984). Otherwise, early generation selection is better done in sole cropping, bearing in mind the traits required for the target cropping system/environment, and advanced lines should then be selected, preferably involving farmers in the selection of genotype for testing in their cropping system/environment.

For bush beans, the interaction between genotype and cropping systems (i.e. sole crop vs. maize intercrop) is usually slight, whereas for indeterminate beans the interaction is often highly significant (Roumen and Schellekens, 1984; Smith and Francis, 1986). When indeterminate beans are intercropped with different maize cultivars, on the other hand, the interaction is usually not significant. Therefore, having decided to breed for intercropping, it is probably not worthwhile trying to select the two crops simultaneously. In the case of beans, it is preferable to select a representative maize cultivar, which should ideally be relatively resistant to lodging and to other constraints like diseases. This is not to say that maize should not also be improved for intercropping with legumes (Woolley and Rodriguez, 1987). However, the interaction of maize cultivars with cropping systems is usually relatively slight, and if present can often be explained in terms of plant height and lodging.
sustainability (Davis et al., 1986). Rather, the specific traits selected for in the maize breeding program should be considered in the light of the target cropping system/ environment. In particular, time to maturity, plant height, lodging resistance, standing ability after maturity (for relay cropping), leaf width and internode length are all traits which affect the suitability of a maize cultivar for intercropping.

**Traits for Intercropping**

**Time to maturity**

Competition between two crop species can be reduced by maximizing the time separation between flowering and seed development. This can be achieved by altering the relative planting dates, but this is limited by the length of the growing season. Otherwise, it can be achieved by selecting appropriately for earliness or lateness. However, it should be borne in mind that maturity differences have to be large to obtain the benefits of temporal separation. This can be achieved when there are large differences in photoperiod response (e.g. cowpeas intercropped with cereals in Nigeria, Steele and Mehre, 1980). Otherwise, breeding earlier cultivars may allow changes in relative planting dates. Woolley and Smith (1986) suggested using less leafy maize cultivars to permit the sowing of beans earlier in the relay system in Central America. The less leafy maize competes less for light, allowing the planting date of the beans to be advanced, meaning they are less liable to face end of season drought.

**Plant type**

Above ground competition is controlled by the density and spatial arrangement of the crops, and by the plant type of each crop species. For maize, the most important traits are plant height, internode length and leaf width. For beans, node number, branching and climbing ability are the most important traits.

Maize genotypes with short internodes and broad leaves shade beans relatively more than genotypes with long internodes and narrow leaves. Tall maize genotypes generally shade understorey crops more (Davis and Garcia, 1983). The significance of the competition from maize depends on the density of planting, and the relative planting dates. If the maize is planted simultaneously with beans and the maize plant population density is in the order of 40-60,000 plants/ha, then competition will be intense. In this situation, climbing beans usually compete better than bush beans. In much of Africa, however, it is common to find the maize plant density is rather low (10-20,000 plants/ha). This situation is ideal for intercropping with bush or semi-climbing beans. If climbing beans are planted in relay with maize, then there will be little competition. In this situation, climbing beans usually compete better than bush beans. In much of Africa, however, it is common to find the maize plant density is rather low (10-20,000 plants/ha). This situation is ideal for intercropping with bush or semi-climbing beans. If climbing beans are planted in relay with maize, then there will be little competition. In this situation, climbing beans usually compete better than bush beans. In much of Africa, however, it is common to find the maize plant density is rather low (10-20,000 plants/ha). This situation is ideal for intercropping with bush or semi-climbing beans. If climbing beans are planted in relay with maize, then there will be little competition. In this situation, climbing beans usually compete better than bush beans. In much of Africa, however, it is common to find the maize plant density is rather low (10-20,000 plants/ha). This situation is ideal for intercropping with bush or semi-climbing beans. If climbing beans are planted in relay with maize, then there will be little competition. In this situation, climbing beans usually compete better than bush beans. In much of Africa, however, it is common to find the maize plant density is rather low (10-20,000 plants/ha). This situation is ideal for intercropping with bush or semi-climbing beans. If climbing beans are planted in relay with maize, then there will be little competition.

Beans vary enormously in their ability to climb. Indeterminate beans normally produce more nodes when presented with a support, and this response varies according to the genotype (Davis et al., 1984). Kretchmer et al. (1977) also found that certain genotypes of beans are stimulated to climb by a change in light quality of the sort expected to occur under a canopy of maize.

The ability to climb determines to a large extent the competitive ability of a bean variety (competitive ability defined as intercrop yield/sole crop yield), and this in turn is correlated with the maize yield reduction (Davis et al., 1986). It has also been found that relatively unbranched climbing genotypes of beans are more competitive (Davis and Garcia, 1987). In this situation, where maize and bean yields are negatively correlated, it is a good idea to group the breeding material by growth habit.

For cowpeas, the situation is somewhat similar. Wien and Smithson (1981) demonstrated significant interactions of genotypes by cropping systems, and found that plant size (vigour) in late pod fill was consistently correlated with seed yield in intercropping. They concluded that an initial screening could be made in a sole crop, selecting for disease and insect resistance, and eliminating plants with low vigour and erect (bush) plant type.

**Tolerance to soil constraints**

There is much less known about below ground competition than competition above ground. Given that intercropping is widespread in relatively marginal conditions, varieties bred for intercropping should be as tolerant as possible of relevant soil constraints, such as drought, low soil phosphorus and Al toxicity. The legume component should be selected for efficient nodulation, so that it does not compete for nitrogen with the cereal, and contributes to soil fertility for the following crop.

The scope for complementarity between beans and maize below ground seems great, especially since beans can fix nitrogen. Indeed, the negative correlation between bean and maize yields is usually only found when competition is mainly for light. When soil factors become limiting beans do not usually reduce maize yield, and in fact there may be a slight positive effect (Davis et al., 1987). Below ground competition deserves more attention.
Disease and pest resistance
The incidence of certain diseases and pests may be reduced by intercropping (Altieri and Liebman, 1986). This may result in different priorities being set in a breeding programme for intercropping. If there is above ground competition between crop species, a disease or insect which attacks one species in the vegetative stage and reduces vigour will tend to give the competitive advantage to the other crop species. If, on the other hand, the attack occurs in the reproductive phase, there will probably be no compensatory effect. The combination of intercropping with genetic resistance is surely an attractive method of achieving sustainable disease and pest control. Related to this is the use of genetic mixtures which combine different resistance genes (Panse, 1988).

Selection and Yield Evaluation
Single plant selection of beans and other legumes is normally best done in a sole crop. An exception to this is climbing beans, where it may be simpler and cheaper to plant with maize (one bean plant to one maize plant).

Early generation evaluation of progeny is also usually better done in a sole crop. However, climbing beans are readily evaluated with maize, and early generation yield trials have been found to be effective (Davis et al., 1983). The efficiency of these can be increased by using hill plots (Roman, 1987). In Colombia, single hills consisting of two maize plants and two bean plants, spaced 0.92 m apart on the square, with four replicates, were found to give satisfactory yield estimations which correlated well with yields from normal plots. The amount of seed required is low, and the plot size is small, allowing large numbers to be handled in a small area. Hill plots are also attractive in that the maize has been found to lodge significantly less when planted in this way than in rows (Davis and Garcia, 1987). If the conditions on the experiment station are insufficiently representative of the target areas, hill plots could also be used for testing relatively large numbers of lines on farm without taking up too much space.

For advanced trials, larger plots must be used than for sole cropping. Beans are usually an understorey crop and the effect of shading must be considered. This would apply to beans under maize or sorghum, and even more so to beans under bananas, a common cropping system in Central Africa. Light penetrates from the edge of a small plot and this can improve the yield of the understorey crop, leading to an overestimate of the Land Equivalent Ratio (LER), and especially overestimating the yield of the less competitive varieties (Davis et al., 1981). The LER is defined as the ratio of the intercrop to sole crop yields of the beans plus the same ratio for maize. With tall maize (>2.5 m) it is preferable to discard 1 m at either end of the plot for yield measurements, while 50 cm is sufficient with short maize (<2 m).

If there is a significant competitive effect of one crop on the other, and this varies according to the variety, it is not enough to select only on the basis of the yield of one crop. The LER, while estimating the efficiency of the intercrops relative to the sole crops, is not an adequate selection criterion for a breeding program since it is based on ratios, not on absolute values. An alternative is to select on the basis of income, by multiplying the yield of each crop by the price. Costs of production are unlikely to vary significantly for different varieties. However, the price of the product may vary if the market class of the varieties differs considerably. If this is the case, it is preferable to group the varieties by market class. The price ratio can be used to calculate an 'equivalent yield' (Davis et al., 1987). For example, if the price of beans is three times the price of maize, then bean equivalent yield is calculated by dividing the maize yield by three and adding it to the bean yield.

If there is a strong negative correlation between the yields of the two crops, varieties might be selected which show a significant positive deviation from regression (Davis and Garcia, 1983). These are varieties which yield well and yet interfere relatively less with the other crop species.

Harvest index is sometimes worth studying in conjunction with grain yield. Bean harvest index is normally reduced by competition from maize, but the amount of the reduction varies widely from one genotype to another (Davis et al., 1984). Where the breeding program aims to improve efficiency of the intercrop, harvest index may be a valid selection criterion.

Farmer Participation
The complexity of cropping systems and the need for new varieties to fit existing cropping systems, or to provide the opportunity for changing the cropping systems in a way which is compatible with farmers' goals, mean that it is important to involve farmers in the breeding program. Visits of groups of farmers, especially those who already are considered experts in their region, to the experiment station, can provide valuable insights to guide the breeding program. Farmers expressing most interest in particular groups of breeding materials, advanced lines, or agronomic practices, will probably be the cooperators most interested in testing those materials or practices on their farms. Plans for on farm trials can be developed through joint farmer-researcher discussion, and this is especially relevant for cropping systems research.
References


Weed Control in Maize/Legume Intercrops

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Introduction

Maize is the most important cereal crop produced in eastern Africa and it is often intercropped with legumes. The most important intercrop combinations are: maize with beans, cowpeas, and with pigeon peas. Almost all the farmers in eastern Africa that practise intercropping can be defined as small-scale farmers. It has been suggested that the small-scale farmer intercrop maize and legumes primarily for the following reasons: to maximize the productivity of land, particularly in the high rainfall areas where land is often limited; to produce the variety of food that is preferred in the diet of the farm family; and to minimize the risk associated with unreliable rainfall. Though land is mentioned as a constraint to the small-scale farmer, labour is often even more limiting. It is estimated that hand weeding may utilize 35-70% of the total agricultural labor. Maximizing the returns to labor, and spreading out the demand for labor throughout the growing season when possible are logical strategies used by the farmer.

Competition for light, mineral nutrients, water and space by weeds is one of the most serious constraints to achieving the economic yield potential of maize based cropping systems in the tropics. Though the actual yield losses due to weeds vary from environment to environment, and from year to year and even from farmer to farmer, almost every farmer must expend considerable scarce resources to ensure that these losses are within tolerable limits. Weed control is often a year long process that includes factors such as the method and timing of land preparation as well as the actual removal of weeds from the growing crop.

Here I will briefly describe the methods of weed control commonly used in eastern Africa, describe some of the issues related to weed control in intercrops, and conclude by discussing some general aspects of weed control that need further research.

Current Methods of Weed Control

Weed control in most environments begins with the preparation of land for planting. Land preparation is done by hand, with the use of animal traction and with tractors. The principal objective of land preparation related to weed control is to destroy any living vegetation, and to remove subterranean plant parts from which perennial weeds will propagate. Weeds arising from rhizomes and rootstalks often cause the most damage to the crop and require the most effort to control once the crop is established. In areas of high weed pressure, such as the coast of Kenya and the ‘fertile crescent’ in Uganda, tractor-pulled implements are the preferred means of preparing land, because they do a better job of burying existing vegetation and destroying vegetative shoots. Land prepared using tractors on the coast of Kenya requires significantly less labor for the first weeding than does land prepared by hand. For the most part, land preparation by tractors consists of a single ploughing with a disc plough.

Animal traction is often used in the drier areas of Eastern Africa, and throughout Ethiopia. One advantage of preparing land with animals is that significantly more area can be ploughed in a day than can be prepared by hand. In some environments, there is considerable advantage in delaying the final ploughing until after the onset of the rains and the first flush of weed seeds has germinated, thus reducing weed pressure early in the season. This is practised in some areas where moisture conservation is not an overriding consideration.

Land preparation, using a hand hoe, usually begins well before the onset of the rains. In some areas large beds are used for planting. These beds are split at the time of land preparation, and a new bed is formed from the sides of two neighboring beds. This method allows for the inversion of the soil and the burying of weed seeds and rhizomes up to 30 cm deep in the soil. This method is usually restricted to small areas because it is time consuming, and labor demanding. In most areas hand hoeing merely scrapes the soil surface and rarely inverts the soil to any depth. Plant residues are often burned in conjunction with the hoeing. In areas where perennial weeds are a problem, a hoe is used (sometimes a forked hoe) to bring the rhizomes to the surface of the soil to allow them to dry and die before the onset of the rains. In farms where weed control has been good throughout the season, very little soil disturbance may be required, and land preparation begins while the crop is still in the field (in areas of bimodal rainfall where maize/beans is followed by maize/beans e.g. Embu district in Kenya).

With the exception of areas where animal traction is abundant, most weeding during the cropping season is done by hand. When planting patterns permit, inter-row weeds are controlled using a hand hoe. Typically the hand hoes used for weeding have a smaller blade than those used for land preparation. In plantings where there are no distinct interrows, weeds are removed by hand, or with the blade of a cutlass or knife. The number of weedings required for good weed control will vary from area to area, but generally two are sufficient. Depending on competing activities,
weed control commences soon after the emergence of the crop. In some systems, the planting of the legume may correspond with the first weeding of the maize crop. The quality and timeliness of the first weeding is critical for efficient production. Research has shown that crop yields are not affected if the first weeding is thorough and timely, regardless of the method of land preparation used (Kamau and Odhiambo, 1987). The first weeding is often delayed, however, because of adverse weather. Not only is the first weeding delayed for at least part of the field, an essential second weeding may also be omitted (Vernon, 1978).

In systems where animals are abundant, the first weeding is often done using draught power. If animals are used, the spatial arrangement of the intercrop must be such that it will allow the passage of the animal and implement without destroying the crop, necessitating the planting of the maize and the legume in the same row. Even when using draught animals, the timeliness of the first weeding is often dependent on the availability of animals, particularly if the animals are hired. Intra-row weeding is usually done by hand, and can be a serious constraint to production (Seubert et al., 1985).

**Issues Related to Weed Control in Intercrops**

Generally, the most important issues related to weed control within an intercrop are similar to those of monoculture maize. These issues include the timeliness of weeding and the reduction of weed seed levels in the soil. I highlight only those issues that are more related to intercrops.

**Issues related to labor requirement**

The amount of labor required to adequately control weeds in an intercrop relative to a monocrop depends largely on the cropping system and the spatial arrangement of the intercrop. Generally, given the management practices used in Eastern Africa, the amount of labor required for the first weeding in a maize/bean intercrop greatly exceeds the amount required for monoculture maize. In eastern Africa, maize is planted in rows and beans are planted in a random fashion throughout the maize interrow space. This spatial arrangement requires that weeding be done around each plant, precluding the rapid weeding of the relatively large unobstructed interrow area that is characteristic of row planted monoculture maize. In systems where the beans or other legumes are planted in the same row or in the same hill as maize, the differences in time requirement for weeding an intercrop and a monocrop are generally minimal.

The yield of the legume in the latter type of arrangement is predictably lower than the former, however. Planting a single row of legume equidistant between maize rows results in a substantial increase in the productivity of the legume when compared to the within-row planted system, yet it requires substantially less labor during the first weeding than the randomly planted legume system. The major drawback of the single legume row, is that it apparently requires more labor at planting than either of the other systems described (I have no hard data to support these last statements, they are based primarily on discussions with researchers and farmers addressing this issue).

In a well managed intercrop, the second weeding will generally require less labor than for a pure stand of maize. This is because the additional crop plants out-compete the weeds for vacant ecological niches (Mugabe et al., 1982).

**Issues related to herbicide use**

Herbicides are not widely used in eastern and southern Africa nor are they likely to become important over an extensive area in the near future given current agricultural policies. Nevertheless there are several areas where herbicides are and will be an important technology for the small-scale farmer. These areas include environments with high levels of weed pressure such as the humid lowland tropics and where the majority of the weeds are perennial. A second area where herbicides are used is where there is significant off-farm activities, so the farmer has cash but little time to farm. Farming systems that include labor intensive cash crops such as coffee and tea, may also lend themselves to the effective utilization of herbicides.

One problem of using herbicides in a maize/legume intercrop is that there is a limited selection of herbicides that will control weeds without also injuring one or both of the crops. Atrazine, the most commonly used and least expensive maize herbicide, for example, cannot be used on a maize/bean intercrop because of its phytotoxicity to the beans. By the same token a bean herbicide like chloramben, cannot be used because of its phytotoxicity to maize. Though the selection might be limited there are a few herbicides available for use in a maize/bean intercrop (see Table 1). Of these herbicides the most readily available in eastern Africa are: Linuron, alachlor, metolachlor, bentazon, and pendimethalin. Mixtures of suitable herbicides are also commercially available; linuron plus alachlor is the most common in Kenya, and metolachlor plus chlorbromuron in Tanzania. CIAT recommends fenmetaline, EPTC + protector, and...
linuron + fluorodifen as other useful herbicides for a maize/bean intercrop (Davis and Smithson, 1986).

One of the main drawbacks of herbicide use in eastern Africa is the fact that proper application requires a relatively high level of skill. There is substantial risk involved for the small-scale farmer when purchasing inputs, particularly when they are improperly applied. Appropriate application techniques need to be developed and/or taught if herbicides are going to gain widespread use in the farming systems for which they are well suited.

Some of the questions that need to be asked in the development of a research program relative to the issues raised here are:

**Labor and weeding:**

a) Is the farmer interested in distributing the labor demand over a longer period of time, and what activities compete with the labor required for land preparation, planting and weeding?

b) What is the relative importance of the maize and the legume to the farmer? How much maize or bean yield would the farmer be willing to sacrifice for a saving of labor?

c) At what period is labor most limiting (valuable)?

**Herbicide use:**

a) Does the farmer have an excess of cash relative to labor?

b) Is the farmer currently hiring labor for weeding?

c) Are there problem weeds in the system that defeat the farmer’s attempts to control them by hand?

d) Can the resource requirements, other than just those used for weeding the intercrop, be reduced through the use of herbicides (i.e. can the need for resources for both tillage and weeding be reduced through the application of herbicides in a zero tillage approach)?

e) If the labor required for weeding an intercrop can be reduced, are there other enterprises that will benefit?

**Areas Needing Further Research**

It is a difficult task to describe in general terms what research is needed, as the problems and circumstances of each environment can vary substantially. There are some general points that should be considered in the development of a weed control program in a maize/legume intercrop, however.

The first point is that research on weed control should not be undertaken unless there is a well-defined problem. Doing research on weed control in an intercrop just for the sake of doing research is a waste of resources. Identifying weed control problems is best done through interaction with the farmers, and by observing the crop in the field (i.e. through diagnostic activities).

Secondly, it is important that the objectives of the farmer for growing an intercrop are well understood, and that the research takes these objectives into account. For example, there is little point spending time to develop intercropping technologies that might conflict with the farmer’s desire to spread out the demand for labor uniformly throughout the season.

I believe that these points in addition to the issues raised earlier in this paper indicate that future research related to weed control in maize/legume intercropping must look more closely at the labor used/required in controlling weeds. When developing a research program it is beneficial to bear in mind that weed control requires more labor than probably any other crop management activity and that in order for a new technology to be acceptable to the farmer, it must not increase the demand for labor beyond an acceptable range.

One final point that needs mentioning is that the interaction between any new technology under development and the weed management of an intercrop should be investigated as part of the research process. For example, if the spatial arrangement of an intercrop is altered significantly, information on how this will affect the labor requirements of weeding should also be obtained before the technology is released to the farmers.
References


Table 1. Herbicides with potential for use in a maize/bean Intercrop.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Trade name (How applied)</th>
<th>Compound group (How applied)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alachlor</td>
<td>Lasso</td>
<td>Amide</td>
</tr>
<tr>
<td>Bentazon</td>
<td>Basagran</td>
<td>Benzothiadiazole</td>
</tr>
<tr>
<td>Chlorbromuron</td>
<td>Maluron</td>
<td>Substituted Urea</td>
</tr>
<tr>
<td>EPTC</td>
<td>Eptam</td>
<td>Carbamate</td>
</tr>
<tr>
<td>Fenmetalone¹</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluorodifen¹</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Linuron</td>
<td>Afolan, Lorox</td>
<td>Substituted urea</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>Dual</td>
<td>Amide</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>Prowl, Stomp</td>
<td>Dinitroaniline</td>
</tr>
<tr>
<td>Metolachlor+Chlorbromuron</td>
<td>Galex</td>
<td>-</td>
</tr>
</tbody>
</table>

¹ No technical information was found on these herbicides.
Fertilizer Research in Intercrops

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Introduction

Intercropping is the predominant cropping system in the tropical regions of the world (Willey, 1979). It is a traditional practice in many parts of Africa, Asia, and Latin America (Okigbo and Greenland, 1976; Harwood and Price, 1976; Pinchinat et al., 1976). Maize is a staple food crop in many tropical countries. Farmers have traditionally produced their maize under various intercropping systems with other crops, notably pulses. Beans are the predominant pulses grown with maize in many parts of Africa and Latin America. In Malawi 94% of all cultivated area was sown to mixtures of crops (Malawi Government, 1970). And 99% of all pulse production in Malawi was in various forms of intercropping with other crops, mostly maize. It is important to remember that traditionally these systems operated virtually without the application of artificial fertilizer.

Characteristics of smallholder farmers include: (a) small area per household, (b) limited credit for inputs, (c) low income, (d) mostly human and animal power source, and (e) stable yield requirement (Edje, 1979). Crop yield increases for such farmers have not been achieved. One of the problems is that fertilizer technology, expensive though it is, has been developed for monoculture systems of the developed world but fertilizer research in intercropping systems has been limited. Consequently there are practically no fertilizer recommendations under such cropping systems.

In this paper we review recent work done on fertilizer application in intercrops and provide a framework for future research.

Cropping Systems

Palaniappan (1985) has defined a cropping system as the "yearly sequence and spatial arrangement of crops or of crops and fallow on a given area of a farm and their interaction with farm resources, other farm enterprises, and available technology which determine their make up". Intercropping is a cropping system that has been described as the simultaneous growing of two or more crops in the same field during the same growing season (Willey, 1979). More recent definitions of intercropping have incorporated a measure of inter-crop competition (Willey, 1981; Ofori and Stern, 1987). In this case, two crops growing simultaneously in the same field experience inter-crop competition apart from the intra-crop competition that already exists in sole crops.

In some forms of intercropping (sequential, strip, and relay) inter-crop competition is greatly reduced. Here, fertilizer recommendations for sole crops may still be applicable. However, in other intercropping systems inter-crop competition is significant and recommendations for such systems are not generally available.

Nutrient Uptake in Intercropping

Nutrient uptake and requirement

The amounts of fertilizers recommended for application depend largely on the total nutrient requirement of the crop and how much is supplied by the soil. The time of fertilizer application, on the other hand, depends a great deal on the pattern of growth of crops in intercropping. In order to design an effective fertilizer scheme one needs to know the amounts of nutrients which a given component crop requires and is able to extract from the soil. But crops differ widely in nutrient requirements and so a given fertility level of a soil may lead to varied crop responses in intercropping. Oelsligh et al. (1976) proposed that data on total nutrient removal under intercropping systems would be a good place to start when estimating and determining fertilizer practices for such systems. The rate of nutrient uptake varies with component crops as well as with plant age, and the period of maximum nutrient demand of one component crop may not necessarily coincide with that of the other. And also, within the same component crop, the uptake curves for nutrients may be different.

Sole crop data on nutrient requirements and accumulation patterns are probably directly applicable to the less intensive forms of intercropping, namely: sequential, strip and, in certain circumstances, relay intercropping. Such data may not apply in intensive intercropping systems because the total nutrient uptake in harvested products must be greater under intercropping if combined yields are to be significantly increased. Greater nutrient uptake by intercropping has been reported for N by Kassam and Stockinger (1973), Dalal (1974), Liboone and Harwood (1975), Lakhani (1976), Rego (1981), Wahua (1983), Waghmare and Singh (1984), Bandopadhyay and De (1986), and Ofori and Stern (1986), for P by Wahua (1983); for K by Dalal (1974), Hall (1974), and Wahua (1983); for Ca by Dalal (1974) and Wahua (1983); for Mg by Dalal (1974). Therefore, it seems inevitable that intercropping systems remove more nutrients than comparable sole crops. This leads to more rapid...
depletion of natural soil fertility or the need for higher fertilizer application rates (Mason et al. 1986).

Research at Ibadan (7.23°N, 3.56°W), Nigeria (Wahua, 1983) and Waroona (32.85°S, 115.92°E), Australia (Ofori and Stern, 1986) on intercropping of maize and cowpeas will be used to illustrate nutrient uptake patterns in intercropping systems. Wahua (1983) determined accumulation curves for nitrogen, phosphorus, potassium and calcium. We have plotted accumulation curves for nitrogen from data of Ofori and Stern (1986). Wahua (1983) suggested that in interpreting and discussing nutrient uptake by each component, attention should be focused on both nutrient accumulation with time and mean rates of nutrient uptake at a given time. This is important because competition for a nutrient is indicated only when there is a significant difference between the uptake of that nutrient in intercropping and in sole crops. Conversely, the absence of competition is indicated only when none of the components of an intercrop shows a difference in uptake at any of the growth stages examined. The growth stage when such a difference is first noticed tends to indicate the onset of competition for that nutrient.

The patterns of nitrogen uptake by maize and cowpeas are shown in Figures 1 and 2. In Fig 1 maize assimilated N almost linearly with time irrespective of cropping system. However, for maize this seems to change after 77 days after planting (DAP) (Fig 2). Uptake of N is sole maize was greater after 77 DAP than that in intercropped maize. This was at the time of tasselling. Nitrogen uptake in sole cowpea was also linear when no fertilizer was applied. With fertilizer application, the rate of uptake became progressively less after about 40 DAP. The nitrogen uptake pattern of cowpeas under intercropping was similar up to about 40 DAP to sole cowpea. After 40 DAP uptake decreased significantly (Fig 1). Cowpea intercropped with SR99 maize variety (tall, early maturing) hardly took up any further nitrogen after 82 DAP (Fig 2) whereas that intercropped with XL66 variety (short, late maturing) continued its linear uptake rate. This was probably due to competition for both light and nutrients imposed by the tall SR99 which, being an earlier variety, presumably reached peak uptake rates earlier.

The uptake patterns of phosphorus by maize and cowpeas (Wahua, 1983) are shown in Fig. 3. At lesser fertilizer rates intercropped maize took up more phosphorus than sole maize. At higher fertilizer rates, sole maize took up more phosphorus. Across fertilizer levels there was no significant difference in phosphorus uptake between intercropped and sole maize. Uptake of P by sole cowpeas was almost linear with time. However, intercropped cowpeas deviated from that pattern at 40 DAP, although generally uptake increased thereafter. Competition is again indicated at flowering, but is expressed clearly only by the cowpeas.

Potassium uptake pattern by maize and cowpeas are shown in Fig 4. At lower fertilizer rates there was more potassium uptake by intercropped than sole maize. However, sole maize absorbed more potassium than intercropped maize by anthesis when the fertilizer mixture was applied at the rate of 200 kg/ha. When fertilizer was not applied the difference in K uptake between intercropped and sole cowpeas started to occur at 40 DAP, sole cowpeas absorbing more K than intercropped cowpeas. With fertilizer application, the intensity of competition for K, indicated by the difference between intercrop and sole crop uptake, tended to be reduced except where 75 kg N/ha (urea) was added over and above 200 kg/ha of the fertilizer mixture.

When maize is grown with an associated legume crop, fertilizer applications increase the yield of the maize grain (Rego, 1981; Chui and Shibles, 1984; Ofori and Stern, 1986) and usually the legume does not respond (Hardter, 1985) or yield is significantly decreased (Searle et al., 1981; Edje, 1983/84ab; Chui and Shibles, 1984; Ofori and Stern, 1987). The reduction in yield of the legume is ascribed to greater competition for light from improved maize growth (Edje, 1983/84a; Chui and Shibles, 1984; Ofori and Stern, 1987). Under this system the yield of the legume is said to be a bonus because only recommendations for the staple crop (maize) are followed. However, we believe nutrient uptake is greater in intercropping systems and so some of the nutrients supporting the system must be derived from the soil supply. As it turns out, one of the obscure features of this cropping system is the negative soil N balance after harvest. This may be due to the fact that the legume will also be dependent on the applied fertilizer or nitrogen released by the soil because its nitrogen fixation capacity is inhibited by N fertilizer application. This contention of reduced yield advantages from intercropping under fertilized conditions has been disputed by Willey (1979). In northeastern Brazil Faris et al. (1983), working with sorghum or maize with beans or cowpeas, found that the two legumes were responsive to fertilizer application. Work done on fertilizer application in intercrops in Costa Rica (North Carolina State University, 1973, 1974) also reported the responsive nature of beans. Odurukwe (1986) reported improvement in LER with fertilizer application to maize-yam intercrops. Thus, improved management through fertilizer usage may be
appropriate without the loss of the advantageous effects realized from intercropping.

Under low fertility systems, there seems to be competition from maize due to the fact that it is more aggressive and is better able to forage the soil for nutrient resources (Wahua, 1983). This may be due to it having a fibrous rooting system as opposed to the tap-root system of legumes. This competition by maize is short-lived because it is diminished by N\textsubscript{2}-fixation of the legume later in the season (Chang and Shibles, 1985a). Under a low N regime LER was better than under a high N regime (Ahmed and Rao, 1982; Chang and Shibles, 1985a; Ofori and Stern, 1986). Under low P the growth of maize is more limited than that of cowpea and its competitive ability is, therefore, reduced. This led to an improved LER with the low P regime (Chang and Shibles, 1985b). One of the most important aspects of intercropping under low fertility is the fact that it invariably results in a positive soil N balance (Eaglesham, 1982).

The role of legumes in intercropped cereals is beneficial especially in low soil or applied N availability situations. Most farmers that practise intercropping live in marginal areas and so the system benefits them. In high N availability situations (e.g. estate farming in Malawi) the role of nitrogen fixation in balancing N economy is relatively unimportant. Under such circumstances N is balanced by chemical fertilizers because these farmers can afford them.

Nutrient availability
The level of availability of nutrients to plants, whether present in the soil or added to it as chemical fertilizers, is largely determined by the soils through their mineral reserves, pH, organic matter content, cation exchange capacity, base saturation, sesquioxide content, permeability, and moisture retention capacity. The amounts of nutrients released to the crop will depend on these soil features and their interaction. Limitations to plant growth on most tropical soils include poor exchange capacity, nutrient deficiencies, excessive acidity, low organic matter content, and inadequate release of nitrogen, poor porosity and high soil compaction impeding deep root development and water percolation (Charreau and Rouanet, 1986). Other factors may provide a platform on which the above soil features interplay. Out of the world's total land area about 22.5% is characterized by mineral nutrient stress, 27.9% by drought stress, 12.2% by excess water, 24.2% by shallowness and only 10.1% are soils in which stress features are least pronounced (Dudal, 1976).

In designing fertilizer strategies for intercropping systems, encouragement and support should be given to the determination of the initial levels of all nutrient elements and the soil characteristics that determine the release of nutrients to crops as enumerated above. Particular emphasis needs to be placed on soils with specific stress features and these need to be mapped accordingly so that fertilizer schemes can be developed for those areas that are prone to stress problems. Development of varieties that tolerate such stresses in these areas should be given some priority in breeding programs.

**Contribution of Nitrogen by Legumes in Intercropping**

Legumes have been known for decades to fix nitrogen and enrich the soil. In intercropping systems an earlier report (Agboola and Fayemi, 1972) indicated that legumes do not benefit the associated crop in terms of nitrogen from dinitrogen fixation processes unless they decay. However, with newer \textsuperscript{15}N isotope dilution methods, results to the contrary have been reported. Much of the work in this area has been in grass-legume mixed pastures. Recently, with ryegrass-clover mixtures in Wales, Goodman and Collison (1986) used the \textsuperscript{15}N isotope dilution method to detect N transfer from the legume (clover) to the grass (ryegrass). Nitrogen transfer may be shown in two ways: the total Kjeldhal N in grass plants mixed with white clover may exceed that in the monoculture grass, or the isotope ratio may differ between mixtures and monocultures. In the latter case, N\textsubscript{2}-fixation causes the isotope ratio to be less in clover than in grass, so that if transfer occurs, N becomes more diluted in grass mixed with clover than monoculture grass. Either way, Goodman and Collison (1986) reported evidence of N transfer from white clover to ryegrass.

In grain crop species similar results have been reported. Bandyopadhay and De (1986) used the \textsuperscript{15}N dilution technique on an intercrop of sorghum and legumes. They indicated greater N uptake in intercropped sorghum than in sole sorghum. In an intercrop of sorghum and mung, 18% of the total N removed by sorghum was derived from the fertilizer urea and 81.9% came from the soil pool; the latter included 21.9% N derived from current fixation by the legume. The yield of wheat after sole crops of legume was greater than after their mixture with sorghum. The latter was, however, greater than its yield after sole sorghum crops. This indicates that not only did the legume partially supply N to the cereal in intercropping but more N was left for the next crop in rotation. The former may have been through N excretion and the latter through N residues (Saito, 1982). Results (Ofori et al., 1987) to the contrary have been reported in a maize-cowpea intercropping system.
where a current intercropped maize crop did not benefit from the associated cowpea crop. This aspect of N contribution to crop production needs further research.

**Contribution of Phosphorus by Mycorrhizae in Intercropping**

'Mycorrhizae' is a term that refers to a mutualistic, symbiotic relationship formed between fungi (Greek *mukes*) and living roots (Greek *rhiza*) of higher plants (Miller et al., 1980). This type of association has been observed in most plant species except the Cruciferae and Chenopodiaceae. Mycorrhizae have been classified (Harley and Smith, 1983) through a description of seven types, namely vesicular-arbuscular, ecto-, ectendo-, arbutoid, ericoid, monotropoid, and archid mycorrhizae. The vesicular-arbuscular mycorrhizae (VAM) comprise the major type observed in crop plants. They produce structures known as vesicles and arbuscules, as well as hyphae and spores. Arbuscules are intracellular, haustoria-like structures that develop by repeated, dichotomous branching of hyphae. Vesicles are sac-like, usually terminal swellings at the tip of hyphae. The hyphae can be formed both within the root and outside it. The transfer of mineral nutrients from the soil to the host plant is mediated by these hyphae.

Phosphorus is a notoriously immobile nutrient in the soil, and is absorbed only when growing roots come in contact with organic or inorganic materials containing available forms of the nutrient. Wahua (1983) contends that the reduction in P uptake by intercropped cowpeas was a result of higher competition by maize roots which were more extensive and could forage for P more effectively. Cowpea-VAM associations have been reported (Kwapata and Hall, 1985). The increase in plant growth in such associations is through greater P uptake as a result of reduction in the distance that the nutrient must diffuse to plant roots (Abbott and Robson, 1984). The VAM increases the surface area of the roots several-fold and so a plant in association with VAM may compete more favorably for P under intercropping systems.

**Future Approaches on Nutrition in Intercropping**

Palaniappan (1985), Davis and Garcia (1983), Ahmed and Rao (1982), and Ofori and Stern (1987) have all identified research areas that need attention as regards nutrition in intercropping systems. These will be mentioned briefly but in order of importance. Firstly, soil maps incorporating the problem areas (like saline and alkaline patches; compact sub-soil zones, chronic micronutrient deficient areas, etc.) and fertility status of the soil need to be prepared. Secondly, soil fertility in intensive cropping systems should be monitored. So far recommendations have been for sole crops but available information suggests considerable scope for economies in fertilizer use. As alluded to elsewhere, the residual effect of nutrients applied to previous crops, contribution of legumes included in the system, addition of residues by component crops, temporal differences in nutrient requirement, spatial differences in foraging and differential response of crops to nutrients all add to the complexity of the problem. Thirdly, information on the interaction between the root systems of the component crops, the soil layers in which they forage, nutrient dynamics and depletion of soil moisture is lacking.

Research is also needed on the following: (1) the application of low rates of N fertilizer early in order to encourage N fixation of the associated legume, as well as later application of N during the peak vegetative stage of the cereal in order to minimize competition for N; (2) the effects of applied N on N fixation of the associated legume; (3) the effectiveness of slow-release N fertilizers to establish whether they minimize losses of applied N leading to minimization of competition; (4) the identification of crop combinations for use under various ecosystems and management levels, and (5) the contribution of rhizosphere N by cereals and mycorrhizal phosphorus uptake by legumes to the nutrient economy of intercropping systems.

**Conclusion**

Intercropping is the predominant cropping system for the smallholder subsistence farmer and will probably remain so for many years to come. Due to the fast rate of population growth and limited farmland expansion, higher crop productivity per unit area has become necessary and so intercropping becomes even more important and could even be of relevance to large-scale agricultural producers also. Sustainable agriculture cannot be achieved if the demand for nutrients by crops is not matched with the supply by the soil. Therefore, clear objectives in this research area need to be formulated. Sole crop fertilizer recommendations are probably directly applicable in the less intensive forms of intercropping, e.g sequential, strip and relay intercropping. But for the intensive intercropping systems, e.g mixed and row, more nutrients than those needed by sole crops are required. In order to prevent rapid depletion of nutrients under intensive intercropping systems researchers are urged to identify ways and methods in which nutrients could be replenished each year.
The role of legumes in intercropping would be important for balancing the nitrogen economy in marginal areas for smallholder farmers. Under these conditions legume genotypes that are able to fix more and leave more N in the soil and those that are more compatible with prevalent mycorrhizal fungi (for P uptake) need to be identified for the more competitive intercropping systems. Under estate farming (large-scale production) the role of legumes for balancing the nitrogen economy may be relatively unimportant because under high N and P (from fertilizers) conditions symbiotic N$_2$-fixing systems and mycorrhizae are suppressed. Therefore, compatible associations between legume genotypes, rhizobia and VAM that tolerate high levels of N and P are preferable if they could be identified. Generally, crop components that respond to fertilizer application would be appropriate for intercropping in order to maximize productivity under improved fertility levels of estate farming. Alternatively, competition between crops could be minimized by selecting crops of different phenological development because these would reach peak demands for nutrients at different times. This would allow fertilizer applications to be split to enhance the productivity of one crop without either inhibiting that of other component crops or the nitrogen fixation of the legume component.

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Figure 1. N-uptake (kg ha⁻¹) by intercropped maize and cowpeas given different N fertilizer combinations. (Adapted from Wahua 1983)
Figure 2. N-uptake (kg ha⁻¹) by two varieties of maize intercropped with cowpea. (Drawn from the data of Ofori and Stern, 1986).
Figure 3. P-uptake (kg ha\(^{-1}\)) by intercropped maize and cowpeas given different P fertilizer combinations (Adapted from Wahua, 1983).
Figure 4. K-uptake (kg ha⁻¹) by intercropped maize and cowpeas given different fertilizer combinations.
Effect of Intercropping on Insect Populations: The Case of Beans

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Introduction

Intercropping is a practice that evolved largely from farmers' experience. In adopting intercropping, farmers attempt to obtain greater land productivity and greater insurance against crop failure or unstable market prices of a given commodity (Litsinger and Moody 1976; Perrin and Phillips 1978).

According to Altieri et al. (1978), Litsinger and Moody (1976), Perrin and Phillips (1978) and Risch et al. (1983), it is generally accepted that crops grown in intercrop are usually less prone to outbreaks of diseases and pests than crops grown in monoculture. This review attempts to summarise information on the effect of intercropping on insect populations with particular reference to beans, a crop largely grown in association with other crops throughout Africa and Latin America.

Insect Populations and Intercropping

In a relatively recent review, Risch et al. (1983) point out that, in general, diversification of the vegetative component of agricultural habitats often significantly lowers pest populations. A review of more than 150 papers dealing with 198 herbivore species revealed that 58% of those species decreased in numbers in diversified systems, 18% increased, 20% showed a variable response, and 8% showed no change (Table 1). Unfortunately, only 19 of the papers reported yield data and of these, only four showed an increase in yield of the crop components under study, implying that direct benefits of intercropping in terms of yield gains need further assessment.

Table 2, modified after Altieri et al. (1978), illustrates some examples of insect regulation as a result of changes in intercropping patterns. Regulation has been ascribed to a number of factors such as enhanced natural enemy activity, pest divergence from a given crop component, chemical repellency by the companion crop, and shading by a taller companion crop (Litsinger and Moody 1976, Perrin and Phillips 1978, Altieri et al. 1977).

In trying to explain insect regulation by intercropping, Tahvanainen and Root (1972) created the concept of "associational resistance". According to this concept, higher taxonomic and microclimatic complexity of natural vegetation tends to reduce outbreaks of herbivores in diverse communities. Still within the concept of "associational resistance", Perrin and Phillips (1978) illustrated different stages in pest population dynamics which may be affected by mixed cropping (Figure 1). More recently, Risch et al. (1983) postulated that "associational resistance" can be based on two major hypotheses:

1. The natural enemies hypothesis: intercropping increases the numbers of natural enemies as a result of greater pollen and nectar sources available for beneficial insects, increased ground cover which in turn favours the activity of nocturnal predators, and increased alternate hosts/prey for beneficial insects.

2. The resource concentration hypothesis: associated plant species may have different effects on the ability of a herbivore to find and utilize its host plant. Thus, associated plants may mask the herbivore's host-finding stimuli (visual and chemical) so that colonization of the host plant is lower. Emigration from the host plant may also be affected.

In their analysis, Risch et al. (1983) concluded that, in general, the resource concentration hypothesis is more important in affecting insect pest populations in diversified systems than are natural enemies.

The Case of Beans

Intercropping of beans is a common practice in tropical regions (Trenbath 1976). It is estimated (CIAT, unpublished statistics) that the contribution of intercropping in bean production in Africa is 81% and 75% in Latin America. Beans in these regions are intercropped with a range of crops such as maize, sorghum, sugar cane, cocoa, coffee, fruit trees, rubber, cassava, bananas, sunflower, sweet potato, potato and cabbage.

With some exceptions, intercropping has a significant regulatory effect on the populations of bean insects. This is illustrated by work on the regulation of the leafhopper, Empoasca kraemeri (Ross & Moore), the major pest of beans in Latin America. Altieri et al. (1978) and Hernandes et al. (1984) conducted a series of trials on the effect of intercropping maize and beans on leafhopper populations and damage. Consistently, populations and damage levels were significantly lower in beans associated with maize than beans grown in monoculture. When maize was planted earlier than beans, fewer leafhopper adults and less damage occurred, suggesting that maize acted as a barrier to the spread of leafhopper adults (Figure 2) (Altieri et al 1978). This was confirmed by Hernandez et al. (1984) who concluded that the higher the plant density of maize in the system, the lower were the levels of leafhopper attack (Table 3). In addition to reduced colonization ability, two factors contributed to lower E. kraemeri populations: repellency by ground cover (Cardona et al. 1981) and increased egg parasitism by
Anagrus sp (Hymenoptera: Mymaridae) in intercropped beans than in monoculture (Hernandez et al. 1984).

In studies on intercropping of sugar cane and beans, Garcia et al. (1979) found that when beans were planted later than sugar cane, significant reductions of leafhopper populations occurred. This may have been due to reduced colonization ability due to interference of the sugar cane canopy.

Highly polyphagous insects such as the chrysomelid beetle Diabrotica balteata (LeConte), may show variable responses to intercropping. Thus, Hernandez et al. (1984) reported higher populations in intercropping (Table 3) while Risch (1980) found significantly lower populations when beans were associated with bananas (Figure 3) and when beans were associated with maize. In the latter case (Risch 1981), the effect may possibly have resulted from a significant increase in the number of adult beetles emigrating from maize, and from maize-beans associations, as compared to bean monoculture (Figure 4).

When insects are monophagous, the addition of a non-host plant can also be a factor in reducing populations. Risch (1981) found significantly lower populations of the beetle Acalypha thiemei (Baly), a squash feeder, in squash intercropped with maize and/or beans than in monocultured squash, possibly as a result of increased movement in polycultures.

Planting of a less preferred companion crop can also reduce pest incidence in intercropping. In Malawi, Farrell (1976) observed that the hooked trichomes of Phaseolus beans trapped dispersing individuals of Aphis craccivora (Koch) and effectively reduced aphid-borne rosette virus infection in adjacent groundnut monocultures.

As stated before, species' responses to intercropping can be quite diverse. This is illustrated by the effect on populations of the Mexican bean beetle, Epilachna varivestis (Mulsant) and the pod weevil, Apion godmani (Wagner), two major pests of beans in Central America. As shown in Figure 5, while intercropping with maize significantly reduced E. varivestis populations, the system increased A. godmani infestations (Sanchez 1977).

Another example of diverse responses to intercropping was provided by the work conducted by Tingey and Lamont (1988) who found regulatory effects of intercropping wheat and beans on leafhopper and aphid populations at the expense of increases in the populations of Lygus bugs and Systena beetle populations (Figure 6).

In summary, in general, intercropping is a system that regulates several bean insect pests. There is a need to further understand the ecological mechanisms responsible for changes in pest populations and to quantify in terms of yields the direct impact of intercropping.

References


Table 1. Numbers of herbivore species more or less abundant in diversified agroecosystems compared to monocultures1 (Taken from Risch et al. 1983).

<table>
<thead>
<tr>
<th>Category</th>
<th>Numbers</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased</td>
<td>36</td>
<td>18.2</td>
</tr>
<tr>
<td>No response</td>
<td>18</td>
<td>9.1</td>
</tr>
<tr>
<td>Decreased</td>
<td>105</td>
<td>53.0</td>
</tr>
<tr>
<td>Variable response</td>
<td>39</td>
<td>19.7</td>
</tr>
<tr>
<td>Total</td>
<td>198</td>
<td>100.0</td>
</tr>
</tbody>
</table>

150 studies were reviewed

Table 2. Examples of intercropping effects on insect pest populations.

<table>
<thead>
<tr>
<th>System</th>
<th>Pest regulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENHANCED NATURAL ENEMY ACTIVITY:</td>
<td></td>
</tr>
<tr>
<td>Cotton-cowpea</td>
<td><em>Anthonomus grandis</em></td>
</tr>
<tr>
<td>Peaches-strawberry</td>
<td><em>Grapholita moltesta</em></td>
</tr>
<tr>
<td>Cotton-alfalfa, maize-soybean</td>
<td><em>Helothis zea</em>, <em>Trichoplusia ni</em></td>
</tr>
<tr>
<td>Cotton-sorghum, Cotton-maize</td>
<td><em>Helothis zea</em></td>
</tr>
<tr>
<td>Groundnut-maize</td>
<td><em>Ostrina nubilalis</em></td>
</tr>
<tr>
<td>PEST DIVERGENCE:</td>
<td></td>
</tr>
<tr>
<td>Cotton-alfalfa</td>
<td><em>Lygus hesperus</em></td>
</tr>
<tr>
<td>CHEMICAL REPELLENCY:</td>
<td></td>
</tr>
<tr>
<td>Tomato-cabbage, tobacco-cabbage</td>
<td><em>Phyllotheta cruciferae</em></td>
</tr>
<tr>
<td>Tomato-cabbage</td>
<td><em>Plutella xylostella</em></td>
</tr>
<tr>
<td>SHADING BY TALLER COMPANION CROP:</td>
<td></td>
</tr>
<tr>
<td>Sesame-sorghum</td>
<td><em>Antigastra sp</em></td>
</tr>
<tr>
<td>Maize-beans</td>
<td><em>Empoasca kraemer</em></td>
</tr>
<tr>
<td>Sugar cane-beans</td>
<td><em>Empoasca kraemer</em></td>
</tr>
<tr>
<td>UNKNOWN:</td>
<td></td>
</tr>
<tr>
<td>Maize-canavalia</td>
<td><em>Spodoptera frugiperda</em></td>
</tr>
<tr>
<td>INTERFERENCE AIR CURRENTS:</td>
<td></td>
</tr>
<tr>
<td>Cowpea-sorghum</td>
<td><em>Ootheca sp</em></td>
</tr>
</tbody>
</table>
Table 3. Effect of intercropping with maize on populations of two bean insects\(^1\) (After Hernandez et al. 1984).

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Adult <em>Empoasca kraemerli</em> per m-row</th>
<th>Adult <em>Diabrotica balteata</em> per m-row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beans in monoculture</td>
<td>126a</td>
<td>8c</td>
</tr>
<tr>
<td>Beans + 5000 plants of maize</td>
<td>100b</td>
<td>13b</td>
</tr>
<tr>
<td>Beans + 15000 plants of maize</td>
<td>67c</td>
<td>18a</td>
</tr>
<tr>
<td>Beans + 25000 plants of maize</td>
<td>49d</td>
<td>3a</td>
</tr>
</tbody>
</table>

\(^1\)Means followed by the same letter are not significantly different at the 5% level (Duncan)

Figure 1. Stages in population dynamics which may be affected by mixed cropping (after Perrin and Phillips, 1978)
Figure 2. *Empeasca kraemerii* populations as affected by planting dates of maize in association with beans

Source: Altieri et al. (1978)

Figure 3. Effect of intercropping on populations of *Diabrotica balteata* (Risch 1980)
Figure 4. Emigration of adult *Diabrotica balteata* from three cropping systems (Risch 1981)

Figure 5. Effect of intercropping on two bean insects (After Sanchez 1977)

Figure 6. Effect of intercropping with wheat on bean insect populations (After Tingey & Lamont 1988)
Introduction

While the influence of intercropping on pest populations has received some attention (see Cardona, this volume), relatively few studies have been made on the effects of cropping system on disease. Also perhaps too little attempt has yet been made to draw parallels between agro-ecosystems and natural plant communities in this respect, for natural ecosystems are likely to provide ideas on developing means of balanced crop protection (Burdon, 1978; Browning, 1981; Dinoor and Eshed, 1987). There are likely to be lessons too from recent studies on the behavior of pathogens in multiline and cultivar mixtures, because the underlying mechanisms that account for their generally protective effect seem likely to operate also in intercropping (Browning and Frey, 1969; Marshall and Pryer, 1978; Barrett, 1980). It seems that the behavior of pathogen populations on mixed hosts is a complex function of the reproduction rate, time, the amount of propagule transfer between hosts, the proportions of the association and the fitness of the pathogen genotypes on each host.

This paper reviews some of the studies that have been made on the effects of intercropping on disease, drawing examples especially from work on cereal-legume associations. This is followed by a discussion of the underlying factors possibly accounting for the observed effects.

Observed Effects of Intercropping on Disease

The most commonly reported effect of associated cropping on disease is that incidence or severity is decreased in the intercrop relative to pure stand. In the maize-bean system, anthracnose (Msuku and Edje, 1982), rust (Moreno, 1979; Msuku and Edje, 1982) and scab (van Rheenen et al., 1981) are among the fungal foliar diseases of beans that may be less severe in the intercrop. The bacterial diseases of halo blight and common blight, as well as the aphid-transmitted bean common mosaic virus have also been reported less damaging in maize association (van Rheenen et al., 1981; Msuku and Edje, 1982).

In the maize-cowpea association, ascochyta blight of cowpea (Moreno, 1975) and three beetle-transmitted virus diseases (Shoyinka, 1976; Allen, 1977; Moreno, 1979) are each reported decreased in the intercrop. Groundnut-bean associations, which are common in Uganda, may decrease the incidence of groundnut rosette (Farrell, 1976; Mukiti, 1982) and the same effect may be found when groundnuts are intercropped with maize (Guillemin, 1952). Mungbean powdery mildew is decreased by intercropping either with sorghum or bulrush millet (Keswani and Mreta, 1982), and mixing Italian ryegrass with red clover may decrease the incidence of red clover necrotic mosaic (Lewis et al., 1985). Potatoes intercropped among either maize or beans are provided protection from bacterial wilt (Autrique and Potts, 1987). The magnitude of the protection so afforded in some of these examples is shown in Table 1.

There are also examples, however, wherein disease development appears unaffected by cropping system and yet others suggest that disease severity may be greater in an intercrop than in pure stand. For example white mould Sclerotinia sclerotiorum in beans was not influenced by maize association in variety trials in Arusha during 1988, although there were varietal differences in susceptibility. Table 2 summarizes the varied effects of crop association on the development of angular leaf spot in beans, emphasizing that the outcome of intercropping on the severity of a single disease does seem to depend upon complex interactions among several factors. Let us now consider what these factors might be.

Factors Responsible for Observed Effects

Physical barriers to spread of aerial pathogens or their vectors
One of the most commonly cited causes of protection from disease in an intercrop is that one of the crop components impedes the dissemination of the pathogen, or of its vector. This so-called “fly-paper effect” (Trenbath, 1977) seems to be implicated in the maize-bean association against bean rust (Moreno, 1979) and in the maize cowpea association against ascochyta blight and cowpea mosaic (Moreno, 1975; Allen, 1977) amongst many others. Clearly, the comparison crop must be resistant to the pathogen for it to act as a barrier to dispersal. Otherwise, one might expect the disease to be exacerbated; however, there are apparently no published examples of the latter.

Trapping
In legume-legume associations, wherein one might expect barrier effects to be less than in cereal-legume intercrops, there is a nice example of one component (beans) acting as a trap of aphids on its hooked trichomes, so decreasing the rate of vector spread of a virus disease on the other component (groundnut) (Farrell, 1976). There is also an example of an underground “trapping” whereby cowpeas or groundnuts intercropped among sorghum apparently can decrease the incidence of witchweed (Striga hermonthica) by stimulating its seeds to germinate (Johnson et al., 1976; C. Parker, personal communication 1977).
Altered microclimate: shading
In a trial in which light intensity was varied both by altered maize spacing and by artificial shade, it was noted that the severity of powdery mildew on the intercropped cowpea increased significantly with increasing shade (Table 3). Conversely, the incidence of cassava bacterial blight has been found to decrease in maize association, again attributable to shading (Arene, 1976).

Altered microclimate: relative humidity
Apparently the only attempt to compare relative humidity in beans alone and in association with maize (Stoetzer and Omunyin, 1984) concluded that the intercrop had a higher relative humidity (and more moderate temperatures) which might be thought to favour disease development. Since maize appears not to afford a barrier to the spread of angular leaf spot (Table 2), then the higher levels of this disease in the intercrop may possibly be attributable to the more favorable microclimate therein (Moreno, 1979). Other evidence comes from observations on web blight, caused by the fungus *Rhizoctonia solani* which is known to be favoured by high relative humidity. In both beans and cowpeas it has been found that web blight incidence may be less in bush cultivars intercropped among maize but the disease is more severe in climbing cultivars among maize than in sole crop (Allen, 1977; Msuku and Edje, 1982).

Temporal arrangement and anthesis
In some maize-legume associations, sometimes quite substantial quantities of maize pollen grains land on legume leaf surfaces, at concentrations that are apparently sufficient to significantly alter pathogen behavior, as illustrated in Tables 5 and 6. Whether or not pollen does influence disease development in the field is not known, but this potential is shown to exist.

Host-pathogen interactions: induced resistance
It has been suggested that the ability of avirulent races of certain pathogens to induce resistance in a normally susceptible host against infection by a virulent race may play a role in the resistance of multilines varieties (Johnson and Allen, 1975). The ability has been quantified and demonstrated to occur in the field. It also seems likely that alien pathogens may also induce resistance to normally virulent pathogens in intercrops, the potential for which is shown in Table 7.

Table 8 summarizes what seems to be the mechanisms most likely to account for the observed effects on the behavior of pathogens in intercropping, but it is evident that much is speculative and more critical work is required.

Future Challenge
From available data, we may conclude that intercropping affords an opportunity to provide protection from diseases, caused by fungal, bacterial and virus pathogens, and that such protection seems to operate against both aerial and soil-borne pathogens. There are also cases of certain diseases becoming more severe in some crop associations relative to monoculture. Too little is known of the relative importance of the mechanisms that apparently underlie the observed effects to be able to effectively harness this potential in the development of stable strategies for crop protection. Properly designed experiments are required to provide the necessary information, and more use should be made of information generated from parallel research on heterogeneous populations, including varietal mixtures and natural ecosystems. There is also a need to quantify in terms of yield the benefits of intercropping as a means to decrease pathogen incidence.

References


Table 1. Examples of influence of cereal intercropping on disease in associated legumes.

<table>
<thead>
<tr>
<th>Crop association</th>
<th>Disease</th>
<th>Parameter (% difference from sole)</th>
<th>Effect</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize/bean</td>
<td>anthracnose</td>
<td>Severity disease index (%)</td>
<td>-32</td>
<td>Msuku &amp; Edge 1982</td>
</tr>
<tr>
<td></td>
<td>rust</td>
<td>Severity at flowering</td>
<td>-33</td>
<td>Moreno, 1979</td>
</tr>
<tr>
<td></td>
<td>halo blight</td>
<td>Severity, mean score (0-5)</td>
<td>-47</td>
<td>Van Rheenen et al, 1981</td>
</tr>
<tr>
<td></td>
<td>common mosaic</td>
<td>&quot;</td>
<td>-28</td>
<td>&quot;</td>
</tr>
<tr>
<td>Maize/cowpea</td>
<td>ascochyta blight</td>
<td>severity (% area affected)</td>
<td>-63</td>
<td>Moreno, 1975</td>
</tr>
<tr>
<td></td>
<td>cowpea mosaic</td>
<td>incidence</td>
<td>-61</td>
<td>Allen, 1977</td>
</tr>
<tr>
<td></td>
<td>severe mosaic</td>
<td>incidence</td>
<td>-59</td>
<td>Moreno, 1979</td>
</tr>
<tr>
<td>Sorghum/mungbean</td>
<td>powdery mildew</td>
<td>severity at 4 weeks</td>
<td>-17</td>
<td>Keswani &amp; Mreta, 1982</td>
</tr>
<tr>
<td>Ryegrass/red clover</td>
<td>red clover necrotic mottle</td>
<td>incidence</td>
<td>-8</td>
<td>Lewis et al, 1985</td>
</tr>
</tbody>
</table>

Table 2. Effect of crop association on severity of angular leaf spot in beans caused by *Phaeoisariopsis griseola*.

<table>
<thead>
<tr>
<th>Crop association</th>
<th>% Difference over sole crop</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize/bean</td>
<td>+37</td>
<td>Msuku &amp; Edje, 1982</td>
</tr>
<tr>
<td></td>
<td>-7</td>
<td>Van Rheenen et al, 1981</td>
</tr>
<tr>
<td></td>
<td>+19</td>
<td>Moreno, 1979</td>
</tr>
<tr>
<td>Maize/cassava/bean</td>
<td>+12</td>
<td></td>
</tr>
<tr>
<td>Maize/sw. potato/bean</td>
<td>+11</td>
<td></td>
</tr>
<tr>
<td>Cassava/bean</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>Sweet potato/bean</td>
<td>-9</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Development of anthracnose (*Colletotrichum lindemuthianum*) and powdery mildew (*Erysiphe polygoni*) in cowpea in association with maize, Ibadan, Nigeria.

<table>
<thead>
<tr>
<th>Crop association</th>
<th>Disease severity (1-7 scale)*</th>
<th>P(0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cowpea alone</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Cowpea/maize (100 X 60 cm spacing)</td>
<td>1.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Cowpea/maize (100 X 30 cm spacing)</td>
<td>1.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Allen (1977)</td>
<td></td>
<td>NS</td>
</tr>
</tbody>
</table>

7 = most severe

Table 4. Effect of plant density and associated crop on development of bacterial wilt in potato, Kisozi, Burundi.

<table>
<thead>
<tr>
<th>Crop association</th>
<th>Wilted plants/plot (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes alone, normal spacing</td>
<td>13.6</td>
</tr>
<tr>
<td>Potatoes alone, wide spacing</td>
<td>7.4</td>
</tr>
<tr>
<td>Potatoes/maize normal spacing</td>
<td>5.4</td>
</tr>
<tr>
<td>Potatoes/beans normal spacing + LSD (5%)</td>
<td>3.9 + 5.76</td>
</tr>
</tbody>
</table>

| Autrique and Potts (1987). |

Table 5. Effect of maize pollen on spore germination and development of cowpea anthracnose (*Colletotrichum lindemuthianum*).

<table>
<thead>
<tr>
<th>Pollen conc (mg/ml)</th>
<th>Spore germination (%)</th>
<th>Development (%) appressoria</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.5</td>
<td>5.0</td>
</tr>
<tr>
<td>0.0016</td>
<td>24.5</td>
<td>9.5</td>
</tr>
<tr>
<td>0.008</td>
<td>26.5</td>
<td>9.5</td>
</tr>
<tr>
<td>0.04</td>
<td>59.5</td>
<td>2.0</td>
</tr>
<tr>
<td>0.2</td>
<td>62.0</td>
<td>2.0</td>
</tr>
<tr>
<td>1.0</td>
<td>73.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Allen and Skipp (1982).
Table 6. Effect of maize pollen on development of necrotic local lesions induced by cowpea mosaic virus in cowpea seedlings.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. local lesions/leaf</th>
<th>Virus Inoculum</th>
<th>Virus Inoculum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1:10</td>
<td>1:50</td>
</tr>
<tr>
<td>Without pollen</td>
<td>40.3</td>
<td>21.0</td>
<td></td>
</tr>
<tr>
<td>With pollen</td>
<td>2.6</td>
<td>2.4</td>
<td></td>
</tr>
</tbody>
</table>

Allen and Skipp (1982)

Table 7. Weight of spores collected from a) bean seedlings inoculated with wheat yellow rust (WYR) (*Puccinia striiformis*) before inoculation with bean rust (BR) and b) from bean seedlings inoculated with maize rust (MZR) (*Puccinia polysora* &/*sorghi*) and bean rust.

**A)**

<table>
<thead>
<tr>
<th>Inoculation</th>
<th>Sporulation (mg/2 leaves)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
</tr>
<tr>
<td>-</td>
<td>BR</td>
</tr>
<tr>
<td>WYR</td>
<td>BR</td>
</tr>
<tr>
<td>µs (error df = 17)</td>
<td>1.15</td>
</tr>
</tbody>
</table>

**B)**

<table>
<thead>
<tr>
<th>Inoculation</th>
<th>Sporulation (mg/2 leaves)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
</tr>
<tr>
<td>-</td>
<td>BR</td>
</tr>
<tr>
<td>MZR</td>
<td>BR</td>
</tr>
<tr>
<td>-</td>
<td>MZR + BR</td>
</tr>
<tr>
<td>-</td>
<td>BR</td>
</tr>
<tr>
<td>µs (error df = 27)</td>
<td></td>
</tr>
</tbody>
</table>

Allen (1975).

Table 8. Speculative causes of altered disease severity in legumes in cereal association.

<table>
<thead>
<tr>
<th>Host effects</th>
<th>Vector barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathogen filter</td>
<td></td>
</tr>
<tr>
<td>Alternate host of pathogen</td>
<td></td>
</tr>
<tr>
<td>Preferred host of vector</td>
<td></td>
</tr>
<tr>
<td>Pollen-induced effects</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Microclimatic effects</th>
<th>Altered humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shading</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pathogen Interaction</th>
<th>Induced resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synergism</td>
<td></td>
</tr>
</tbody>
</table>

Allen (1975).
Spatial Arrangement of the Component Crops in Developing Intercropping Systems: Some Concepts and Methodologies

M. Natarajan, Agronomy Institute, Department of Research and Specialist Services, P.O.Box 8100, Causeway, Harare, Zimbabwe

Summary

An ideal spatial arrangement is the one which maximises the complementarity between the component crops, and enhances physiological efficiency of the intercropping system in a given environment. However, different intercropping situations have different requirements for them to be advantageous and to be adopted by the farmer. So, it is necessary when developing an intercropping system to take into account preferences of the farmer for specific crops and proportions of the produce that he may require. These requirements, to a large extent, can be satisfied by manipulating the spatial arrangement of the component crops and their plant populations. Choice of a spatial arrangement will also depend on several other practical considerations such as convenience in sowing, weeding, harvesting. When one considers all these aspects, it is not possible to have a blanket recommendation on the row patterns for any given intercrop combination. The availability of above-ground and below-ground growth factors will alter the competitive relationships between the component crops greatly, necessitating adjustments in the spatial arrangements. Lastly, because of the inter-relationship between spatial arrangement, and population in intercropping, their effects need to be distinguished and quantified. Special experimental designs may be required to do this and some such designs were discussed in this paper.

Introduction

Spatial arrangement of component crops is one of the most important management factors that determine whether an intercropping system can be advantageous or not. However, this factor is often interrelated with plant density. Plant density is not a subject to be covered in this paper, but it is useful to consider, briefly, some of the concepts associated with plant populations in intercrops since they help in understanding the responses to spatial arrangements.

Plant Population in Intercropping

Total and component populations

In a sole-crop system plant population defines the number of plants per unit area, and size of the area available to an individual plant. In an intercropping situation, two aspects, namely the total population (sum of the population of all the component crops) and the component population (population of each component crop) have to be distinguished. A single plant of one crop is seldom directly comparable with a single plant of another crop, in terms of the plant population "pressure" on resources. Hence, the proportion of component populations and total population of the intercrop vis a vis the sole crops should be expressed in relative terms. For this, the population optima of sole crops are considered comparable. If, for example, they are taken as 100 each, then a simple intercropping system having half the sole crop optimum of each of two components is considered to have a 50:50 component population and the total population pressure is 100. In other words, although the intercrop contains a different number of plant units per se, compared to any one of the sole crops, its plant population pressure is considered to be the same as that of each of the sole crops.

'Replacement' and 'Additive' intercropping systems

In terms of plant population pressure, two broad classes of intercropping systems can be distinguished. One is 'replacement' type of intercropping, in which one component replaces a proportion of another component. This generally consists of crops with similar patterns and durations of development (i.e. similar phenology) and the yield gain in such mixtures is from a simple response to 'reduced' population because of complementarity in 'space', and to some extent to time, or both. There is however, considerable evidence that in many intercropping situations their better use of resources and therefore their yield advantages are maximised by increasing population pressures to greater than the optima for their components as sole crops by an amount proportional to the differences in plant size and duration of the component crops (Baker, 1981). This becomes necessary when the component crops are not plastic enough to take advantage of their lower plant population in the intercrop or when farmer objectives demand a particular proportion of the products.

In intercropping situations which consist of crops with very different crop development patterns or durations, generally one component is added to the other, so that the final plant population is usually more than had either crop been sown sole. These are called 'superimposed' or 'additive' intercrops. In terms of the farmers' yield objectives there can be two types of additive mixtures. In one type farmers place a high value on the yield of the shorter duration component (usually a cereal) which should not be lower than that of its sole crop, whereas the yield of the later maturing component depends upon the rate of recovery following harvest of the earlier component. A...
cereal-long duration pigeonpea combination is one example of this type and will be discussed in some detail later.

The other type is where a longer duration crop is the more preferred one and its yield should be unaffected by the shorter duration intercrops planted in between. A cotton-short season legume combination is a typical example of this type of additive intercrop.

Spatial Arrangement of Component Crops: Some Basic Principles

With regard to the spatial arrangement of intercrops, again, two aspects have to be distinguished (Willey, 1981). The first is 'proportional areas' allocated to each crop at sowing time. Often, the proportional areas are directly related to component populations; thus if a 50:50 component population is achieved by having equidistant alternate rows, proportional areas will also be 50:50. However, this direct relationship need not apply, and component populations and the proportional areas can be varied independently. In other words, the allocation of space to component crops can be altered without changing component populations. A good example of this is the cereal intercropping research carried out in many parts of India. Since the objective there is to produce a full cereal crop with some additional yield of a second crop, a common approach has been to manipulate the spatial arrangement of the cereal crop.

The most effective arrangement has been 'pairing' of the cereal rows, for example, changing a sole crop width of 45 cm to pairs of rows 30 cm apart, with the pairs themselves separated by 60 cm. This allows the second crop to be grown between the pairs. The other approach has been to replace a row of the dominant component with the second component and compensate for the loss of that row by increasing the population within the other rows of the first component. Considerable work has shown that cereal yield can be maintained over a wide range of spatial arrangements and an appreciable increase in the yield of the second crop can be achieved. Similar effects have been shown when the cereal plants are placed in hills to create more space for a component legume (Willey, 1979).

When the row widths of the component crops as sole crops are not the same, it is difficult by simple replacement of rows alone, to have proportional areas that are the same as the proportional populations.

A second aspect of spatial arrangement is how intimately the crops are mixed. Even when the space allocated to component crops is directly related to component populations, the 'intimacy' of the arrangement can still vary. For example, an intercrop with 50:50 proportional areas could be arranged in decreasing order of intimacy, as 1) alternate plants within the row, 2) as alternate rows, 3) alternate double rows and so on (Willey, 1981). Thus the intimacy of an arrangement can still vary with a given space allocated to the components. It has often been suggested that to get maximum benefit from any complementary effects, crops should be as intimately associated as possible and Willey (1979) quoted a number of experiments to support this. But, there have also been reports of no effects and others where increasing intimacy has decreased yield. For example, Osiru (1974) found in alternate row arrangements of sorghum genotypes the shorter genotypes yielded very poorly and overall the yield decreased. In less intimate arrangements the shorter genotype yielded better and yield advantages occurred. Similar effects have been reported by Pendleton and Seif (1962) with maize genotypes. Thus, where the shorter component is particularly susceptible to shading, some degree of 'grouping' of the dominated crops may give greater advantages by ensuring that the component with a shorter canopy receives a reasonable amount of light.

Spatial Arrangement of Component Crops in Determining Yield Advantages in Intercropping Systems

Yield advantages in intercropping can result from a number of mechanisms, but the most common one cited in the literature is that component crops differ in their use of growth resources in such a way that when they are grown in combination they are able to 'complement' each other and so make better overall use of resources. In terms of competition this means that, in some way, the component crops do not compete for exactly the same overall resources. Thus between crop competition is less than the within crop competition. Maximising the degree of complementarity between the components and minimising between crop competition is therefore expected to maximise the intercrop advantages.

Complementarity in an intercropping situation can occur when the growth patterns of the component crops differ in time, so that the crops make their major demands on resources at different times of the season thus giving better temporal use of resources. Complementarity between the component crops can also occur when they make better use of resources in space. For example, a combined leaf canopy may make better spatial use of light especially when the component crops have different leaf canopy heights or...
canopy structures. Or a combined root system may make better spatial use of mineral nutrients and water.

**Situations with temporal complementarity between crops**
Spatial arrangement of the component crops can be manipulated in order to enhance complementarity, and to reduce competition between the component crops in an intercropping situation so that the physiological advantage from combining the two components is maximised. A typical example of this, for intercropping systems with temporal complementarity between crops, can be found in the Indian sorghum-pigeonpea intercropping work. Here the pigeonpea is double the duration of the sorghum. Since the farmers' objective is to produce a full crop of sorghum with some additional yield of the grain legume, these crops were grown together with wide bands of sorghum alternated with one or more rows of pigeonpea. While this ensured the farmer a full yield of sorghum, the very widely spaced pigeonpea rows did not make full use of resources after the sorghum was harvested and produced low yield.

Intercropping work on this combination therefore was aimed at maximising yield of pigeonpea without reducing that of sorghum. The rows of the faster growing and early maturing component (sorghum) were grouped to accommodate the full sole crop optimum population of sorghum while providing the less competitive and slow growing component enough room to grow. However, the spatial arrangement of the pigeonpea rows is now close enough to make better use of the late season resources. This is achieved by grouping or pairing of the dominant and early maturing component or by adjusting within row spacing as indicated earlier. Natarajan and Willey (1980) showed that with a spatial arrangement of 2 rows of sorghum to 1 row of pigeonpea and with each component at its sole crop optimum population density, the sorghum yield could be maintained at a level equal to that of the solecrop (97%) and the proportional pigeonpea yield was substantially higher (70%) than in the traditional system. This situation is typical of the other cereal-pigeonpea intercropping systems that are common in India and some eastern and southern African countries.

Similar enhancement of physiological advantages by the manipulation of spatial arrangement should be possible in intercropping situations involving short season cereals and legumes with slow growing and long duration crops such as cassava and cotton.

**Situations with spatial complementarity between crops**
The need for an ideal spatial arrangement to enhance the complementarity between the component crops, and thus the physiological advantage is even more important in the case of intercropping systems that have little or no difference in their growth durations. Particularly, in the replacement intercropping systems where the population density of each component crop is only a fraction of its sole crop optimum (with the total population pressure being the same as that of the sole crops), spatial arrangement has an important role to play. Trenbath (1976) in his review on plant interactions observed that in simultaneously planted and dense sole crops, as growth proceeds the proximity of roots and shoot systems leads to mutual interference in the interception and absorption of growth factors. As a result, the growth rates of a plant in a community of similar neighbours falls below those found in isolated plants to an extent proportional to the degree of interference. By implication, component crops in a replacement intercrop, each at a lower population density than the respective sole crops, have an advantage provided the two component crops differ in the structure or response of canopy and/or root systems. Exploitation of this advantage in a replacement situation depends on the spatial arrangement of the component crops.

This can be illustrated with the example of a pearl millet-groundnut intercrop, which typifies a tall cereal-low canopy legume combination: the most common intercropping combination. Reddy and Willey (1981) have shown that by having a one pearl millet : three groundnut row proportion with rows constantly spaced at 30 cm, the yield per plant of millet in the intercrop doubled compared to that in a sole crop, whereas the groundnut yield per plant was maintained at sole crop levels. Given that environment, this row pattern was ideal, since it gave intercropped millet greater access to light (underground resources were not limiting) and the distance between the millet rows was wide enough to allow sufficient light to reach the groundnut plants. A narrower row pattern like one pearl millet to one groundnut, or a very wide pattern of one pearl millet to four or five groundnut rows, under those conditions, would have resulted in less or no physiological advantage from the system. In the former, groundnut might suffer from too much shade from millet, whereas in the latter, the proportion of pearl millet in the system, and consequently, its contribution to the intercrop advantages would have diminished. This has been clearly demonstrated in other studies. However, there can be a situation where the shorter component might perform better under shade, and thus do well in a narrow row pattern. Willey and Rao (1981) reported such a situation from an experiment which examined a wide range of row patterns in safflower-chickpea intercropping.
Spatial arrangement plays an important role even in the additive intercrops of phenologically similar crops. As mentioned in the section on plant populations, under some circumstances the population of one of the components needs to be kept high or even at the level of its sole crop optimum, with rows of the second component added to it. Such instances are seen often in Indian literature, where there is an attempt to preserve the cereal yield, while trying to produce as much as possible of the other component (usually a grain legume such as groundnut, mungbean, soybean or cowpea). A similar preference is often noticed in Africa as well. In Zimbabwe, for example, in a maize-cowpea combination the objective of the farmer is to produce as much of cowpea as possible with minimal yield loss in maize. In India, very high yield advantages were achieved in such intercrop combinations, by the pairing of rows and other manipulations in the spatial arrangement of the component crops.

### The Ideal Spatial Arrangement of Component Crops

It is apparent from the above discussions that by the choice of planting arrangement, the farmer can maximise the types of between-component contacts, the complementarity between them and, as a result, the yield advantages from an intercrop. However, the planting pattern which produces the highest physiological advantage cannot always be the one used by the farmer, because the farmer’s choice is likely to be influenced by other considerations such as preference for a specific component, convenience in sowing, weeding and harvesting. Moreover, the planting pattern which produces the highest physiological efficiency may not give the required proportions of the produce and the highest monetary returns.

Different intercropping situations may have to satisfy different requirements for them to be advantageous, and it is important to ensure that research aimed at improving an intercrop recognises those requirements (Willey, 1979). As indicated in the previous sections, there are some situations where the farmer would not accept a loss in the yield of one of the components. In the maize-cowpea combination discussed earlier, a row pattern which produces more cowpea but reduces the maize yield considerably will be less preferred than the one which largely preserves the maize yield, but produces some additional yield of the legume. This is irrespective of the physiological advantage that the former might give. This is also true for the cereal-pigeonpea combination mentioned earlier.

Attempts have been made to establish the ratio of cereal and pulse that the farmer may be willing to produce in an improved system and to use this information to develop an intercrop pattern (Brown, 1985). If the price ratios or other considerations ever make the farmer change his preferences for the proportions of produce, the spatial arrangement can again be used very effectively to alter the yield proportions, as demonstrated by Natarajan and Willey (1985) with a sorghum-pigeonpea intercrop.

In Zimbabwe, an attempt was made to intercrop cowpeas between cotton rows to take advantage of the insecticidal sprays given to cotton (Natarajan and Naik, unpublished). This resulted in cowpea performing well; in some situations yielding more than the unprotected sole crop. But intercropping with cowpea invariably reduced cotton yield. While the physiological efficiency of such a system (as measured by the land equivalent ratio), is high, it is extremely important to consider whether the additional yield of cowpea produced will compensate monetarily for the reduction in the cotton yield, and if it does, whether the farmer would accept such a trade off.

On the other hand, if both crops are of equal importance to the farmer and he can accept any proportions of their produce, because, they can fetch him comparable economic returns, or can satisfy his subsistence requirements equally, then the main consideration in choosing the spatial arrangement should be to maximise the physiological advantage from the system.

### Spatial Arrangement in Relation to the Growing Environment

The availability of growth resources can greatly alter the competitive relationships between component crops. A row pattern which is the most ideal in terms of the physiological efficiency of the system in a given environment, may not necessarily be the best in another situation. Taking the example of a pearl millet-groundnut intercrop discussed earlier, a row pattern of one row of pearl millet to three rows of groundnut was found ideal when water and nitrogen were not limiting. Here the taller and more dominant cereal component grows tall and tillers profusely and its rows need to be kept wide enough not to smother the groundnut but close enough to produce a combined canopy that makes efficient use of incident light. Once water or nitrogen become limiting, the cereal growth is altered and the benefit from keeping the cereal rows wide apart disappears. For the two crops to beneficially interact in using resources, the
cereal rows need to be kept closer. Natarajan and Willey (1986) have shown with sorghum-groundnut and pearl millet-groundnut intercrops that under dry conditions with high evaporative demands, a one row cereal to two row groundnut gave higher yield advantages than the one to three combination.

Similarly, a change from low soil fertility to high fertility seems to produce a reversal of dominance in intercrops (Trenbath, 1976). The competitive relationship between a cereal and a legume, such as maize and cowpea, growing together can be very different on a soil deficient in nitrogen compared to one where the nutrient is not limiting. Cowpea can become quite competitive to maize when nitrogen is deficient. As Trenbath suggested, the early advantage that a component gets might result in it having a greater share of the other growth factors both below and above ground. It can become necessary to alter the spatial arrangement to take care of such differences in the availability of growth factors.

Experimental Designs for Research on Spatial Arrangements in Intercrops

There is a need to distinguish and quantify the responses to different aspects of plant population and spatial arrangement, since often these effects are 'confounded' in intercropping research. The area of plant population and spatial arrangement is one, where the need for improved or special experimental design is most pressing both to facilitate the identification of relationships between these factors and to separate their effects (Willey, 1979).

In experiments which examine different proportions of component crops with constant within-row spacing, by varying the number of rows of each crop the component population effects are not distinguished from the effect of spatial arrangement. This disadvantage is partly overcome by the use of replacement series treatments at different levels of total population. While this separates genuine intercropping effects from those caused by population pressure, it does not give a completely independent assessment of the total population response to each component. Willey (1979) reviewed attempts made at the International Rice Research Institute (IRRI), International Center for Tropical Agriculture (CIAT) and in the Indian national research programs to solve this problem by keeping the population and spatial arrangement of one crop fixed while varying the population of the other.

A simpler and more satisfactory approach was used at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in which a factorial combination of a range of populations of each crop was examined at one or more appropriate spatial arrangements (usually row arrangements). This allows estimation of individual effects or interactions of total and component populations and spatial effects independently. But one of the problems with this approach is that the experiments become very large and complex, necessitating the use of special experimental designs. Several workers have tried to overcome this problem by using a systematic arrangement based on designs suggested for sole crops. The advantage of these designs is that the need for guard rows between treatments is eliminated and as a result, a larger range of treatments can be examined. One of the systematic designs adapted for intercropping research from those developed for sole crops was a 'fan' design. The limitation of the designs adapted from this was that harvest areas tend to be small and this can be a serious problem for intercropping experiments, where the yield of each component is estimated only from part of the harvest area. Also, the positions within the fan do not always give results typical of comparable situations in more conventional designs (Willey, 1979).

Willey and Rao (1981) described a design used at ICRISAT to overcome some of the disadvantages of the fan design. This is a 'parallel row' design in which the row length can be adjusted to give any required harvest area and the parallel rows more closely relate to normal cropping practice. In one sub-block, the within row population of one crop is kept constant and the population of the second crop is changed systematically, with the rate of change generally limited to no more than 10% between adjacent rows. The full factorial arrangement was achieved by running the other sub-blocks at different standard populations of the other crop and the combinations are tested using two or more row proportions. It is possible to vary the populations of both crops systematically by varying the spacing of one crop along the row and the other in the adjacent rows. Such a design is illustrated in a paper by Mead and Stern (1980), but this reduces the harvest area of a given treatment to a single plant or small group of plants. As Mead and Stern (1980) suggest, many new forms of systematic designs and many new uses of the existing ones await exploration.

More specifically on the row arrangements, two systematic designs referred to by Willey (1979) are worth attention. One is used to examine changes in proportions (brought about by changing the number of rows). This is useful where little is known about competitive abilities and how these are affected by row arrangements. This type of design is now being
used with some modification at the Agronomy Institute, Zimbabwe in a maize-bambaranut combination. The other one is used in some Indian studies to determine the optimum spacing of 'paired' rows (two rows of one crop between single rows of a second crop).

Systematic designs can be very useful to gain preliminary information on basic relationships between the component crops. However, great care should be taken in trying to interpret data from them in absolute terms e.g. yield responses. They also require relatively more uniform experimental areas and different statistical treatment of data than in conventional designs. These aspects are dealt with in detail by Willey and Rao (1981) and Mead and Stern (1980). Because of the above mentioned reasons, systematic designs are most useful as forerunners to the conventional experiments.

References


Evaluation of Maize/Bean Intercrops at Sokoine University of Agriculture, Morogoro, Tanzania

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Summary

An evaluation of maize/bean intercrops at the Sokoine University of Agriculture (SUA) was conducted in the 1987 and 1988 cropping seasons. The newly released maize variety TMV1 and the bean cultivar TM 216 were used. Five treatments used during the study were: Maize solecrop, bean solecrop, maize/bean intercrop in the same hole, maize/bean intercrop 1:1 row and maize/bean intercrop alternate within the same row. According to the LER; SLER; RYT and Monetary value (Tanzanian Shilling, Tsh), the maize/bean intercrop in the same hole was the most advantageous. Before appropriate farmer recommendations on intercropping can be made, other aspects such as those related to economic viability and suitability have to be addressed. The study will also be repeated on farmers’ fields in different locations in Morogoro District.

Introduction

Intercropping of at least two crops is a production strategy used by most farmers in Tanzania. The home gardens of most Tanzanian farmers are characterized by an intensive integration of numerous food crops on the same land (Fernandes et al., 1984). Traditionally most farmers in Tanzania intercrop non-legumes such as sorghum, maize and millets with legumes like groundnuts, soybeans and cowpeas.

The types and choices of crops to be grown in an intercropping system are multidependent and have been discussed by Andrews (1972), and Mugabe et al., (1980) among others. Much attention has been placed on research on intercropping systems in Tanzania during the past decade. The symposia in Morogoro (Monyo et al., 1976; Keswani and Ndunguru, 1982) outline some of the recent efforts to improve these systems for farmers.

Several methods are used to evaluate intercropping yield advantage over monocropping. Willey (1979), Mead and Willey (1980), Mead and Riley (1981), and Hiebsch and McCollum, (1987) have reviewed the difficulties of assessing any yield advantage due to intercropping practices, and have discussed some of the methods available for the purpose. Among all the methods mentioned, none of them, by itself, can evaluate all of the factors involved. These factors include competitive effects, relative production potential, labour requirements, water and nutrient use efficiency and socio-economic impact. Fair evaluation requires a team effort involving agronomists, crop physiologists, soil scientists, and agricultural economists (Nadar, 1980).

Among the methods commonly in use is the land equivalent ratio (LER) suggested by Willey (1979). Hiebsch (1978) and Hiebsch and McCollum (1987) argued that LER was not an accurate technique for comparing relative production potentials of intercropping and monocropping systems. They suggested the use of the area time equivalency ratio (ATER) by redefining yield to be quantity/unit area per unit time. Reddy and Chetty (1984) proposed the use of staple land equivalent ratio (SLER) in which a minimum percentage of the pure stand yield of the staple crop component is maintained in the intercropping system. Okigbo (1979) suggested the use of LER, competition coefficient, relative yields, calorific equivalent, and gross return as indices to select efficient crop mixtures.

Experimental designs have also been proposed (Mead and Riley, 1981).

However, as suggested by Hildebrand (1976), the criteria for the choice of an evaluation index should be a) common to all products and inputs and must provide a means of comparing different crops, b) relatively easy to measure, c) capable of reflecting quality differences between the products, d) meaningful to the farmer in such a way that it helps him to allocate his resources between competing uses and e) meaningful to the researcher so that new technologies can be compared with existing ones.

The objective of this study was to evaluate the maize (Zea mays L.) common bean (Phaseolus vulgaris L.) intercrop yield advantages at Sokoine University of Agriculture (SUA) using several different methods described above.

Materials and Methods

Experiment location

The experiments with maize and bean were conducted at SUA, Morogoro, Tanzania located at 6 °S latitude and 37 °E longitude, during the 1987 and 1988 cropping seasons. The elevation is about 525 m a.s.l. The soil is an oxisol with soil characteristics shown on Table 1. The area receives a bimodal average rainfall of 1000 mm with erratic distribution. The short rains occur between November and January and are known as “Vuli”, followed by the long rains in March to June, which are known as “Masika”. A dry spell is experienced in February. The temperature and rainfall data for the two years are in Table 2.

Planting materials

Maize (Zea mays L.): The variety used was EV8311A which was released in Tanzania, February 1988 under the name of...
Tanzania Maize Variety One (TMV1). The variety is composed of intermediate white flint material introduced from the International Maize and Wheat Improvement Centre (CIMMYT), Mexico. TMV1 is resistant to Maize Streak Virus (MSV), downy mildew and Maize Stunt. This makes the variety suitable for the low to mid elevation areas (0-1500 m). The variety takes 110-115 days to mature at low elevations and 125-130 days at medium elevations (Moshi et al., 1988).

It is suitable for planting during the short rainy season in areas which experience a bimodal rainfall pattern. The variety can also be grown as a 'catch-up' variety during the long rainy season when there is delay in the onset of rain or when a farmer has been late in planting the full season variety.

Bean (Phaseolus vulgaris L.): The cultivar used was TMO 216. It originated from CIAT via Uyole Agricultural Centre (UAC) in Mheya as UCA 258. It has a determinate growth habit, is tolerant to Bean Common Mosaic Virus (BCMV) and Angular Leaf Spot (ALS) as reported by Palapala et al., (1984). The cultivar has a dark grey seed colour and takes about 70 days to mature.

Both maize and beans were sown by hand on 30 March 1987 and 25 March 1988. One seed was sown per hole. The spacing used was 75 cm x 30 cm for maize and 50 cm x 15 cm for bean monocrops. The gross plot size was 40.5 m². Gap filling was done 14 days after seeding to achieve the plant population density intended.

**Fertilizer application, pests and disease control**
60 kg N/ha as ammonium sulphate and 70 kg P₂O₅/ha as triple superphosphate were applied as a band application. Weeds were controlled by hoeing 20 and 40 days after sowing, but weeds close to crop plants were removed by hand to avoid shaking off flowers or disturbing the root system.

The common pests in legumes were controlled by application of cypermethrin (Ripcord, a synthetic pyrethroid) and mancozeb (Dithane M45) was applied for the control of diseases.

**Data collection**
Data were collected on plant growth parameters and yield. The samples harvested for yield analysis were from the three central rows in each plot. The data collected are as shown in Tables 4 and 5. Yields were adjusted to 14 and 15% moisture for beans and maize, respectively. A separate statistical analysis was done on data from each year.

**Evaluation of intercrop yield advantages**
Four methods were used to evaluate the intercrop yield advantages:

1. Land equivalent ratio (LER) according to Willey (1979).
4. Monetary value (MV) according to Gomez and Gomez (1983). The prices used in calculating the MV were the current producer prices of maize and beans in Tanzania, i.e. 8.20 and 21.60 Tsh. respectively, per kg (Tanzania Economic Trends, 1988).

**Results and Discussion**
The grain yields and total dry matter/ha for both crops in both years are shown in Table 4. Sole crop yields for maize and beans were lower than those reported by other researchers in Morogoro district. However, maize yield of 1840 kg/ha for 1987 and 1567 kg/ha for 1988, were higher than the average yield of 1061 kg/ha reported in a previous study at SUA using variety TMV1 (Kanju, 1988). The yields from the sole crop of beans were slightly lower than those reported by Kasuga and Rweyemamu (1988). Both component crops of the maize and beans systems yielded less grain and dry matter than did their respective sole crops. Yield components were not affected by the cropping system. However, the grain yield per plant in both crops was highly affected (Table 5). Grain yield in each species was always greater under sole cropping than in intercropping (Table 5).

Yield advantages were determined using LER, SLER, RYT and monetary value (MV) (Table 6). With the first three methods (ratios), the results were higher than 1, indicating a yield advantage of intercropping. The maize/bean intercrop alternate within the same row was the exception. Using monetary values (Tsh), the sole crops had a higher monetary value for both crops than did the intercropping systems. The Maize/Bean intercrop in the same hole had the second highest monetary value.

With all four methods used to evaluate the intercrop yield advantage, the Maize/Bean intercrop in the same hole was superior to other intercrops.
These results are different from those reported by Finlay (1975), who observed that in maize/soyabean and sorghum/soyabean intercrops an alternate-row arrangement was superior to planting in the same hole or on the same row. The results in the present study could have been due to the fact that maize/bean intercropping in the same hole achieved a higher number of plants, better distributed over the area, and thus improved interception of light. This is supported in the literature where it is found that better utilization of radiation is responsible for yield increases due to intercropping (Baker and Yusuf, 1976; Willey and Osiru, 1972; Willey, 1979). However, factors in addition to better light interception could be responsible for the superior performance of the maize/bean intercrop in the same hole. This could result from the suggested transfer of nitrogen from a legume to a non-legume (Agboola and Fayemi, 1971; Finlay, 1975). As suggested by Thompson (1977) and Willey (1979), the depletion of nitrogen by the cereal could have resulted in increased nitrogen fixation. Crops planted in the same hole will have had the greatest root contact. Thus the beans could have been stimulated to a greater nitrogen fixation in the same hole intercropping system. Such factors could have been responsible for the favourable effects produced in the same hole maize/soyabean and maize/cowpea intercrops as reported by Osiru and Willey (1972), Trenbath (1974), and Keswani et al. (1977).

Summary and Conclusions

The change from sole crop to intercrop conditions significantly reduced the yield of each component crop, but did not significantly affect the yield components. Intercropping both crop components in the same hole rather than maize/bean intercrop 1:1 row; maize/bean intercrop alternate within the same row gave the largest number of harvestable plants and highest grain yield.

Four methods of evaluating yield advantages: LER; SLER; RYT and Monetary Value (Tsh.), were applied to the intercropping data. In all the methods used, maize/bean intercrop in the same hole consistently gave the highest yield advantage. This was followed by the maize/bean intercrop alternate within the same row and finally the maize/bean intercrop 1:1 row.

Before recommendations to farmers on maize/bean intercrop planting patterns are possible, other parameters related to economic viability of the intercrop and social acceptability of the component varieties need to be assessed with farmers under their conditions. Similar trials are now being conducted on-farm under the Farming Systems Research (FSR) project sponsored by the International Development Research Centre (IDRC), Ottawa in two villages.

References


Andrews, D.J. (1972). Intercropping with sorghum in Nigeria. Experimental Agriculture 8, 139-150.


Table 1. Soil characteristics (of samples taken at 0-15 cm depth) at the experimental site during the 1987 and 1988 cropping seasons.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Method of Determination</th>
<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil texture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Sand</td>
<td>Hydrometer</td>
<td>50</td>
<td>Sandy clay</td>
</tr>
<tr>
<td>% Silt</td>
<td>pH-meter</td>
<td>17</td>
<td>loam</td>
</tr>
<tr>
<td>% Clay</td>
<td></td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>pH (1:1 water)</td>
<td></td>
<td>6.0</td>
<td>Slightly acidic</td>
</tr>
<tr>
<td>% Total Nitrogen</td>
<td>Semi-micro kjeldahl</td>
<td>0.11</td>
<td>Medium</td>
</tr>
<tr>
<td>Extractable Phosphorus (ppm)</td>
<td>Bray and Kurtz, 1945</td>
<td>1.25</td>
<td>Low</td>
</tr>
<tr>
<td>Extractable Potassium (me/100g)</td>
<td>Ammonium acetate saturation</td>
<td>0.45</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 2. Environmental data for the 1987 and 1988 cropping seasons (March-July).

<table>
<thead>
<tr>
<th>Month</th>
<th>Date</th>
<th>Total rainfall (mm)</th>
<th>Mean air temp (°C)</th>
<th>Mean humidity (%)</th>
<th>Mean Radiation (MJm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max.</td>
<td>Min.</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>1-4</td>
<td>(21.8)*</td>
<td>(32.8)</td>
<td>(22.0)</td>
<td>(63.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.3</td>
<td>34.6</td>
<td>21.8</td>
<td>42.0</td>
</tr>
<tr>
<td></td>
<td>15-31</td>
<td>(43.9)</td>
<td>(31.8)</td>
<td>(21.2)</td>
<td>(56.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>188.6</td>
<td>30.5</td>
<td>21.6</td>
<td>62.5</td>
</tr>
<tr>
<td>April</td>
<td>1-14</td>
<td>(76.3)</td>
<td>(31.7)</td>
<td>(21.3)</td>
<td>(62.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33.5</td>
<td>30.5</td>
<td>21.1</td>
<td>61.6</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>(28.4)</td>
<td>(29.4)</td>
<td>(20.7)</td>
<td>(68.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>53.5</td>
<td>30.4</td>
<td>21.4</td>
<td>64.6</td>
</tr>
<tr>
<td>May</td>
<td>1-14</td>
<td>(104.3)</td>
<td>(28.7)</td>
<td>(19.7)</td>
<td>(70.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.8</td>
<td>29.5</td>
<td>18.2</td>
<td>84.1</td>
</tr>
<tr>
<td></td>
<td>15-31</td>
<td>(28.4)</td>
<td>(29.1)</td>
<td>(18.7)</td>
<td>(67.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.9</td>
<td>29.8</td>
<td>18.7</td>
<td>87.4</td>
</tr>
<tr>
<td>June</td>
<td>1-14</td>
<td>(0.0)</td>
<td>(28.4)</td>
<td>(16.3)</td>
<td>(57.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22.7</td>
<td>27.0</td>
<td>18.7</td>
<td>57.7</td>
</tr>
<tr>
<td></td>
<td>15-31</td>
<td>(3.3)</td>
<td>(28.2)</td>
<td>(14.3)</td>
<td>(52.5)</td>
</tr>
<tr>
<td>July</td>
<td>1-14</td>
<td>(3.3)</td>
<td>(28.2)</td>
<td>(14.3)</td>
<td>(52.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>28.8</td>
<td>18.2</td>
<td>52.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(307.1)</td>
<td>336.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Sokoine University of Agriculture Meteorological Station.
* Data in parentheses correspond to the 1987 cropping season.
Table 3. Treatment and plant population per hectare.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant population per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
</tr>
<tr>
<td>Maize monoculture</td>
<td>44,444</td>
</tr>
<tr>
<td>Bean monoculture</td>
<td></td>
</tr>
<tr>
<td>Maize/Bean Intercrop in the same hole</td>
<td>44,444</td>
</tr>
<tr>
<td>Maize/Bean Intercrop 1:1 row</td>
<td>22,222</td>
</tr>
<tr>
<td>Maize/Bean Intercrop alternate within the same row</td>
<td>22,222</td>
</tr>
</tbody>
</table>

Table 4. Grain yield, total dry matter of sole and intercrops of maize beans.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield in kg/ha</th>
<th>Total dry matter in kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize monoculture</td>
<td>1840a 1567b</td>
<td>4658a 3888a</td>
</tr>
<tr>
<td>Bean monoculture</td>
<td>-</td>
<td>701a 718a</td>
</tr>
<tr>
<td>Maize/Bean Intercrop in the same hole</td>
<td>1810a 1487b</td>
<td>495b 415b</td>
</tr>
<tr>
<td>Maize/Bean Intercrop 1:1 rows</td>
<td>943b 883b</td>
<td>424b 373b</td>
</tr>
<tr>
<td>Maize/Bean Intercrop alternate within same row</td>
<td>893bc 904b</td>
<td>389b 340b</td>
</tr>
</tbody>
</table>

Mean: 1371 1212 552 561 3514 3164 1543 1486
SE: 453 320 146 208 1032 827 417 394
CV%: 33 26 26 37 29 26 27 26

* Means within the same column followed by the same letter are not significantly different using the Duncan’s Multiple Range Test at P = 0.05.
Table 5. Grain yield per plant of sole and intercrops of maize and bean

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield per plant (g)</th>
<th>1987</th>
<th>1988</th>
<th>1987</th>
<th>1988</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize monoculture</td>
<td></td>
<td>37.1</td>
<td>33</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bean monoculture</td>
<td></td>
<td>-</td>
<td>-</td>
<td>4.1</td>
<td>3.8</td>
</tr>
<tr>
<td>Maize/Bean intercrop in the same hole</td>
<td></td>
<td>35.6</td>
<td>28.9</td>
<td>2.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Maize/Bean intercrop 1:1 rows</td>
<td></td>
<td>36.9</td>
<td>31.7</td>
<td>3.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Maize/Bean intercrop alternate within the same row</td>
<td></td>
<td>33.4</td>
<td>32.9</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>35.6</td>
<td>31.6</td>
<td>3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td>1.5</td>
<td>1.6</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>4.1</td>
<td>5.2</td>
<td>18.7</td>
<td>12.7</td>
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</tbody>
</table>

* Means within the same column followed by the same letter are not significantly different using the Duncan's Multiple Range Test at P=0.05.

Table 6. Evaluation of intercrop yield advantages.

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<td>-</td>
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<td>-</td>
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<tr>
<td>Bean monoculture</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>1.5</td>
<td>1.5</td>
<td>1.7</td>
<td>1.5</td>
<td>1.5</td>
<td>14849ab 12278a</td>
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<tr>
<td>Bean/Maize Intercrop 1:1 row</td>
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<td>1.1</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
<td>1.2</td>
<td>7736b 7244b</td>
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<tr>
<td>Bean/Maize Intercrop alternate within the same row</td>
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<td>1.1</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
<td>1.1</td>
<td>7325b 7414b</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
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* Means within the same column followed by the same letter are not significantly different using Duncan's Multiple Range Test at P=0.05.
Effect of Chronological Arrangement, Spatial Arrangement and Varietal Combination on Yield and Economic Feasibility of Maize + Cowpea Intercropped

F.R. Arias, H. Dapaah, S. Ennin and M. Gyampoh, Ghana Grains Development Project, P.O. Box 1639, Accra, Ghana

Abstract

The advantages of intercropping cereals with grain legumes are often limited by inappropriate planting dates, spatial arrangements and varietal combinations. Field studies were carried out in the forest and transition zones of Ghana to determine the effect of combinations of these factors on the agricultural and economic feasibility of intercropping maize and cowpea. Results have shown that simultaneously intercropping maize (Dobidi or Aburotia) with cowpea (Soronko) in double rows is a viable alternative for cowpea farmers. Intercropping combinations make better use of the land, generate higher benefits, reduce economic risk and enhance diet diversification.

Introduction

Farmers in Ghana intercrop cereals with grain legumes. These systems are managed with low technology (low yielding varieties, low use of inputs) which may often lead to low yield and income. Common combinations found include maize (Zea mays) + cowpea (Vigna unguiculata), sorghum (Sorghum bicolor) + millet (Pennisetum americanum), maize + groundnut (Arachis hypogaea) and cereals + bambara nut (Voandzeia subterranea). Efficiency of land use, increased net benefit and diet diversification are some of the advantages of these systems.

It has often been reported that maize depresses the yield of legumes when intercropped. Reported legume yield depressions include for soybean (Wahua and Miller, 1978 and IITA, 1981), groundnut (Koli, 1975 and Mutaare, 1978), beans (Phaseolus spp) (Agboala and Fayemi, 1971) and cowpea (Remison, 1978 and Adetiloye, 1980). Maize yield depressions by intercropping with legumes have also been reported (Fayemi, 1971; Enyi, 1973; Fisher, 1977 and Adetiloye, 1980).

Haizel (1974), Adetiloye (1980), Cunard (1981) and IITA-SAFGRAD (1983) have reported obtaining good cowpea yields (>500 kg/ha) by intercropping simultaneously and by manipulating cereal row spacings and cowpea population. Isenmilla et al. (1981) observed that yield loss of cowpea intercropped with maize could be reduced from 68 to 48% by selecting the proper varietal combination.

The field experiments reported here were carried out in Ghana between 1986 and 1988 to study the effect of varietal combination, spatial and chronological arrangements on the agro-economic feasibility of intercropping maize and cowpea.

Materials and Methods

1986 Trial

Field experiments were conducted at Ejura (forest-savannah transition zone) and Fumesua (forest zone) experiment stations during the major season (April-August 1986). A split plot design was used to evaluate three spatial arrangements (Figure 1) and three chronological arrangements (i.e. time of planting maize).

Both maize ('Aburotia') and cowpea ('Asontem') plant populations were held constant at 100% of the monocrop population (62,500 and 125,000 plants/ha respectively) for all the spatial arrangements. Maize was interplanted into the cowpea stand at three different times; simultaneously, 5 days after planting cowpea (5 DAP) and 10 days after planting cowpea (10 DAP). The maize was fertilized with 76 kg N and 50 kg P2O5 per hectare. Maize was protected against pre- and post-flowering insects. Weeds were controlled by hand, two and four weeks after planting.

1987 Trial

A field trial was conducted at Fumesua experiment station to determine suitable varietal combinations and spatial arrangements for intercropping maize and cowpea. Two varieties of maize, 'Dobidi' (120 days to maturity) and 'Aburotia' (105 days), were simultaneously intercropped with two cowpea varieties, 'Soronko' (80 days) and 'Asontem' (65 days) in three spatial arrangements (Figure 2). Treatments were distributed in the field in randomized complete blocks with a factorial arrangement. Sole crops were included for comparison.

1988 Trial

Two maize varieties, 'Dobidi' (120 days) and 'Aburotia' (105 days) were simultaneously intercropped with two cowpea varieties 'Soronko' (80 days) and 'IT82D-716' (65 days) to evaluate four varietal combinations for intercropping. The treatments were distributed in the field in four randomized complete blocks in a 2 x 2 factorial arrangement.

Double rows of cowpea were simultaneously planted between two rows of maize. Plant population for monocrop and intercrop maize was 62,500 plants/ha (0.8 x 0.4m, 2 plants/hill). Monocrop and intercrop Soronko and IT82D-716 populations
were 125,000 plants/ha. Maize was fertilized with 76 kg N and 50 kg \( \text{P}_2\text{O}_5 \) per ha. Cowpea was protected against pre- and post-flowering insects.

### Results and Discussion

#### 1986 Trial

Maize grain yield was adversely affected by spatial arrangement (Table 1). In general maize grain yield was higher when sole cropped and decreased with delays in planting. Double rows of cowpea reduced maize grain yield, especially when maize planting was delayed. The lowest yields (0.7 and 2.2 t/ha) were observed for double rows -10 DAP at Fumesua and Ejura, respectively. The highest yield (6.9 t/ha) was observed at Ejura with maize sole crop -5 DAP.

In general, intercropping maize into cowpea stands increased cowpea grain yield (Table 1). Visual observations suggest the possibility of a fertilizer effect on cowpea. Plots with double rows of cowpea consistently outyielded those with alternate rows and sole crop cowpea, particularly when maize planting was delayed 10 days. The data suggest that the cowpea variety used exerted strong competition for soil moisture and nutrients.

When maize and cowpea are planted simultaneously, moving from sole crop cowpea (Option B) to double rows intercropped (Option C) presents an economically attractive alternative (Tables 2 and 3). The highest net benefits (Cedis 101,317 and Cedis 139,785) and highest MRR (524 and 570%) observed (Table 4) were for plots planted in alternate rows with maize, and sole crop cowpea (Table 5).

#### 1987 Trial

Land Equivalent Ratio (LER) was higher than one for all the intercrop combinations. This indicated a more efficient use of land when maize and cowpea are intercropped (Table 4). Double rows of cowpea in all varietal combinations and spatial arrangements gave the highest LER values observed (Table 4).

Results of a partial costs analysis indicate that double rows of cowpea generate the highest net benefit (Table 4). Asontem intercropped with Dobidi in double rows resulted in the highest net benefit (Cedis 119,362/ha) followed closely by the Soronko + Dobidi combination (Cedis 100,911/ha). A marginal rate of return analysis showed that if a farmer growing solecrop Soronko decides to intercrop with Dobidi, for every additional 100 Cedis invested, the farmer would recover 190 Cedis (Table 5).

When intercropped, Soronko outyields Asontem by 20%. However, in sole crop, Asontem outperforms Soronko (Table 4). The yield depression in intercropped Asontem may be explained by its climbing habit, which makes insecticide applications difficult. In maize, Dobidi outyielded Aburotia by 45% (Table 4).

An interaction among cowpea and maize varieties was observed (Figure 3). Both cowpea varieties yielded higher when intercropped with Aburotia. Aburotia, being shorter, exerted less competition than Dobidi, which has a faster initial growth rate. Soronko proved to be more competitive than Asontem.

#### 1988 Trial

Maize and cowpea yields were reduced 23 and 47% respectively when intercropped (Table 6). Maize yield, which ranged from 1.9 to 2.9 t/ha was not affected by intercropping maize (Table 6). Generally, cowpea yield was higher when intercropped with Aburotia than with Dobidi (Table 6). While Soronko yielded significantly higher in the Aburotia + Soronko combination, the yield of IT82D-716 was similarly depressed in both combinations.

LER values (Table 6) for all intercrop combinations were all greater than one. Aburotia intercropped with Soronko gave the highest LER value (1.53) followed by the Dobidi + Soronko combination (1.40), the lowest LER value (1.04) was observed in the Aburotia + IT82D-716 combination.

The Dobidi + Soronko and Aburotia + Soronko combination generated the highest net benefit (Cedis 102,803 and Cedis 102,262, respectively) and the more attractive MRR (Table 7). Both intercrop combinations with IT82D-716 had a negative MRR (Table 7), indicating that this variety is not suitable for intercropping.

### Conclusions

The economic analyses and agronomic data suggest that intercropping simultaneously maize and cowpea in double rows is an attractive alternative for cowpea farmers. Soronko intercropped either with Dobidi or Aburotia are appropriate varietal combinations. However for those farmers wishing to spread the labour demand, intercropping maize 5 days after planting cowpea is also viable. These alternatives, besides reducing risks, increase net benefit and MRR. Therefore, it is recommended that these results be verified on-farm. Asontem and IT82D-716 are not suitable for intercropping with Dobidi and Aburotia.
References


Remison, S.U. (1978). Neighbour effects between maize and cowpea at various levels of N and P. Experimental Agriculture 14, 205-212.

Table 1. Maize grain yield (t/ha at 15% moisture) and cowpea grain yield (t/ha at 13% moisture) as affected by spatial arrangement and date of planting, 1986.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Fumesua</th>
<th></th>
<th>Ejura</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Aburotla</td>
<td>Asontem</td>
<td>Aburotla</td>
<td>Asontem</td>
</tr>
<tr>
<td>Simultaneous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sole crop</td>
<td>2.86</td>
<td>1.22</td>
<td>5.72</td>
<td>1.28</td>
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<td>1.55</td>
<td>1.28</td>
<td>3.63</td>
<td>0.84</td>
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<tr>
<td>Double Rows</td>
<td>1.75</td>
<td>1.28</td>
<td>3.10</td>
<td>1.16</td>
</tr>
<tr>
<td>5 DAP</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Sole crop</td>
<td>2.29</td>
<td>0.91</td>
<td>6.90</td>
<td>1.53</td>
</tr>
<tr>
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<td>0.90</td>
<td>1.25</td>
<td>3.73</td>
<td>0.94</td>
</tr>
<tr>
<td>Double Rows</td>
<td>0.77</td>
<td>1.38</td>
<td>3.53</td>
<td>1.31</td>
</tr>
<tr>
<td>10 DAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sole crop</td>
<td>1.91</td>
<td>0.94</td>
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<td>1.31</td>
</tr>
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<tr>
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<td>0.70</td>
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<td>1.28</td>
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<td>CV(%)</td>
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<td>16.5</td>
<td>20.4</td>
<td>17.6</td>
</tr>
<tr>
<td>LSD(P=0.01)</td>
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<td>0.37</td>
<td>1.63</td>
<td>0.42</td>
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</table>

Table 2. Net Benefit of Maize + Cowpea Intercropped as Affected by Arrangement and Maize Planting Date, 1986.

<table>
<thead>
<tr>
<th>Time of maize planting</th>
<th>Solecrop Maize (A)</th>
<th>Solecrop Cowpea (B)</th>
<th>Alternate Rows (C)</th>
<th>Double Rows (D)</th>
<th>Cedis/ha</th>
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<tr>
<td>FUMESUA</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous</td>
<td>49,206</td>
<td>69,428</td>
<td>96,965</td>
<td>101,317</td>
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<tr>
<td>5 DAP</td>
<td>37,603</td>
<td>47,800</td>
<td>81,489</td>
<td>87,410</td>
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<tr>
<td>10 DAP</td>
<td>29,822</td>
<td>49,959</td>
<td>94,772</td>
<td>94,611</td>
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<tr>
<td>EJURA</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Simultaneous</td>
<td>108,078</td>
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IUS$ = 60 Cedis
Table 3. Marginal Rates of Return as Affected by Spatial Arrangement and Maize Planting Date, 1986.

<table>
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<th>Time of maize planting</th>
<th>Marginal Rates of Return</th>
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<td>A to D</td>
<td>B to C</td>
<td>B to D</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Simultaneous</td>
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<td>372</td>
<td>322</td>
<td>373</td>
</tr>
<tr>
<td>5 DAP</td>
<td>313</td>
<td>355</td>
<td>394</td>
<td>463</td>
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<td>463</td>
<td>462</td>
<td>524</td>
<td>522</td>
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<tr>
<td>EJURA</td>
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</tr>
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<td>Simultaneous</td>
<td>11</td>
<td>87</td>
<td>419</td>
<td>544</td>
</tr>
<tr>
<td>5 DAP</td>
<td>Neg</td>
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<td>314</td>
<td>570</td>
</tr>
<tr>
<td>10 DAP</td>
<td>99</td>
<td>184</td>
<td>414</td>
<td>404</td>
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</tbody>
</table>

* A = Maize Solecrop, B = Cowpea Solecrop
C = Alternate Rows, D = Double Rows


<table>
<thead>
<tr>
<th>Spatial arrangement</th>
<th>Cowpea Variety</th>
<th>Maize Variety</th>
<th>Grain yield Cowpea t/ha</th>
<th>Maize t/ha</th>
<th>LER</th>
<th>Net benefit Cedis/ha</th>
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<tr>
<td>Alternate Rows</td>
<td>Asontem + Dobidi</td>
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<td>0.63</td>
<td>3.71</td>
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<td>1.01</td>
<td>4.07</td>
<td>1.48</td>
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<td>2 Rows Cowpea, Maize 120cm apart</td>
<td>Asontem + Dobidi</td>
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<td>1.07</td>
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<td>81,547</td>
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<td>0.82</td>
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<td>54,391</td>
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<td>1.33</td>
<td>62,447</td>
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<td>1.44</td>
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<tr>
<td>Alternate Rows</td>
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<tr>
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<td>1.20</td>
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<tr>
<td>2 Rows Cowpea, Maize 120cm apart</td>
<td>Soronko + Aburotia</td>
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<td>1.13</td>
<td>1.19</td>
<td>1.37</td>
<td>68,980</td>
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<td>60,429</td>
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<td>1.70</td>
<td>1.71</td>
<td>1.86</td>
<td>79,186</td>
</tr>
<tr>
<td>2 Rows Cowpea, Maize 120cm apart</td>
<td>Soronko + Aburotia</td>
<td></td>
<td>1.55</td>
<td>1.04</td>
<td>1.55</td>
<td>58,236</td>
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<tr>
<td>Sole Soronko</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>47,741</td>
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<tr>
<td>Sole Dobidi</td>
<td>-</td>
<td>4.67</td>
<td></td>
<td></td>
<td></td>
<td>94,048</td>
</tr>
<tr>
<td>Sole Aburotia</td>
<td>-</td>
<td>3.02</td>
<td></td>
<td></td>
<td></td>
<td>53,828</td>
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</tbody>
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1 US.$ = 145 Cedis
Table 5. Marginal Rates of Return as Affected by Varietal Combination and Spatial Arrangements, 1987.

<table>
<thead>
<tr>
<th>Varietal combination</th>
<th>Marginal rates of return'</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B to C**</td>
<td>%</td>
<td>D to C</td>
</tr>
<tr>
<td>Asonterm + Dobidl</td>
<td>134</td>
<td>276</td>
<td></td>
</tr>
<tr>
<td>Asonterm + Aburotia</td>
<td>-</td>
<td>7.6</td>
<td></td>
</tr>
<tr>
<td>Soronko + Dobidl</td>
<td>34</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>Soronko + Aburotia</td>
<td>124</td>
<td>113</td>
<td></td>
</tr>
</tbody>
</table>

* Other options were dominated
** B = Maize Sole crop, C = Double rows and D = Cowpea Sole crop

Table 6. Maize and cowpea grain yield, LER and net benefits as affected by intercropping and varietal combinations, 1988.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield</th>
<th>LER</th>
<th>Net benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize t/ha</td>
<td></td>
<td>Cedis/ha</td>
</tr>
<tr>
<td>Sole crop Dobidl</td>
<td>3.6</td>
<td></td>
<td>89,511</td>
</tr>
<tr>
<td>Sole crop Aburotia</td>
<td>2.9</td>
<td></td>
<td>65,970</td>
</tr>
<tr>
<td>Sole crop Soronko</td>
<td>1.8</td>
<td>2.0</td>
<td>93,200</td>
</tr>
<tr>
<td>Sole crop IT82D-716</td>
<td></td>
<td></td>
<td>110,716</td>
</tr>
<tr>
<td>Dobidl + Soronko</td>
<td>2.8</td>
<td>1.1</td>
<td>1.40</td>
</tr>
<tr>
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<td>2.3</td>
<td>1.2</td>
<td>1.53</td>
</tr>
<tr>
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<td>0.7</td>
<td>1.20</td>
</tr>
<tr>
<td>Aburotia + IT82D-716</td>
<td>1.9</td>
<td>0.8</td>
<td>1.04</td>
</tr>
</tbody>
</table>

|                          |             |     |            |
| LSD (P=0.05)             | N.S.        | 0.13|             |
| CV(%)                   | 45.6        | 13.5|             |

1 US $ = 230 Cedis

Table 7. Marginal rates of return as affected by intercropping and varietal combination, 1988.

<table>
<thead>
<tr>
<th>Variety combination</th>
<th>Marginal rates of return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A to C</td>
</tr>
<tr>
<td>Dobidl + Soronko</td>
<td>20</td>
</tr>
<tr>
<td>Aburotia + Soronko</td>
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</tr>
<tr>
<td>Dobidl + IT82D-716</td>
<td>-13</td>
</tr>
<tr>
<td>Aburotia + IT82D-716</td>
<td>-45</td>
</tr>
</tbody>
</table>

A = Sole crop Maize, B = Sole crop, C = Intercrop
Figure 1. Maize (M) + Cowpea (C) Spatial arrangement under study

Option 'A' Maize Solecrop

Option 'B' Cowpea Solecrop

Option 'C' Alternate Rows

Option 'D' Double Rows
Figure 2. Spatial Arrangement of Maize and Cowpea Intercrop Experiment.
Planning of On-Farm Intercrop Trials

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Introduction

Experimentation with intercropping in on-farm research (OFR) can be complex and expensive. Hence OFR experimental programs with intercrops need to be carefully planned and justified. The potential number of combinations of crops, plant densities, plant arrangements, inputs and management practices may be huge, but the most appropriate choice of intercrop pattern and management often is not necessarily the one that maximizes output. It is often determined more by types and amounts of land and labour available to the farmer, household food needs and preferences and marketing conditions for the different crops (Byerlee and Tripp, 1988). All of these factors may need to be taken into account when planning on-farm intercrop trials. Planning may, therefore, become complicated but is an essential component of priority setting.

The basic aim of OFR trials to be planned is to look at possible technologies that offer potential for increasing the productivity of smallholder farmers, usually within the short term (3-5 years). Because success depends on early adoption by farmers, these trials are carried out on farmers’ fields with farmer participation.

If OFR trials are carefully designed with clear objectives in mind, the analysis and interpretation of results becomes easier and much more productive. Because intercropping technologies can be complex, a systematic approach to developing clear objectives and related appropriate treatments for trials becomes more important than ever.

General Aspects of Planning

In on-farm experimentation the emphasis is on trials that examine solutions to technical production problems identified during diagnosis. The planning of on-farm trials is basically a process of taking information from diagnostic sources (surveys, agronomic monitoring work, diagnostic trials), and results from other trials to identify experimental factors for incorporation into new trials, or to modify those factors in existing trials. During planning we then go on to organize trials with relevant objectives and think about aspects of trial design, data to collect and the role of the farmer and the researcher in that process. In planning we rely on an adequate appreciation of circumstances and factors influencing the farming system and the reasons farmers have for their current practices and variations.

In a publication widely available in eastern and southern Africa Tripp and Woolley (1989) describe a set of tested step-by-step procedures for the planning of problem orientated OFR trials. Woolley (this volume) covered the early steps in planning, showing how output from diagnostic efforts can be organized as input into an effective planning process. We look more closely at later steps of planning (called ‘Identifying possible solutions to the problems’ and ‘Evaluating possible solutions’, by Tripp and Woolley, 1989) in the context of developing solutions for inclusion in on-farm intercropping trials that address well-understood problems. Many of the considerations important in planning intercrop trials can be addressed in those steps. Additional issues are discussed later.

Special Concerns for Intercropping

Identifying Possible Solutions

How might the fact that we are dealing with an intercrop affect the choice of possible solutions?

First it is important to be clear about which of two possibilities a researcher is operating in:

a) Change in components of an existing intercropping system -- where one or more modifications of an existing farmer practice of intercropping is to be tested. This may address changes in variety or management practices for one or more of the component species.

b) Change of cropping pattern -- where one or more new intercrops is to be tested as a replacement for an existing farmer practice of sole cropping, or where an intercrop may be replaced with a sole crop.

Change in Components of an Existing Intercropping System

Here farmers already employ a set of intercrop production practices to achieve a set of outputs. Any new technology will need to be evaluated against the current intercrop practice.

New technologies selected for test will be closely related to the current situation, since we will be looking towards making one or a few changes at any one time. This implies that the crop species and most of the practices will be determined by what farmers are already doing. The modification(s) under test may only involve one of the component species. If the treatments diverge too much from current practice farmers will be less likely to adopt the technology and the results will be rather meaningless, since the interaction effects between treatments and non-
experimental variables may be quite different from when one or two small modifications are applied to farmers' current practices.

It is also necessary to be clear about what the farmer's objectives of his/her present intercropping strategy are. A modification may control weeds or erosion better, but if the farmer's main concern is to save labour inputs, the modification may be unacceptable, even if it works technically in terms of weed or erosion control.

Modifications that change the mix of crops must be consistent with farmers' demands for each of the crops. The farmer may need to balance all component crops in the intercrop to satisfy dietary requirements, spread labour peaks, or reduce risks due to pests and diseases or volatile markets (Reddy, 1988). In many parts of eastern and southern Africa, farmers that practise intercropping are aiming for a full yield of a main staple food crop (usually a cereal like maize) and some yield of the secondary crop as a bonus (Reddy, 1988). Improved technologies that raise the yield of the secondary crop greatly but reduce the yield of the main crop slightly may not be considered by farmers as suitable for adoption.

Similarly, doubling the cowpea mix in a maize/cowpea intercrop may increase total productivity, but if half the cowpea leaves remain uneaten and there is no market for excess cowpeas, the modification will not be acceptable.

Change of Cropping Pattern
This will usually involve substantial changes in practices and resource use, and will be difficult to introduce piecemeal given farmers preferred stepwise adoption behavior. The implication is that few farmers will be keen to adopt all aspects of a new system at once. Appropriate research should plan experiments to look at different major component groupings to suggest a range of options and perhaps a sequence of adoption.

Since a change in components of an existing intercrop system is the more common in OFR work the rest of the paper lays emphasis on that situation.

Evaluating Possible Solutions
Tripp and Woolley (1989) suggest seven criteria to use to make sure only possible solutions with a high chance of success will be included in the experimental program. These criteria are:

1) Probability that the technology will function
2) Profitability
3) Compatibility with the farming system
4) Contribution to reducing risk
5) Need for institutional support
6) Ease of testing by farmers
7) Ease of carrying out the experimental program

We now look at aspects of these criteria that are more relevant to planning intercrop research.

Probability that the technology will function
From the technical point of view there are major doubts about the worth of intercropping in some semiarid areas of Africa. For example, in Botswana in average rainfall years the sorghum-cowpea intercrop commonly employed by farmers seems to provide only a slight increase in LER and gross income but it does give greater returns to the limited resources of labour and draught (Lightfoot and Taylor, 1987).

Care is also needed when planning on-farm intercrop trials on the basis of yield benefits or improved land equivalent ratios (LER) obtained from on-station trials. Such benefits may disappear on-farm or be masked by large amounts of variability encountered on-farm. In this case, a degree of flexibility on some agronomic aspects of intercrops is useful at the design stage.

Profitability
In some cases profitability is likely to be a less important criterion for use in screening intercropping solutions and it may be more difficult to assess than for many other types of interventions. Intercrops tend to be grown by farmers in part for subsistence and sometimes entirely for subsistence. In this case, non-monetary criteria may be the most important for the farmer.

Where it is valid to use net returns to assess the worth of possible intercrop technologies for inclusion in on-farm trials, the calculations needed are made more difficult by multiple outputs, each of which requires the assignment of a different monetary value per unit of produce.

Nevertheless, it will often be useful to make some estimate of the likely returns to the major scarce resource in the system for a changed or introduced intercrop (an example of a partial budget for an intercrop experiment is given in CIMMYT, 1988). If labour is scarce the introduction of an intercrop or a modification to an existing system will only be acceptable if returns to the extra labour required are adequate.

There is conflicting evidence on whether intercropping increases or decreases returns to labour. Studies show intercropping may not allow more efficient use of labour for weeding at least (Reddy, 1988), and intercropping may give low cash returns to labour (Mwania, 1988) but other sources cite more efficient use of labour as a major reason why farmers adopt intercropping (Wood, 1984). More labour may be needed per unit of land with intercrops.
Hand weeding or other mechanical means are often slower in some intercrops and herbicides more difficult to use. These may have implications for the spatial arrangements of component crops in experimental treatments, e.g., management is easier if component crops are on the same row.

Essentially the profitability criterion needs to be assessed in terms of returns to investing, or the cost of saving on, a unit of the output-limiting resource(s) in the system, and on a valuation of expected outputs.

Compatibility with the farming system
The compatibility criterion will have vastly different implications depending on whether we are looking at replacing sole cropping with intercropping or just modifying an existing intercrop.

If the research is looking at introducing an intercrop, the new intercrop is likely to involve a big shift from current management practices and big changes in farmer resources and knowledge may be needed to make the technology work. These may mean some other important activity would have to be modified or even discontinued, something the farmer is not likely to do unless the benefits from the intercrop are large.

Modifications of current intercrops should have fewer implications for the system. Nevertheless these may be important e.g. there may be a change in labour pattern for an earlier variety or new management practice, or different consumer acceptability of a new variety.

Contribution to reducing risk
How does the intercrop technology affect risk? Most research on intercropping indicates that compared to a sole crop it should reduce the risk of crop failure from drought, pests and diseases. Most of these findings come from humid and sub-humid areas, but in drier areas yield stability is little affected (Lightfoot, Dear and Mead, 1987) and can even decrease with intercrops if there is excessive competition for limited moisture. Even in wetter areas, intercropping may increase risk in the farming system if the greater labour requirement of the intercrop increases the likelihood of losses in other parts of the system where the degree of risk is linked to labour or to the amount of time spent on the enterprise.

Need for institutional support
Complex intercrop interventions, especially involving replacing a sole crop with an intercrop, may require training support for farmers from the extension service. Also new inputs such as seed may need to be provided by support institutions.

Ease of testing by farmers
This is a function of the complexity of the modified aspects of technology, whether or not these can be tried out a little at a time and the amount of new learning needed. Most new intercrops are quite complex and therefore fairly difficult for farmers to try out, particularly if farmers have little previous experience of intercrops or of sole crops with the new component. Some modifications of an existing intercrop (e.g. change of component genotype) may be easy to try.

Ease of carrying out the experimental program
Experimental aspects of work with intercrops are almost always more difficult than for sole crop situations.

Additional Considerations
Objectives for Intercropping
It is well recognized that the farmers' objective in intercropping is often more than a desire to maximize output (e.g. Willey, 1985; Byerlee and Tripp, 1988). The farmer will have to contend with various practical constraints that determine what amounts or proportions of different crops need to be grown.

Solutions involving intercropping may be related to a problem concerning an existing intercrop pattern used by the farmers, or some form of intercropping may be proposed as a solution to a problem which in itself is not related to an intercropping practice by farmers.

Sole Crop Plots vs Plots of the Farmers' Practice
Mead and Stern (1980) make it clear that the number and type of sole crop plots needed in intercrop trials depends on the objectives of the trial. As mentioned earlier, in on-farm intercrop trials the most common aim is to test a modified intercrop against the farmer's current intercrop. There is often little thought of sole crops being a realistic alternative that may be taken up by the farmer. In these trials the use of sole crop plots is wasteful of researcher effort and farm space since calculations of LER are of marginal value.

Usually the important comparison is between the new technology and the farmer's current intercrop technology. Thus, far more important than plots of sole crops are plots of the farmer's current practice or expected practice in several years time. As with other on-farm trials the non-experimental variables should normally be set at current farmer levels. Even defining a current farmer level for inclusion as a treatment may raise difficulties with intercrop trials, because there is more chance for variation in spatial pattern of the component crops etc. (e.g. Mwania, 1988).

It may be useful to calculate LERs if land is clearly a limiting resource. This should be checked before including sole crop plots that allow the LER to be calculated. Even then, the use of sole crop plots can
only be justified if a likely option for farmers is a move away from intercropping to sole cropping.

Output Comparisons
During the planning of trials it is important to make tentative decisions about how the trial may be analyzed and assessed. This will help decide the types of data to be collected.

When analyzing OFR intercrop trials, often the most meaningful comparison for the farmer is total output from one or more experimental intercrops and total output from the farmer’s existing intercrop or sole crop. In this situation, use of methods that place outputs on a comparable basis is necessary to assess possible advantages. At its simplest then, this would involve some way of combining one economic yield component each from two crops, e.g. maize grain and bean seeds, but may need to involve multiple parts of three or more plants, all with different values to the farmer.

Possibilities are to use some indicator of nutritional value (e.g. calorie output) or to weight yields or other outputs according to monetary value. Choice of method will depend on uses to which the farmer puts the output. In an area where there is a ready market and where the farmer sells at least some of the output then combined monetary value per unit of output is most appropriate. Most farmers in eastern and southern Africa have access to a market and monetary value should be more appropriate in most cases. The monetary values (or nutritional values) will be calculated per plot and then be subjected to analysis of variance. Obtaining the relevant money and nutritional values to apply to the outputs then becomes an important aspect of the trial.

Given the multiple objectives of intercropping, as with other more ‘subsistence’ orientated cropping, there may be a strong role for farmer assessment of intercropping alternatives.

Farmer Participation in Planning Intercrop Trials
The acceptance or rejection of a new intercrop technology is the farmers’ decision. There will be more chance of acceptance if the farmer was involved in orientating the research during key stages in the research process.

Farmer participation in implementing and evaluating on-farm trials has recently been given a lot of space in journals (e.g. Farrington and other papers in the July 1988 edition of Experimental Agriculture). Adequate farmer participation is even more critical and cost-effective in work on complex systems such as intercrops, than with simpler crop systems (e.g. Sumberg and Okali, 1988). Farmers should be involved in defining the research agenda, the conduct of research, evaluation of results and dissemination of findings. For these complex and variable systems the role of OFR is more to develop an understanding of the range of management options available to farmers and how they can use those options to fulfil their various objectives, rather than to come up with a prescriptive, rigid recommendation (Sumberg and Okali, 1988). Farmers’ views on possible intercrop technologies need to be taken into account in planning (as well as clearly in evaluation) if likely technical benefits of a new intercrop technology are also going to be perceived as benefits by farmers. Planning for farmer participation in implementing and evaluating intercrop trials is important as well.

Intra-household Considerations
Intra-household issues may become a particularly important factor to consider in intercropping trials because the questions about “who does what work when?”, “who controls the resources and makes the decisions?”, “who benefits?” (Feldstein, Poats & Rocheleau, 1987) may become conflicting in intercropping situations, especially where the intercrop includes both cash and subsistence crops.

For example the “who does what work when?” question may be complex where one crop in an intercrop is planted by females and the other by males. Then decisions on the preferred resource allocations within the intercrop may differ according to gender. Sikana (1987) describes how separate field days for men and women in Northern Province, Zambia clearly demonstrated that women were most interested in bean trials, while the men expressed most interest in hybrid maize trials.

Other experience from Zambia (Chabala and Ngwiru, 1986) indicates how gender can influence the acceptability of intercropping interventions. Maize/beans intercrop trials were introduced to alleviate labour shortages in land preparation, where maize and beans had been cropped separately before. Males were enthusiastic about the trial, but females were not, since they saw a threat to their independent control of the bean output if the beans were mixed with maize – a male dominated crop.

Balancing out such conflicts is clearly a difficult, perhaps impossible task. Nevertheless, good intercrop planning requires that the researcher remains aware of such issues, even if it is not possible to fully account for them in the trial design.
Conclusion

As in all experimentation, the systematic and careful planning of intercrop trials pays many dividends in saving time and effort, ease of implementation and worth of output. Because there is greater inherent complexity, it is less easy to do useful trial work without careful planning for an intercrop compared with a sole crop. Above all, researchers need to have a clear vision of the objective of the trial in the context of the farming system for which the results are intended. And, given that we are looking to develop options that farmers will adopt, we need to involve farmers as fully as possible in the planning as well as the implementation and evaluation stages of research.

Acknowledgement

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References


Appropriate Experimental Designs 
and Treatment Structures for Intercropping

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The material in this paper is substantially drawn from previous papers and books which may be consulted for further discussion of the various aspects of design.

Why is it Necessary to Design Experiments?

The purpose of designing experiments is to produce unambiguous, precise, information which is relevant to practical situations. The concepts of design will be rather different for experiments at research stations and for those on farms. This is because the objectives and constraints of these two experimental situations will be different.

In experiments on research stations it should be possible to produce a high level of control of the environmental and plant variation. This in turn enables objectives to include questions relating to the form of causative mechanisms as well as the more agronomic questions of performance. I believe that research station experiments inevitably have an element of artificiality which arises simply because of the level of resources which can be applied. Given those resources the statistical concepts of experimental design should be employed to control the variability of experimental units and thus to maximize precision.

It might appear, initially, that there was less scope for statistical design concepts in on-farm experimentation. On-farm experimentation will tend to use fewer, but larger, experimental plots, there will be less choice of plots and, often, fewer resources available for characterizing and assessing the plots. However, these difficulties make it even more important to use statistical concepts of design to utilize the reduced information available, while recognizing that different concepts may be relevant. Instead of the geographical blocking systems normally employed on research stations, plots in on-farm experiments will be characterized in a manner similar to that in medical research experiments where potential differences due to patients being of different ages, different sex, different sizes and with different histories may well be recognized and used to adjust measurements of performance.

The underlying principles of design are, inevitably no different for intercropping experiments than for any other area of experimentation. There will be a tendency for experimental units to be large and this has implications for several classical design concepts. First, two fundamental concepts of design must be emphasized.

The three stages of experimental design

The design of any intercropping experiment consists of three stages:

(i) Identification of appropriate experimental plots, followed by recognition of inherent characteristics of those plots which are likely to lead to predictable patterns of performance. By using the experimenter's specialist knowledge about the plots it should be possible to control the level of variability in the set of plots through systems of blocking.

(ii) Identification of the objectives of the experiment in the form of specific questions, and the selection of treatments to provide answers to the questions. The statistical concepts of treatment structure may be employed to provide more information for each question.

(iii) The marriage of the chosen treatments to the structured set of units. Stages (i) and (ii) should be considered independently and any apparent incompatibility will be overcome in the third stage which involves allocating treatments to particular units within the overall recognized structure of units. Sometimes particular facets of the treatment set will require particular patterns of treatment allocation.

Design resources

In an experimental design there are n experimental plots and the resources, represented by the (n-1) degrees of freedom, are used in three ways:

(i) Blocking, or variation control, (including covariance)

(ii) Estimation of \( \sigma^2 \)

(iii) Answering treatment questions

Typically in an experiment with blocking control the block size will be between 4 and 12 plots and therefore the degrees of freedom required for (i) will usually be between \( n/12 \) and \( n/4 \). The minimum requirement of degrees of freedom for (ii) is about 10; the maximum degrees of freedom that should be allocated to (ii) is about 20. The remaining degrees of freedom are allocated to (iii).

An experiment may be inefficient in many ways:

a) Not enough d.f. for (i)
b) Not enough d.f. for (ii)
c) Too many d.f. for (ii)
d) Not using sufficient treatments to use the d.f. available for (iii)
e) Not using other methods of controlling \( \sigma^2 \)
Proper Use of Replication, Blocking, and Randomization

Good experimental design is at least as important in intercropping experiments as in monocropping experiments. The choice and structuring of experimental plots are extremely important and the third basic principle of design requires a proper system of allocation of treatments to units.

First, the experimental plot must be chosen so that sufficient plot replication is possible and so that the yields from a plot may be considered properly representative. Intercropping tends to need rather larger plots than sole cropping both because of the need to have sufficient plants of both crops and because of the need for large guard areas. If the guard areas are a very substantial proportion of the experimental area, as may easily happen when spacing treatments are involved, then a systematic arrangement of treatments may be appropriate.

The important concept of blocking in intercropping is the same as in sole cropping, i.e. to recognize groups of plots which are likely to behave homogeneously. Thus a researcher’s specialized knowledge about the experimental land is vital, and no rules about the type of design or size or shape of plots or blocks should be allowed to override such information. Researchers have traditionally sought to use their knowledge about the available land by dividing it into homogenous blocks of equal size, and using randomized blocks or some other design for which the analysis was straightforward. This approach reflected the available computer programs for the analysis of designed experiments which, until recently, could only analyze experiments which could also be analyzed ‘by hand’. Much more powerful statistical packages are now available, such as GENSTAT (1977), and the ever decreasing cost of computer store means that even these fairly large packages can now be used in relatively modest computers. It is therefore no longer so important that the number of plots per block should equal the number of treatments, or even that the number of plots should be the same in each block.

Most intercropping experiments are in the tropics, using land which has only recently been adapted for experimental work and which may not therefore be as homogeneous as in the well-established research institutes in temperate climates. Consequently, it will often be difficult to pick out areas of equal and sufficient size to serve as blocks in a randomized block experiment. Recognizing both the advantages offered by improved computing facilities, and the constraints imposed by the available experimental land, I reiterate that while the thoughtful identification of groups of plots likely to be homogeneous should be the overriding consideration in designing an experiment, there is now much less restriction on the size and shape of the blocks than has previously been assumed.

Many existing experiments on intercropping, which include two or more factors, use a split-plot design, but I believe that there are relatively few occasions when such a design is appropriate. The only good reason for using split plots is that some treatments can only be applied to large plots whereas a large plot is not necessary or desirable for others. I suspect that split plot designs are often used for simplicity in allocating treatments or from habit.

Finally the importance of random allocation of treatments to plots in all blocks cannot be over-emphasized. Randomization provides the justification for the analysis of variance because it ensures that the data are genuinely a random sample. There is no excuse for copying designs from textbooks without randomizing treatment allocation within each block for each experiment.

Systematic Designs

A specific area of experimental design in which there has recently been increased interest is the use of systematic designs in experiments on the spatial arrangement of intercrops. The fundamental idea of the systematic design is that crop density (or spatial arrangement) changes consistently from row to row across a plot in such a way that each density change is small (usually 15% or less). If many densities are used, a large overall range can be considered. Since each row is surrounded by others at nearly the same density the usual requirement for guard, or discard, areas round each plot can be avoided. This reduction in guard area makes the systematic design potentially important to intercropping experimentation, where it will certainly be necessary to consider a wide range of spacing treatments combined factorially with many other factors. To demonstrate the greater efficiency of land use (in terms of harvested area), two alternative designs are illustrated for investigating the effects of changing the density of one component crop. Figure 1 (a) shows a randomized design for four densities and Fig 1 (b) a systematic design with twelve densities. The harvested area indicated for each design is based on typical intercropping plot dimensions of 9 meters with 45 cm row widths, and the greater land use efficiency of the systematic design is clearly apparent.

Of the systematic designs so far used in intercropping, Huxley and Matting (1978) and Wahua and Miller (1978) have used modifications of Nelder’s (1962) fan
design (Fig. 2). The idea of the 'fan' is that the spatial arrangement remains constant for all individual plants, apart from changing density which varies consistently along each radius. Wahua and Miller (1978) used different segments of the fan for sole crops and intercrops.

For intercropping there may be considerable potential in designs developed from Bleasdale's (1967) row modification of the fan design, and an example allowing the densities of the two component crops to be varied independently is shown in Fig 3. This design has been used at Reading to investigate intercropping carrots and onions. I suspect that many new forms of systematic design, and many new uses of existing ones, await discovery.

While convinced that systematic designs have an important place in intercropping research, it is important to realize that they raise new problems which must be considered in the context of the complete experiment. Typically, systematic variation of a spatial factor will be only one component of an experiment which also includes other treatment factors (nutrients, genotypes) applied to whole systematic plots. The experiment thus resembles a split-plot design with spatial treatments as systematic split-plot treatments and the other treatments randomized and replicated on the main plots in the usual way. As discussed in the previous section, it is important to check that the experiment is viable in terms of comparing the main plot treatments. Main plots within which a spatial factor is varied systematically will be larger than typical plots in a conventional randomized block design, usually about four times as large (as indicated in Fig 1). Any trend across a systematic plot will bias the estimation of the response curve for the plot, thereby making the curves for different replicates less consistent, so it is particularly important to avoid such trends. Variation between main plots is 'error variation' in the usual randomization experiment sense, and within-block homogeneity is desirable exactly as it would be for the larger number of smaller plots in a fully randomized experiment.

Regarding the analysis of systematic designs we must obviously recognize that the data have different properties than for randomized designs. The conventional analysis of variance for split-plot designs is inappropriate for examining the differences between yields for different spacings because of the lack of randomization, and also because the null hypothesis, of no yield variation over different spacings, is usually of no interest since it is clearly untrue. In cases where the dominant source of error variation is plant variability an ordinary split-plot analysis of variance may have some value as a preliminary indicator of patterns of variation.

The use of a wide range of densities or spatial arrangements implies an interest in the response of yield to quantitative spacing factors, and the analysis of data from a systematic design should usually start by examining the relationship of yield to density (or some other spatial factor). This should first be done graphically, followed by fitting a response function of yield on the factor that varies in each systematic plot. Subsequent analysis will involve comparison of the response curves for the different main plot treatments in what is essentially an analysis of variation of response curves. The replication of the other factors provides information on the consistency of the response curves for a particular main plot treatment in the same way that replication in a standard design provides the standard errors of treatment means.

Use of Sole Crop Plots in Intercrop Experiments

Most of the intercropping experiments reported in the literature have included a large proportion of sole crop plots, often up to 50% of the total experiment, and sometimes even more. I believe that the inclusion of many sole crop plots is largely due to force of habit and suggest that the extent to which sole crop plots should be included in an experiment is one of the major questions to be considered by the researcher when designing his experiment.

In considering this question it is necessary to be very clear about the aims of the experiment. If the primary aim is to assess the benefits of growing mixed crops as compared with sole crops, under a range of conditions, then it may be appropriate to have as many sole crop as intercrop plots. However, if the main objective is to discover how best to grow intercrops, then the requirement for sole crop information is simply to provide a good estimate of sole crop yields, to use in standardizing the intercrop yields. The situation is analogous to that of 'control' treatments in monocrop experiments, where the need is often not to have a control which can be compared statistically with the other experimental treatments (which are known a priori to differ from the control), but rather to have information about the background level of yield if no treatments are applied. In intercropping experiments the need to have information on sole crop yield, without the intention of making formal statistical comparisons of sole crop and intercrop yields, gives the researcher considerable flexibility in the size and positioning of the sole crop plots. For example, in some experiments it may be useful to grow the sole crop in fewer larger plots around or alongside the experimental intercrop plots. This
would provide good estimates of sole crop yield for standardizing the intercrop yield, while allowing the blocks within which the intercrop treatments to be compared are grown to be smaller and therefore more homogeneous.

It is also worthwhile to examine which sole crop treatments are required. For example, in a genotype and spacing trial it may be sufficient to have sole crop plots for only one or two genotypes at the spacing recommended for sole crops.

### Factorial Structures

The use of factorial treatment structure with many factors in each experiment is essential if intercropping research programs are to be efficient. Compared with monocropping research programs, there are more factors to be considered in intercropping research, basically because of the two crops. Thus whereas in monocropping one might consider varying:

1. Genotype
2. Sowing date
3. Several nutrient factors
4. Crop arrangement
5. Crop density
6. Irrigation regimes

For intercropping research the factors that have to be considered include:

1. Two genotype factors
2. Two sowing dates
3. Two crop densities
4. Two crop arrangements
5. The relative arrangement (intimacy) of the two crops
6. Several nutrient factors
7. Irrigation regimes

Instead of, say, 8 factors with 28 two-factor interactions we have to consider 13 factors with 78 two-factor interactions. Only by the use of factorial experiments with 3 or more factors can we hope to assess the effects of these factors.

Since the early days of monocropping research, the knowledge of the advantages of factorial structure, particularly in the early stages of research programs, has become well established. The major contribution of statistics to efficient use of experimental resources has been the demonstration that it is much more efficient to ask several questions in a single experiment through the use of factorial structure than by the previous philosophy of controlling all factors except one in each experiment. It would be appalling if experimenters were to ignore this knowledge and continue as before.

There are two further aspects of design connected with factorial treatment structure. Many factorial experiments are arranged in a split plot design. In some cases this is essential because of the nature of the treatments, and in such cases of practical necessity the split plot design is useful. However, in general split plot designs are inefficient and should be avoided. The inefficiency results from the splitting of information into two levels at one of which (the main plots) the precision of comparisons is usually very poor with few degrees of freedom. It is sometimes suggested that split plot designs are appropriate when interactions are of more interest than one set of main effects. This is misleading. The loss of information of the main effect is much greater than the gain on the interaction SS and the gain is largely illusory because results are presented as tables of means for which the main effect is required in addition to the interaction.

In contrast to the popular but inefficient split plot design, confounded designs provide the solution to the conflicting requirements of many factors and small blocks. The construction of designs using small blocks, from which all the main effects and two-factor interactions of interest can be estimated, is extremely simple.

### A Confounding Example

An experiment to compare two nitrogen levels, three spatial arrangements and two maize genotypes for a maize/cowpea intercrop is planned in four randomized blocks of twelve plots each. The experimenter wishes to include also two different genotypes of cowpea, but does not wish to have more than twelve plots per block. The initial design includes the twelve original combinations in each block and the analysis of variance structure is:

<table>
<thead>
<tr>
<th>Degrees of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
</tr>
<tr>
<td>Spacings (S)</td>
</tr>
<tr>
<td>Maize genotypes (M)</td>
</tr>
<tr>
<td>NS interaction</td>
</tr>
<tr>
<td>NM interaction</td>
</tr>
<tr>
<td>SM interaction</td>
</tr>
<tr>
<td>NSM interaction</td>
</tr>
<tr>
<td>Error</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

It is worth noting that 33 degrees of freedom are amply sufficient for the estimation of $\sigma^2$ and that the resources which are represented in these 33 df could be more effectively used to estimate further treatment effects.

To introduce two different cowpea genotypes, while a) retaining all the information on the first three treatment factors, b) keeping a block size of twelve plots, and c) obtaining information on the cowpea genotype main effects and the interactions of cowpea genotypes with each other factor, certain simple restrictions on the design can be specified. First,
all 24 treatment combinations should be replicated twice so that all the main effects and interactions of the four factors are mutually orthogonal (independent). Second, each block of twelve units already includes all twelve combinations of the three original factors so that all estimates of effects for these three factors are unaffected by block differences.

Finally, the two genotypes (C₁ and C₂) should be allocated in such a way that each effect involving the factor C is not affected by block differences. A sufficient requirement for a treatment effect to be estimated independently of block effects is that each level or combination of levels included in the definition of the effect shall occur equally frequently in each block. We can now consider the allocation restrictions for C₁ and C₂ in terms of the main effects of C and the interactions involving C. Initially we consider only two of the four blocks of the original experiment.

Clearly the requirements for (v) and (vi) are impossible in blocks of twelve units. The other requirements are all individually possible, and the design problem is simply a question of whether they are simultaneously possible. The design adjacent is easily achieved. More details are given in Mead (1984).

A Philosophy for On-farm Experimentation

The history of on-farm experimentation in agricultural research and extension is not, I believe, a very happy one. Experiments carried out on farms tend to have been derived as small-scale poor relations of experiments on research institutes and tend to produce conclusions that:

i) are very imprecise

ii) suggest farms are very different from research institutes

iii) do not convince anybody, and

iv) are not always valuable as demonstration plots.

Since it is clear that there should be benefits from performing experiments in the conditions on farms, for which the conclusions of research experiments are intended to be predictive, it is important that we should look again at the opportunities and restrictions of on-farm experimentation and at the statistical expertise available for designing on-farm experiments. The ideas presented here have been stimulated by collaboration with Peter Huxley at the International Council for Research in Agroforestry (Huxley and Mead, 1988) and by examining the apparent differences of statistical philosophy for designing experiments in agricultural, medical and industrial contexts.
The crucial requirements for experiments using "plots" on farms are:

a) Controlling variability, while
b) Utilizing environmental variation
c) Allowing treatments to be applied to plots
d) Providing replication,
e) With randomization validity

First, how shall we define a plot? This will be an area of land including both crops; it will be fairly small 3-20m² and will be clearly definable in size, shape and context within the normal activity of the farm. On any farm there could be very large numbers of potential plots, of which only a small number (15-30) might be used in an experiment. A single experiment might include sets of plots from several farms.

The traditional method of controlling variability in agricultural crop experiments is through blocking, which has become identified with the procedure of selecting compact sets of adjacent plots to be recognized as blocks. Many such blocking systems are quite effective in achieving sets of homogeneous plots within blocks, though many blocking systems are set up without any real thought about the purpose of blocking. If blocking is to be successful the units allocated to a block should be expected to perform very similarly and correspondingly units in different blocks would be expected to perform very differently. For this objective it is not necessary that plots in a block be physically adjacent. The blocking principle is utilized in medical experiments where each experimental unit is a patient. Patients do not occur in geographically compact groups but it is still possible to determine groups (or blocks) of patients who because of their physical characteristics and history might be expected to perform similarly.

So we can think of plots in a farm as grouped into blocks by shape, altitude, orientation, previous history as well as, possibly, proximity.

However, some of the effects of the characteristics which we could utilize in thinking about controlling variability by blocking may be of interest in themselves. We could use soil fertility as a "blocking" characteristic for plots but we could also be interested in differences caused by different soil fertility levels, possibly in combination with applied treatments. Again the analogy with medical experiments is useful. It would often be expected that men and women would react differently to a particular drug and this could lead to using sex as a blocking factor. However, in many medical trials there would be interest in precisely how the response to different drugs differed between males and females and sex could then be thought of as a treatment factor. Of course sex cannot be randomly allocated to individual patients. Similarly soil fertility is a characteristic of each plot and cannot be randomly chosen. I think a suitable name for such a treatment is an "existing treatment" (in contrast to an "applied treatment"); other people have used the names "ecological treatment" or "environmental treatment".

There will often also be treatments to be applied to plots in on-farm experiments. There will also be decisions to be made about the amount of replication that can be afforded on a single farm and how much we have to use several farms to provide adequate overall replication. It is also important that the actual plots included in an on-farm experiment should be a random sample from some recognizable set of possible plots, in the same sense as plots included in an agricultural survey are randomly selected from a population of possible plots.

The analysis of data from an on-farm experiment would involve separating out the effects of the blocking factors, the "existing treatment" factors, the "applied treatment" factors and the interactions between "existing" and "applied" treatment factors. This analysis can be achieved through fitting a general linear model which allows for the inevitable lack of completeness in the occurrence of combinations (for example, we will probably not be able to find plots for each combination of each level of a blocking factor with each level of an "existing treatment" factor).

References


Figure 1. Comparison of harvested areas for randomized and systematic design.
Figure 2. Wahua and Miller's fan design, modified from Nelder (1962).

Figure 3. Two-way systematic spacing design for two crops (x and o) with densities varying in the perpendicular direction.
Introduction

This paper does not pretend to be a comprehensive guide to the implementation of on-farm intercrop experiments. Instead, two particular themes: farmer and site selection, and farmer participation, are discussed. Most of what is said applies to sole crop on-farm experiments as well as intercrop experiments. This paper draws heavily on a paper by Tripp (1982) which is recommended.

Farmer and Site Selection

On-farm research aims to develop recommendations for groups of farmers with similar problems and resources. They are, hence, likely to be able to adapt to their needs the same recommendation. Such groups of farmers are often referred to as “recommendation domains” (RDs). In fact RDs are identified tentatively from a diagnosis and are adjusted as research proceeds (Harrington and Tripp, 1984).

An on-farm trial usually needs to be planted at several sites within an RD in order to take account of the variability between sites. Usually we talk of seeking “representative” sites, and the rest of this section has this orientation. However, as Professor Mead pointed out in his first paper, it may sometimes be advantageous to seek out sites with certain known characteristics within the RD.

In order to choose “representative sites”, the farmers who cultivate those plots must be “representative”. Gender, farm size, resources available to the farmer and whether he or she farms full- or part-time, may all be important. Only those which are directly included in the RD description need to be used as criteria for rejection or inclusion. However, it will be advisable to cover a range of farmer characteristics in the other criteria, just in case some of these criteria are later found to influence the results. Farmers who are more advanced technically, or are local leaders, should not appear in the sample at a greater frequency than in the rest of the population; otherwise, the results and recommendations may be biased towards their needs and possibilities. This is especially important for small-plot trials placed with few farmers. Tripp's (1982) summary of criteria for site selection emphasizes the importance of flexibility so that RDs can evolve and makes other useful suggestions (Table 1).

The sites selected for the trial should also be representative in:

* Previous cropping history and place in the rotation sequence.
* Soil texture, color and stoniness
* Nitrogen, phosphorus, pH or other chemical characteristics.
* Slope.

A good way of ensuring that farmers' rotations are respected is to ask the farmer to assign for the trial part of a field which he or she was anyway going to plant to that cropping system. There is usually not time to obtain the results of soil analyses before planting the trial. In this case, soil analysis serves to check how trials were distributed and to help interpret results.

Just as when selecting farmers, it is useful to select sites which sample the range of variation within the RD. Uniformity within each block of a trial increases the precision of the results. However, a site chosen for an on-farm trial is often by its very nature heterogeneous. Flat alluvial soils should not be chosen for a trial if the RD has mainly steep slopes and stony soils. The results would be precise but irrelevant to farmers. Thus, uniformity should be sought but only after satisfying the main criteria for site selection. An indication of the gradients or non-uniformity in a field can often be obtained by seeing the previous crop, or if not possible, by asking the farmer where the previous crop developed well or badly. Weed growth, soil color and erosion marks are other useful indicators. With this information about uniformity, blocks can be placed perpendicular to gradients, within large patches of similar conditions or avoiding small patches which would divide a block.

In practice, the selection of sites which sample the variation within a RD is difficult, because a number of important characteristics vary simultaneously. It is especially difficult when choosing, say, four sites for an exploratory or determinative trial, less so when choosing maybe 8 to 15 sites for a verification trial. Procedures for practical site selection tend at present to be highly empirical. An example will illustrate guidelines and dilemmas.

In the example (Table 2), three sites need to be chosen for a soil fertility trial. After preliminary selection, six sites are available which have typical farmers and soil appearance. It has been decided that soil organic matter, P and K levels and slope are the most likely to influence response. The aim, therefore, is to choose a set of sites which cover the range for each of these four characteristics and whose median value for each is close to the estimated median of the RD. Since three sites are needed, ideally the first quartile, the median and the third quartile of the RD for each characteristic should be approximated by one of the sites. It is not possible to achieve this objective completely. The combination of sites 1, 3 and 6 is a generally acceptable solution. Of course, it does not test the possible combinations of low, median and high levels of each characteristic.
Farmer participation in trial management

The efficiency of on-farm research should be improved by farmer participation at various stages. These include diagnosis (either passively as when being interviewed, or actively, as in diagnosis by farmer groups), trial design (sometimes attempted by discussing technical principles with farmers and incorporating their suggestions and questions into the treatment design), trial management and trial evaluation. Only participation in trial management will be discussed here.

Tripp (1982) makes useful suggestions (Table 3) which complement and extend those written here.

In most trials it may be wise to have the non-experimental variables applied by the farmer. This increases farmer involvement and may ensure that the trial is executed under conditions typical of the RD. Exceptions to this practice are when researchers need to run the experiment with non-experimental variables different from those of the farmer, for instance to study factors at high yield levels.

In Colombia, we found that the participation of farmers in planting was an important way to familiarize and involve them with the trial. A further step was to have farmers apply some of the different experimental treatments, for example, two different chemicals for foliar disease control in a verification trial. This is more complex, and needs a way of checking whether farmers applied the different treatments as intended, but pays dividends in greater farmer understanding of the trial.

It must be remembered that some researcher practices may be disliked by farmers. Leaving unplanted borders may be insensitive on a small farm. Similarly, including sole crop treatments may be regarded as a waste of space by a farmer who grows intercrops. Sole crops are usually not necessary in on-farm intercrop trials, as many in this workshop have pointed out.

When farmers broadcast seed, it may be difficult to imitate or use farmers’ planting practices in small-plot on-farm trials. One alternative is to make plots a little larger and to ask the farmer to broadcast the seed as well as he can within a small area. Plant stand and distribution should later be checked against large fields which have been broadcast-seeded by the farmer. Another alternative is illustrated by a region of northern Peru, where farmers plant maize in rows, but broadcast at low density a mixture of bush and climbing beans when the maize has emerged. The farms are small, so trials cannot be large. In this case, we decided to row-plant the bean mixture in small-plot trials designed to evaluate changes in other technological components.

Often, the most difficult farmers’ practice to imitate is planting date, because it depends on the arrival of the rains, or other conditions which vary from year-to-year. If the trials are simple and the plots are large, say with two or three varieties and for one or two practices, it may be possible to leave the farmer to plant the trial when he/she thinks the moment is right. Alternatively, trials could be divided into clusters in a number of villages. A local technician living in each village would be able to plant the trials with help from farmers when the moment is right.

Conducting on-farm research with limited resources

On-farm research can be costly if badly planned. Its efficiency can be increased in many ways. Suggestions which relate to trial implementation follow. Trials may be placed in clusters, as previously suggested, rather than randomly spread through a large RD. If clusters are used, the cluster locations should be changed every one or two seasons to reduce bias in trial results, and reach more farmers. Whether working with clusters or not, we usually recommend adding at least 50% of new farmers each year and not working with any one farmer for more than two years.

Costs may also be reduced by choosing sites near roads and staffed locations. The sites must, however, still be as representative as possible. We must ask: “do more remote farmers in this RD have similar conditions to those whose land is more accessible?”

Maximizing farmer participation in trial management is a good way to reduce costs. Farmer participation in planting and in applying non-experimental and even experimental variables has already been discussed. Superimposed trials are another useful technique to reduce costs and ensure typical farmer management. If the treatments can all be applied after planting, the researchers divide a field which the farmer has already planted into the plots required by their experimental design and apply the treatments, usually with help from the farmer. If the treatments have to be applied at planting (varieties or soil treatment, for example), the farmer is asked to plant as usual, varying only the components which appear in the treatments.
References


Table 1. Criteria for site selection (Tripp, 1982).

| 1. Ensure site conforms to characteristics of R.D. |
| 2. Check distribution of other characteristics which might later be used to redefine R.Ds. |
| 3. Assure site fits requirements of trial (rotation history, cropping systems to be used). |
| 4. Arrange trial sites to permit visits. |
| 5. Strive to expand work to new areas and collaborators. |
| 6. If trials may be used later as demonstrations, get extension agent suggestions on their siting. |
| 7. Identify and correct previous biases. |

Table 2. Example of site selection.

<table>
<thead>
<tr>
<th>Domain description</th>
<th>1st quartile</th>
<th>Median</th>
<th>3rd quartile</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Sites available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%)</td>
<td>4.0</td>
<td>10.0</td>
<td>17.0</td>
<td>5.0</td>
<td>8.0</td>
<td>Site 3</td>
</tr>
<tr>
<td>O.M. (%)</td>
<td>2.8</td>
<td>3.2</td>
<td>4.0</td>
<td>3.1</td>
<td>2.6</td>
<td>Site 4</td>
</tr>
<tr>
<td>P ppm</td>
<td>7.9</td>
<td>13.8</td>
<td>22.0</td>
<td>8.2</td>
<td>32.0</td>
<td>Site 5</td>
</tr>
<tr>
<td>K meq/100g</td>
<td>0.6</td>
<td>0.8</td>
<td>1.1</td>
<td>0.8</td>
<td>1.1</td>
<td>Site 6</td>
</tr>
</tbody>
</table>

Table 3. Communicating with farmers (Tripp, 1982).

- Mark off the field well before planting
- Make sure the farmer understands the trial
- Obtain data on previous history of field before planting
- Understand farmers' plans for the field (makes fixing non-experimental variables and checks easier)
- Make sure farmer is present at planting
- Have time for casual, broad-ranging conversations
- Treat farmers as equals, encourage them to express opinions
This paper seeks to address two major areas: what could be done if the capability existed for detailed biological simulation of cereal-legume intercropping, through the use of robust, portable models; and current progress towards attaining such a capability. These are discussed in this order, since the first contains the rationale and the motivation for work on the second. The paper concludes with a consideration of the promising directions that modelling might take and the prospects for success. It is clear that much work remains to be done before managers and economists will have access to generic intercropping models of the important crop associations in Africa and elsewhere, to generate information that can be used in the decision making process.

Applications

Assume that an intercropping model exists that exhibits the following characteristics:

a) it simulates the growth and development of bean plants and maize plants, whether these are grown alone or in association;
b) it reacts in meaningful ways to changes in
   - cultivar
   - soil type
   - weather sequences
   - nitrogen, phosphorus and potassium fertilization
   - irrigation
   - planting patterns, population and timing
   - disease, pest and weed burdens.

Assume further that the model has been successfully validated for a number of locations in a region characterized by a good degree of homogeneity in the bio-physical environment. There are also a number of weather stations in the locality, each with 20 years' historical time-series of daily maximum and minimum temperatures, soil temperature, rainfall, and solar radiation.

There are two major ways in which such a model could be used.

1) The model can be used in an attempt to reproduce, with tolerable accuracy, a historical field trial -- that is, a bean-maize experiment carried out in the past where enough data were collected from the field trial to enable the model to be run, ostensibly under identical conditions: in the same soil, with the same weather sequence, the same management inputs, the same cultivars. Such a use of the model constitutes a validation exercise.

Assessment of model outputs thus entails comparing observed results from the field trial with simulated results from the computer-based experiment. Obviously, an important output from both is final yield of beans and maize. The hypothetical model, however, contains a high level of biological detail, so this enables the experimenter to compare observed and simulated growth over time -- for example, the dates of attainment of various growth stages in the physiological development of the two crops. If enough data were collected from the field, the experimenter could also compare the uptake of nitrogen by the maize crop over time or the uptake of phosphorus by the bean crop.

As the model had been validated for a number of sites in the region, and provided the field trial was located near to one of these sites, it could be assumed that the agreement between the observed and simulated performance of the two crops was good. There is some degree of subjectivity in deciding what constitutes close agreement between observed and simulated growth processes, but simulated response within 5 per cent either side of the observed response could safely be regarded as excellent, in view of the modelling process in general and the complexity of the phenomena involved in particular.

2) The intercrop model could be operated in a predictive mode. The essence is that the experimenter, having compared model results with the corresponding field trial results, perhaps for 3 or 4 of these spread across years and locations using different cultivars, feels enough confidence in the performance of the model to give serious credence to the results generated by the model even if he does not necessarily have the corresponding real data with which to compare simulated output. There is a certain act of faith in this process, but as the model is tried and tested successively over time, the experimenter is required to make less and less of a leap in the dark. In any case, this leap in the dark is not much different from the traditional cereal variety selection process; implementing a general recommendation of a particular cultivar in a region or a country, based on variety trials at a handful of sites over a couple of years, is in itself no less an act of faith. The essential difference is the explicitness of the "model" used in the recommendation process -- i.e., a body of visible, testable mathematical equations as opposed to what may well be a comparatively unformalised idea in the collective brain of a body of crop scientists.

The implications of arriving at the point where the intercrop model can be used in a predictive capacity are highly significant. It becomes possible to observe the effects of changing input conditions on model output. For instance, the effects can be investigated not only of planting the beans two weeks earlier, but of planting the maize and beans on the same date, for the same inputs, in a different year with a different weather sequence.

The ability to assess performance of the intercrop over a wide range of different weather sequences allows the experimenter to say something about the stability and the weather-related risk involved in particular bean-maize varieties. These
weather sequences may consist of historical meteorological measurements, or they may be simulated using a statistical weather variable generator, such as that of Richardson (1985) or Dennett et al. (1983). Uncertainty is the very essence of real-life decision making, and the intercrop model allows this to be addressed explicitly, through providing information on crop responses to variability of production practices and environmental factors over time.

A bean-maize intercrop model might produce information for decision makers at a number of levels. At the research level, the model could be used to help with variety selection trials. Once the relevant cultivar characteristics are encoded into the model, various bean-maize intercrops can be simulated in a variety of soils each over a number of years of simulated time. Such mixtures could also be assessed under low input conditions, for example, to examine the timeliness of decision making. The working hypothesis of such a conjecture is that technology designed and assessed in a way that takes account of the total environment of farming should have a better chance of being adopted than technology designed without taking such factors into account, since it should be more relevant to farmers’ actual needs and conditions (Dent and Thornton, 1988).

The intercrop model might be used within an even broader framework. In the technology design and assessment stages of Farming Systems Research projects, the model could be used in a manner that takes account not only of the bio-physical environment within which farmers have to operate, but also of the economic, social and cultural factors that impinge on their decision making. The working hypothesis of such a conjecture is that technology designed and assessed in a way that takes account of this total environment of farming should have a better chance of being adopted than technology designed without taking such factors into account, since it should be more relevant to farmers’ actual needs and conditions (Dent and Thornton, 1988). How such a framework might be constructed is an interesting and difficult question that is outside the immediate scope of this discussion, save to say that it is already being attempted at a number of institutions.

An intercrop model would undoubtedly constitute a powerful weapon in the armoury of researchers and extensionists who have to deal with such cropping systems. Such a tool should also find a home within the practice of traditional Farming Systems Research, in the design and assessment of alternative agricultural practices for a location.

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The ability of the model to simulate monocrops as well as intercrops gives the investigator considerable flexibility in the choice of agronomic strategies that can be examined. For example, different patterns of intercropping can be compared with sequential cropping of beans and maize, or with various bean-maize rotations, over extensive periods of simulated time.

In this way the model can complement, and enhance the efficiency of, field experimentation. Sets of input data with which to run the model still have to be based on field or laboratory measurements, and the ultimate test of any model’s predictions is always going to involve the assessment of the relevant package in experimental plots at the research station and in farmers’ fields. The point is that an intercrop model would allow objective pre-assessment of large numbers of possibilities across a range of weather sequences for a particular location, so that scarce experimental resources are expended only on particularly promising alternatives.

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Table 1 shows the results of a comparison between variables predicted by the bean model (BEANGRO) and field data for 2 simulations involving the cultivar Porrillo Sintetico, a small, black-seeded bean, grown at the Centro Internacional de Agricultura Tropical (CIAT), Colombia, and in Gainesville, Florida in well-watered experiments run during 1986. In addition, the graph in Figure 1 shows model-predicted biomass accumulation over time for the plant canopy, pods and roots, together with observed data for the same treatment of the CIAT experiment (Hoogenboom et al., 1987).

To illustrate the use of CERES-Maize, Table 2 shows predicted and measured dates of silking of the hybrid B73 X Mo17, for a number of sites in North America and Europe over a number of years. (The large errors are all under-estimates, attributed to inaccurate predictions of germination and seeding emergence dates, possibly due to particularly dry or cold soil conditions.)

Figure 2 shows the results of 25-year simulations involving three varieties of maize grown in Gainesville in rain-fed conditions. For all simulations, the crop was sown at the end of March, and nitrogen was assumed to be non-limiting. The variability of yields under such conditions, and the non-zero probability of total crop failure, are worthy of note.

Both BEANGRO and CERES-Maize have been developed further since these computer experiments were carried out, and are in the process of extensive validation using data sets from a number of locations in Latin America.

**Intercrop Modelling**

If the motivation for constructing an intercropping model is apparent, then even more evident is the fact that the transition from single crop models to models of intercropping involves sobering degrees of complexity added to already complicated processes. The complexity of intercropping systems stems in part from the wide range of management options to evaluate, but in addition the effect of management will often depend on the bio-physical and socio-economic environment of the farmer.

It was argued above that an intercropping model was desirable on the grounds that it could provide useful and timely information for decision makers. When it comes to an examination of the intercropping problem itself, it is apparent that an intercrop model is the only reasonable approach for evaluating the multitude of feasible combinations of management system and environment. It would simply be impracticable to carry out field trials for a significant proportion of such combinations; on the other hand, a suitable model would allow computer simulations to be rapidly carried out for a large number of these.

When the number of possible species a farmer could grow concurrently in his field is considered, it is clearly impracticable to develop a separate intercrop model for each possible combination. A generalized approach is needed. The standardization of soil water models and data formats that exists in BEANGRO and CERES-Maize, for instance, is particularly helpful in this regard. However, there are problems in attempting to combine such models to take account of intercropping, since some of the relevant biological processes are represented at the plant level, rather than at the community level. Separate leaf area indices, for example, may often have to be calculated for each component species (i.e., the population level) and for the intercrop canopy as a whole (i.e., the community level).

Also absent in the single crop models are mechanisms that allow for the possibility of interactions between species. Competition is the process by which the "demand" of one species is not met because of the "demand" of another for the same...
resource -- for example, light, water and nutrients. Demand in this sense is the amount of resource the single species would have used in the absence of the competing species.

There would appear to be two major approaches to modelling multispecies interactions. In the first approach, the intercrop community is simulated as a unit. The contribution of each population is then calculated by dividing the total among the components.

The second approach involves starting at the population level and integrating up to the community level. Each population's demand for resources is calculated first. The amount of that demand subject to competition is then estimated, based on the extent to which the populations share a common resource pool. Next, total community resource use is calculated from the population demands and the amount of competition. Finally, resource allocation for each population is estimated by considering its competitiveness relative to the other populations.

These approaches are illustrated in various models of aboveground and belowground competition.

**Aboveground Competition**

The enhanced efficiency of light resource use in an intercrop may be due to a number of factors: component leaf area index development curves over time may overlap only partially, or the component species may have markedly different canopy heights, for example (Trenbath, 1986). This increased efficiency was illustrated in sorghum-pigeonpea experiments at ICRISAT, where the intercrop treatments exhibited a greater rate of conversion of light energy to total dry matter than did the sole crops, at the start of the growth period (Natarajan and Willey, 1980).

Models of competition between species have been developed. Examples are provided by McMurtrie and Wolf (1983; a tree-grass model) and Rimington (1984; a grass-legume award). Both models assume homogeneity of leaf area within layers of the canopy, which will usually be an untenable assumption in intercropping situations. Graham et al. (1988) made the same assumption in their analysis of weed-crop competition for light.

Many types of row and strip intercrop systems cannot be considered homogeneous within layers of the canopy. These systems may contain widely spaced hedges, or strips of a tall species. An example is the work of Acock and Juo (1988) on a model that considers spatial separation of foliage in a maize-Leucaena alley crop. The light interception routine developed employs a two-dimensional geometric representation of the alley crop. Light interception is then integrated with regard to both direct and diffuse light. This approach is robust enough to simulate a great number of the intercrop systems of interest, and it may lay the foundations for a more general model of interspecific competition for light.

Research currently underway at the University of Hawaii involves the evaluation of a population-based approach to modelling competition for light. The approach involves dividing the problem into three steps:

1. Demand for light is calculated for each species based on the relationships used in the respective single crop model. In CERES-maize, for example, demand for light is equated with the fraction of light intercepted in the absence of competitors.
   \[ I_o = 1 - \exp(-0.65*\text{LAI}) \]
   where \( \text{LAI} \) is the leaf area index.

   BEANGro uses a different model that relates demand for light to both leaf area index and the rectangularity of plant spacing.

2. The amount of light subject to competition is determined by the degree of association between foliage of the intercropped species. The level of competition is at its lowest, and canopy interception the highest, when the foliage of each species is negatively associated, that is, displayed in separate spatial regions. Maximum competition occurs when there is a high, positive association between the intercropped foliage; the efficiency of the canopy in intercepting light in this case is low. For example, if maize and bean each demand 40% of the radiation, combined canopy interception might range from 80%, in the absence of competition, to 40%, where competition is complete.

3. The fraction of light actually allocated to each population is then estimated. As well as its "own" light, each species will also intercept some part of the light for which it competes. That fraction depends on the competitiveness of the species. For instance, the taller of two species will receive a greater share of the light that is subject to competition.

These concepts are illustrated for a simulated bean-maize relay intercrop in Figure 3. Field bean was planted on day 6 and intercepted all the light demanded until the maize crop emerged (day 44). Over the following 30 days, competition between the species became intense, with maize intercepting the major part of the light involved in competition. As the bean crop approached maturity, its leaf area and demand for light dropped to zero. Subsequently, maize intercepted all the light demanded, in the absence of competition.
The advantages of this second approach are its simplicity and its compatibility with the current IBSNAT models. Experimentation is being carried out with various models of the degree of foliage association (step 2 above). Independent variables being considered include plant height, lateral extent (width), and the degree of separation or overlap in the foliage. The competitiveness of each component species might then be related to relative plant height.

Belowground Competition
Available experimental evidence suggests that belowground competition in species mixtures can be pronounced, and in a number of cases these interactions have been shown to be more intense than those aboveground (Snaydon and Harris, 1981). The processes that are involved, and the nature of this competition, are largely unknown. For example, individual roots may deplete soil resources to levels not accessible to the roots of competitors; alternatively, root competition may be more a matter of simple occupation of the soil profile to the partial or total exclusion of the roots of a neighbouring plant (Caldwell, 1987).

The structural features of root systems and their distribution in the soil may well have greater effects on competitive ability than particular physiological properties of the same roots. There is, however, little direct evidence for that supposition, and the theoretical models that have been proposed take a highly simplified approach to root system architecture (Caldwell, 1987).

Relative yield advantages to intercrops have been attributed to a number of mechanisms; for example, a) the component species may take up water and nutrients at different times of the growing period;

The inherent difficulties of studying below ground interactions have retarded research in this important area. Measurement of root distributions is laborious, and most researchers have avoided the problem of discriminating between species within a given root sample. Knowledge of root distributions is important for an understanding of the structure of intercrop communities, but the principal concern is the activity of the roots in taking up water and soil nutrients. No simple methods exist for measuring root activities for each component species and integrating the activities throughout the soil profile.

Some complex models, both process-orientated and statistical, have been assembled to describe the spatial aspects of root growth. In BEANGRO, a certain amount of root length is formed in each soil horizon, depending on the total amount of biomass partitioned to the roots. Root elongation is also controlled by the water status of each soil layer and the layer's relative rooting potential.

The University of Hawaii intercrop model is based upon the hypothesis that the current soil water model operates properly on community-level variables, particularly leaf area index and root length densities per soil layer. Potential transpiration and root water uptake are first calculated for the entire community using the standard model. These values are then divided among each of the populations. Factors for water stress are calculated for each species based on the results. This approach should be able to predict reduced transpiration, and the corresponding reduction of moisture stress, for the intercrop component low in the canopy.

Ecologists have often taken a different approach. Cormack (1979) describes a variety of statistical techniques to account for intraspecific competition, ranging from regular lattice models to irregular plant spacings (analysis of Dirichlet tessellations), to describe a particular plant's sphere of influence. The suitability of such techniques for the interspecific situation, and the problems involved in scaling up from the plant level to the community level, remain to be investigated.

The concept of foraging behaviour has recently been applied to natural plant communities (Sutherland, 1987), following on from its application to animal behaviour and its origin in economic theory. In an attempt to explain how environment modifies plant morphology, proponents produce experimental evidence to show that, for some species, reduced nutrient levels in the soil lead to a redistribution of plant material through vegetative growth: fewer stolon or rhizome branches, or longer internodes, for example. While this ability of the plant to respond to its environment has been demonstrated for some species, it appears to be no general phenomenon. Whether the concept of plant foraging behaviour has any role to play in intercrop modelling is an intriguing but somewhat speculative question at present.

Concluding Remarks
Considerable research is still needed before enough is known about the mechanisms that give plants their competitive ability, particularly belowground, to be able to construct satisfactory intercrop models. Until such a stage is reached, modelling efforts will necessarily be essentially empirical rather than mechanistic,
with concomitant restrictions on the general applicability and usefulness of the resultant models. One such approach is that of Vandermeer (1986), where a computer-based algorithm is used to estimate intercropping yields, based on the manipulation of a matrix of the interaction effects. These effects are estimated from field experiments; only the first-order interactions are considered, and these are assumed to be linear. As a short-term solution, there may be considerable scope for using such an approach in conjunction with the single crop models.

The modelling of bean-maize yields in association, in the absence of weeds, pests and diseases, deals with only part of the intercropping phenomenon. In considering the economics of species mixtures, Lynam et al. (1986) note that net revenue from an intercrop or from monocrop stands of the same two species will sometimes vary, in relative terms, depending on the year: in one season, the monocrops may perform better, while in other seasons, the intercrop may bring in more revenue. Intercropping is usually practised by small farmers, apparently as a risk-reducing measure. Rao and Willey (1980) demonstrated this for sorghum-pigeonpea intercropping systems at ICRISAT, where for any given disaster level, the probability of failure of the intercrop was one-third to one-sixth that of either of the crops grown in monoculture. Yield per se may not be the overriding consideration. It would appear to be crucial that intercrop models exhibit sensitivity to weeds, pests and diseases, before much use can be made of them in generating relevant information for researchers, extensionists and policy makers, for the ultimate benefit of small farmers in many parts of the world. The question of how may it be possible to incorporate such effects in an intercropping model, to allow the risk-reduction benefits of intercropping systems to be simulated successfully, is slowly starting to be answered.

The potential benefits to the use of intercropping models are considerable; a full appreciation of these may act as a stimulant to the carrying out of the research necessary to overcome some of the considerable technical problems associated with their construction.

Without wishing to implicate him in any way, the comments and criticisms of Gareth Hughes are gratefully acknowledged.

References


Table 1. A comparison between variables predicted using BEANGRO and field observations for the variety *parrillo sintetico* at Gainesville and at CIAT, Colombia in 1986 (Hoogenboom et al., 1987).

<table>
<thead>
<tr>
<th></th>
<th>Gainesville</th>
<th></th>
<th>CIAT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted</td>
<td>Observed</td>
<td>Predicted</td>
<td>Observed</td>
</tr>
<tr>
<td>Flowering Date</td>
<td>131</td>
<td>132</td>
<td>304</td>
<td>305</td>
</tr>
<tr>
<td>First Pod</td>
<td>138</td>
<td>136</td>
<td>309</td>
<td>-</td>
</tr>
<tr>
<td>Full Pod</td>
<td>142</td>
<td>144</td>
<td>313</td>
<td>-</td>
</tr>
<tr>
<td>Physiological Maturity</td>
<td>170</td>
<td>160</td>
<td>336</td>
<td>342</td>
</tr>
<tr>
<td>Pod Yield (kg/ha)</td>
<td>4030</td>
<td>3605</td>
<td>4530</td>
<td>4747</td>
</tr>
<tr>
<td>Seed Yield (kg/ha)</td>
<td>2940</td>
<td>2667</td>
<td>3460</td>
<td>3692</td>
</tr>
<tr>
<td>Shelling Percentage</td>
<td>73</td>
<td>74</td>
<td>76</td>
<td>78</td>
</tr>
<tr>
<td>Seed Number (m²)</td>
<td>1332</td>
<td>1458</td>
<td>1651</td>
<td>2086</td>
</tr>
<tr>
<td>Seeds per Pod</td>
<td>6.0</td>
<td>5.0</td>
<td>6.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Maximum LAI</td>
<td>4.9</td>
<td>4.9</td>
<td>6.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Biomass at R8 (kg/ha)</td>
<td>5920</td>
<td>5737</td>
<td>6250</td>
<td>7326</td>
</tr>
<tr>
<td>Stalk at R8 (kg/ha)</td>
<td>1590</td>
<td>1252</td>
<td>1430</td>
<td>1881</td>
</tr>
</tbody>
</table>

Table 2. Predicted and measured dates of silking of maize hybrid B73 x Mo17 using *CERES-MAIZE*.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Predicted</th>
<th>Observed</th>
<th>Silking date (day of year)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbia, MO, USA</td>
<td>1978</td>
<td>192</td>
<td>203</td>
<td>-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>195</td>
<td>195</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Bloomington, IL</td>
<td>1979</td>
<td>201</td>
<td>209</td>
<td>-8</td>
<td></td>
</tr>
<tr>
<td>Temple, TX</td>
<td>1979</td>
<td>186</td>
<td>197</td>
<td>-12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>150</td>
<td>157</td>
<td>-7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1983</td>
<td>161</td>
<td>164</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Swift Current, Canada</td>
<td>1979</td>
<td>232</td>
<td>246</td>
<td>-14</td>
<td></td>
</tr>
<tr>
<td>Mons, France</td>
<td>1978</td>
<td>235</td>
<td>248</td>
<td>-13</td>
<td></td>
</tr>
<tr>
<td>Fuchs, France</td>
<td>1978</td>
<td>215</td>
<td>220</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>Rome, Italy</td>
<td>1978</td>
<td>204</td>
<td>202</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Debrecen, Hungary</td>
<td>1978</td>
<td>220</td>
<td>219</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Zaječar, Yugoslavia</td>
<td>1978</td>
<td>215</td>
<td>209</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Radzikow, Poland</td>
<td>1978</td>
<td>238</td>
<td>236</td>
<td>2</td>
<td></td>
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</tbody>
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Figure 1. Beangro: Canopy, pod and root dryweight evolution for the cultivar porrillo sintético at CIAT during 1986 (Hoogenboom et al., 1987)

Figure 2. Ceres-maize: grain yield over 25 simulated seasons for 3 varieties grown at Gainesville, Florida
Figure 3. Proportion of light intercepted in a simulated bean-maize relay intercrop
Evaluation of the productivity of intercropping systems should preferably be done in quantitative terms. It is relatively easy to compare the productivity of crops and agricultural systems that produce similar products and use similar resources. If the products (e.g. crude protein, carbohydrates), and the resources used (e.g. fertilizers, land, labour) can be defined, then evaluation is possible.

Before the productivity of a cropping system can be assessed, the basis upon which the output(s) will be measured must be decided. For monocultures the most usual expression of output is some measure of yield weight per unit of land (e.g. kg/ha). In intercropping systems, however, because yield output of different crops cannot simply be added together or compared directly with each other, special methods have to be used. Many different methods of assessing output (Yield) advantages from intercrops have been developed. One possibility is to compare component yields with their sole crop yield for every crop in the mixture and add the ratios together. Another possibility is to compare the land area needed to obtain similar component yields in sole and intercrops. Evaluations can be made on the basis of whole plant dry weight or grain dry weight or plant constituents such as calories, fat, crude protein, lysine, methionine, or on the basis of net income. All these possibilities have their advantages and disadvantages and the method used depends on the objectives of the research.

Assessment of Yield Advantage

The use of the Land Equivalent Ratio (LER) has become common practice in intercropping studies as a way of assessing yield advantage, because it is a relatively simple concept.

In addition to the LER concept, there are also a number of "competition functions" proposed in the literature to describe competitive relationships and which give some indication of yield advantages. These have been developed to study plant competition but several have been tried in the analysis of intercropping experiments. They include the Relative Crowding Coefficient (De Wit, 1960), the Competition Index (Donald 1963), and the Aggressivity (Mc Gilchrist, 1965).

The Land-Equivalent Ratio (LER)

The LER may be defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping. It is usually stipulated that the level of management must be the same for intercropping and sole cropping.

An important concept inherent in the use of LERs is that, whatever their type or level of yield, different crops are placed on a directly comparable basis. Although based on land areas, LER also reflects relative yields i.e. the LER can be taken as a measure of relative yield advantage. See for example Mead and Willey (1980) and Riley (1984) for how to calculate the LER. A ratio greater than 1 signals yield advantage and a ratio less than 1 a yield disadvantage. For example, a LER 1.2 indicates a yield advantage of the intercrop over the sole crops of 20%, i.e. sole crops would require 20% more land to achieve the yield obtained by the intercrop.

In this way the LER represents the increased biological efficiency achieved by growing two crops together in a specific environment. The LER term is usually applied to combined intercrop yields but can equally be applied to the intercrop yield of each component crop. As the LER is a relative figure, it does not reflect the absolute yields. Large values for LER can be obtained because of low yields in corresponding sole crops. Therefore absolute yield figures need to be reported together with the LERs. This method alone allows comparison of different intercropping situations.

In practice, the intercropping combination with the highest LER is not always the best one, as far as the farmers needs are concerned, because in most situations component crops are not equally acceptable and one crop is needed or preferred more than another one. When assessing the yield advantages of intercrop combinations, farmers requirements should not be neglected, otherwise the research aimed at improving the intercropping situation is not based on sound objectives. If the LER is taken as a measure of the available yield advantage, there is the implicit assumption that the yield proportions embodied in that LER are those required by the farmers. This raises particular difficulties when comparing LERs with different yield proportions, because a straight comparison implies that either yield proportion is equally acceptable (which is not the case in practice).

Generally when calculating the LER, the sole crop yield of the same variety as that employed in the intercrop is used. There are situations where it is not advisable, however. When studying different genotypes for their suitability for intercropping, the intercrop yield should be compared with the sole crop yield of the best genotype (as a sole crop) (e.g. Mead and Willey, 1980). A similar approach may be used in experiments combining different genotypes for each crop. To determine the highest overall yielding combination, comparisons might be made with the highest yielding genotypes of each crop.

The number of sole crop yields to use will vary according to the type of trial and its objective(s). A good example of when a single

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Measurement of Biological Output in Intercropping

M.S. Reddy, FAO Maize Agronomist (UNDP/FAO/GRZ Maize Improvement Project), Mount Makulu Research Station, Private Bag 7, Chilanga, Zambia
standardizing sole crop yield would be agronomically valid is where treatments consist of different plant populations and spacings because as Huxley and Maingu (1978) have emphasized, all intercrop yields should be compared with the sole crop at its optimum population and spacing. Populations and spacings are cheaply adjusted (at least in theory) and intercropping should therefore be compared with sole plots which are at maximum productivity in this respect. There are other situations where it seems sensible to use more than one measure of the sole crop yield. In an experiment designed to examine the advantage of intercropping at different levels of fertility it should be appropriate to standardize any given intercrop yield against the sole crop yield at the same fertility level. Farmers may not be able to change their fertility level and it is pertinent to know how intercropping and sole cropping compare at any given level of fertility (Mead and Willey, 1980).

**Competition Functions**

Several Competition Functions can be used to assess yield advantages. The Relative Crowding Coefficient was proposed by De Wit (1960) and examined by Hall (1974a, 1974b). It assumes that mixture treatments form a replacement series. Each species has its own coefficient (k) which gives a measure of whether that species has produced more, or less, yield than expected. If a species has a coefficient less than, equal to, or greater than one it means it has produced less yield, the same yield or more yield than expected, respectively. The component crop with the higher coefficient is the dominant one. To determine if there is a yield advantage of mixing, the product of the coefficients is formed: this is usually designated K. If K is greater than 1 there is a yield advantage, if K = 1 there is no difference and if K is less than 1 there is a yield disadvantage.

Aggressivity was proposed by McGilchrist (1965). It also assumes that mixtures form a replacement series and it gives a simple measure of how much the relative yield increase in species A is greater than that for species B. It is usually denoted by AG. An aggressivity value of zero indicates that the component species are equally competitive. For any other situation, both species will have the same numerical value but the sign of the dominant species will be positive and that of the dominated negative; the greater the numerical value the bigger the difference in competitive abilities and the bigger the difference between actual and expected yields.

The Competition Index was suggested by Donald (1963). The basic process is the calculation of two 'equivalence factors', one for each component species. For species A the equivalence factor is the number of plants of species A which is equally competitive to one plant of species B. If a given species has an equivalence factor less than one it means it is more competitive (on a plant-for-plant basis) than the other species. The competition index is the product of the two equivalence factors. If the competition index is less than one there has been an advantage of mixing. The index has been tried in a number of intercropping situations (Willey and Osiru, 1972; Osiru and Willey, 1972; Lakhani, 1976), but has the disadvantage that the sole crops have to be present at a range of plant populations so that equivalent plant numbers can be estimated. This estimation is not a very accurate procedure, though Lakhani (1976) has suggested it can be improved by using some quantitative relationship between yield and plant population. But even with this refinement, accuracy of the final competition index is poor. Thus, although the concept is good, its practical use is limited.

Thus, in conclusion the LER is usually the most useful measure of yield advantage. It is relatively simple to calculate and it can be applied to any intercropping situation.

**Measurement of Input and Biological Output**

In general terms, efficiency (E) can be described as an output (O) per unit of some input (I) (Spedding, 1973). Algebraically this can be represented as:

\[ E = \frac{O}{I} \]

The output (O) may be measured in weight, money, energy or protein while the input (I) may be expressed in terms of land area used, energy, labour, fertilizer, time, or any other resource utilized. Time, land area and energy are normally important inputs in multiple cropping since they are scarce resources. Labour can be of less importance in measuring efficiency where family labour is used and where there are no alternative employment opportunities. Energy can be divided into "solar energy" used for photosynthesis and "added energy" (e.g. soil, electricity, farm machinery, fertilizers).

It is theoretically possible to compute the total energy used per unit of agricultural product and the energy value of the final crop product, and thus calculate the efficiency of a production system. By using a book-keeping approach a balance can be made of energy input and output. Although this approach has received a great deal of attention in the past, the methodology is still not fully developed and cannot, as yet, be adopted as a standard method for evaluating cropping systems.
Another factor to consider is the efficiency of solar energy use. By measuring total photosynthesis per unit area of land it would theoretically be possible to estimate the "productivity" of a cropping system. Photosynthesis is closely related to leaf area and measurement of leaf area index, canopy cover and light transmission of canopies has, in some cases, been a valuable tool in assessing productivity. These methods, however, only help to explain differences and cannot be used as standard measures of productivity.

Assessment of Biological Productivity Based on Food Value

Productivity can be assessed in terms of efficiency of energy and protein production per unit area of land per unit of time. It is usually sufficient to consider only energy and protein since these factors are of primary importance in most diets. Energy and protein must be considered separately since food crops contain both in different quantities and proportions. The balance between energy, protein and the constituent amino acids of the proteins must also be considered. The amino acids lysine and methionine are particularly important in tropical diets since lysine is often the major limiting amino acid in maize, which is a major staple crop, while methionine is the limiting amino acid in all sources of leaf protein. There are several ways of measuring the energy and protein production of intercropping systems. All depend on the use to which the product is put (e.g., consumption by humans and animals of various kinds). The diagram in Figure 1 outlines the procedures which are generally followed (Beets 1976). The yield of the crops are translated into their constituents which are then summed and converted to energy. The gross energy does not, however, necessarily represent the "value" of the yield of a cropping system. The quality of the protein varies from product to product and a combination of two or more products in a particular proportion may have higher "biological value" than would be expected from the gross energy yield. This is illustrated in the histogram in Figure 2, which compares the yields of three mixed cropping systems (two systems with maize and soyabean and one with maize and groundnuts). In the maize/soyabean system, on the basis of mass or energy, the maize monocultures gave the highest yields followed by the maize/soyabean intercrop and the soyabean monocultures. In terms of fat (ether extract), crude protein and methionine, the highest yield was given by the maize/soyabean mixed crop. In terms of lysine, one soya monoculture check gave a higher yield than the corresponding mixed culture. In another system (No. 2) the mixed culture gave the greatest yield in terms of energy, mass, crude protein and methionine. From the point of view of fat and lysine, however, the groundnut monoculture provided the highest yield with the maize/groundnut mixed crop a close second.

Tarhalkar (1975) found that mixed cropping systems provide produce of higher nutritive value. In particular cereal/legume mixtures contain proteins of superior nutritive value than monocultures because they usually supplement the deficient amino acids. Mixed cropping of sorghum with soyabees and groundnuts increased the lysine yield by up to 219 and 76 per cent respectively. This benefit of mixed cropping is of special importance in areas with protein deficient diets. Such areas exist in most developing counties and it is in these areas that intercropping often has greatest potential.

The land equivalent ratio compares yields of different cropping systems on the basis of the land required. As different crops have a different importance for human nutrition, however, there are situations where it is more appropriate to compare yields on the basis of food value constituents of crops, such as calories, fat and crude protein. This is especially important for protein, because consumption of animal protein is very limited in rural areas and the main protein resources are pulses. For example, substitution of yam and cocoyam by higher yielding cassava or the displacement of groundnut or cowpea by maize, for whatever reason, lowers the quality of human nutrition in spite of increased LERs. All tropical staple crops, especially root crops and tubers such as cassava, sweet potato, yam and cocoyam or banana provide a high yield in terms of carbohydrates but only small quantities of protein.

In Latin America one hectare of traditionally cultivated cassava intercropped with black beans can produce 10,000 kg of cassava and 600 kg of beans (Leihner, 1982). This corresponds to 13,400 kcal and 168 kg of protein. Thus one hectare could supply enough food (balanced in terms of calories and protein) for 4.6 persons during one year, leaving a surplus of approximately 6 tonnes of cassava for sale. The cassava yield in this example is not high and could be increased by changes in the cropping system but these should not reduce the bean yield in favour of cassava.

In the previous example only the crude protein yield was considered. In human nutrition, however, importance is attached to the proportion of essential amino acids such as lysine and methionine. Thus, maize protein with a low proportion of lysine (166 mg/gN) can be much better utilized when used concurrently with pulses, e.g., cowpea, which has a much higher
lysine content (467 mg/gN). Not only does a maize/cowpea intercrop produce an approximately 10% higher crude protein yield than sole cropped maize but this protein can be also better utilized in the human diet (Ahmed and Gunasena, 1979).

References


Figure 1. Diagrammatic presentation of a method of evaluating intercropping systems by converting yields to "energy"

<table>
<thead>
<tr>
<th>Cropping System</th>
<th>Mass</th>
<th>Energy</th>
<th>Fat</th>
<th>Protein</th>
<th>Lysine</th>
<th>Methionine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Three rows of soybeans between single rows of maize.</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>2) Nine rows of soybeans between single rows of maize</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>3) Four rows of groundnuts between single rows of maize.</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>

Figure 2. Comparison of the yields of three multiple cropping systems and their monoculture checks in terms of Mass, Energy, Fat, Protein, Lysine and Methionine (Beets, 1976).
Introduction
This paper discusses the evaluation of on-farm intercropping trials. The type of research covered is that conducted at a very applied level, with a view to testing improved technology or conducting exploratory trials under farmers' conditions. The argument is that farmers should be fully involved in the evaluation of new technology with reduced reliance on conventional statistical methods of experimental evaluation. Farmer assessment is emphasized during evaluation because the acceptance or rejection of a new intercropping technology is the farmers' decision.

The emphasis placed on farmer evaluation does not override the value of existing methods to evaluate intercropping trials. Measures such as "land equivalent ratios", "returns to scarce resources", "returns to cash", "expected net returns" and "nutritional values" are all useful tools for screening intercropping technologies (Steiner, 1984; Beets 1982; Chowdry, 1979). However, it is argued that these methods are more relevant and more easy to apply when on-station type experimental designs are used and yield data is reliable.

The use of farmer evaluation methods takes into account farmers' intercropping objectives. Where intercropping is practised a multiplicity of objectives prevail (Jodha, 1979). To make the research results meaningful, the evaluation should take into account all the farmers objectives. A single measure of outcome is therefore unlikely to cover the farmers' interests completely. Rather than develop complex statistical measures and procedures to cover multiple objectives, it is more cost-effective to conduct a qualitative evaluation of on-farm intercropping experiments, with maximum involvement from farmers.

A qualitative evaluation is advocated, not only because more complex methods of experimental evaluation are difficult to implement on-farm, but because it also orientates the research more to the target group of farmers to whom the recommendations are intended. The paper describes qualitative experimental evaluation using a very simple questionnaire-based survey to assess the benefits of intercropping innovations on-farm. A questionnaire is advocated because it enables a systematic collection of farmer opinion about a new technology quickly and at a low cost.

Before implementing a survey, it is necessary to look at the kinds of factors which the farmer is likely to consider in evaluating intercropping technologies.

Questions to Consider in Evaluating Intercropping Trials
A number of questions may be considered when evaluating an intercropping trial on-farm. While most of these should normally have been considered in the planning of the trial, it is useful to reconsider them before embarking on trial evaluation.

What will be measured as output?
Often the farmer will value other parts of the crop in addition to the grain, such as the leaves and the stem residue. If legumes or other plants such as cassava and sweet potatoes with edible leaves are being intercropped, will the leaves be measured, and how? Is the residue valued as animal fodder?

What are the labour implications?
The technology in the trial may demand extra labour during the peak labour periods such as land preparation, planting, weeding, pest control and harvesting. Does the trial have implications for labour use and distribution in the household? For example, in Zambia analysis of intercropping trials in Luapula Province has included a computation of the impact of new technologies on female labour (GRZ, 1987).

Has intercropping changed the nature or timing of operations?
While intercropping may increase returns to scarce resources it may at the same time make certain operations more difficult for the farmer. For example, if different row spacings are introduced in a system where farmers usually plant behind the plough, the farmer may be forced to change the system of planting.

If row spacing remains the same, the timing of other operations such as mechanical weeding may have to be changed in order to accommodate intercropping. For example, in cases where farmers use a ridger or plough to ridge up the stems in...
order to cover top-dressed fertilizer and smother weeds in the row, the intercropped plants (such as beans) may be adversely affected.

**What are the cash implications?**
Does the technology involve a greater investment of cash? Is extra cash required during a critical period? Is one of the crops, such as the maize, likely to be part of a credit package and if so what will be the effect of this on ability to repay the loan? Who will benefit from sale of any of the crops?

**What are the risk implications?**
If adequate experimental data is available from past research to support results on-farm, it may be possible to gauge the risk implications of the new technology. Does the technology carry greater risks than the farmers' current practice, or does it reduce the farmers' risks?

**What are the land implications?**
Intercropping is often associated with land scarcity. Will more land be required in order to fully implement the technology if the farmer is to meet current targets for particular crops? For example, if maize is to be intercropped with a legume, even though the value of yield of the combined crops may be higher from a given land area, the farmer may still require more land in order to produce a given target of the staple crop.

**How does the technology relate to decision making within the household?**
The technology may affect household decision making. For example, if the technology involves intercropping a cash crop controlled by men with a food crop controlled by women adoption may not occur. For example, a maize-bean intercropping trial conducted in Zambia showed very promising returns to land and labour but the technology was not accepted because in that particular area maize is a cash crop controlled mainly by men while beans is both a food and cash crop, normally grown in separate fields controlled by women. The men farmers wanted to claim the beans intercropped with the maize as their crop to be sold for cash, but the women objected to this (Chabala & Ngwiru 1986).

**How will the technology affect household food supply?**
The production of more food crops does not necessarily mean an improvement in the household food supply. As indicated in the above example, some intercropping situations have the effect of converting a food crop such as beans into a cash crop and thereby weakening the household food base.

**Are new crops or varieties being introduced through intercropping?**
When new crops and varieties are being introduced into the system it may be difficult to get the views of farmers on the intercropping technology being proposed. Introducing too many new things into an experiment makes it difficult for the farmer to evaluate. For example, if a new bean variety is included in a maize-bean intercropping system where beans are normally grown as a sole crop, the farmer may have difficulty in evaluating both the new variety and the intercropping patterns.

**What are the chances that inputs required will be available?**
This is a very important question when new crops or varieties are being introduced into the system. It may be difficult to get seed companies to produce enough seed for legume crops such as beans and groundnuts.

This list of questions is not exhaustive, and it will not be possible to cover all aspects fully using a simple farmer survey. However, it is useful to go through such a list before implementing a survey in order to identify the issues which are likely to be important for the target group farmers.

**Implementing a Survey for Evaluating On-farm Trials**
Intercropping trials provide a particularly good opportunity to involve the farmers in the evaluation of a new technology. The differences between treatments are by comparison with other types of trial, very easy for the farmer to identify and understand. However, accurate measurement of output from the trial is likely to be more difficult than with other types of trial due to differences in crop maturity and the tendency of farmers to harvest parts of the trial, such as green leaves and fresh grains, as they mature. Because of problems of accurate measurement, the qualitative aspect of evaluation assumes relatively greater importance compared with other types of evaluation method.

While surveys are sometimes tedious and time consuming, they can provide very useful feedback from the farmer to assist with the overall design and direction of research. It is usually dangerous to simply ask a few farmers what they think about the trial, or to expect farmers to volunteer comments during field days or when the researcher is visiting the trial. On such occasions, the farmer often keeps quiet or, wanting to be polite and pleasant, restricts comments to aspects of the trial which will not offend the researchers or other important visitors present. Moreover, the researcher has a tendency to remember only the comments which support what he or she has read in the literature or experienced in other situations.

While surveys always give valuable feedback on a trial, they will be particularly useful if the questions
listed above have not been considered during the planning of the trial.

A simple open-ended questionnaire is the best format for collecting data. Leading questions should be avoided in favour of open-ended questions which enable the farmer to present his or her views. The questionnaire can be divided into four parts, as in the example provided in Annex 1.

The first part contains basic information on both the farmer and the trial. It is important, when looking at differences in response between farmers, to look at how these relate to basic differences in resource base, cropping choices and household structure. To relate such differences in household characteristics to the types of responses obtained will usually require a sample size of 15-20 at a minimum.

The second part of the questionnaire concentrates on a treatment by treatment evaluation of advantages and disadvantages.

The third part is a simple ranking by the farmer of the different treatments in the trial.

Finally, and very important, the last part contains general comments by the farmer. In completing this part a statement of what, if anything, he or she intends to copy from the trial on a larger scale the following season should be recorded.

In the last three parts, appropriate follow-up questions, such as "why did you rank this treatment 1st?" are very important as they provide valuable insights into what is important for the farmer, and what his or her evaluation criteria are.

Both husband and wife should be involved in the survey. Husbands and wives may rank the same treatments differently and may have completely different feelings for a treatment. If only one sex is represented this should be indicated on the questionnaire.

A survey can be conducted by the trial assistant under the supervision of the agronomist or social scientist involved with the trial programme. It is vital for the researchers involved in the design of the trials to be involved in the design of the questionnaire and implementation of the survey. It is also essential that the survey be carried out at the site of the trial while the crops are in the field. If both husband and wife are available for interview each should be questioned separately. This will ensure that gender differences are captured as well as increase the number of respondents available for analysis.

While it is normally only possible to conduct one evaluation survey during the season, the survey can be repeated if necessary, focusing on critical cultural practices and/or stages of crop growth.

The points made above are now illustrated by describing a survey conducted to evaluate an on-farm intercropping trial in Lusaka Province, Zambia.

Farmer Evaluation of an Intercropping Trial in Lusaka Province, Zambia

The trial was an exploratory trial, attempting to test novel types of intercropping in a system where intercropping was practised only on a very modest scale. Rather than modify the existing system of intercropping (involving earlier planted maize at low densities with other food crops), the trial aimed to substitute the mono-cropping of late planted maize with maize intercropped at high rates with either sunflower, beans or cowpeas. There were two types of crop mix; inter-rows of maize and the intercrop or within-row mixtures with maize. All was at a standard row-spacing of every third furrow of the ox plough. The trial was planted at 16 sites with two replications at each site.

The aim of the trial was to examine ways of reducing risk to the farmer. Many farmers normally plant their maize very late in the season, thereby losing yield. An intercrop of a shorter duration would reduce the risk of crop failure and also increase returns to the land cultivated. It was not thought feasible to replace maize with a shorter season crop because maize is the farmers' staple food.

The farmer evaluation was conducted by administering a questionnaire to 15 of the 16 farmers hosting the trial including five women and 10 men. The questionnaire was administered at the site of the trial just before harvest.

Farmers' Ranking

The ranking was easy to implement, but had to be interpreted with caution (Table 1). A high ranking did not mean the farmer would adopt the practice. Many farmers ranked certain intercropping treatments as first but at the same time reported no advantages of these over their current practice. However the ranking was particularly useful in getting farmers to pick out the most promising treatments from the trial.

While the ranking by most farmers revealed a clear preference to continue with mono-cropping late planted maize, several ranked intercropping of alternate rows of maize and beans as first. The ranking indicated a preference for intercrops in alternate rows, rather than for the crops mixed in the row. Two farmers ranked high the intercropping of maize/sunflower in alternate rows. However they expressed a preference to plant the two crops separately (in both cases the sole maize was planted on a poorer part of the trial site).
Comments on Advantages and Disadvantages
In general, farmers found it easy to discuss the advantages and disadvantages of the treatments in the trial. Commenting on the sole cropping of maize, five of the farmers lent support to the logic behind the trial by pointing out disadvantages such as risk of crop failure (3 cases) and limited variety of food crops (2 cases). Further support was given by more favourable comments on the sole maize in earlier planted trials where fertilizer had been applied, rather than the later planted trials where no fertilizer was applied. Most farmers showed interest in the sole beans treatment, particularly on the easiness of weeding and harvesting, and also less shading and plant competition from maize. The negative comment came from a farmer whose beans were mostly destroyed by stem-maggot. Some farmers said the beans in the trial were planted earlier than they normally plant beans. They were concerned with incompatible planting times. All farmers were positive about sole cowpeas, even though cowpeas are most often intercropped in the system. Favourable comments related to good yield and also easier weeding and harvesting. The only negative comment related to the trial management: too high plant densities and too close row spacing in the trial. All farmers preferred to grow sunflower as a sole crop. Their reasons included less plant competition, easier weeding, and better crop growth. Negative comments related to too early planting. Competition with food crops was mentioned by a female head of household who, in retrospect, preferred to intercrop maize with a legume instead.

Comments on mixing intercrops with maize in rows were mainly negative although this is the current farmer practice. Two out of five farmers commented positively. Mixing maize and beans received more favourable comments. One farmer noted that beans did not adversely affect the maize, and another indicated that the practice gave two crops from one plot and that the maize enabled the beans to climb. However, three farmers did not like the practice because of weeding difficulties. No farmers favoured mixing cowpeas in the row with maize although this treatment (at much lower rates of cowpeas), is currently practiced. However, all farmers commenting on this trial were men. Women may give a different response. Disadvantages related to weeding, plant competition, depressed maize yields, and harvesting were pointed out. Mixing of maize with sunflower was rejected outright by all farmers. Problems mentioned included weeding and harvesting difficulties, and differences in crop maturity. All farmers noted a negative effect of sunflower on maize growth.

Comments on inter-row treatments were more positive. One farmer felt beans could provide fertilizer for the maize while another noted that if one of the crops failed the other would survive. Another farmer said harvesting was easier than when the crops are mixed in the same row. Disadvantages mentioned were related mainly to extra space required to produce enough maize for consumption. One farmer mentioned that the maize shaded the beans and retarded growth. While most farmers commented positively on the maize/cowpeas inter-row treatment, this was not reflected in their rankings of the treatments. Positive comments related mainly to the advantages over mixing in the same rows. These included easier harvesting, more air space for crops, easier interrow cultivation, and bigger maize cobs. Farmers did not like the inter-row maize/sunflower arrangement but some noted that it was at least better than mixing the crops in the same row.

General Comments by Farmers
These represented a fairly consistent set of views. Although the trial was in its second year, most farmers had a limited understanding of its main objective. For example, most of the farmers said that the seed came late and the trial should have been planted earlier, not realizing that intercropping was intended as an alternative strategy for a late planted sole maize crop. Most farmers also stated that there should have been bigger plots with fertilizer provided. Many of the farmers had a negative attitude to intercropping. Only one saw intercropping as a way of maximizing land use, and two as a way of reducing risks. It is possible that if more of the plots had been planted later, the risk spreading benefits would have come out more strongly from farmers’ comments.

Reasons against intercropping related mainly to greater difficulties in performing certain operations, particularly weeding, ox-cultivation and harvesting. Differences of crop maturity were also mentioned, particularly between sunflower and maize. With regard to trial management, some farmers commented critically on the spacing and plant densities used.

Farmers were also asked to comment on the cooking and other qualities of the improved varieties of beans and cowpeas used in the trial. No farmers objected to the colour. Most commented on the small size of the improved seed compared with the local varieties, but said this would not stop them growing it. In terms of cooking time, no difference was noted, but farmers interviewed said they preferred the taste of one of the improved beans to the other.

Value of the Survey
While some yield data were collected, they proved very difficult to analyze because of site to site variation and the mixing up of some of the treatments harvested by the
The survey, combined with visual inspection of plots therefore served as the primary method of experimental evaluation. The survey clearly suggested that some of the treatments, such as intercropping of maize and sunflower, were not worth repeating. However, the high ranking of some treatments, particularly inter-row maize/beans and maize/cowpeas may warrant further investigation. Within-row maize/cowpeas, although ranked quite low may also be worth repeating with more attention on women farmers. Other treatments are probably not worth repeating on-farm. In view of the complaints about waste of land, narrower row spacings may be tried, planting every second furrow instead of every third furrow. If sunflower is to be included, it could be tried out as an intercrop in alternate rows with beans or cowpeas for ox-owners able to plant their maize on time. One factor to be very seriously considered in any trials with cowpeas or beans is the prospect for seed availability at the local depots.

The factor which most hampered the farmers' evaluation was their limited understanding of the trial design and objectives. This points to the importance of involving farmers in the design of trials and of encouraging field staff to clearly explain the purpose of trials to the farmer.

Concluding Remarks

A farmer survey is a useful tool for a qualitative evaluation of intercropping trials on-farm. It can provide very useful feedback in a short space of time and with minimal resources. An evaluation survey should not however be regarded as a substitute for existing proven methods of experimental evaluation but a complement. Both qualitative and quantitative methods are important. Careful observation of both the trial and farmer practice during the growing season is still extremely important. In the example discussed above, during the site visit the researchers found the farmer busy selling green maize to marketeers from a late planted field adjacent to the trial. This was an advantage of late planted maize which had been overlooked in the trial design. Moreover, visits to trials revealed that site variation had greatly distorted differences between treatments in terms of crop performance. This effect may not have come out in a simple aggregating of yields across sites.

When on-farm yield data are very accurate, economic analysis using a range of parameters, can effectively complement qualitative evaluation. Parameters for economic analysis can be selected in the light of the farmers' expressed objectives for intercropping, such as land shortage, labour shortage, food security and risk reduction.

However, statistical analysis, whether agronomic or economic, can never be substituted for asking the farmer to evaluate the technology as tested in his or her field.

Acknowledgements

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References


Annex 1.

Lusaka Province Arpt Questionnaire:
Farmer Feedback on On-Farm Trials/Tests/Observation Plots

Season. _______ Date. ______ Interviewer ________________
Target Area ________________ Farmer ________________
Trial/Test Name ____________________________________________
Date of planting __________ Farmers
List of treatments: Ranking
T 1 ____________________________________________________________________________
T 2 ____________________________________________________________________________
T 3 ____________________________________________________________________________
T 4 ____________________________________________________________________________

Description of farmer practice treatment is trying to improve on (e.g. variety, cultural practice etc.)
______________________________________________________________________________

Farmers' Reaction

Treatment 1
Advantages over farmer practice
Disadvantages

Treatment 2
Advantages over farmer practice
Disadvantages

Treatment 3
Advantages over farmer practice
Disadvantages

Treatment 4
Advantages over farmer practice
Disadvantages

Farmers' General Comments (include intention or not to adopt as last question):
Notes to Farmer Feedback Questionnaire

This is an all purpose instrument to enable a quick and systematic farmer assessment of on-farm trials, tests and demonstrations to add to the agronomic and economic analysis. It can be used for a trial with up to four treatments, in addition to the farmer practice. The questionnaire can be administered once, or more often during the season, depending on the objectives of the trial. It may be specially useful when researchers have limited contact with farmers through the growing season.

Guidelines

1. Start the interview at the trial site with the farmer and as many of his or her household present as possible.

2. If necessary make a sketch map of trial site showing location of treatments - this can be done in the "GENERAL COMMENTS" section.

3. Description of trial to include master number if there is one.

4. "List of treatments" to contain a brief description of the different treatments, highlighting the differences between the treatments.

5. "Description of farmer practice" should describe what the farmer is actually doing on most of his or her land relevant to the technology to be tested (e.g. crop/varieties grown, method of tillage, specific cultural practices etc.). If it is a variety trial record the actual variety name the farmer is using, rather than "local variety/saved hybrid". DO NOT use a blanket description of farmer practice derived from previous survey work.

6. "FARMERS REACTION" Take one treatment at a time, making sure the farmer is clear about what that particular treatment is. Try to avoid asking LEADING QUESTIONS, and give the farmer time to consult with other household members and talk for as long as possible before you record the response.

7. "FARMERS RANKING", again make sure the farmer knows what he or she is ranking. Don't force the farmer to rank and if reluctance is shown write "NO RANKING" and give the farmers explanation of reluctance to rank in the general comments section.

8. "GENERAL COMMENTS", can be used to follow up on the ranking, to get reasons why certain treatments have been ranked first and others last. This will allow a check against the consistency of previous responses on the advantages and disadvantages of the different treatments.

Remarks on other aspects of the trial can also be recorded here, especially if the farmer intends to adopt any of the treatments, general relevance to the farmer, trial design, and also factors such as site variation or seasonal effect which have influenced the performance of a particular treatment or the whole trial site.

Table 1. Farmer ranking of treatments in the maize intercropping trial.

<table>
<thead>
<tr>
<th>Farmer ranking</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole Maize</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sole Sunflower</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Sole Beans</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Sole Cowpeas</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Mix in Row Mz/Sf</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Mix in Mz/Bns</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Mix in Mz/C Peas</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Alt Rows Mz/Sf</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Alt Rows Mz/Bns</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Alt Rows Mz/C Peas</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

(15 responses, plus three for split plots)
Introduction

Intercropping is a popular and traditional cropping system of long standing. It is a strategy used by smallholder farmers for increasing crop yields, crop diversity and the stability of crop production (Gomez and Gomez, 1983).

Intercropping is popular in the tropics (Francis, Flor and Prager, 1978) because of several advantages. These include: increased crop yields (Willey and Osiru, 1972; Edje, 1982), more efficient use of labour (Norman, 1968), soil improvement (Agboola and Fayemi, 1972), reduction in pest incidence (Pearson, 1979) and Gomez, 1983).

Although intercropping is popular among smallholder farmers in the tropics, little research had been done until the 1970s when researchers started “...going outside the research stations and talking to farmers who have been experimenting with intercropping for centuries.” This led to renewed interest in intercropping in Africa, Asia and Latin America and in the warmer parts of Australia and the U.S.A. Consequently, according to Rao (1984, unpublished and cited by Francis (1986)), a total of 1986 papers had been published on intercropping by 1980.

Methods of Evaluating the Productivity and Efficiency of an Intercrop

Different methods or indices have been used for evaluating the productivity and efficiency of intercrops. These include: comparison of single and combined yields, relative yield total (RYT) (de Wit and van den Bergh, 1965; van den Bergh, 1968), land equivalent ratio (LER) (IRRI, 1974, 1975), area time equivalent ratio (ATER) (Hiebsch and McCollum, 1987), staple land equivalent ratio (SLER) (Reddy and Chetty, 1984), relative crowding coefficient (de Wit, 1960), aggressivity (McGilchrist, 1965), income equivalent ratio (IER) (Andrews and Kassam, 1976), financial value index, crop equivalent (Mead, 1986), bivariate analysis (Ezumah et al., 1987) etc.

Calculation of energy from maize

According to Platt (1962), 100g of refined maize meal (60% extraction), called ufa in Malawi (for nsima) or unga wa sembe in Tanzania (for ugali), contains 354 calories or 1483.3 J, (354 x 4.19 J). From Table 1, 10348 kg of maize will produce 6209 kg of ufa (60% of 10348 = 6209). If 100g of ufa contains 1483.3 J, (or 0.0014833 MJ), 6209 kg of ufa = 92.1 MJ. By similar calculations 9974 kg ha⁻¹ of maize in association with beans, equals 5984 kg ha⁻¹ of ufa (60% of 9974). 5984 kg of ufa will contain 88.8 MJ.

Calculation of energy from beans

Again using Platt’s conversion table in which 100g of the edible portion of bean seed contains 339 calories or 1420.4 J (339 x 4.19 J) or 0.0014204 MJ. Therefore the 1673 kg of bean yield in monoculture will contain 23.8 MJ. By similar calculation, 760 kg ha⁻¹ of beans in association with maize will contain 10.8 MJ.

Calculation of protein from maize

Using Platt’s table, with 8% protein in ufa, the 10348 kg ha⁻¹ maize yield in monoculture should produce 6209 kg (60% of 10348) of ufa and 497 (8% of 6209). The 9974 kg of maize, being yield of maize in association with beans, should produce 5984 kg of ufa (60% of 9974) and 479 (8% of 5984) of protein.

Protein from beans

Using a conservative estimate that beans contain 20% protein, 1673 kg (the yield of beans in monoculture) and 760 kg (yield of beans in association with maize) should yield 335 and 152 kg ha⁻¹ of protein respectively.

From the yields in Table 1 both the energy (megajoules, MJ) and protein yields can be calculated from conversion tables (Platt, 1962).
and the total for both crops in association are 92.1, 23.8 and 99.6 MJ, respectively. The protein yield for the corresponding cropping systems are: 497, 335 and 631 kg ha⁻¹, respectively.

Theoretical Calculation for Feeding Humans

The Food and Agriculture Organization (FAO) has estimated that a 55 kg-active person requires 10.48 KJ of energy and 65g of protein daily (Latham, 1971). The energy from both maize and beans in association (99.6 MJ) should meet the requirement of 26 persons for one year and the same cropping system enough protein (631 kg) for 27 persons for one year. If on the other hand, a farmer has planted one half hectare of his field to maize and the other to beans (both pure stand), the farmer could have realized 58.0 MJ (that is half of 92.1 + 23.8 MJ) enough protein for 15 persons and by similar calculations the farmer could have realized 416 kg of protein (half of 497 + 335), enough for 18 persons for one year. In other words the yields from the associated crop could have produced enough food to meet the energy and protein requirements of 26 persons for one year compared to only 15 persons that the yields of maize and bean could have supported if both crops were grown in pure stand. Clearly humans should not live on a diet of maize and bean alone. This will be monotonous, although monotony could be reduced by the use of various maize and bean recipes. Nevertheless, there will be need to include other foodstuffs to meet nutrient needs and to satisfy appetite.

Crop Residue for Livestock Feed

At a recent workshop in Addis Ababa, Ethiopia, the importance of crop residues for feeding livestock in smallholder farming systems and the relationship between crop and livestock production was emphasized (McDowell, 1988). According to Brumby (1987), African countries recording increases in crop production have also recorded a corresponding increase in livestock numbers. Despite the importance of this relationship and the possible availability of farmyard manure for crop production, most agriculturists have not included non-grain dry matter yields in their assessment of cropping systems. Nor have plant breeders been concerned with non-grain yields. The low mass of non-grain plant parts in new cultivars has often resulted in their low rate of adoption by small-scale farmers.

One area in which there is strong dependence on crop residue for livestock production is the Hai District of Kilimanjaro region in N.E. Tanzania. It is densely populated with up to 650 persons per Km² (Shem and Davis, 1988). Hai district has two ecological zones (lowland, below 900m above sea level and middle belt, 900-1800m above sea level. Because of pressure on land, farmers have their homestead, their coffee, banana and livestock in the highlands of the middle belt and their arable fields (mostly an intercrop of maize and beans) in the lowlands. There is a mean distance of about 18 km between the homestead and the arable fields. Because there is no land for forage production in the highlands, crop residues (the most important livestock feed) from the arable fields in the lowlands are transported on the heads of women and children and sometimes on pickups. Often the lower leaves of maize are removed for livestock feed while still greenish yellow. Maize is also detasselled around physiological maturity and used as fodder.

Beans are harvested by pulling the entire plant and carrying to the homestead where they are shelled and the crop residues (stems, shells, some leaves) are fed to livestock. In Arusha and Kilimanjaro regions, the bean stems are preferred to maize stover, for livestock feed, because beans have a higher quality and higher proportion of edible stems than maize (Shem et al., 1988).

Farmers in the lowland zone who have no livestock or have surplus fodder sell the fodder at the roadside. Here maize stover and bean haulms sell for 2.5 and 6.5 Tanzania shillings per kg, respectively. Large-scale farmers who grow beans for seed, bale bean stems for sale.

Because of the importance of crop residues in Arusha and Kilimanjaro regions, Shem et al., (1988) have carried out livestock feeding trials using bean straw. They reported that bean straw could meet the nutrient requirement, except for phosphorus, of a 400 kg lactating cow producing less than 8 kg of milk per day.

Crop Residue Yields as an Index of the Productivity of a Maize/Bean Intercrop for Livestock Feed

One other possible index of the productivity of maize/bean intercrops is the production of crop residues for livestock production. This will be illustrated using data from a trial conducted by Edje (1984). The trial was planted at Bunda College of Agriculture, Lilongwe, Malawi during the 1982/83 crop season. Maize, MH12 and a climbing bean cultivar, 499/5, were used. Both crops were grown in
monoculture and in association. Crop husbandry practices were as described earlier for the experiment on energy and protein yields. Dry matter data are given in Table 3.

Taking the weight of an average Malawi Zebu cow as 318 kg and assuming that 2.5% of body weight will be fed as dry matter per day, then each livestock unit will consume 7.95 kg of roughage per day. If 7.95 kg of dry matter is fed per day, then the 6025 kg of dry matter from both crops in association (from Table 3) can be fed for 758 days. Since it takes about 165 days to fatten a steer, the associated cropping system will provide enough maize stover and bean stems to feed 4.6 livestock units.

If on the other hand a farmer had planted one half hectare of land to maize in pure stand and the other half to beans in monoculture, he should have realized 3439 kg (\( \frac{1}{2} \text{ of } 5861 + 1017 \)). This will have provided enough fodder to fatten 2.6 livestock units only.

It should be noted that both maize stover and bean stems are used as roughage. These in themselves do not supply sufficient energy and crude protein for cattle production purposes. Therefore, to balance the energy and crude protein requirement, supplements such as maize bran (madeya) will have to be used. Maize bran will not be hard to find since it is a by product from the processing of maize flour (ufa). The inclusion of bean chaff (broken bean plant parts, mostly shells) in the diet could reduce the amount of madeya fed as supplement. These are higher in crude protein and phosphorus than the straw alone (Shem et al., 1988). It might also be necessary to include molasses to provide fermentable energy and increase dry matter intake; and urea for rumen micro-organisms.

The direct use of farmyard manure to increase soil fertility and improve soil characteristics in this system should not be ignored. The availability of methane gas from biogas for lighting, cooking and heating and the eventual use of the effluent as farmyard manure are also important aspects of the use of crop residues.

**Concluding Remarks**

Attempts have been made in this paper through illustrations, to show how energy and protein from seeds and fodder of maize and beans in association could be used as indices of productivity. The calculations made have been to some extent theoretical, but are simple and are easy to interpret.

These indices can produce directly useful values e.g. the number of humans that can be fed on grain or livestock on fodder. It is hoped that human and livestock nutritionists will be able to translate these indices into more substantive aspects of human and livestock health and productivity.

**References**


Table 1. Yield of maize and beans in monoculture and in association at Bunda College of Agriculture.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Seed yield (Kg ha⁻¹)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Beans</td>
<td></td>
</tr>
<tr>
<td>Monoculture maize</td>
<td>10,348</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Monoculture beans</td>
<td>-</td>
<td>1,673</td>
<td></td>
</tr>
<tr>
<td>Maize and beans in association</td>
<td>9,974</td>
<td>760</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Energy (MJ) and protein yields of maize and beans in monoculture and in association

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Energy (MJ ha⁻¹)</th>
<th></th>
<th></th>
<th>Proteins (Kg ha⁻¹)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Beans</td>
<td>Total</td>
<td>Maize</td>
<td>Beans</td>
<td>Total</td>
</tr>
<tr>
<td>Sole maize</td>
<td>92.1</td>
<td>-</td>
<td>92.1</td>
<td>497</td>
<td>-</td>
<td>497</td>
</tr>
<tr>
<td>Sole beans</td>
<td>-</td>
<td>23.8</td>
<td>23.8</td>
<td>-</td>
<td>335</td>
<td>335</td>
</tr>
<tr>
<td>Maize and beans in association</td>
<td>88.8</td>
<td>10.8</td>
<td>99.6</td>
<td>479</td>
<td>152</td>
<td>631</td>
</tr>
</tbody>
</table>

Table 3. Dry matter (kg ha⁻¹) of maize and beans in monoculture and in association.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Dry matter (kg ha⁻¹)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Beans</td>
<td>Total</td>
</tr>
<tr>
<td>Sole maize</td>
<td>5861</td>
<td>-</td>
<td>5861</td>
</tr>
<tr>
<td>Sole beans</td>
<td>-</td>
<td>1017</td>
<td>1017</td>
</tr>
<tr>
<td>Maize and beans in association</td>
<td>5602</td>
<td>423</td>
<td>6025</td>
</tr>
</tbody>
</table>
Measurements and Analysis

The first thing to recognize is that there is not a single form of statistical analysis which is appropriate to all forms of intercropping data. Even for a single set of experimental data it will be important to use several different forms of analysis. For the two components of an intercropping system the data may occur in different structural forms. In general data structures from intercropping experiments will be complex with different forms of yield information available for different subsets of experimental units.

Valid Comparisons

In considering alternative possibilities for the analysis of data from intercropping experiments it is essential that the principle of comparing "like with like" is obeyed. If yields are measured in different units, or over different time periods, or for different species, then in general comparisons will not be valid and should not be attempted. To illustrate the difficulties and possibilities we consider a set of ten "treatments". Any actual experiment would be unlikely to include such a diverse set of treatments though there would typically be several representatives of some of the "treatment types" illustrated. The structure for the ten treatments is as follows:

<table>
<thead>
<tr>
<th>Legume Crop Species</th>
<th>Yield</th>
<th>Cereal Crop Species</th>
<th>Yield</th>
<th>Monetary Value</th>
<th>Σ Relative Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I</td>
<td>r</td>
<td>-</td>
<td>-</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>2) II</td>
<td>r</td>
<td>-</td>
<td>-</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>3) -</td>
<td>-</td>
<td>A</td>
<td>a</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>4) -</td>
<td>-</td>
<td>B</td>
<td>b</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>5) I</td>
<td>r</td>
<td>A</td>
<td>a</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>6) I</td>
<td>r</td>
<td>A</td>
<td>a</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>7) I</td>
<td>r</td>
<td>B</td>
<td>b</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>8) I</td>
<td>r</td>
<td>B</td>
<td>b</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>9) II</td>
<td>r</td>
<td>A</td>
<td>a</td>
<td>r</td>
<td>-</td>
</tr>
<tr>
<td>10) II</td>
<td>r</td>
<td>B</td>
<td>b</td>
<td>r</td>
<td>-</td>
</tr>
</tbody>
</table>

A comparison is valid only when the units of measurement are identical. Thus it is valid to investigate the effect of different cereal crops on legume yields of one species($\gamma$, $\delta$, $\xi$, $\eta$) or of the other species ($\tau$, $\varphi$, $\chi$, $\psi$). Similarly the effect of different legume environments on crop yield ($\alpha$, $\beta$, $\gamma$, $\delta$) or ($\omega$, $\theta$, $\zeta$, $\iota$). The effects of different treatment systems on pairs of yields may be assessed by comparing the pair ($\gamma$, $\delta$) or ($\epsilon$, $\zeta$) or ($\eta$, $\iota$). Particular combinations of the pair of yields may also be compared so that ($\gamma$, $\delta$, $\epsilon$, $\zeta$, $\eta$, $\iota$) or ($\epsilon$, $\zeta$, $\eta$, $\iota$). However it is not valid to compare ($\gamma$, $\delta$, $\epsilon$, $\zeta$, $\eta$, $\iota$) because the divisors are different. In interpretation of these sums of ratios as 'Land Equivalent Ratios' (Willey 1979; Mead and Riley 1981) the sum of ratios is thought of in terms of land areas required to produce equivalent yields through sole crops. However, land areas required to grow crop A are not comparable with land areas to grow crop B. Comparison of biological efficiency through LER's cannot be valid for different crop combinations.

The only measure by which all different component combinations can be compared must be a variable, such as money, to which all component yields can be directly converted, and which has a practical meaning.

The Variety of Forms of Analysis

The only form of analysis which retains all the available information is multivariate. When the performance of each component crop may be summarized in a single yield then a bivariate analysis of variance is the most powerful technique available. However only those experimental units for which both yields may be measured can be included in a bivariate analysis.

Analysis of each crop yield separately is also likely to be useful, though it is important to check that the variability for monocrop yields is the same as that for intercrop yields. Analysis of crop indices may also be useful.

Bivariate Analysis

A bivariate analysis is a joint analysis of the pairs of yields for two crops intercropped on a set of experimental plots. The philosophy is that because two yields are measured for each plot, and the yields will be interrelated, they should be analyzed together. The interrelationship is important since it implies that conclusions drawn independently from two separate analyses of the two sets of yields may be misleading. There are two major causes of interdependence of yield of two crops grown on the same plot. If the competition
between the two crops is intense, then it might be expected that on those plots where crop A performs unusually well, crop B will perform unusually badly and vice versa. This would lead to a negative background correlation between the two crop yields, quite apart from any pattern of joint variation caused by the applied treatments. Failure to take this negative correlation into account could lead to high standard errors of means for each crop analyzed separately, which could mask real differences between treatments.

Alternatively it may be that on apparently identical plots, the two crops respond similarly to small differences between plots producing a positive background correlation. Again looking at separate analyses for the two crops distorts the assessment of the pattern of variation.

To see how consideration of this underlying pattern of joint random variation is essential to an interpretation of differences in treatment mean yields some hypothetical data are shown in Fig 1. Individual plot yields are shown for two intercrop systems (A and B), the mean crop yields for the two systems being identical for three situations. In Fig 1a the pattern of background variation corresponds to a strongly competitive situation (negative correlation), whereas for Fig 1b there is a positive correlation of yields over the replicate plots for each treatment. In Fig 1c there is no correlation between the two crop yields. In all three cases the comparisons in terms of each crop yield separately would show no strong evidence of a difference between the two systems. However, the joint consideration of the pair of yields against the background variation shows that the difference between the system is clearly established in Fig 1a, that Fig. 1b suggests strongly that the apparent effect is attributable to random variation, and that in Fig 1c the separation of the two systems is rather more clear than could be established by an analysis for either crop considered alone.

The Form of Bivariate Analysis

The calculations for a bivariate analysis are formally identical with those required for covariance analysis. The difference is that, whereas in covariance analysis there is a major variable and a secondary variable whose purpose is to improve the precision of comparison of mean values of the major variable, in a bivariate analysis the two variables are treated symmetrically. Bivariate analysis of variance consists of an analysis of variance for $X_1$, analysis of variance for $X_2$, and a third analysis (of covariance) for the products of $X_1$ and $X_2$. Computationally this third analysis of sums of products is most easily achieved by performing three analyses of variance for $X_1X_2$ and $Z = X_1 + X_2$. The covariance terms are then calculated by subtracting corresponding SS for $X_1$ and for $X_2$ from that for $Z$ and dividing by 2. The bivariate analysis including the intermediate analysis of variance for $Z$ are given in Table 1 for a maize/cowpea experiment involving 3 maize varieties, 2 cowpea varieties and 4 nitrogen levels in 3 randomized complete blocks.

The bivariate analysis of variance, like the analysis of variance, provides a structure for interpretation. In addition to the sums of squares and products for each component of the design, the table includes an error mean square line which provides a basis for assessing the importance of the various component sums of squares and products. The general interpretation of this analysis is quite clear and is essentially similar to the pattern of analysis of cowpea yield. There are large differences attributable to the different maize varieties and to the variation of nitrogen level; there is also a suggestion that there may be an interaction between cowpea variety and nitrogen level.

Diagrammatic Presentation

We have argued earlier that interpreting the patterns of variation in maize and cowpea yields without allowing for the background pattern of random variation can be misleading. The primary advantage of the bivariate analysis is that it leads to a simple form of graphical presentation of the mean yields for the pair of crops making an appropriate allowance for the background correlation pattern. The graphic presentation uses skew axes for the two yields instead of the usual perpendicular axes. If the yields are plotted on skew axes with the angle between the axes determined by the error correlation and if, in addition, the scales of the two axes are appropriately chosen, then the resulting plot, such as Fig 2, has the standard error for comparing two mean yield pairs equal in all directions. The results in Fig 2 are for the three maize varieties from the example, and the size of the standard error of a difference between two mean pairs is shown by the radius of the circle.

Construction of the skew axes diagram is based on the original papers of Pearce and Gilliver (1978, 1979) and detailed instructions for construction are given by Dear and Mead (1983, 1984). The form of the diagram given in Fig 2 treats the two crops symmetrically, in contrast to the original suggestion of Pearce and Gilliver, in which one yield axis is vertical and the other is diagonally above or below the horizontal axis, depending on the sign of the error correlation.

The interpretation of the diagrams is extremely straightforward. The results in Fig 2 show that the differences among the three maize varieties are important for both maize and cowpea yields, with the
difference between varieties 2 and 3 clearly less than between either variety and variety 1. There is a clear consistency through the sequence of varieties 1 to 2 to 3, with the increase in maize yield being directly reflected in a decrease in cowpea yield. The three points fall nearly on a line illustrating the strongly less than between either variety and variety 1. There is a sequence of varieties 1 to 2 to 3, -0.98). Remember that random correlation between the two crop yields has been allowed for by the skewness of the axes and the displayed pattern is additional to the background correlation pattern.

The results for nitrogen main effects and the interaction of cowpea variety with nitrogen are shown in Figs 3 and 4. The four nitrogen levels produce four pairs of mean yields in an almost straight line. The dominant effect is on the yield of maize which increases consistently with increasing nitrogen. In addition there is a clear pattern of compensation between the two crop yields with cowpea yield decreasing as maize yield increases. The pattern of yields for the cowpea variety/nitrogen interaction emphasizes the two effects of yield increase for one crop and compensation between crops. For variety A the effect of increasing nitrogen is simply an increase of maize yield, the "line" of the nitrogen level means being almost exactly parallel to the maize yield axis. In contrast, for variety B the dominant effect is the change in the balance of maize/cowpea yields with the maize yield increasing consistently with increasing nitrogen and the cowpea yield showing a corresponding decline.

Significance Testing
There are two forms of test that are useful in bivariate analysis, and these correspond to the t and F tests used in the analysis of a single variate. We have already mentioned in the discussion of the skew axes plot that the standard error of a difference is the same in all directions in these diagrams. Because of the scaling of axes, which is part of the construction of the diagram, the standard error per observation is 1. The standard error of a mean of n observations is therefore 1/\sqrt{n} and the standard error of a difference between two points is \sqrt{2/n}.

Confidence regions for individual treatment means can be constructed as circles with radius \sqrt{2F/n}, where F is the appropriate percentage point of the F distribution on 2 and e degrees of freedom (e is the error degrees of freedom). The analogue for a bivariate analysis of the F test in a univariate analysis of variance is also an F test. The basic concept on which the test is based is the determinant constructed from the two sums of squares and the sum of products. Suppose that the error SSP are E_1, E_2, and E_{12}, then the determinant is

\[ E_1 \times E_2 - E_{12}^2 \]

and it reflects both the sizes of E_1 and E_2 and the strength of the linear relationship between x_1 and x_2. To assess the treatment variation for a treatment SSP with values T_1, T_2 and T_{12} we calculate a statistic, L, which compares the determinant of treatment plus error with that for error.

\[ L = \frac{(T_1 + E_1)(T_2 + E_2) - (T_{12} + E_{12})^2}{E_1 \times E_2 - E_{12}^2} \]

The test of significance then involves comparing

\[ F = (\sqrt{L-1})(1/e/t) \]

with the F distribution on 2t and 2(e-1) degrees of freedom, where t is the degrees of freedom for the treatment component. For the maize variety effect

\[ T_1 = 17.52 \quad T_2 = 0.4094 \quad T_{12} = -2.632 \]
\[ E_1 = 15.90 \quad E_2 = 0.5993 \quad E_{12} = -1.414 \]

\[ (33.42)(1.0087) - (-4.046)^2 \]
\[ (15.90)(0.5993) - (-1.414)^2 \]

F = 11.90 on 4 and 90 df and is very clearly significant.

The results of the various bivariate F tests are seen in Table 1 for the maize/cowpea data. Perhaps even more than univariate F ratios, such F statistics should be interpreted only as general indications of overall changes in variation pattern. It is still true, as in univariate F tests, that the overall F test may not reach significance while particular treatment comparisons are significant. In addition, because the bivariate F test summarizes variation over all treatment levels for both variables, the scope for particular comparisons to be significant while the overall statistic is not, is greater.

Nonetheless the analysis produces a fairly clear picture, supplemented by the plots in Figs 2 through 4. The effects of maize varieties and nitrogen levels are large (much greater than the 0.1 percent level) and the pattern of response of the two crops is shown in Figs 2 and 3. There is a clear suggestion that the pattern of nitrogen is modified by an interaction with cowpea varieties (interaction significant at 5 percent on F on 6 and 90 DF).

Indices
Indices are used in many forms of data summary to combine information. If we wish to compare systems of cropping involving two or more measurements then we must either accept that the systems are not comparable because they differ in several aspects, or convert yields onto a single scale. Consider, for example, mean yields for four treatments in a maize/cowpea experiment.
Treatments 1 and 2 involve both crops; the other two treatments are for sole maize and sole cowpea. In any assessment of the overall performance of treatments 1 and 2 we have to balance the lower maize yield and higher cowpea yield of 1 against the higher maize yield and lower cowpea yield of 2. It is simply not possible to say in any absolute terms that 2 is better than 1 because such a judgement would imply some limit on the relative values of maize and cowpea.

The same problem occurs if we compare intercrop treatments with sole crops. The comparison of 2 with 3 is clear in that 2 must be preferred to 3 since it provides more yield for both crops. However, even in this case the question of how much better 2 is than 3 does not have a simple answer. The comparison of 2 with 4 is, once again, a question of balancing gains against losses.

Those arguments lead naturally to the conclusion that only comparisons involving simultaneous consideration of both crop yields are valid in that they retain all the available information. However, practical considerations require that conclusions are sometimes based on a single value for each treatment. The gain from being able to make quantitative comparisons of treatments simply on a single scale will often outweigh the loss of information. Further, different indices lose different components of information and it must therefore be expected that if several indices are used, contradictory conclusions will result. Experimenters, and even statisticians, sometimes express surprise that two different indices appear to lead to different comparative conclusions; such a reaction merely means that they have not realized that they are expecting the impossible.

### Simple Value Indices

Simple indices involve the allocation of a value to each crop and the subsequent calculation of a total value from the sum of the values for the separate crops. If the values of two crops are assessed as $K_1$ and $K_2$, then the total value of an intercrop treatment producing mean yields $Y_1$ and $Y_2$ is

$$V = K_1Y_1 + K_2Y_2$$

The most frequently used value index is that of financial return. Other value indices include protein and dry matter. The main criticism made specifically of financial indices is that prices fluctuate and hence the ratio of $K_1$ to $K_2$ may vary considerably. A partial answer to this criticism is to employ several price ratios.

### Index of Biological Advantage

The most important index of biological advantage is the relative yield total (RYT) introduced by de Wit and van den Bergh (1965), or land equivalent ratio (LER) reviewed by Willey (1979). The index is based on relating the yield of each crop in an intercrop treatment mixture to the yield of that crop grown as a sole crop. If the two crop yields in the intercrop mixture are $M_A$, $M_B$, and the yields of the crops grown as sole crops are $S_A$, $S_B$, then the combined index is

$$L = \frac{M_A}{S_A} + \frac{M_B}{S_B}$$

The interpretation embodied in LER is that $L$ represents the land required for sole crops to produce the yields achieved in the intercropping mixture. A value of $L$ greater than 1 indicates an overall biological advantage of intercropping. The two components of the total index, $L_A$ and $L_B$, represent the efficiency of yield production of each crop when grown in a mixture, relative to sole crop performance.

### Comparison and Analysis of LER Values

The assessment of advantage of a single intercrop combination requires careful thought. When it is desired to compare different intercrop treatments using LER values, the need to calculate the LER to produce meaningful comparisons is accentuated. There are now two problems.

The first is the choice of divisor, and I believe that comparisons of LER values are valid in their practical interpretation only if the divisors are constant for all the values to be compared. If different divisors are used for different intercrop treatments then the quantities being compared may be considered as

\[ \frac{M_{A1}}{S_{A1}} + \cdots \cdots + \frac{M_{A2}}{S_{A2}} \]

\[ \frac{M_{B1}}{S_{B1}} + \cdots \cdots + \frac{M_{B2}}{S_{B2}} \]

The interpretation of any difference between $L_1$ and $L_2$ cannot be assumed to be the advantage of intercropping treatment 1 compared with intercropping treatment 2, since the difference could equally well be caused by differences between sole cropping treatments $S_{B1}$ and $S_{B2}$ or between $S_{A1}$ and $S_{A2}$.

Although LER values using different divisors are often compared, the concept that is being used as the basis for comparison is the value one of efficiency which is not interpretable in any practically measurable form of yield difference.
between different intercropping treatments. We should recognize that such comparisons are of a theoretical nature only and are not practically useful.

The form of the LER, which is the sum of two ratios of yield measurements, has prompted concern about the possibility of using analysis of variance methods for LER values. More generally the question of the precision and predictability of LER values has been felt by some to be a problem.

The comparison of LER values within an analysis of variance is, I believe, usually valid provided that a single set of divisors is used over the entire set of intercropping plot values. Some statistical investigations of the distributional properties of LERs were made by Oyejola and Mead (1981) and Oyejola (1983). They considered various methods of choice of divisors including the use of different divisors for observations in different blocks. Allowing divisors to vary between blocks provided no advantage in precision or in the normal distributional assumptions: variation of divisors between treatments was clearly disadvantageous. The recommendation arising from these studies is therefore that analysis of LER values is generally appropriate, provided that constant divisors are used, and with the usual caveat that the assumptions for the analysis of variance for any data should always be checked by examination of the data before, during and after the analysis.

The question of precision of LERs and, by implication, their predictability, is an unnecessarily confusing one. If LERs are being compared within experiments the standard errors of comparison of mean LERs are appropriate for comparing the effects of different treatments. Experiments are inherently about comparisons of the treatments included rather than about predictions of performance of a single treatment. The precision of a single LER value must take into account the variability of the divisors used in calculating the LER value. However, a more appropriate question concerns the variation to be expected over changing environments and this must be assessed by observation over changing environments. No single experiment can provide direct information about the variability of results over conditions outside the scope of the experiment. This, of course, does not imply that single experiments have no value since we may reasonably expect that the precision of estimation of treatment differences will be informative for the prediction of the differential effects of treatments.

**Extensions of LER**

In the last section it was mentioned that there were two problems in making comparisons of LER values for different intercropping treatments. The second problem is that the concept of the LER as a measure of advantage of intercropping assumes that the relative yields of the two crops are those that are required. The calculation of the land required to achieve, with sole crops, the crop yields obtained from intercropping makes this assumed idea of the actual intercropping yields clear. However, with two (or more) intercropping treatments the relative yield performance \( L_A : L_B \) will inevitably vary and hence the comparison of LER values for two different treatments can be argued to require that two different assumptions about the ideal proportion \( L_A : L_B \) shall be simultaneously true.

This difficulty led to the proposed "effective LER" of Mead and Willey (1980) which allows modification of the LER to provide the assessment of advantage of each intercropping treatment at any required ratio (i.e. \( \lambda = L_A / (L_A + L_B) \)). The principle is that to modify the achieved proportions of yield from the two crops we consider a "dilution" of intercropping by sole cropping. The achieved proportion of crop A could be increased by using the intercropping treatment on part of the land and sole crop A on the remainder, the land proportions being chosen so as to achieve the required yield proportions. Details of the calculations are given in Mead and Willey (1980). It is important if the use of a modification of the LER is proposed that the reason for using the effective LER is clearly understood. It is not primarily a form of practical adjustment but arises from the philosophical basis of the LER.

It may be that in using the LER as a basis for comparison of different treatments the emphasis is not on the biological advantage of intercropping but on the combination of yields onto a single scale, in terms of yield potential. In this view the LER becomes another form of value index, the two values being the reciprocals of the sole crop yields. When a range of price ratio indices is used, it is almost invariably found that the ratio of the LER values is well in the center of the price ratio range. The principle of the argument for using an effective LER is no longer essential but there may still be advantages in making practical comparisons of treatments in terms of performance at a particular value of \( \lambda \). There are, however, other possible ways of modifying the LER as a value index, not arising from the philosophy of the LER, and the most important of these is the calculation of combined yield performance to achieve a required level of crop yield \( A \).

Arguments for, and details of, this alternative modified LER are given by Reddy and Chetty (1984) and Oyejola (1983).
References


Table 1. Bivariate Analysis of Variance for Maize/Cowpea Yield Data (0.001 kg ha⁻¹) in an Intercrop Trial.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Maize SS (X₁)</th>
<th>Cowpea SS (X₂)</th>
<th>SS for (X₁ + X₂)</th>
<th>Sum of products</th>
<th>F</th>
<th>Correlation</th>
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<td>-0.058</td>
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<tr>
<td>M variety</td>
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<td>17.52</td>
<td>0.4094</td>
<td>12.665</td>
<td>-2.632</td>
<td>11.90</td>
<td>-0.98</td>
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<tr>
<td>C variety</td>
<td>1</td>
<td>0.03</td>
<td>0.0060</td>
<td>0.062</td>
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<tr>
<td>Nitrogen</td>
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<td>28.50</td>
<td>0.1131</td>
<td>25.081</td>
<td>-1.766</td>
<td>10.59</td>
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<tr>
<td>M x C</td>
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<td>1.11</td>
<td>0.0099</td>
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<td>-0.099</td>
<td>0.62</td>
<td>-0.95</td>
</tr>
<tr>
<td>M x N</td>
<td>6</td>
<td>1.25</td>
<td>0.0676</td>
<td>0.920</td>
<td>-0.199</td>
<td>0.64</td>
<td>0.93</td>
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<tr>
<td>C x N</td>
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<tr>
<td>M x C x N</td>
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<td>1.28</td>
<td>0.1354</td>
<td>1.349</td>
<td>-0.033</td>
<td>1.40</td>
<td>-0.08</td>
</tr>
<tr>
<td>Error (MS)</td>
<td>46</td>
<td>15.90</td>
<td>0.5993</td>
<td>13.671</td>
<td>-1.414</td>
<td>-0.46</td>
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<tr>
<td>Total</td>
<td>71</td>
<td>(0.346)</td>
<td>(0.0130)</td>
<td>(0.031)</td>
<td>-6.318</td>
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Figure 1. Different correlation patterns for yields with the same values of the individual crop yields: (a) negative correlation, (b) positive correlation, (c) no correlation. The two axes are for the yields of the two crops. Two intercrop systems give yields represented by △ and □.

Figure 2. Bivariate plot of pairs of mean yields for three maize varieties (1, 2, 3). Maize and cowpea yields are in kilograms per hectare.
Figure 3. Bivariate plot of pairs of mean yields for four nitrogen levels (0, 40, 80, and 120 kg/ha). Maize and cowpea yields are in kilograms per hectare.

Figure 4. Bivariate plot of pairs of mean yields for two cowpea varieties: A (▲) and B (○) for four nitrogen levels (0, 40, 80, and 120 kg/ha). Maize and cowpea yields are in kilograms per hectare.
Introduction

In Malawi, most on-farm intercropping field trials are aimed at giving a “bonus” crop (in this case a legume) to the farmer on the same piece of land that he grows his main food crop -- maize. This “bonus” may be in terms of money from sales of the legume or in terms of satisfying the dietary needs of the household.

In more detail, the trials attempt to:

i) Find a legume that intercrops “best” with maize. “Best” is interpreted as that legume that does not adversely affect the yield of maize.

ii) Determine appropriate plant spatial arrangements, time of planting, fertilizer inputs etc., once the “best” legume has been identified.

This paper presents an overview of the statistical methods used to analyze data from on-farm intercropping trials in Malawi.

Mode of Statistical Analysis

The statistical analysis of on-farm intercropping trials, like the statistical analysis of any other field trial, will depend on the following:

i) the statistical design used in carrying out the field trial.

ii) the basic research issues/objectives the field trial is addressing. These can include economic use of both land and labour resources, maximizing yield per unit area of land, food security, satisfying dietary needs, etc.

iii) the available analytical tools and expertise.

When it comes to the statistical analysis of on-farm intercropping trials in Malawi the lack of computing facilities has constrained analysis and, to some extent, so has the lack of expertise to handle data from intercropping trials. Data from intercropping trials have been analyzed just on a per crop per site basis; i.e. the yields from the different crops have been analyzed separately. Such an analysis fails to show the intercropping effects unless at some later stage in the analysis the two yields are in some manner to be compared to each other. Furthermore, in most cases the F-tests of these separate single site analyses are very insensitive because the degrees of freedom for error are usually less than 12.

As an example, consider the following on-farm researcher-managed experiment with the objective of finding out a legume that “best” intercrops with maize. The statistical design was a Randomized Complete Block Design in three blocks. The treatments were as follows:

- $T_1$: Maize (MH15) intercropped with Groundnuts (Chalomba)
- $T_2$: Maize intercropped with Soybeans (Hardee)
- $T_3$: Maize intercropped with Phaseolus beans (253/1 or “Nasaka”)
- $T_4$: Maize intercropped with Ground beans (“Mbawa”)
- $T_5$: Sole crop of Maize
- $T_6$: Sole crop of Groundnuts
- $T_7$: Sole crop of Phaseolus beans
- $T_8$: Sole crop of Ground beans
- $T_9$: Sole crop of Soybeans

All legumes were planted at the same time and on the same ridge with maize i.e. between maize stations. Maize received the recommended rate of fertilizer (92 kg ha$^{-1}$ of N and 40kg ha$^{-1}$ P$_2$O$_5$) but no fertilizers were given to the legumes. Gross plot size was four ridges, 90 cm apart and 6 meters long. Net plot size was two middle ridges, 5.7 meters long.

Data on stand per plot at harvest and yield per hectare are presented in Table 1.

With the per crop per site statistical analysis, the legumes are omitted from the analysis; each one of them has six plots out of 27 plots with 2 degrees of freedom for Error; i.e.

<table>
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<th>Error</th>
<th>Total</th>
</tr>
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<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Concentrating on maize the ANOVA Table is as in Table 2.

As already pointed out, the analysis above is not very informative. The F-test shows that the difference between the treatments is statistically not significant at the 10% level of significance. The farmer may therefore opt for any one of the legumes without adversely affecting the maize yields (Table 3). But then the pertinent question to ask, and answer, here is why include the sole crops for legumes? What purpose do they serve in this experiment? How does one relate legume yields to maize yields?

As an improvement on the analysis in Table 2, the idea of using Land Equivalent Ratios (LER’s) was suggested.

Table 4 gives the LER’s for the data in our example.

I am using the convention that any sole crop has a LER of unity.
The LER helps us to answer the question: to what extent can more crop be obtained from a piece of land by intercropping and not what is the best legume for intercropping with maize. So here one cannot state convincingly that the Phaseolus bean is the best legume to intercrop with maize just because it has the highest LER. Thus information in Table 4 cannot help to answer the objective of this experiment.

Furthermore, being a ratio any yield in the intercrops associated with high yields in the sole crops are bound to give small or smaller LER values. Therefore it is important to ask when planning an experiment whether LER is going to be useful and thus whether plots to calculate LER are necessary.

One might ask, why not subject the LER values per plot to traditional ANOVA techniques? There have been difficulties here because of uncertainties about the distributional attributes of the LER values and so we cannot guarantee that the assumptions underlying the applications of ANOVA techniques are not violated. However it appears that LERs can be used in an ANOVA provided that a single set of divisors is used over the entire set of intercropping plot values (see the paper on statistical analysis by Mead, this volume).

Another alternative method tried for analyzing on-farm intercropping trials is the bivariate method. The only criticism against this method is that it is very difficult to state unequivocally that a particular method is best for handling data from on-farm intercropping trials, simply because the best method(s) will depend on the objective of the field trial. In addition to this, there is need to improve upon the way on-farm (and on-station) intercropping trials are run in Malawi. Some suggestions are:

i) Plant populations in intercrops should be the same as in sole crops because any real treatment differences observed should not be confounded with differences in plant populations.

ii) There is a need to fully understand the farmers' current practice and objectives for intercropping.

iii) The question of appropriate plot sizes for such trials remains to be resolved.

iv) The role of sole crops has to be spelled out.

But at the end of the day the real question should be: Why reduce a bivariate/multivariate situation to a univariate one? That is what the various methods proposed aim to achieve.

Conclusion

This paper has given an overview of the methods we have explored in Malawi in handling on-farm intercropping trials. The debate still continues on what is the best approach. At the moment an economic analysis approach is the most popular one. The traditional per crop approach is also popular.

It is very difficult to state unequivocally that a particular method is best for handling data from on-farm intercropping trials, simply because the best method(s) will depend on the objective of the field trial. In addition to this, there is need to improve upon the way on-farm (and on-station) intercropping trials are run in Malawi. Some suggestions are:

References


<table>
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<tr>
<th>Block 1</th>
<th>Treatment</th>
<th>Stand per plot at harvest</th>
<th>Yield (kg ha⁻¹)*</th>
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<td>5494</td>
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<td>97</td>
</tr>
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<td>6271</td>
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<table>
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* 1. Maize yields at 12.5%MC
2. Legumes' yields are shelled yields.
Table 2. Analysis of variance for maize yields.

<table>
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<tr>
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Grand Mean = 6076  
Coefficient of variation = 14.94%

Treatment means (maize yields)

\[
\begin{align*}
T_1 &= 5807 \\
T_2 &= 6123 \\
T_3 &= 6473 \pm 524.0 \\
T_4 &= 5788 \\
T_5 &= 6182 \\
\end{align*}
\]

Table 3. Mean yields (kg Ha\(^{-1}\)).

<table>
<thead>
<tr>
<th></th>
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<th>Legume</th>
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<tbody>
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Table 4. Land equivalent ratios.

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<td>1.05</td>
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<td>1.55</td>
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<td>T_4</td>
<td>0.94</td>
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<tr>
<td>T_9</td>
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Note that the potential yield (in sole crop) for:  
MH15 = 8000 Kg Ha\(^{-1}\)  
Chalimbana = 1400 Kg Ha\(^{-1}\)  
Hardee = 2000 Kg Ha\(^{-1}\)  
P. Beans (Nzasika) = 2500 Kg Ha\(^{-1}\)  
Ground beans = 1200 Kg Ha\(^{-1}\)  
All as shelled weights.
Agronomic Interpretation of On-Farm Intercropping Trials

J.K. Ransom, Agronomist, CIMMYT Maize Program, P.O. Box 25171, Nairobi, Kenya

Introduction

On-farm research can play an important role in the overall research process. Problem identification can be effectively accomplished through on-farm diagnostic techniques. On-farm experimentation can assist the researcher in prioritizing and determining the causes of perceived farmer problems. It can also be used to determine the optimal economic level of an input such as fertilizer, for a well defined socio-agro-ecological zone. Moreover, on-farm research is a way of verifying the stability and acceptability of a given technology, within a given environment.

Correctly interpreting the results of an experiment is one of the final steps in the research process. Interpretation is the process whereby the results are described and clarified so that others who are exposed to them will understand their meaning and sense their importance and application. Statistical and economic analysis are used in the interpretation of on-farm experimental results. For methods used in the economic evaluation of results from intercropping trials see Anandajayasekeram, Low and Durr (this volume).

There are several items that are essential to an effective interpretation of on-farm experimental data. A trial must be well designed and the data must be reliable. A good understanding of the management of the trial is also important. Often unusual results can only be explained by non-experimental factors (i.e. drought, erosion, damage by animals, etc.) that can only be noted when the researcher is well informed on the management of the trial and the climatic conditions that prevailed. A good comprehension of the principles of physiology and ecology of the crops, and how they may be influenced by the treatments in the trial is also helpful. Finally, in order to be able to infer from the results and relate these to the problems of the farmers, a thorough understanding of the farmers' circumstances (both social and physical) and the farmer's objectives is needed. This information is best obtained through effective interaction with farmers.

Rather than going into great detail on the theory of data interpretation, this paper reviews the concepts used in the interpretation of trial results by going through an example of the analysis and interpretation of an on-farm maize/bean trial. The procedures of analysis presented here are easy to understand and yet provide adequate information to effectively interpret the results. Certainly other methods of statistical analysis can be used in the analysis of intercropping experiments. The principles of data interpretation will no doubt apply regardless of the method used as long as the techniques are appropriate and well understood.

Discussion

Data from a simple intercropping trial is used to illustrate the steps proposed in evaluating such trials. The objective of this trial was to determine the effect of spatial arrangement on the productivity of an intercrop. The trial consisted of three intercropped treatments (maize in rows, beans in alternate rows; maize in rows, beans in the same row but between maize hills; and maize in rows, beans in the same hills as maize) in addition to the two sole crop treatments. The design was a RCB with three replications. The ANOVA tables are not included in this paper. However, the F-tests for the treatment effects for all ANOVAs were significant at the 5% level. The complete data set is included as Appendix 1.

The following steps in data analysis are useful in providing information to effectively interpret the results of an experiment.

Step 1. Perform an ANOVA for the yield of each species.

This allows one to look at the yield of each species in each treatment separately as well as compare the intercropped yield of that species with its sole crop yield (sole crops are not always included nor should they necessarily be included in all experiments). It also allows one to examine any apparent interactions between species, though these interactions are not quantified. Table 1 gives the mean yield values for maize and beans analysed separately.

Though this analysis, as mentioned previously, does not allow one to quantify any of the interactions between the species grown in the intercrop, it does allow one to look at the effect of the treatment on each component of the intercrop. This information is usually obscured by the analysis using combined values such as LER and monetary units. The following information about the component crop reaction to the treatments can be noted. Bean yield was more affected by intercropping than maize yield, though the yields of both crops were significantly reduced by intercropping. Beans yielded best when the spatial arrangement placed them away from the maize. Furthermore, spatial arrangement had little effect on the maize yield.

Step 2. Convert the output of each crop into monetary units, sum over all crops, and perform an ANOVA.
The monetary value of each crop is obtained by multiplying the yield by the market price of that crop. The monetary units for each component crop in each treatment are then summed. In this example, maize was valued at 2 shillings per kilo and beans at 4 shillings per kilo. After summing over species an ANOVA can be performed. Table 2 contains the means from the analysis of the combined monetary units of maize and beans.

Based on the monetary value of the treatments, the maize/bean intercrops out-performed the sole crops of either maize or beans. Among the intercropped treatments, alternate rows and same row arrangements were similar, however alternate rows produced significantly more monetary units than did the same hill treatment. Differences among these intercropped treatments can largely be explained by the differences in bean yield since maize yield was only slightly affected by spatial arrangement, as illustrated by the analysis summarized in Table 1. Finally, it can also be noted that maize out-performed beans in terms of monetary units, given the maize/bean price ratio used.

**Step 3. If the market values of the crops within the intercropping system vary greatly during the season, evaluate the treatment effects in the experiment over a range of market price rates.**

Since the market value of farm produce is often erratic, the stability of a treatment over a range of price ratios can be evaluated by weighting the value of one component relative to the other(s). In the case of maize and beans one could look at the treatment effects when the bean price is doubled and the maize price is constant or vice versa. This would allow one to identify treatments that will become important if the pricing structure changes drastically. It should be mentioned here that if the price of each component increases or decreases proportionally, the ANOVA will not be affected (i.e., if both maize and bean prices increase by 50%, the mean values in the analysis will increase, but the F ratios and the number of declared significant differences will not change). Table 3 gives monetary values for each treatment at various maize/bean price ratios.

At the 1 to 1 price ratio, the output of the maize sole crop was similar to the output of the intercropped treatments. The maize/beans alternate rows and the maize/beans in the same row were similar in output and were superior to the maize/beans same hill treatment. At the 1 to 4 price ratio, the sole crop bean treatment out-performed all other treatments. Furthermore, intercropping was superior to growing maize alone. At this price ratio the M/B alternate row was significantly better than the other intercropped treatments but not better than bean sole crop. Nevertheless, the relative ranking of the intercropped treatments was similar for all M/B monetary units over a wide range of market conditions.

**Summary of the Trial Results**

The results of the trial presented in this paper indicate that for this environment intercropping maize and beans is as or more productive than growing maize and beans alone except when the market value of beans is extremely high relative to the market value of maize (4 to 1 or greater). At all price ratios, maize/bean grown in alternate rows and the maize/bean grown in the same row were superior to the maize/bean same hill treatment. At the 4 to 1 bean/maize ratio, the maize/bean alternate rows out-performed all other intercropped treatments. Differences between intercropped treatments were largely due to differences in bean yield, as the maize yield did not differ greatly regardless of spatial arrangement. As the distance between the maize and bean decreased, the bean yield decreased, undoubtedly due to an increase in competition for light, nutrients and moisture, by the larger more vigorous maize plant.

**Conclusion**

The interpretation of the results of the trial data presented in this paper was straightforward for the most part because the trial was simple and the data fairly predictable. More difficult designs and erratic results require the researcher to draw on information other than just the treatment means, however. Knowledge of trial management, the climate, and past experience with similar factors is helpful. The interpretation of the results from on-farm research will be easier if the following points are considered in the research process:

1. Keep the trials as simple as possible.
2- Carefully select the factors and treatment levels that are included in a trial.

3- Non-experimental variables should be carefully chosen based on the objectives of the experiment.

4- Have a thorough understanding of the actual trial management.

5- Choose a method of analysis that is simple to understand and will provide you with the information needed to effectively describe your data.

6- Research experience makes the process easier. Reviewing research already done by others facilitates the understanding of the treatment effects under consideration and helps you in the description of the results.

Appendix 1

The complete data set for all variables included in the analysis of a maize/bean intercrop experiment.

<table>
<thead>
<tr>
<th>Rep</th>
<th>Treatment</th>
<th>Maize Kg ha⁻¹</th>
<th>Bean Kg ha⁻¹</th>
<th>1 to 1 (K Shillings ha⁻¹)</th>
<th>1 to 2 (K Shillings ha⁻¹)</th>
<th>1 to 4 (K Shillings ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2790</td>
<td>390</td>
<td>3180</td>
<td>3570</td>
<td>4350</td>
</tr>
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<td>2800</td>
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<td>3170</td>
<td>3540</td>
<td>4290</td>
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<td>250</td>
<td>2960</td>
<td>3210</td>
<td>3700</td>
</tr>
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<td>1</td>
<td>4</td>
<td>3100</td>
<td>-</td>
<td>3100</td>
<td>3100</td>
<td>3100</td>
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<td>5</td>
<td>-</td>
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<td>1170</td>
<td>1170</td>
<td>4680</td>
</tr>
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<td>2590</td>
<td>290</td>
<td>2880</td>
<td>3170</td>
<td>3750</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
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<td>2690</td>
<td>2900</td>
<td>3320</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
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<td>170</td>
<td>2670</td>
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<tr>
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<td>5</td>
<td>-</td>
<td>1080</td>
<td>1080</td>
<td>2160</td>
<td>4320</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2690</td>
<td>340</td>
<td>3030</td>
<td>3450</td>
<td>4050</td>
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<td>2</td>
<td>2640</td>
<td>290</td>
<td>2930</td>
<td>3220</td>
<td>3800</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2605</td>
<td>210</td>
<td>2815</td>
<td>3025</td>
<td>3445</td>
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<td>4</td>
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<td>2915</td>
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</tr>
<tr>
<td>3</td>
<td>5</td>
<td>-</td>
<td>1125</td>
<td>1125</td>
<td>2250</td>
<td>4500</td>
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<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maize and Beans in separate rows</td>
</tr>
<tr>
<td>2</td>
<td>Maize and Beans, same row</td>
</tr>
<tr>
<td>3</td>
<td>Maize and Beans, same hill</td>
</tr>
<tr>
<td>4</td>
<td>Maize sole crop</td>
</tr>
<tr>
<td>5</td>
<td>Beans sole crop</td>
</tr>
</tbody>
</table>
**Table 1. The effect of spatial arrangement of a maize/bean intercrop on the yield of maize and beans.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Maize Yield (kg ha⁻¹)</th>
<th>Bean Yield (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/B alternate rows</td>
<td>2690</td>
<td>340</td>
</tr>
<tr>
<td>M/B same row</td>
<td>2640</td>
<td>290</td>
</tr>
<tr>
<td>M/B same hill</td>
<td>2605</td>
<td>210</td>
</tr>
<tr>
<td>Maize sole crop</td>
<td>2915</td>
<td>-</td>
</tr>
<tr>
<td>Beans sole crop</td>
<td>-</td>
<td>1125</td>
</tr>
<tr>
<td><strong>LSD 0.05</strong></td>
<td><strong>83</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

**Table 2. Total monetary value of a maize/bean intercrop as affected by spatial arrangement.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total monetary value (shillings ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/B alternate rows</td>
<td>3383</td>
</tr>
<tr>
<td>M/B same row</td>
<td>3220</td>
</tr>
<tr>
<td>M/B same hill</td>
<td>3081</td>
</tr>
<tr>
<td>Maize sole crop</td>
<td>2915</td>
</tr>
<tr>
<td>Beans sole crop</td>
<td>2250</td>
</tr>
<tr>
<td><strong>LSD 0.05</strong></td>
<td><strong>182</strong></td>
</tr>
</tbody>
</table>

**Table 3. The effects of several maize/bean price ratios and planting methods on the total monetary value of a maize bean intercrop.***

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1 to 1</th>
<th>Maize/bean price ratio (shillings ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 to 2</td>
<td>1 to 4</td>
</tr>
<tr>
<td>M/B alternate rows</td>
<td>3030</td>
<td>3383</td>
</tr>
<tr>
<td></td>
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<td>4050</td>
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<td>M/B same row</td>
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<td></td>
<td>3800</td>
</tr>
<tr>
<td>M/B same hill</td>
<td>2815</td>
<td>3081</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3445</td>
</tr>
<tr>
<td>Maize sole crop</td>
<td>2915</td>
<td>2915</td>
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<tr>
<td></td>
<td></td>
<td>2915</td>
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<td>Beans sole crop</td>
<td>1125</td>
<td>2250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4500</td>
</tr>
<tr>
<td><strong>LSD 0.05</strong></td>
<td><strong>134</strong></td>
<td><strong>182</strong></td>
</tr>
</tbody>
</table>

*Base maize price is 2 shillings kg⁻¹.
Economic Evaluation and Interpretation of Intercropping Trials

P. Anandajayasekeram, Regional Economist, CIMMYT, Nairobi, A. Low, Regional Economist, CIMMYT, Harare, and G. Durr, Project Coordinator, Fertilizer Use Recommendation Project, Kenya

Introduction

Most of the agricultural production from the small farmers in Africa and throughout the tropics is heavily dependent on traditional farming systems where intercropping and multiple cropping are the order of the day. Complex systems involving annual-annual (cereal-cereal, cereal-legume, cereal-tubers, legume-tubers), annual-perennial (coffee-banana, sugarcane-potato) and perennial-perennial (coffee-banana, coconut-pasture) are combined in a single field. Recognizing the importance of multiple cropping and intercropping production systems in the tropics, considerable research efforts are being directed towards developing technologies to improve the productivity of such systems. Though more than one product is produced from the same unit of land, in terms of evaluating intercropping experiments, traditionally each product in the mix is treated separately and the statistical analyses are performed independently. Recently researchers have started using bivariate analysis (Huxley et al, no date; Ezumah et al. 1987) which recognizes that there is an underlying relationship between the yields of the two component crops and makes allowances for this when comparing pairs of yields for different treatments. Biologists have also often used criteria such as the Land Equivalent Ratio (LER), Area Time Equivalent Ratio (ATER) (Hiebsch and McCollum, 1987) and Comparative Ratio (Willey and Rao, 1980) in assessing the relative efficiency of the intercropping system over sole cropping systems. In the recent past some researchers have extended their analysis beyond this to look at the economics of intercropping technologies by using net benefit as the criterion for selection (Joseph, 1987; Davis and Smithson, 1986) and some have even attempted to use returns to resources as criteria in evaluation (Lightfoot et al, 1987). However, if the objective of the intercropping experimentation is to make recommendations to farmers then the trial should be evaluated in the manner a farmer would use the information to make the decision. The criteria and comparisons used in the assessment need to be consistent with those of the target group of farmers, to whom the recommendation is to be made. In this paper we first consider three types of economic comparisons that may be relevant in intercropping trials. We then discuss some key considerations in conducting meaningful economic analyses of trials. The paper ends with a worked example which emphasizes the importance of using the appropriate output value in assessing economic returns.

Use of Economic Comparisons in Intercropping Trials

Researchers only need to be concerned about economic analysis of trials if they wish to go beyond testing the technical aspects of the technology in trials. That is, if they also wish to check whether these technical responses are likely to be sufficiently attractive for farmers to accept and use the tested technology.

Economic analysis can guide decisions on recommendations as well as guide the selection of treatments and levels in early stages of experimentation.

Essentially, economic analysis involves making comparisons between gains and losses incurred in changing from one situation to another. If gains (increased output or reduced cost) outweigh losses (extra costs or reduced output), the change is judged worthwhile.

Comparisons of gains and losses can be made in different ways according to what elements are changing. We can consider three situations in which the relevant gain/loss comparison is different and each of these situations may be relevant in intercropping trials.

a) Comparison of output gains, caused by incremental changes in the levels of a key input, with the extra cost of each unit of input.

In an intercropping situation we would be concerned to value the combined output gains (from all the crops in the intercrop) and compare that with the cost of an extra unit of the key input. An example would be the examination of the economics of increased fertilizer use in fixed intercrop combinations (as in the worked example given later).

b) Comparison of different combinations of intercrops given a fixed level of inputs.

Here the relevant comparison would be the output gained from increasing Crop A with the output lost by decreasing Crop B. In some cases there may be extra cash or gains related to changes in input associated with increasing the relative proportion of one crop.

An example would be the evaluation of an alternative maize/beans intercrop spatial arrangement whereby the bean population is doubled by placing plants between, as well as at, each maize station.

c) Comparison of different combinations of inputs for a given level of output.

This introduces the possibility of factor substitution. For example a legume intercrop may allow the maintenance of soil fertility and output with lower cash requirements for inorganic fertilizer, but with higher labour demands.
The economics of this type of factor substitution will depend very much on the relative value of the input being substituted. Thus the value of the inputs saved will be compared with the value of the extra inputs required. Since outputs will seldom be completely unchanged, these gains or losses will generally also need to be considered.

Comparison types a) and b) will be relevant where the objective of the trial is to make modifications to existing intercrop situations. Comparison type c) will generally be relevant where a pure crop is being compared with an intercrop.

The point is that the relative comparison of gains and losses will depend on the nature and objective of the trial. It is important for the researcher to be aware of the type of economic comparison to be made so that relevant data can be collected in the course of the trial.

Performing Meaningful Economic Analyses

In order to make sure that the economic evaluation of the treatment or trial is meaningful it is important to pay attention to a number of considerations.

Treatment selection
Unless a completely new crop is being introduced into a system, farmers already employ a set of production techniques and any technology to be introduced implies them changing from their current practice to the new ones. Thus, to evaluate the new technology, we must know how it performs relative to the farmer’s current technology. The implication is that one of the levels of any experimental variable/treatment should represent the farmer’s current practice if an economic analysis is to be meaningful.

Representativeness of the sites
It is important to make sure that the experiments were planted at locations that are representative of farmers’ conditions. Sites that are representative of the target farms, but exhibit differences in response should be considered for combining into sub-groups. Combining into sub-groups should be based on clearly defined criteria.

- Significant and large site x treatment interaction in the ANOVA should be the major basis for considering re-grouping
- Heterogeneity in error variance between sites should not dictate recombination (account can be taken of heterogeneity by adjusting degrees of freedom)
- Sites should only be re-grouped on the basis of large treatment x site interactions if explanatory factors can be found that explain the differences in response at the different sites and if these factors can be used as predictors of sub-groups.

Levels of non-experimental variables
The non-experimental variables should be set at the current farmer levels, so that the response of the treatment reflects the response that farmers can expect if they make the change to the new technology. Under all circumstances, if non-experimental variables are managed by the farmers then the non-experimental variables at each location/site should be carefully monitored and recorded to make sure that they are representative.

Valuing inputs and outputs
It is important to make sure that:

- All sources of benefits (direct and indirect) and costs (explicit and implicit) to farmers are included into the analysis
- The realism of costs, prices and yields are as important as the type of analysis chosen.

The real costs of inputs and outputs to a farmer will usually differ from market prices. A typical limitation of many economic analyses is that they use market prices and not the actual price received by the farmers. Similarly, the yield that benefits the farmer is frequently less than the reported yield by the researcher depending on the location of the trial, complexity of the trial, type of management, etc. The net effect of these biases is to overestimate the gross benefit and underestimate the variable cost. Therefore it is important to make sure that proper coefficients are used in the calculations.

Selection of response means to be included in the analysis
The results of the statistical analysis dictates the way budgets are constructed and the actual yield figures used in the analysis. It is only necessary to perform a full economic analysis if the response means of the treatments are significantly different from one another. If the means are not significantly different, the cheaper of the two treatments would be the most economical and it is only necessary to consider the difference in costs between treatments.

In factorial trials, economic analysis is based on factors and not on individual treatments. Based on the results of the statistical analysis, and the observed interactions, budgets are constructed for possible combinations. If there are no interactions then factors are looked at individually. The economic optimum is determined independently and the yields are pooled across the other factors to obtain the mean yield for that treatment. If there are no significant differences in yield for the treatments then the least cost level of the factor should be chosen.
In intercropping trials another question arises as to whether to look at the responses to the individual crops or to the overall weighted value of the crops combined, reflecting farmers aims and objectives. It makes sense in most cases to look at the response to the weighted combined value of the output. This implies that the statistical analysis should be performed on this combined value. There are several advantages of using the combined value product:

- it is common to all products and it is possible to aggregate the different crop outputs
- quality differences can be taken into account
- it is easy to measure once the yields and prices are known
- it provides a means to compare different intercropping systems
- the researcher can evaluate different alternatives on the same basis as the farmers. The farmer is usually comfortable with valuing outputs in monetary terms.

However, it should be kept in mind that when the relative prices of the product mix changes, then there is a need to repeat the ANOVA using the new prices. Changes in the relative weights may change the results of the analysis. This is a potential danger in using the monetary value in statistical analysis.

Additional consideration:
Farmers will seldom be interested only in average returns. It is a known fact that farmers attempt to protect themselves against the risks of loss of benefit and often tend to avoid choices which would increase the element of risk, even though these choices may on the average yield them positive benefits. Yield stability is much more critical for many smallholder farmers. This aspect also should be considered in performing economic analysis before a recommendation is made. If the technology is profitable and does not increase the risk substantially, then its suitability to the production system should be assessed in terms of:

- objectives and preferences of the farmers
- resource availability and use pattern
- institutional and infrastructural capabilities and
- social acceptability

**Interpretation of economic analysis results**
Partial budgets are most commonly used to compare gains and losses between one treatment and another. The rates of return (to cash or labour) estimated from partial budgets reflect the return to the extra amount or value of resources used by treatment B over treatment A. It is not meaningful to calculate the rate of return to individual treatments using a partial budget. The output of partial budget analysis should never be interpreted as returns to a resource in any single treatment.

**Intercrop Trial Analysis - An Example from Kenya**
The results of a maize-bean intercropping trial carried out in central Kenya are given in Tables 1 and 2.

The experiment also included pure beans and pure maize. Since the farmers are already intercropping in the study area, except for calculating LER the pure crop response is redundant. Thus for our purposes we consider the intercropped plots only.

**Economic Interpretation of the Results**
An ANOVA was carried out on the combined value of maize and beans. At market prices the ANOVA on the combined value of maize and beans output gave a significant P response only. Therefore the economic analysis should focus on this factor alone.

The economic question then reduces to:

"Given the response what is the most economic level of P?", or

"On the basis of these results, what level of P can be recommended?"

To answer either of these questions, a key consideration will be related to the farmers’ intercropping practices and objectives. If farmers are not already intercropping and intercropping is therefore an option that may or may not be taken up, attention would need to focus on whether economic returns to P are acceptable in both the intercrop and pure crop situations and, if so, the most appropriate level in each. Since farmers are already intercropping in this case we can restrict the analysis to the intercropping situation only. The economic information required to perform the analysis is given in Appendix 1.

**The Most Economic Level of P in the Intercrop**
In this situation the most economic level of P will depend on farmers’ objectives for growing each of the intercrops and the critical resource constraint.
The value the farmer places on the output will depend on whether the crop is grown for the market or for own consumption. When there are two or more crops, these values influence the relative weighting given to yield responses from a particular treatment. Where crop responses are different (this will generally be the case), the appropriate weighting of these responses becomes important in interpreting the results from the farmers perspective. One could visualize five possible scenarios.

a) Both maize and beans are grown for the market only

b) maize for consumption and beans for market

c) Beans for consumption and maize for market

d) Both maize and beans are grown for consumption only

e) Maize and beans are grown both for consumption and market, i.e., a proportion is consumed and the rest sold.

In our analysis we will consider the first four of these. However, if the different proportions (consumption vs sale) are known, then the same approach could be used to evaluate the fifth option.

Farmers' resource constraints will also have a bearing on the value of responses and the actual criteria used in the evaluation and interpretation. If a critical resource is in short supply, (it may be cash, labour, draught power) it will be the returns to that resource (and not others) that will determine whether the treatment is attractive to the farmer or not. In this particular case, since the purchase of fertilizer involves cash and cash is in short supply, the rate of returns is calculated for cash.

In Table 3 the marginal returns for cash from the partial budget are summarized for different assumptions about the values of each crop. The minimum acceptable rate of return per unit of cash invested for the farmer is considered to be 50%.

Given that there are significant differences between the mean values of output at each level of P, the results from this table can be interpreted as follows.

1. Both maize and beans are sold:

   If maize and beans are destined for the market, then it is not economical to apply any fertilizer. It is worth noting when one moves from 0 kg to 25 kg of P, the rate of return is 17% and this increases to 56% when one moves from 25 kg ha\(^{-1}\) to 50 kg ha\(^{-1}\). Under these circumstances one should calculate the rate of return for moving from 0 P to 50 kg of P. The rate of return for cash for moving from 0 to 50 P is 36% which is less than the minimum acceptable rate for the farmers in the study area. Therefore, though the P response is significant, it is not economical to apply P when both maize and beans are destined for the market.

2. Maize is consumed and beans sold:

   The results indicate that if the maize is grown for consumption and beans are grown for the market then it is economical to use 75 kg of P. However the rate of return per unit of money used in P fertilizer is maximized at 50 kg P, and if cash is in extremely short supply (i.e. minimum acceptable rate of return is 400 - 500%), then 50 kg P would be the appropriate recommendation.

3. Beans for consumption and maize for market:

   If beans are grown for consumption and maize is grown for market, the economic use of P on the intercrop is very marginal. The MRR for 0 P to 50 P is 49% whereas the minimum acceptable rate is 50%. If the farmer has ready access to cash, then one could encourage the farmer to use fertilizers.

4. Both maize and beans are grown for home consumption:

   If both beans and maize are grown for home consumption and thus have a higher value to the farmer than the market price, the higher level of 75 kg ha\(^{-1}\) of P would be attractive.

These results, which suggest higher economic rates of P if maize is used for own consumption, rest on the higher value of maize in home consumption than in the market. Such results need to be interpreted carefully. Where cash availability depends on marketing the major crop (maize), such a result is clearly not very helpful. But if other cash sources exist, the results imply an economic advantage in using this cash to purchase fertilizer and reduce maize food purchases, but a much lower economic advantage in using cash to purchase fertilizer to enable higher maize sales.

The main objective of this example is to illustrate the importance of using realistic values since conclusions can be misleading if inappropriate values are applied to outputs as well as inputs.

Sensitivity Analysis

Where it is unclear what values (for inputs or outputs) should be used, a sensitivity analysis using different possible values can be useful for deciding how important it is to
establish relevant values. For example, if the conclusions in Table 3 had not changed whatever objectives were assumed, a recommendation could be made regardless of farmers' marketing strategy. In this example the economics of fertilizer use is sensitive to marketing strategy and we need to take account of this in planning further research or making a recommendation.

Conclusion

Economic analysis of intercropping trials is no different in principle to the analysis of pure crop trials. However intercropping analyses can be somewhat more complex and their interpretation less straightforward.

It becomes even more important to keep in mind that the analytical comparison being made is between what farmers are currently doing and how they may change and do things differently. Thus a comparison between pure and intercrop performance is relevant ONLY where one of the change options being examined is from pure to intercropping or vice-versa. Often in adaptive on-farm research, this will not be the case, and the relevant analysis then is related to options for improving the performance of the intercrop.

In analyzing options to improve intercrop performance, it becomes important to be clear about farmer objectives and values vis-a-vis the two or more intercrops (as our analysis example indicates). Clearly these types of consideration should be an integral part of trial planning. The objective of the trial and selected treatments should reflect current practice and farmer objectives as well as potential improvement options. If trials have been appropriately designed, economic analysis becomes more straightforward. Relevant comparisons for the economic analysis should be determined at the outset so that all necessary data for both economic and agronomic assessments can be obtained. Thus if an intercrop is included only for consumption (e.g. cowpea leaves), information on how farmers value the output from this crop is essential for a realistic economic analysis.

In addition, a common basis should be selected for aggregating the outputs and this aggregated value of the combined output should be used in statistical evaluation. It is important to keep in mind that any variations in price ratio could alter the results of the statistical analysis.

It is important to include the economic perspective at the outset in the planning and design of on-farm intercropping trials. Merely tagging an economic analysis at the end of a trial report will generally involve making a host of assumptions (explicit and implicit) about farmer values and objectives and will only be as useful as the assumptions are accurate.

References


Appendix 1

Experimental Data On Fertilizer Response of Maize-Beans Interplanted.

The experimental data are part of a comprehensive fertilizer experiment which is currently being established in Kenya. The experiment is located in central Kenya, in a relatively dry area. The data refer to the 1987 long rain cropping season. Planting was done about April. It should be noted that the season was particularly dry and therefore yield levels were low and are possibly inconsistent with fertilizer application rates.

Economic Information is as follows:

- Selling Price of Maize: 2.00- per kg
- Selling Price of Beans: 5.00- per kg
- Transport cost (Maize & Beans): 0.10- per kg
- Harvesting and shelling: 10.00- per quintal
- Cost of Fertilizer: 12.00- per kg N
- (Including Transport Cost): 13.00- per kg P
- Labour Requirement per Application: 3 mandays per ha
- Wage Rate: 25.00- per day

All P applied at planting time
All N top-dressed as single application

Yield Adjustment: 10%

Table 1. Maize-Bean Intercrop -- Maize Yield (Qu ha⁻¹).

<table>
<thead>
<tr>
<th>N Level (kg ha⁻¹)</th>
<th>0</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.10</td>
<td>6.60</td>
<td>6.20</td>
<td>13.55</td>
<td>7.13</td>
</tr>
<tr>
<td>25</td>
<td>4.00</td>
<td>4.20</td>
<td>10.45</td>
<td>8.70</td>
<td>6.84</td>
</tr>
<tr>
<td>50</td>
<td>1.40</td>
<td>3.20</td>
<td>5.90</td>
<td>14.25</td>
<td>5.65</td>
</tr>
<tr>
<td>75</td>
<td>3.15</td>
<td>6.80</td>
<td>9.70</td>
<td>2.25</td>
<td>4.03</td>
</tr>
<tr>
<td>Mean</td>
<td>2.66</td>
<td>5.20</td>
<td>8.08</td>
<td>9.69</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Maize-Bean Intercrop - Bean Yield (Q/ha⁻¹).

<table>
<thead>
<tr>
<th>N Level (kg ha⁻¹)</th>
<th>P₂O₅ level (kg ha⁻¹)</th>
<th>0</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.25</td>
<td>0.50</td>
<td>0.20</td>
<td>0.50</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0.20</td>
<td>0.65</td>
<td>0.60</td>
<td>0.30</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.25</td>
<td>0.15</td>
<td>0.40</td>
<td>1.00</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>0.45</td>
<td>0.25</td>
<td>0.70</td>
<td>0.30</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.29</td>
<td>0.39</td>
<td>0.48</td>
<td>0.53</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Rate of return for cash for different levels of P with different objectives (MRR%).

<table>
<thead>
<tr>
<th>Objectives</th>
<th>P₀--P₂₅</th>
<th>Treatment</th>
<th>P₂₅--P₅₀</th>
<th>P₅₀--P₇₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean &amp; maize for market</td>
<td>17</td>
<td>56*</td>
<td></td>
<td>Dominated</td>
</tr>
<tr>
<td>Maize for consumption Bail for market</td>
<td>143*</td>
<td>199*</td>
<td></td>
<td>67*</td>
</tr>
<tr>
<td>Bean for consumption and maize for market</td>
<td>30</td>
<td>67*</td>
<td></td>
<td>Dominated</td>
</tr>
<tr>
<td>Bean &amp; maize for consumption</td>
<td>157*</td>
<td>211*</td>
<td></td>
<td>74*</td>
</tr>
</tbody>
</table>

*Acceptable treatments MRR > min acceptable rate of return
**MRR P₀--P₅₀ is 36%
***MRR for P₀--P₅₀ is 49%
**Malawi Experiences in Intercropping Research**

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### Introduction

Intercropping, including mixed, row or ridge, strip and relay intercropping, is the growing of two or more crops simultaneously on the same area of land (Andrews and Kassam 1975). Where intercropping is practiced, there is also a significant amount of between crop competition.

In Malawi, intercropping is a traditional popular farming system practiced by smallholder farmers as a strategy for increasing crop yields, crop diversity and the stability of crop production. It also serves to satisfy dietary requirements, spread labour peaks, or spread risks caused by weather, pest and disease attack or market fluctuations (Willey, 1979).

About 94 percent of the total cultivated land area in Malawi is under some form of intercropping. It is estimated that 94 percent of maize; 90 percent of groundnuts; 99 percent of pulses including beans (*Phaseolus vulgaris*); 89 percent of cassava; and 97 percent of sorghum and millets are grown in association with other crops (Table 1) (Anonymous 1970 and 1981). The predominant combination involves grain legumes such as beans, cowpeas, groundnuts, pigeon peas, or peas grown in association with cereal crops such as maize, sorghum and millets. Associations with maize are the most common (Table 2).

The intensity of farming in smallholder farmers generally increases as the farm size decreases. Since the average landholding in Malawi is 1.5 ha, this could be one reason why intercropping is widespread (Hansen 1981). More intercropping is practiced in the Southern Region of Malawi where the average farm size is just 0.5 ha.

Because farmers intercrop and there is much reported information supporting this practice, Malawi has placed considerable emphasis in recent years on intercropping agronomic research, to understand how yields in intercropping can be maximised.

This paper attempts to highlight intercropping experiences in Malawi with emphasis on cereals and legumes, especially maize and beans.

### Crops in Intercropping Systems in Malawi

Hansen (1981) in surveys in several areas covering all the three regions of the country observed several combinations of crops. Intercropping maize with other crops was found to be the most common in all the four areas surveyed.

The different combinations classified by major crop and geographic area are given below:

#### Maize Mixtures

**Phalombe:**
1. Maize, cowpeas
2. Maize, pigeon peas
3. Maize, sorghum
4. Maize, cowpeas and pigeon peas
5. Maize, cowpeas and chickpeas
6. Maize, groundnuts and pigeon peas
7. Maize, sunflower and grams
8. Maize, sunflower, cowpeas and velvet beans
9. Maize, pigeon peas, cowpeas, grams, sorghum and groundnuts
10. Maize, pigeon peas, grams, groundbeans and groundnuts

**Lilongwe:**
11. Maize, beans

**Chitipa:**
12. Maize, beans
13. Maize, groundnuts
14. Maize, cassava
15. Maize, groundnuts
16. Maize, beans and cowpeas
17. Maize, beans, groundnuts and groundbeans

**Tsangano:**
18. Maize, wheat

#### Sorghum Mixtures

**Phalombe:**
1. Sorghum, maize
2. Sorghum, sunflower
3. Sorghum, cassava and grams
4. Sorghum, cowpeas and pigeon peas.

**Chitipa:**
1. Millet, cassava
2. Millet, sorghum, sesame

#### Finger Millet Mixtures

**Chitipa:**
1. Millet, cassava
2. Millet, sorghum, sesame
3. Cassava, maize
4. Cassava, grams

#### Cassava Mixtures

**Phalombe:**
1. Cassava, grams
2. Cassava, velvet beans

**Chitipa:**
3. Cassava, maize
4. Cassava, grams

#### Groundnut Mixtures

**Lilongwe:**
1. Groundnut, cowpeas
2. Groundnut, maize

#### Tobacco Mixtures

**Phalombe:**
1. Tobacco, pigeon peas
2. Tobacco, grams
3. Tobacco, tomatoes
4. Tobacco, pumpkins and cucumbers.
Types of Intercropping Systems Practiced in Malawi

Mixed Intercropping
This is the growing of two or more crops on the same piece of land during one cropping season with no distinct row arrangement. This is not common in Malawi since most farmers plant their crops on ridges. However, there are some areas where mixed intercropping is practiced in dryland farming and in dimba (river valley) gardens. This system is practiced with crops which are planted by broadcasting such as upland rice, wheat, sorghum, and bulrush and finger millets mixed intercropped with other cereal crops, potatoes, vegetables and legume crops.

Row Intercropping
The growing of two or more crops on the same row or ridge. This is the commonest type of intercropping in Malawi where most crops, including maize, are planted on ridges. However some farmers plant their crops in rows on the flat. This is practiced in dimbas (river beds) and in the Shire Valley in Southern region.

In both the mixed intercropping and the row intercropping, there is substantial between crop competition for most of the growth cycle of one or both crops. This is because both crops may be planted at the same time on the same hill or one crop planted during the vegetative stage of another, e.g. maize and groundnuts and maize and beans.

Row intercropping is common on the Lilongwe Plain and areas with similar rainfall where the delay in planting the second crop will cause substantial reductions in seed yield primarily because of inadequate moisture for the crop to produce reasonable yields and also by shading from an associated maize crop. According to Johnson (1973), the rainfall which begins in Lilongwe district about November 25 and ends about March 19 is fairly low, only 830 mm, has a net season length of 118 days, 72% wet pentades and 80% reliability index. Areas with similar rainfall characteristics to Lilongwe and which have soils suitable for groundnut production should plant maize and groundnuts as an intercrop about the same time, but beans should be planted under maize no later than when maize is knee high (Edje, Mughogho and Rao, 1975). The maize in Table 3 was planted at the same time i.e. beginning of the rain. The beans in treatments 2 to 5 were planted at the same time as the maize while the beans in treatments 6 to 9 were planted when maize was knee high (45-50 cm) or 4 weeks after planting maize. Inter-planting maize with dwarf beans at the same time produced a seed yield of 760 kg/ha. However, a delay in undersowing maize with dwarf beans until the maize was knee high yielded only 220 kg/ha of beans (71% yield reduction).

Relay Cropping
Here a second crop is planted when the first crop has reached its reproductive stage but before it is ready for harvest (Andrews and Kassam, 1975). At times the second crop is planted when the first crop has reached physiological maturity, e.g. a maize relay crop planted with beans, peas, potatoes or wheat. Relay cropping is common in Thyolo, Mulanje and Chiradzulu in Southern region, Ncheleng and Dedza in Central region, and Rumphi in Northern region. Relay cropping is practiced:
1) in areas with average net season lengths of 140 days and over, a season reliability index over 75% and about 80% wet pentades.
2) in locations with bimodal rainfall, e.g. Karonga in Northern region which has in addition, 84% wet pentades, net season's length of 147 days and season's reliability index of 85% (Johnson, 1973), where there is adequate residual moisture for a reasonable yield from a relayed crop and
3) in places like Thyolo where the annual rainfall is about 1230 mm with about 109 mm falling in the dry season (May-October) as mist.

Spurling (1972) reported that it was possible to obtain a relay crop and a double crop of beans from Bvumbwe in Thyolo (Table 4).

Strip Cropping
The growing of two or more crops simultaneously in different strips, e.g. about four to five rows of say maize or sorghum with four or more rows of cotton, beans or groundnuts. The rows of the crops are wide enough to allow independent cultivation but narrow enough for the crops to interact agronomically. This cropping system, though not very common in Malawi, is practiced by some smallholder farmers in all the three regions of the country. Strip cropping systems are not confined to any location with a particular rainfall pattern.

Interculture
The growing of arable crops below perennial crops, e.g. growing pulses or cereals below coffee bushes before their canopies are closed up. Citrus crops are also intercultured with cereals or legumes. This system is practiced in all areas where perennial crops are grown in Malawi.

Advantages of Intercropping Systems in Malawi

Higher Yields (Seed and Monetary Value)
The main objective of crop production is to increase yield per unit of land and many experiments on mixed cropping have shown that one means of increasing crop yields is by intercropping rather than
monoculture, as shown in Table 5. Edje, Mugogho and Rao (1979) conducted intercropping trials with maize and beans over a three-year period. The advantages of intercropping are well illustrated in this experiment. By growing maize and beans in association, the farmer obtained a combined maize and bean yield of 11,540 kg/ha compared to monoculture maize yield of 10,523 kg/ha. If, however, the farmer had grown one half hectare to a pure stand of maize and the other half hectare to beans, he should have obtained only 6,671 kg/ha (1/2 of 10,523 + 1/2 of 2,818). Similarly the intercropping system produced 46.4% more gross revenue than the pure stand. It should be noted here that the bean yield was a bonus crop because no additional fertilizer was applied to the bean crop when sown under maize; nor was additional land used since both crops were planted on the same ridge. The land equivalent ratio was 1.24 indicating that 1.24 hectare of pure stand of both crops was needed to produce the same yield from one hectare of mixed stand. Similar results were obtained in unpublished work (Tables 6, 7 and 8).

Energy and protein yields
When a farmer practices intercropping, more energy and protein yields can be produced than in monoculture (Table 5).

Using conversion tables, 100 g of maize flour (ufa) with 60% starch extraction contains 354 calories while 100 g of beans contains 339 calories and 100 g of the edible portion of maize and beans contains 8.0 g and 24.0 g, respectively (Platt, 1962).

Using FAO estimates that 2,500 megacalories and 65 g protein is the daily requirement of a 55 kg active man, the maize and the bean mixture per hectare should provide enough energy for 44.7 men and enough protein to feed 42.7 men per year. However, if the farmer had practiced monocropping and planted a half hectare to each crop, he should have produced enough energy and protein to feed only 27.9 and 32.0 men, respectively.

Pest and disease control
Maize and cotton strip cropping in Malawi may reduce the incidence of Heliothis attack on cotton. The maize acted as a trap or diversionary crop. Several eggs were laid on the ear but only one larva survived, reducing the population of Heliothis. Interplanting cowpeas with maize and cowpeas impeded the movement of Ootheca spp. and caused them to be more aggregated than when they had a continuous pure crop of cowpeas. The dilution effect produced by crops in the mixture, especially where there are non-host plants reduces the colonization efficiency and subsequent population density. Some plants also produce chemical repellants.

Physical interference of non-host crops in a mixture have been reported to act as trap crops for fungal or bacterial spores. Rust of maize has also been reported to control the rust of Phaseolus beans. Despite these advantages, it has also been reported that both pests and disease situations are sometimes higher in mixed than in pure stands because of the denser microclimate in intercrops.

Stable yield and need for security
Farmers in Malawi practice intercropping as an insurance against insects, diseases, weather and price fluctuations, to ensure stable yields.

More efficient light utilization and weed control
The oversowing and overlapping of crops enables more efficient light utilization especially in a polyculture system of maize, climbing beans and pumpkin (Edje, et al 1980). The beans climbed on the maize stalk exposing the bean leaves to light without excessive shading while the pumpkin leaves growing prostrate on the ground helped to suppress weeds while at the same time intercepting solar radiation, especially during the early growth of the maize and bean crop when full canopy had not been developed.

Resource maximization
On a given area of land, mixed or intercropping maximizes the returns from the most limiting factors such as labour and fertilizer.

Wind and soil protection
Strip cropping is sometimes used to shelter crops from wind. Mixed cropping generally produces a field with a denser canopy, possibly for a longer time during the crop season than pure stand. Consequently, the soil is protected by layers of overlapping leaves which reduce the rainfall impact thereby lessening water and soil erosion.

Soil Fertility maintenance
Higher retention of soil fertility with nitrogen fixation by legumes, root excretions, micorrhiza effects, roots feeding at different levels and over different periods of time and adaptation of planting to changing soil conditions are all important factors in an intercropping soil management system. Malawian farmers therefore benefit from intercropping their maize fields with legumes.

Disadvantages of Intercropping in Malawi
Intercropping is not without problems in Malawi, and the main ones frequently mentioned include:

1. Difficulties in mechanization and thus it is hard to carry out on a large scale. However, in Malawi, with the average land holding size of 1.5 ha for smallholders, mechanization is not an issue.
2. Difficulties in using chemicals such as herbicides, fungicides and insecticides due to different reactions of the two species to the chemicals and because of physical obstruction. This is to some extent true for our farmers in Malawi.

Conclusion

The intercropping of maize and legumes in Malawi by smallholder farmers is a very common practice and therefore more systematic research is needed to better understand the system and provide farmers with the most efficient combinations. Nutrient recycling to address soil fertility decline due to continuous cropping of land to maize needs special attention through long term intercropping and rotation trials.

References

Andrews, D.J. and A.H. Kassam (1975). The importance of multiple cropping in increasing world food supplies. In: Multiple Cropping, Special publication No. 27. pp.41-50. American Society of Agronomy, Madison, WI, USA.


Johnson, D.J. (1973). Crop production in phase with the Climate (mimeo).


Table 1. Percentage of cultivated hectare grown In pure and mixed stand.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Pure stand</th>
<th>Mixed stand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>6.4</td>
<td>93.6</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>9.7</td>
<td>91.3</td>
</tr>
<tr>
<td>Pulses</td>
<td>1.0</td>
<td>99.0</td>
</tr>
<tr>
<td>Cassava</td>
<td>11.0</td>
<td>89.0</td>
</tr>
<tr>
<td>Millet and sorghum</td>
<td>2.9</td>
<td>97.1</td>
</tr>
<tr>
<td>Potato (European &amp; sweet)</td>
<td>5.1</td>
<td>94.9</td>
</tr>
<tr>
<td>Mean</td>
<td>6.0</td>
<td>94.0</td>
</tr>
</tbody>
</table>

Anonymous, 1970

Table 2. Crop combinations in mixtures in Malawi.

<table>
<thead>
<tr>
<th>Crops</th>
<th>With maize</th>
<th>With other crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundnuts</td>
<td>34</td>
<td>44</td>
</tr>
<tr>
<td>Pulses</td>
<td>77</td>
<td>45</td>
</tr>
<tr>
<td>Cassava</td>
<td>24</td>
<td>19</td>
</tr>
<tr>
<td>Millet and sorghum</td>
<td>43</td>
<td>33</td>
</tr>
<tr>
<td>Potato (European &amp; sweet)</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Mean</td>
<td>38.6</td>
<td>31.0</td>
</tr>
</tbody>
</table>

Anonymous, 1970
Table 3. Yield of maize and beans grown in pure and mixed stands.

<table>
<thead>
<tr>
<th>Treatment number</th>
<th>Treatments</th>
<th>Maize (kg/ha)</th>
<th>Bean (kg/ha)</th>
<th>Total (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pure stand of maize</td>
<td>10348</td>
<td>-</td>
<td>10348</td>
</tr>
<tr>
<td>2</td>
<td>Pure stand of dwarf beans</td>
<td>-</td>
<td>1673</td>
<td>1673</td>
</tr>
<tr>
<td>3</td>
<td>Pure stand of climbing beans</td>
<td>-</td>
<td>2620</td>
<td>2620</td>
</tr>
<tr>
<td>4</td>
<td>Maize and dwarf beans</td>
<td>9974</td>
<td>760</td>
<td>10734</td>
</tr>
<tr>
<td>5</td>
<td>Maize and climbing beans</td>
<td>10005</td>
<td>493</td>
<td>10498</td>
</tr>
<tr>
<td>6</td>
<td>Pure stand of dwarf beans</td>
<td>-</td>
<td>878</td>
<td>878</td>
</tr>
<tr>
<td>7</td>
<td>Pure stand of climbing beans</td>
<td>-</td>
<td>1965</td>
<td>1965</td>
</tr>
<tr>
<td>8</td>
<td>Maize and dwarf beans</td>
<td>10725</td>
<td>220</td>
<td>10945</td>
</tr>
<tr>
<td>9</td>
<td>Maize and climbing beans</td>
<td>10428</td>
<td>108</td>
<td>10536</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>10296</td>
<td>1090</td>
<td>6689</td>
</tr>
<tr>
<td><strong>S.E. ±</strong></td>
<td></td>
<td>179</td>
<td>57</td>
<td>330</td>
</tr>
</tbody>
</table>

Table 4. Yield of maize and beans as an intercrop, relay and double cropping.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yields (kg/ha) and season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize Nov.</td>
</tr>
<tr>
<td>Maize in November intercropped with beans in March</td>
<td>4407</td>
</tr>
<tr>
<td>Maize in November interplanted with beans in November, relay planted with beans in March.</td>
<td>4238</td>
</tr>
<tr>
<td>Beans monoculture in November replanted with beans in March</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5. Seed, revenue, energy and protein yields of maize and beans in pure and mixed stand.

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Maize (kg/ha)</th>
<th>Beans (kg/ha)</th>
<th>Total (kg/ha)</th>
<th>Money value (MK)</th>
<th>Energy (mega calories/ha)</th>
<th>Protein (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize (pure)</td>
<td>10523</td>
<td>-</td>
<td>10523</td>
<td>636.64</td>
<td>37251</td>
<td>-</td>
</tr>
<tr>
<td>Beans (pure)</td>
<td>-</td>
<td>2818</td>
<td>2818</td>
<td>371.98</td>
<td>-</td>
<td>9553</td>
</tr>
<tr>
<td>Maize and beans</td>
<td>10975</td>
<td>565</td>
<td>11540</td>
<td>738.56</td>
<td>38848</td>
<td>878</td>
</tr>
</tbody>
</table>
Table 6. Effect of bean planting pattern and population on yield of both local maize and beans in Ntcheu. (kg/ha), 1985/86.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Maize</th>
<th>Beans</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pure maize</td>
<td>1360</td>
<td>-</td>
<td>1360</td>
</tr>
<tr>
<td>2. Maize/beans same station</td>
<td>1390</td>
<td>280</td>
<td>1670</td>
</tr>
<tr>
<td>3. Maize/beans one station between maize</td>
<td>1330</td>
<td>470</td>
<td>1800</td>
</tr>
<tr>
<td>4. Maize/beans two stations between maize</td>
<td>720</td>
<td>360</td>
<td>1080</td>
</tr>
<tr>
<td>S.E. i.e.</td>
<td>138</td>
<td>155</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Seed yield and land equivalent ratio (LER) of maize/legume intercropping systems at Chitedze in 1985/86.

<table>
<thead>
<tr>
<th>Cropping System</th>
<th>Seed yield (kg/ha)</th>
<th>LER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Legume</td>
</tr>
<tr>
<td>Sole crop maize (UCA)</td>
<td>5764</td>
<td>-</td>
</tr>
<tr>
<td>Maize/groundnuts</td>
<td>7252</td>
<td>265</td>
</tr>
<tr>
<td>Maize/soybeans</td>
<td>6472</td>
<td>247</td>
</tr>
<tr>
<td>Maize/cowpeas</td>
<td>6901</td>
<td>298</td>
</tr>
<tr>
<td>Maize/groundbeans</td>
<td>6959</td>
<td>140</td>
</tr>
<tr>
<td>Sole-crop groundnuts</td>
<td>-</td>
<td>754</td>
</tr>
<tr>
<td>Sole-crop soyabeans</td>
<td>-</td>
<td>699</td>
</tr>
<tr>
<td>Sole-crop cowpeas</td>
<td>-</td>
<td>546</td>
</tr>
<tr>
<td>Sole-crop groundbeans</td>
<td>-</td>
<td>773</td>
</tr>
<tr>
<td>S.E. Mean</td>
<td>769</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 8. Seed yield (kg/ha) and land equivalent ratio (LER) of maize/legume intercropping systems at Chitedze in 1986/87.

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Seed yield (kg/ha)</th>
<th>LER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Legume</td>
</tr>
<tr>
<td>Sole Crop Maize (UCA)</td>
<td>6182</td>
<td>-</td>
</tr>
<tr>
<td>Maize/Groundnuts</td>
<td>5807</td>
<td>130</td>
</tr>
<tr>
<td>Maize/Soybeans</td>
<td>6128</td>
<td>715</td>
</tr>
<tr>
<td>Maize/Cowpeas</td>
<td>6319</td>
<td>-</td>
</tr>
<tr>
<td>Maize/Phaseolus Beans</td>
<td>6873</td>
<td>488</td>
</tr>
<tr>
<td>Sole-crop Groundnuts</td>
<td>-</td>
<td>975</td>
</tr>
<tr>
<td>Sole-crop Soyabeans</td>
<td>-</td>
<td>1657</td>
</tr>
<tr>
<td>Sole-crop Cowpeas</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sole-crop Groundbeans</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Sole-crop Phaseolus Beans</td>
<td>-</td>
<td>650</td>
</tr>
<tr>
<td>S.E. Mean</td>
<td>496</td>
<td>-</td>
</tr>
</tbody>
</table>
Cereal/Legume Intercropping Research in Kenya

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Introduction

Intercropping evolved in traditional agriculture as a strategy to diversify and increase food production. In Kenya, the number of farmers adopting the system has, for some reasons, increased steadily over the years. This has attracted many researchers, whose work has recorded some remarkable achievements towards improvement of the productivity of cereal/legume intercrops.

This paper presents some background information on the development of cereal/legume intercropping research in Kenya; the past achievements and constraints experienced and some suggestions for future directions of the research.

Background and Adoption of Cereal/Legume Intercropping

Leakey's description of the cropping system practised by the Kikuyu peasant and its rationale (Leakey, 1934) indicates that cereal/legume intercropping is an old practice in Kenya. Since Leakey's time the spread of cereal/legume intercropping to most arable parts of the country has been dictated by both agro-ecological and socio-economic factors. Various reasons have been given for the adoption of the system in Kenya (Mwania, 1987). These include:

a) Risk of crop loss caused by adverse conditions, such as frequent droughts, frost, hailstorms, diseases, insect pests and poor seed quality.
b) The need for different crops to provide a balanced diet and cash.
c) The need for crops with different maturity attributes to serve as stop-gap sources of food and income.
d) The desire to optimize the use of often scarce labour.
e) The need to optimize the use of a fixed land area in the face of increasing population pressure.
f) Introduction of crops by immigrating farmers to satisfy their eating habits and farming experiences.
g) Changed eating habits which altered peoples' attitudes towards certain crops.
h) The availability of ready markets for certain saleable crops encouraged farmers to grow those crops.
i) Farmers noticed that cereals and legumes exploit productive resources at different levels and that soil productivity could be better sustained in cereal/legume associations than with the sole-cropping of cereals.
j) Farmers were impressed by the high yields obtained from demonstrations on intercropping.

Justification of Intensified Research on Intercropping

Firstly, intercropping is a traditional cropping system developed by farmers out of necessity and long experience and cannot, therefore, be neglected by research. Cereal/legume intercropping provides the family with a range of caloric and protein sources as well as high value animal feeds. It is highly valued by farmers. For example, in government irrigation schemes intended to step up the production of special crops such as rice and cotton, new settlers allocate large portions of their farms to staple cereal/legume associations.

Secondly, the available land for producing food to feed a rapidly increasing human population is small and diminishing. Only about 18% of Kenya's total area is high potential arable land, the rest has marginal rainfall or is semi-arid. The country has little mineral wealth and the available land and current agricultural production cannot satisfy for long a population of 23 million people, growing at 3.8% per annum, and at the same time produce enough cash crops to generate much needed foreign exchange for national development (Anon, 1981, 1986). Much of the high potential land is occupied by cash crops, mainly coffee, tea and sugarcane and elsewhere by forests whose cultivation would only lead to environmental degradation. Already, indiscriminate encroachment and destruction of natural forests has prompted the government to initiate "Nyayo Tea Zones" to help protect the forest environment.

Livestock production requires part of the arable land for grazing or fodder production. Zero-grazing is not possible in the short-term because local animals are still highly prized and to some communities large cattle numbers are regarded as a status symbol.

Cereal/legume crop associations are known to improve soil fertility and have nutritional benefits to humans and livestock. By improving soil chemical and physical conditions through biological nitrogen fixation, leaf fall, mineral nutrient cycling and reduced run off and evapotranspiration, intercropping can raise the long term productivity of a farming system.

Intensifying research on cereal/legume intercropping would, therefore, be promoting regenerative or sustainable agriculture taking advantage of low-cost resources available on or near the farm and making more effective use of elements of production internal to the cropping system. The relevance and need for advancing regenerative agricultural technologies, otherwise termed as information-intensive as...
opposed to capital-intensive systems, for the developing world, is vividly discussed by Francis, et al (1986).

Cereal/Legume Intercropping Research in Kenya

Past Achievements and Constraints
Until the early 1970's, intercropping in Kenya was considered by most researchers and extension workers as a primitive and unproductive system suitable only for peasant farmers. As a result, past research work emphasized the improvement of individual crop species in order to produce cereal and legume varieties with high yield potential in monoculture-based cropping systems. Most of the varieties proved to be less than perfectly compatible when intercropped.

Systematic research on intercropping was initiated at the University of Nairobi in 1972 and was later extended to the regional research centers. In focus was mainly on maize/bean intercropping but subsequently work also included other intercrops, such as maize/cowpea, maize/pigeon pea, sorghum/pigeon pea and sugarcane/beans. Various experiments were conducted relating to spacings and planting patterns, variety evaluation, fertilizer and manure use and the economics of intercropping. These research efforts have recorded some remarkable achievements as well as uncovering constraints.

Nitrogen Fixation by Legumes
There has been substantial experimentation on rhizobia to investigate the efficiency of legume-nitrogen fixation (Keya, et al. 1982; M.O.A. 1982; Chui and Nadar, 1983.) This work has resulted in the mass production of Rhizobium inoculants which are currently on the market for use by farmers. However, the efficiency of legume-nitrogen fixation has been shown to be confounded with environmental factors and cropping systems (Chui and Nadar, 1983; Nadar, 1983a, 1983b, 1983c; and Nadar and Faught, 1983). Further research is, therefore, necessary to investigate these interactions under farm conditions before farmers can exploit fully the benefits of cereal/legume intercropping.

Maize/Bean Intercropping
The national maize and bean research programmes have produced several high yielding varieties suited to different agro-ecological conditions of the country (Rheenen, et al. 1984; Muthoka, et al. 1987). Research has shown that, with proper choice of maize and bean varieties and satisfactory management, beans constitute a bonus harvest, without significant reductions in maize yield, particularly in the high rainfall areas (Fisher and Hasselbach, 1979; M.O.A. 1982).

Intercropping maize with beans shows an advantage in land use over pure stands, with relative yield totals (RYTs) greater than unity provided planting time and patterns are appropriate (M.O.A., 1982; Nadar, 1983a). Under less-than-adequate rainfall conditions, yields of both maize and beans may be reduced but the RYTs still reflect an advantage for intercropping (Chui and Nadar, 1983; Nadar, 1983a; Nadar and Faught, 1983; Chui, 1987). Often, when maize is adversely affected by conditions such as drought, hailstorms, frost, poor germination or low soil fertility, beans exhibit a compensatory performance and may serve as an insurance crop (Fisher, 1976; and Mwania, 1987). Maize/bean intercropping is, thus, recommended in both high rainfall areas and where rainfall is not very predictable. Table 1 shows the yields of beans and maize in a relatively high potential rainfall area while Table 2 shows yields under unpredictable rainfall.

Recent on-farm research work, however, has revealed that some of the components of the technologies developed by research are not quite appropriate under farm conditions. Mwania (1982), Zoebi (1984), Mwania, et al. (1987) and Onyango, et al. (1987) observed that planting and weeding labour costs would be particularly constraining when certain planting patterns and fertilizer application methods are used. Maize varieties for the high rainfall zones produce a lot of foliage and compete strongly with the beans, reducing their yields by more than 50%. The need for certified bean seeds each year and routine spraying against diseases and insect pests for the current bean varieties constitutes a major cost to the farmer. The need to screen maize varieties for their suitability in intercropping has been recognized (Muthoka, et al. 1987) and so has that for beans (Rheenen, et al. 1981; Muigai and Rheenen, 1982; Stolzer and Omunyin, 1983). Further liaison is, therefore, required between breeders, agronomists, plant pathologists, agricultural engineers and socio-economists in order to produce varieties which combine high yield potential, intercrop compatibility and palatability; and also to develop suitable planting and weeding technologies for this intercropping system. Tables 3 and 4 show some economic aspects of maize/bean intercropping.

Maize/Cowpea and Maize/Pigeon pea Intercropping
The best potential for these intercrops is in the warm, medium and marginal rainfall areas and in the semi-arid, coastal and lowland zones. Breeding of cowpeas and pigeon peas, utilizing both local and introduced germplasm has led to the release of some drought resistant, early maturing and high yielding
Agronomic trials have indicated that under favorable rainfall conditions, intercropping maize with cowpeas or pigeon peas has a beneficial effect on yields and gross returns of both the associated and the subsequent maize crops (Nadar, 1983b, 1983c; Nadar and Faught, 1983; Chui, 1987). However, released improved varieties lack the desired disease and insect pest resistance, thereby, making farmers averse to their adoption. Moreover, adaptive trials and on-farm demonstrations have not been conducted extensively enough, mainly because cowpeas and pigeon peas are either not very popular as food or because their marketability is uncertain in many parts of the country.

**Sorghum, Millet or other Cereal/Legume Intercropping**

Sorghum and millet production have been declining mainly because of changing food preferences in favour of maize. However, they are still important in Western Kenya and the marginal and semi-arid rainfall areas. Past research has been directed at producing varieties which are drought resistant, high yielding, less-prone to bird damage, and with acceptable palatable grain types (Kermali et al., 1983). Efforts to develop suitable methods of processing and utilizing sorghum and millet products have been made; these have registered remarkable success. Little attention has, however, been paid to sorghum or millet/legume intercropping.

Information is available about research on minor intercrops involving maize, sorghum, millets, sugarcane or ley grasses with other legumes, such as groundnuts, soybeans or forage legumes, but this has not made much impact on the farming systems in Kenya either because the intercrop is scattered or the research inconclusive.

**Current and Future Research Approach**

A lot of data pertaining to intercropping has accumulated in research station annual reports but has not been translated into technology recommendations for use by farmers. This can be attributed to weakness in the research methods used. Due to a lack of recognition of the multiplicity of farmers' constraints, opportunities and goals, many researchers have tended to solve non-problems or have had objectives quite at variance with the farmers' circumstances, goals and priorities. This misdirection has resulted from the lack of interdisciplinary cooperation and lack of farmer participation in research. Furthermore, conventional experimental designs and statistical procedures often cannot be used to handle complex intercropping situations. Experimental variables in conventional approaches may not produce conclusive results. Ashby (1986) demonstrated vividly the importance of proper farmer participation and experiment planning in on-farm trials.

Considering the high cost and little benefit of haphazardly conceived intercropping trials, there will be need to equip the scientists with necessary skills in on-farm research. The on-the-job training should be intensified through short-courses, workshops, seminars and conferences on new methods and procedures in various scientific disciplines related to intercropping research. Also, collaboration is required between various institutions. Scientific disciplines could contribute to effective cereal/legume intercropping research in the future as follows:

a) **Agronomists**: Characterize and evaluate the intercropping systems practised in various AEZs; design alternative improved production technologies; also rationalize resource use relating to crop species/variety mix, crop nutrition and soil fertility management, land preparation, planting time and patterns, crop protection and mechanization, to reconcile national food policy and farm family goals. Cereal/ legume mixtures in agro-forestry or agro-livestock systems should also be considered.

b) **Breeders**: Design, develop and evaluate cereal and legume cultivars for compatibility in intercropping with respect to physical and physiological competition and pest aspects, while satisfying farmers' multiple preferences -- such as food, cash, animal feed or green manure -- rather than just high yield.

c) **Soil Scientists**: Evaluate the biochemical and physical relationships of the cereal/legume association and the soil, especially legume nitrogen fixation, so as to utilize nitrogen fixation to save on mineral fertilizer costs; or at least to sustain soil productivity.

d) **Plant Pathologists**: Determine disease and insect pest incidence and occurrence in various intercropping systems as a guide for development of resistant/tolerant varieties and also development of suitable integrated pest management programmes.

e) **Crop Physiologists**: Determine the anatomical and physiological basis of competition and yield of intercropped cereal and legume species -- as related to crop morphology, fertilizer use efficiency or efficiency of nitrogen fixation -- to be used as criteria for selecting suitable cultivars for intercropping.
f) **Agricultural Engineers:** Develop suitable, simple implements for planting, fertilizer application and weeding in cereal/legume intercrops, to allow farmers to attain desirable levels of agronomic management and reduce field operational labour costs.

g) **Biometricians:** Assist biological scientists in developing suitable field plot techniques and statistical designs for on-farm intercropping trials.

h) **Socio-economists:** Assist the technical scientists in determining socio-economic factors related to current farming systems; developing suitable criteria for evaluating cereal/legume intercrop associations and delineating recommendation domains in order to design experiments and generate innovations acceptable by the farmers.

i) **Food Technologists:** Assist breeders in identifying crop varieties which have high nutritional value, storability, taste and palatability, and also to develop suitable processing technologies which can enhance palatability and marketability of unpopular crops such as sorghum, millets, and pigeon peas, in order to promote their adoption.

National agricultural research in Kenya has been re-organized, with the creation and strengthening of national and regional research centers. This remarkable change is intended to ensure proper prioritization, coordination and continuity of on-going research. The regional research centers will cater for all adaptive research, based on agro-ecological zones and socio-economic conditions throughout the country. In the new structure more emphasis could be put on multiple cropping systems. All this will benefit the local farming community as well as increase overall national food production.

**References**


### Table 1. Yields and relative yield totals (RYT) of maize and beans in intercrop systems planted during 1975-76.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Maize Yields (t/ha) Pure</th>
<th>Maize Yields (t/ha) Mixed</th>
<th>Bean Yields (t/ha) Pure</th>
<th>Bean Yields (t/ha) Mixed</th>
<th>Relative Yield</th>
<th>RYT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>Kakamega</td>
<td>5.21</td>
<td>4.89</td>
<td>0.94</td>
<td>1.05</td>
<td>0.29</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Kisil</td>
<td>2.70</td>
<td>2.83</td>
<td>1.05</td>
<td>0.85</td>
<td>0.73</td>
<td>1.78</td>
</tr>
<tr>
<td>1976</td>
<td>Kakamega</td>
<td>6.21</td>
<td>7.05</td>
<td>1.14</td>
<td>0.45</td>
<td>0.23</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td>Kisil</td>
<td>10.04</td>
<td>9.86</td>
<td>0.98</td>
<td>0.82</td>
<td>0.30</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>Thika</td>
<td>7.63</td>
<td>6.74</td>
<td>0.88</td>
<td>2.45</td>
<td>0.43</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>Embu</td>
<td>5.16</td>
<td>4.85</td>
<td>0.94</td>
<td>1.39</td>
<td>0.20</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>Nyeri</td>
<td>6.33</td>
<td>6.37</td>
<td>1.01</td>
<td>0.38</td>
<td>0.24</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Source: Fisher and Hasselbach (1979)

### Table 2. Yields and land equivalent ratios (LERs) of maize and beans in the sole crop and intercrop systems planted during short rains 1980/81.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yields (10⁸ kg/ha) Maize</th>
<th>Yields (10⁸ kg/ha) Beans</th>
<th>Partial LERs Maize</th>
<th>Partial LERs Beans</th>
<th>Total LERs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole-crop maize</td>
<td>0.775</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Sole-crop beans</td>
<td>-</td>
<td>0.771</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Maize/beans intercrops</td>
<td>0.259</td>
<td>0.259</td>
<td>0.38</td>
<td>0.34</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Source: Nadar (1983a)
Table 3: Gross margins and land equivalent ratios (LER) analysis of maize and beans in sole crop and intercrop systems.

<table>
<thead>
<tr>
<th>Treatments*</th>
<th>Yields (kg/ha)</th>
<th>Labour cost (Ksh/ha)</th>
<th>Total costs (Ksh/ha)</th>
<th>** LER</th>
<th>*** GM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Beans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6750</td>
<td>-</td>
<td>1105</td>
<td>4257</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>1620</td>
<td>1885</td>
<td>5370</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>7200</td>
<td>900</td>
<td>2275</td>
<td>7339</td>
<td>1.62</td>
</tr>
<tr>
<td>4</td>
<td>7200</td>
<td>630</td>
<td>1664</td>
<td>6461</td>
<td>1.46</td>
</tr>
<tr>
<td>5</td>
<td>7200</td>
<td>540</td>
<td>1846</td>
<td>6495</td>
<td>1.40</td>
</tr>
</tbody>
</table>

* 1: Maize sole crop; 2: Bean sole crop; 3: Maize + bean (2 rows in between maize); 4: Maize + beans (same hole); 5: Maize + bean (separate holes, same row)

** LER = Land equivalent ratio, *** GM = Gross margin

Source: Mwanla (1982)

Table 4: Gross margin analysis of maize-bean intercrop research packages against farmers practice.

<table>
<thead>
<tr>
<th>Production technology</th>
<th>Yields (kg/ha)</th>
<th>Gross returns</th>
<th>Total variable costs (Ksh/ha)</th>
<th>Gross margins (Ksh/ha)</th>
<th>Invest. return per Ksh</th>
<th>Invest return per unit labour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research 1</td>
<td>5355</td>
<td>675</td>
<td>14335</td>
<td>6485</td>
<td>7850</td>
<td>1.21</td>
</tr>
<tr>
<td>Research 2</td>
<td>5468</td>
<td>603</td>
<td>14235</td>
<td>6110</td>
<td>8125</td>
<td>1.33</td>
</tr>
<tr>
<td>Farmers'</td>
<td>4455</td>
<td>450</td>
<td>11405</td>
<td>2970</td>
<td>8435</td>
<td>2.84</td>
</tr>
</tbody>
</table>

Introduction

Intercropping is a cropping system involving the growing of two or more crops on the same piece of land at the same time. This farming practice is a popular crop production system used in subsistence tropical agriculture and is very common in the semi-arid areas of Africa. In Ethiopia, intercropping is traditionally practised in many parts of the country. Different crops are grown in mixtures by small farmers to satisfy dietary needs, spread the period of peak demand for labour and minimize the risk associated with the weather.

The most important intercrop mixtures used by farmers in Ethiopia can be grouped into three broad categories:

1. Cereal-cereal association (wheat-barley, sorghum-millet, maize-sorghum, etc.)

2. Cereal-legume association (sorghum-beans, maize-beans, sorghum-chickpea, maize-groundnut, etc.)

3. Trees-annual crops (chat (Chata edulis)-sorghum, enset-legume, coffee-beans, etc.)

Legume-legume (e.g. faba bean and field pea) associations are also practised. The intercropping of a cereal with a legume, however, is the most common. Cereals are the major food sources in Ethiopia and farmers regard the cereal as the major component of an intercrop. Indeed, the traditional objective has been to produce a full yield of cereal (as much as with a sole crop) with the legume serving only to produce some additional yield. The most commonly grown cereal crops include: Teff (Eragrostis teff), sorghum (Sorghum bicolor), maize (Zea mays), barley (Hordeum vulgare) and wheat (Triticum aestivum) while the major pulse crops grown in Ethiopia are faba bean (Vicia faba), field pea (Pisum sativum), chickpea (Cicer arietinum), lentil (Lens esculenta) and common bean (Phaseolus vulgaris). The area under cultivation, elevation above sea level of the major cereal and pulse crops grown in Ethiopia is given in Table 1.

Various researchers have reported considerably higher yields resulting from intercropping compared to pure stand. Singh (1979) reported an 8-34% sorghum yield increase in a sorghum-legume intercropping system over sole crop sorghum. Osiru and Willey (1976) reported up to 25% higher yields of the mixture than could be achieved by growing the two crops (maize or beans) separately. Brhane (1976) enumerated some advantages of intercropping sorghum with maize, chat with beans and seed potato in the Chercher highlands of Eastern Ethiopia. Intercropping practices by small farmers reflect the traditional wisdom or rationality applied to their cropping decisions (Jadha, 1977).

In view of the benefits to be had from intercropping and the compatibility with farmer practice, several cereal-legume intercropping trials were conducted in selected areas of Ethiopia (Table 2) with the following objectives:

1. To identify cereal and legume crops which increase yield or give better total harvest when intercropping as opposed to pure stand.

2. To assess the advantages of cereal-legume intercropping in minimizing the incidence of crop failure and pest or disease infestations.

The intent of this paper is to assess that past and ongoing cereal/legume intercropping research work, identify research gaps and present future research priorities.

Research Highlights

On station cereal/legume intercropping research

Sorghum/legume intercropping

About 20% of total sorghum production in the country is from intercrops with legumes (Yilma, 1977). Some preliminary sorghum/legume intercropping trials were conducted at Kobo during the 1975/76 cropping season to identify the influence of growing legumes (mung bean, cowpea, pigeon pea, hyacinth beans and chickpea) in association with sorghum using several different planting methods and spacings. The results indicated that sorghum yield can be significantly increased by 26% by growing sorghum intercropped with mung bean. On the other hand, sorghum yields were significantly reduced when intercropped with hyacinth bean, cowpea, chick pea and pigeon pea (Table 3). The yields of all the legumes when intercropped were low. Only mung bean and cowpea gave reasonable yields. Unfortunately, there were no sole crop plots of the pulses to compare the effect of sorghum on their yields. The results clearly show that if sorghum is intercropped with mung bean not only is an extra yield of 235 kg/ha of mung bean achievable but also an extra yield of 495 kg/ha of sorghum. That association appears to be synergistic. Possibly the ability of mung bean to stimulate the germination of Striga reduced the parasitic load on the sorghum (Whiteman, 1977).

Some preliminary experiments were also conducted at Melkassa during the 1982/83 cropping seasons to study the influence of sorghum-cowpea, sorghum-haricot bean, and sorghum-mung bean associations on the seed yield of sorghum and pulses. The results indicated that sorghum could be intercropped with mung bean and haricot bean successfully resulting in about 70% and 45% seed yield increase respectively.
Sorghum-haricot bean intercropping

Sorghum and haricot bean are among the most important food crops grown at Melkassa in the lowlands of the rift valley. These two crops are traditionally grown as sole crops mostly on the same piece of land year after year. This practice results in low soil fertility and increased disease, pest and weed infestations. Thus crop yields are usually low and crop failures are encountered when there is moisture stress. In many parts of the semi-arid tropics small farmers traditionally practise intercropping as insurance against crop failure due to environmental stress, disease, pest problems and to utilize resources efficiently.

A sorghum-haricot bean intercropping trial was conducted at Melkassa to determine the optimum plant population densities of sorghum and haricot bean as well as the best intercropping patterns. A replacement series was used at a range of plant population densities (3 population levels for sorghum and 3 for haricot beans). The results of this experiment indicated that sowing two rows of sorghum with a row of haricot bean at a population density of 89,000 and 375,000 plants/ha was the best method of intercropping for Melkassa and similar areas. This intercropping system consistently showed land equivalent ratios (LER) greater than 1. 33-110% seed yield advantage was obtained from the intercropping system as compared to sole cropping. Similar results were reported by Mbowe (1984) in a sorghum, cowpea-green gram intercropping trial in Tanzania.

Almost all the beans produced in the Chercher highlands of eastern Ethiopia, where they form an important part of the diet, are grown in association with sorghum or maize. Therefore, intercropping trials involving various sorghum varieties adapted to high elevations and legumes were conducted at Alemaya. The results indicated that an intercrop of the late maturing variety Alemaya-70 and the haricot bean cultivar Ethiopia-10 gave a total yield of 5,800 kg/ha compared to 4,400 kg/ha for the pure stand of sorghum and 2,000 kg/ha for the highest yielding legume in pure stands. The highest yield was obtained when both sorghum and haricot bean were planted simultaneously early in the crop season. Thus the results pointed out that the best combination of intercropping at Alemaya appears to be the use of a late maturing sorghum variety and an early maturing legume both planted at the same time (Brhane, 1976).

A similar sorghum-bean intercropping trial was planted at Bako during the 1982-83 cropping season. The results showed that without affecting sorghum yield, extra yield of haricot bean could be obtained by intercropping with sorghum (Table 4). The land equivalent ratio indicated that intercropping at the end of May made better use of land (23-38% yield advantage) than early or delayed planting. Delaying the planting date of haricot bean beyond June 20 resulted in a 7-13% yield reduction in the intercrop combinations.

Maize-haricot bean intercropping

Maize-haricot bean intercropping is traditionally practised by few farmers in the Bako area. A maize-haricot bean intercropping trial was conducted at Bako during 1981/82 and 1982/83 cropping seasons. Maize was planted at a normal planting date while for haricot beans six different planting dates (starting from May 10 at 10 days intervals) were used. The intercropping pattern was the planting of haricot bean within the rows of maize at two seeds per hill to maintain a standard population. The results of this trial indicated that a reasonable grain yield of haricot bean could be obtained without substantial decrease in maize yield. This pointed out the possibility of increasing bean production at the farm level to satisfy the requirements of farmers for the production of pulses.

Intercropping of bush beans and maize is common in the high rainfall areas of Awassa, Southern Ethiopia. Therefore, relay cropping trials based on cereal/legume associations are also underway at Awassa Research Center.

Maize-soybean intercropping

Intercropping or mixed cropping of beans with maize is common in the lowland areas of the rift valley. Because of this a trial on intercropping soybean with maize was conducted at Awassa for three years. The treatments included two varieties of soybean, four different cropping patterns and pure stands of both soybean varieties and maize. The results of this trial revealed that paired rows of each crop on alternate positions was the best intercropping arrangement with a high total yield per unit area and an LER of 1.36 and 1.40 for soybean varieties Clark 63 K and Williams respectively. All the intercrop treatments gave higher total yield per unit area than sole cropping.
with LERs ranging from 1.2 to 1.4 (Table 5). Yields of maize were generally higher in the intercrop treatments than in the sole crop, while the reverse was true for soybeans. Disease and pest infestation were lower in the intercropped treatments than in the sole crop. In the intercrop treatments the composite crop was better able to suppress weeds than the sole crops of each species (Amare, 1987).

Another maize-soybean intercropping trial was conducted at Jimma in Western Ethiopia during the 1981/82 and 1982/83 cropping seasons. The trial consisted of pure stands of both maize and soybean, soybean intercropped between maize rows, soybean intercropped within maize rows and broadcasting soybean in maize rows. The results pointed out that higher grain yield of both maize and soybean crops could be obtained when grown in pure stands compared to intercrop yields. However, the estimated gross return of both crops in the mixture showed more benefit than sole crops. The highest gross return was obtained when soybean was intercropped within maize rows and this cropping pattern is recommended for the Jimma area.

**Alley cropping**

Alley cropping of woody species with herbaceous crops of various forms is widely practised by traditional farmers in the tropics (Kang et al., 1981). This old practice despite its potential is still a much neglected area of research and needs a lot of quantification to improve productivity. There is evidence to show that alley cropping can result in higher productivity, allow better control of the environment and can safeguard against unfavourable conditions.

In view of this, some preliminary studies were conducted to determine the adaptation of some selected legume trees and shrubs (Sesbania sesban, Leucaena leucocephala, Cajanus cajan) and their suitability for alley cropping with several food crops (sorghum, maize, haricot bean, wheat, teff and faba beans) under semi-arid conditions of Ethiopia at Melkassa, Sirinka and Kobo Research Centers during the 1986/87 cropping season.

Results indicated that in general there is a possibility of producing both crops without reduction in yield. At almost all testing sites the grain and stover yield of the food crops from alley cropping was equal to or better than the yield from pure stands (Tables 6 and 7). In addition, the legume trees, especially Sesbania sesban and Cajanus cajan produced substantial amounts of dry matter which can be used for animal feed, fuelwood or as a green manure or mulch to improve soil fertility (Table 8). Similar results were obtained with alley cropping pigeon pea and sorghum in Malawi (Edje, 1984). Although caution is needed in drawing conclusions from these preliminary studies, Sesbania sesban, Leucaena leucocephala and Cajanus cajan appear promising as alley crops for Kobo, Sirinka and Melkassa areas. The results further indicated the great potential of alley cropping these leguminous trees with almost all crops tested. Alley cropping also appears to be an attractive alternative to the traditional monocropping system in that it helps to integrate crop production with animal production.

**Crop protection in intercrops**

It is commonly stated that the incidence of pest and disease is lower in an intercrop than in a sole crop. One of the advantages of mixed cropping is the possibility that the resulting increase in complexity will provide a less favourable habitat for some of the major pests than when crops are grown separately.

Detailed work on cereal-legume intercropping in relation to pest control has not been carried out in Ethiopia so far. However, some preliminary trials on the possible use of trap crops in the integrated management of African Bollworm (ABW) were carried out during the 1981/82 to 1983/84 cropping seasons. Results indicated:

(a) where haricot beans were interplanted with maize (as a trap crop) for every larva found in haricot there were 18 on maize.

(b) when five trap crops (hyacinth bean, lupin, maize, pigeon pea and sunflower) were compared with haricot bean, all trap crops caught a significantly greater number of ABW than haricot bean. However, haricot bean plots interplanted with maize showed statistically lower percent pod damage than the rest of the treatments (Tsedeke, 1985).

At Kobo, another intercropping trial was conducted to determine the effect of planting of mung bean on the incidence of Striga and on sorghum yield. Results indicated that the number of Striga plants was significantly higher (by a factor of 2 - 3) when sorghum was grown alone compared to sorghum-mung bean intercropping (Table 9). However, although mung bean significantly reduced the incidence of Striga, it did not result in increased yield as it did in the previous wet season. The disadvantage of competition for limited moisture probably had a greater effect than the advantage of reduced Striga load. There was no effect of mung bean on either sorghum or Striga if it was planted before sorghum and removed, or planted at the same time as sorghum. But, sorghum yield was less when mung was planted earlier and left to mature. Mung bean reduced Striga infestation if allowed 1-3 weeks growth before removal as seedlings before sorghum was sown.
On-farm Cereal Legume Intercropping Research

Agricultural production in the Bako area takes place in a small mixed crop-livestock farming system. Cereals are the major food source. The major cereals are maize and "teff". The most common cropping system is monocropping and more than 85% of cereals are grown in pure stand.

The highland pulses, faha bean and field peas, are also grown in pure stand and very occasionally in mixtures. Haricot bean is produced in pure stand and under intercropping. Sole haricot bean is planted along fences and on the borders of maize fields. The fence and maize serve as supporting materials. Bushy types are grown in pure stand and in mixture with maize. When intercropped, beans are planted at random within maize fields. Resulting bean plant populations are very low because some plants are lost during maize weed management practices i.e. hoeing and 'shilshallo' (inter-row cultivation using oxen).

In Bako there is a shortage of draft power and labour during peak season. Thus, weeds and their management are priority constraints and largely limit expansion of crop production. The average land area cultivated per household is 1.5 ha. About 65% of the farmers do not have sufficient oxen. From June to August, various farm activities for different crops overlap and increases the competition for draft power and labour. Farmers give priority to cereals (especially maize and teff) in resource allocation during that period (Legesse et al 1987) and this reduces haricot bean production. Although, haricot beans are produced on farm, farmers have to buy extra pulses from the market. On station research results at Bako indicate that reasonable (economic) yield can be obtained from haricot beans intercropped in maize, without a substantial decrease in maize yield. These findings raised the possibility of increasing haricot bean production to make the farmers self-sufficient in pulse production (Legesse et al., 1982).

Considering the need for pulses for subsistence, resource limitations, and the on-station results, an on-farm experiment was initiated to find out the effect of intercropping haricot beans with maize under farmer management. The procedure used to develop and implement the on-farm maize/haricot beans intercropping experiment will now be discussed in brief. Highlights of experimental results will also be presented.

Methodology

In this experiment maize was considered the principal crop and the intercropping with haricot beans was designed not to affect maize management practices. Two factors, draft power and labour shortage, were assumed to limit the adoption of intercropping. An attempt was made to ensure that the resource requirement for maize-haricot bean intercropping would be within the limits on draft and labour. Since farmers give priority in the allocation of resources it was felt that if an improvement does not consider farmer priorities and objectives then they will not be willing to adopt the improvement. Thus the time of planting the beans was fixed to coincide with the second weeding of maize, which involves "Shilshallo" (inter-row cultivation using ox-plough). This saves on draft power and labour for land preparation by combining weeding and land preparation/planting.

In designing the experiment, diagnostic survey results were utilized and researchers made a preliminary selection of treatments. Farmers were asked to comment on the selected treatments. From these comments two treatments preferred by farmers were promoted to on-farm testing. These were: 1) maize/haricot beans - haricot beans planted within the maize row; 2) maize/haricot beans broadcast under row-planted maize. Sole maize was included as a control. For both intercropping treatments, haricot beans were planted at the time of maize inter-row cultivation (when maize was about knee-high).

Farmers to host the trial were selected based on the criteria set for defining the recommendation domain. All non-experimental variables were held at the farmers level (average farmers practice). The management and execution of the experiment was jointly done by researchers and farmers. Farmers implemented experimental variables under supervision from the researcher and the non-experimental variables on their own.

In evaluating the experiment, statistical and economic analyses were carried out. In addition, farmer assessment was solicited during the season. A short questionnaire was developed and questions were asked at several stages.

Highlights of results

Haricot bean broadcast under row-planted maize showed good yield response and gave the highest gross benefit (P<0.1). Maize/haricot beans - haricot beans planted within maize row was not significantly different from the control, perhaps because of inter-plant competition. This treatment needed 50 man-hours ha\(^{-1}\) for planting haricot beans as compared to 3 man-hours ha\(^{-1}\) required by treatment maize/haricot bean - haricot bean broadcast under row-planted maize.

Intercropping haricot bean through the broadcasting method gave a net benefit of 799 and 850 birr ha\(^{-1}\) at the Agricultural Marketing Corporation (AMC) and informal market prices, respectively. The marginal rate of return (MRR) as we change maize cropping system from sole to intercropping through...
broadcasting haricot beans under row planted maize were 313% at the AMC price and 323% at the market price and these rates are substantially higher than the acceptable minimum rate of return.

Farmers expressed interest in intercropping because of the additional haricot bean yield. They selected the treatment maize-haricot beans - haricot beans broadcast under row planted maize, because of its yield advantage and minimum labour requirement for intercropping the haricot beans.

Future Research Directions

1. In order to minimize the problem of environmental degradation due to ecological imbalance, some conservation oriented cropping system activities (alley cropping) will be given due emphasis in future research.

2. Research results from other countries indicate that mixed cropping can reduce pest incidence. Therefore, in order to develop successful cultural and biological practices, investigations on pest interaction and incidence in mixed cropping will be one of our research focuses.

3. In the past mixed cropping, the conventional practice used by smallholder farmers, was not included. Inclusion will be considered in future.

4. Most previous intercropping research activities were limited to cereals (sorghum and maize) and legumes (haricot bean and soya bean) and done in restricted areas. In the future, intercropping research using other crop species and covering wider agroecological zones of Ethiopia will be conducted.

5. In the past, intercropping trials were conducted by agronomists only. However, for proper planning, execution and assessment of intercropping studies, collaborative work by agronomists, crop physiologists, crop protection specialists and others is indispensable.

References


Table 1. Area under cultivation, yield, production and elevation for major crops (cereal and legumes) in Ethiopia.

<table>
<thead>
<tr>
<th>Crop species</th>
<th>Area ('000 ha) 1984/85</th>
<th>1985/86</th>
<th>Yield (kg ha⁻¹) 1984/85</th>
<th>1985/86</th>
<th>Production ('000 tons) 1984/85</th>
<th>1985/86</th>
<th>Elevation (m.a.s.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>774.0</td>
<td>872.5</td>
<td>1030</td>
<td>1000</td>
<td>797.9</td>
<td>869.6</td>
<td>(1800-3000)</td>
</tr>
<tr>
<td>Maize</td>
<td>992.2</td>
<td>840.5</td>
<td>1150</td>
<td>1200</td>
<td>1060.3</td>
<td>1009.5</td>
<td>(1500-2000)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>662.0</td>
<td>725.9</td>
<td>620</td>
<td>1080</td>
<td>385.2</td>
<td>782.5</td>
<td>(1500-2000)</td>
</tr>
<tr>
<td>Millet</td>
<td>167.6</td>
<td>152.6</td>
<td>710</td>
<td>800</td>
<td>119.5</td>
<td>122.0</td>
<td>(500-2000)</td>
</tr>
<tr>
<td>Teff</td>
<td>1253.6</td>
<td>1204.7</td>
<td>670</td>
<td>750</td>
<td>843.0</td>
<td>899.5</td>
<td>(100-2800)</td>
</tr>
<tr>
<td>Wheat</td>
<td>603.7</td>
<td>722</td>
<td>1040</td>
<td>1010</td>
<td>630.5</td>
<td>724.1</td>
<td>(1800-3000)</td>
</tr>
<tr>
<td>Pulses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickpea</td>
<td>157.3</td>
<td>109.9</td>
<td>500</td>
<td>690</td>
<td>79.3</td>
<td>75.4</td>
<td>(1400-2300)</td>
</tr>
<tr>
<td>Field pea</td>
<td>128.1</td>
<td>123.9</td>
<td>620</td>
<td>520</td>
<td>79.6</td>
<td>64.4</td>
<td>(1800-3800)</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>43.4</td>
<td>45.0</td>
<td>610</td>
<td>510</td>
<td>26.6</td>
<td>23.1</td>
<td>(1400-2000)</td>
</tr>
<tr>
<td>Faba bean</td>
<td>346.4</td>
<td>268.0</td>
<td>810</td>
<td>830</td>
<td>28.5</td>
<td>221.9</td>
<td>(1800-3800)</td>
</tr>
<tr>
<td>Lentil</td>
<td>32.6</td>
<td>39.9</td>
<td>550</td>
<td>550</td>
<td>15.0</td>
<td>21.9</td>
<td>(1400-2300)</td>
</tr>
</tbody>
</table>

Source: Ethiopian Statistical Abstracts - 1986

Table 2. Description of experimental sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation</th>
<th>Rainfall</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alemaya</td>
<td>9°26'N</td>
<td>43°03'E</td>
<td>2000 m</td>
<td>800 mm</td>
<td>Eastern Zone</td>
</tr>
<tr>
<td>Jimma</td>
<td>7°46'N</td>
<td>36°0'E</td>
<td>1750 m</td>
<td>1505 mm</td>
<td>Western Zone</td>
</tr>
<tr>
<td>Awassa</td>
<td>7°05'N</td>
<td>38°29'E</td>
<td>1700 m</td>
<td>1103 mm</td>
<td>Southern Zone</td>
</tr>
<tr>
<td>Bako</td>
<td>9°08'N</td>
<td>37°5'E</td>
<td>1610 m</td>
<td>1176 mm</td>
<td>Western Zone</td>
</tr>
<tr>
<td>Melkassa</td>
<td>8°24'N</td>
<td>39°21'E</td>
<td>1550 m</td>
<td>767 mm</td>
<td>Central Zone</td>
</tr>
<tr>
<td>Kobo</td>
<td>12°2'N</td>
<td>39°38'E</td>
<td>1470 m</td>
<td>610 mm</td>
<td>North Eastern Zone</td>
</tr>
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</table>
Table 3. Sorghum-pulses intercropping.

<table>
<thead>
<tr>
<th>Planting method</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure sorghum</td>
<td>18.87</td>
<td>23.96</td>
<td>15.90</td>
<td>19.12</td>
</tr>
<tr>
<td>+ chickpeas</td>
<td>13.53</td>
<td>19.02</td>
<td>14.34</td>
<td>15.53</td>
</tr>
<tr>
<td>+ mungbeans</td>
<td>27.25</td>
<td>24.95</td>
<td>20.00</td>
<td>24.07</td>
</tr>
<tr>
<td>+ pigeon pea</td>
<td>17.59</td>
<td>14.89</td>
<td>18.44</td>
<td>16.97</td>
</tr>
<tr>
<td>+ hyacinth bean</td>
<td>8.17</td>
<td>13.31</td>
<td>11.17</td>
<td>10.69</td>
</tr>
<tr>
<td>+ cowpea</td>
<td>9.00</td>
<td>12.48</td>
<td>10.69</td>
<td>10.73</td>
</tr>
</tbody>
</table>

Mean 15.57 18.10 15.07 16.25

5% LSD - between any two treatments = ±5.26 q
- between planting methods = ±2.15 q
- between intercropped sorghum mean = ±3.04 q
= ±4.06 q (P=0.01)
= ±5.34 q (P=0.001)

planting methods

- B = Broadcast and buried to leave 45 cm ridge and furrow

- C = Sorghum in alternate furrows, at 90 cm apart

- D = Sorghum in every third furrow, at 135 cm apart

Table 4. Mean grain yield in kg ha⁻¹ and land equivalent ratios from sorghum and haricot bean intercropping trial conducted at Bako, 1982-1984.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sorghum</th>
<th>Haricot bean</th>
<th>Total</th>
<th>3 years mean LER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum May 10-21</td>
<td>5800</td>
<td></td>
<td>5800</td>
<td>1</td>
</tr>
<tr>
<td>Haricot bean June 19-23</td>
<td></td>
<td></td>
<td>2300</td>
<td>1</td>
</tr>
<tr>
<td>Haricot bean May 10-21</td>
<td>4230</td>
<td>1140</td>
<td>5370</td>
<td>1.23</td>
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<tr>
<td>Haricot bean May 20-31</td>
<td>4520</td>
<td>1860</td>
<td>5880</td>
<td>1.38</td>
</tr>
<tr>
<td>Haricot bean May 30-June 10</td>
<td>5300</td>
<td>860</td>
<td>6160</td>
<td>1.29</td>
</tr>
<tr>
<td>Haricot bean June 9-20</td>
<td>5600</td>
<td>340</td>
<td>5940</td>
<td>1.28</td>
</tr>
<tr>
<td>Haricot bean June 19-30</td>
<td>5350</td>
<td>260</td>
<td>5010</td>
<td>0.93</td>
</tr>
<tr>
<td>Haricot bean June 29-July 10</td>
<td>5020</td>
<td>110</td>
<td>5130</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Table 5. Maize-Soyabeen Intercropping at Awassa 1983-85.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Sb</th>
<th>Mz</th>
<th>Total</th>
<th>LER</th>
<th>Sb</th>
<th>Mz</th>
<th>Total</th>
<th>LER</th>
<th>Sb</th>
<th>Mz</th>
<th>Total</th>
<th>LER</th>
<th>Sb</th>
<th>Mz</th>
<th>Total</th>
<th>LER</th>
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<td>36.06</td>
<td>37.39</td>
<td>1.07</td>
<td>6.05</td>
<td>31.03</td>
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<td>3.36</td>
<td>31.39</td>
<td>34.75</td>
<td>1.25</td>
</tr>
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<td>18.58</td>
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<td>16.28</td>
<td>-</td>
<td>16.28</td>
<td>1.00</td>
<td>27.50</td>
<td>-</td>
<td>27.50</td>
<td>1.00</td>
<td>20.79</td>
<td>-</td>
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<td>1 row Sb, : 1 row Mz</td>
<td>2.70</td>
<td>26.17</td>
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<td>36.06</td>
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<td>1.07</td>
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<td>31.03</td>
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<td>1.38</td>
<td>3.36</td>
<td>31.39</td>
<td>34.75</td>
<td>1.25</td>
</tr>
<tr>
<td>In row sb, : 1 row mz</td>
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<td>-</td>
<td>18.58</td>
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<td>-</td>
<td>20.79</td>
<td>1.00</td>
</tr>
<tr>
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<td>-</td>
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<td>5.49</td>
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<td>-</td>
<td>13.52</td>
<td>1.00</td>
<td>10.72</td>
<td>-</td>
<td>10.72</td>
<td>1.00</td>
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<td>alt. pos.</td>
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</tr>
</tbody>
</table>

Sb, = Soybean (Clark 63k) Sb, = soybean (Williams) Mz = maize (A511)
A randomized complete block design In four replications was used in all treatments.

Table 6. Effect of alley cropping Sesbania sesban and Leucaena leucocephala on seed yield of sorghum, wheat, F. bean and teff at Sirinka during 1986-88.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Sorghum</th>
<th>Wheat</th>
<th>F. Bean</th>
<th>Teff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole</td>
<td>1993</td>
<td>2324</td>
<td>2165</td>
<td>747</td>
</tr>
<tr>
<td>Sesbania</td>
<td>2057</td>
<td>1707</td>
<td>2828</td>
<td>716</td>
</tr>
<tr>
<td>Leucaena</td>
<td>2075</td>
<td>2809</td>
<td>2158</td>
<td>637</td>
</tr>
</tbody>
</table>
Table 7. Effect of alley cropping *Sesbania sesban*, *Leucaena leucocephala* and *Cajanus cajan* on seed yield of sorghum, maize and haricot bean at Melkassa during 1987.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Seed yield (kg ha(^{-1}))</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sorghum</td>
<td>Maize</td>
<td>Haricot bean</td>
</tr>
<tr>
<td>Sole crop</td>
<td>2500</td>
<td>4644</td>
<td>1299</td>
</tr>
<tr>
<td><em>Sesbania</em></td>
<td>2641</td>
<td>3944</td>
<td>1232</td>
</tr>
<tr>
<td><em>Leucaena</em></td>
<td>2809</td>
<td>5799</td>
<td>1371</td>
</tr>
<tr>
<td><em>Cajanus</em></td>
<td>3048</td>
<td>5914</td>
<td>1694</td>
</tr>
</tbody>
</table>

Table 8. Total biomass production in kg ha\(^{-1}\) of *Sesbania sesban* and *Cajanus cajan* in alley cropping systems with sorghum, maize and haricot bean at Melkassa during 1987.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Dry matter (kg ha(^{-1}))</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sorghum</td>
<td>Maize</td>
<td>Haricot bean</td>
</tr>
<tr>
<td><em>Sesbania</em></td>
<td>2265</td>
<td>2507</td>
<td>1942</td>
</tr>
<tr>
<td><em>Cajanus</em></td>
<td>1760</td>
<td>1639</td>
<td>1942</td>
</tr>
</tbody>
</table>

Table 9. Effect of planting date of mungbean on *Striga* incidence and sorghum grain yield.

<table>
<thead>
<tr>
<th></th>
<th>Sorghum</th>
<th>Mung bean</th>
<th><em>Striga</em></th>
<th>plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure sorghum (2/8/76)</td>
<td>1770</td>
<td>-</td>
<td>29.5</td>
<td></td>
</tr>
<tr>
<td>Pure mungbean (2/8/76)</td>
<td>672</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Sorghum (2/8/76) + mungbean (22/7/76)</td>
<td>887</td>
<td>728</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Sorghum (2/8/76) + mungbean (22/7/76) but removed on 2/8/76</td>
<td>1513</td>
<td>-</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>Sorghum + mungbean (2/8/76)</td>
<td>1275</td>
<td>399</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>13.44</td>
<td>5.38</td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>SE±51.5</td>
<td>SE±2.13</td>
<td>5%LSD±16.6</td>
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</tr>
</tbody>
</table>
Experiences of Intercropping Research in Tanzania

A.E.M. Temu and C.M. Mayona, Maize Agronomist and Bean Agronomist, Uyole Agricultural Center, P.O. Box 400, Mbeya, Tanzania

Introduction

Intercropping is one of the major cropping systems practised by small farmers in Tanzania (Evans, 1960, Finlay et al. 1974, Mwambene, 1975). It is estimated that up to 90% of the peasant farmers practise some kind of intercropping (or mixed cropping), the commonest system involving cereal-legume intercropping; the cereal as the major crop and the legume as the minor. Unlike mixed cropping, intercropping entails the growing of two or more crops on the same piece of land at the same time and in a definite row pattern. The system is characterized by minimal use of agricultural inputs such as fertilizer and pesticides (Nyambo et al. 1980). The types and choice of crops grown in this system depend on biological, social, physical and economic factors such as soil characteristics, temperature and rainfall regimes, tastes and traditions, risks, market prices and general infrastructure (Mwambene, 1977). Other types of farming systems common in Tanzania have been described in detail by Karel and Ndunguru (1980) and Anandajayasekeram (1982).

Intercropping research in Tanzania received little or no attention before the early 1970s because it was considered by researchers to be a backward and archaic system of farming when compared with “modern” sole or monocropping (Mwambene, 1977; Nyambo et al. 1980). Studies to closely investigate the merits and demerits of the system, since the early 1970s intercropping has received the attention it deserves. This paper is an attempt to highlight intercropping research experiences in Tanzania with particular emphasis on the variability of crops included in the system, the diversity of intercropping research and future work on intercropping in Tanzania.

Basic Crops in Intercropping Systems in Tanzania

Several crops are widely grown as intercrops or other cropping combinations in Tanzania.

Cereals: maize, sorghum, rice, bulrush millet, finger millet.

Leguminous crops: common beans, cowpeas, soybeans, groundnuts, green gram, pigeon peas, bambara nuts.

Fibres: cotton, sisal

Roots and Tubers: Cassava, sweet potatoes, Irish potatoes.

Oil crops: sesame, sunflower

Beverage crops: coffee

Vegetable crops: several leafy vegetables

Perennial trees, including fruit trees: coconuts, bananas.

The most widespread combinations, grouped as major and minor crops are:

<table>
<thead>
<tr>
<th>Major crops</th>
<th>Minor crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>common beans, cowpeas, green gram, groundnuts, sunflower, finger millet, sorghum.</td>
</tr>
<tr>
<td>Sorghum</td>
<td>groundnuts, maize, cotton, sweet potatoes.</td>
</tr>
<tr>
<td>Bulrush</td>
<td>millet bambara nuts.</td>
</tr>
<tr>
<td>Cassava</td>
<td>groundnut, maize, cotton, sweet potatoes.</td>
</tr>
<tr>
<td>Cotton</td>
<td>pigeon peas, cassava, sorghum</td>
</tr>
<tr>
<td>Pigeon peas</td>
<td>maize, millet, sorghum, beans, cowpeas, green gram.</td>
</tr>
<tr>
<td>Rice</td>
<td>maize, cassava</td>
</tr>
</tbody>
</table>

The diversity of crops that are intercropped and the numerous combinations possible, make intercropping research a complex field of study.

Institutions Involved in Intercropping Research

Most of the intercropping research work in Tanzania is carried out by the Sokoine University of Agriculture (Morogoro), Tanzania Agricultural Research Organization (TARO) centers at Lyamungu (Moshi), Selian (Arusha), Mingano (Tanga), Ukiriguru (Mwanza), Naliendele (Mtwara), Ilonga (Kilosa) and the Uyole Agricultural Center.
Intercropping Research in Tanzania

To date, the spatial arrangement of plants in a given area is one aspect of intercropping that has received considerable agronomic attention in the literature (e.g. May and Misangu, 1980). Also, many intercropping trials have centered on maize intercropped with beans, soybeans, green grams, cowpeas, groundnuts, pigeon peas, sunflowers, and to a lesser extent with sorghum, millet and crotalaria. A few trials on groundnut-cassava, sesame-sorghum and sorghum-cowpea intercropping systems have also been reported mainly from work conducted at TARO Naliendele Center (Mbeya). Most research work has been centered on the main stations, some on sub-centers and very little on-farm research.

Highlights of Results from Intercropping Research

- Planting pattern in an intercrop has not been found to have significant effects on yields and other characteristics, although certain row orientations may have advantages in terms of better solar energy harvest (Mongi et al., 1976; Ndakidemi and Mbuya, 1985).

- Highest cereal grain yields of both maize and millet were achieved when soybean as the intercrop was planted one week later. However, the highest soybean yields were obtained when the legume was planted before the cereal (Table 1, Nnko and Doto, 1982).

- Green grams planted 1 - 2 weeks before bulrush millet, increased the proportion of legume grain in the total harvest (May 1982).

- Relay cropping of cowpeas or green gram in a maize-legume system within four weeks of planting the cereal at 44,000 plants ha⁻¹ (for cowpeas) and 200,000 plants ha⁻¹ (for green gram) gave the best combination in the cropping system (Mbowe, 1988).

- Fertilizer
  
  There is limited literature on fertilizer evaluation in intercropping situations. Finlay (1975), Uriyo, et al., (1982) and Mongi et al., (1982), studied respectively N and P fertilization in a maize soybean system.
intercrop, foliar NPK contents and the yield of maize and cowpeas as influenced by cropping methods. These investigations revealed that:

- Maize grain yield increased with N and P applications, while the yield of beans did not. Maize grain yields were also increased by bean inoculation.

- P increased yields of monocropped maize but not that of intercropped maize or monoculture beans.

- P fertilizer should be banded or drilled.

- N increased yields of beans and maize under both monoculture and intercropping conditions.

- CAN as a source of N was preferred particularly when soils are of low pH.

- P and K contents of maize were not affected by any of the intercropping methods (alternate rows, same hole), but N was significantly increased by intercropping maize in the same hole as cowpeas.

In the Southern Highlands of Tanzania 120kg N ha⁻¹ and 30-60 kg P ha⁻¹ are currently being used under intercropping systems. The phosphorus is applied in full at planting to both crops while N is split applied, half at planting and half when the maize is 80 cm tall.

**Plant Protection**

It has often been observed that the incidence of pests, diseases and weeds in intercropping systems is lower than in monoculture and is probably a factor contributing to the widespread use of this system (Keswani 1982). Research on plant protection in intercropping is a complex task. This may explain why intercropping has received little attention from plant protectionists. The study is made more complicated by the fact that each crop in a mixture is infected or infested with different insects and diseases, and that fields contain a wide variety of weed species (Keswani, 1982). The few studies from Tanzania were carried out at the Sokoine University of Agriculture, Morogoro.

**Insect Studies and Their Control**

Two experiments were conducted at Morogoro by Karel et al., (1982) and Kato et al., (1982) with maize-cowpea and sorghum-sim sim intercrops, using different plant populations of the component crops. Both experiments revealed that:

- Oviposition and later damage by insects was higher in pure stands than in mixtures, and the cereal crop seemed to act as a barrier to the dispersion and entry of many pests in the mixtures.

- Combined (overall) yield advantage recorded in intercropped cereal (e.g. sorghum, maize or millet) and legume or sim sim was attributed to less damage by pests (like shootfly, midges and aphids in intercropped sorghum and ootheca, flower thrips, bruchids and other minor pests in intercropped cowpeas).

- Significant differences in oviposition and damage between sprayed and un sprayed treatments were recorded in both cropping systems in the various plant populations (Kato et al., 1982).

- Inoculum transfer being made much more difficult by the presence of alternating rows of legumes and cereals.

- Wind velocity reduction, reducing pathogen spread.

- Reduction in spread of pathogen by rain splash (Keswani and Mreta, 1982; Katunzi et al., 1987).

- There was a varietal difference in disease reaction in legumes when they were intercropped with cereals. This suggests that varieties react differently to disease under the two cropping systems, and as such they have to be bred/selected to suit them (Katunzi et al., 1987).

**Disease Studies and Their Control**

Studies on the effects of intercropping on disease incidence on legumes, also done at Morogoro, have shown that:

- Intercropping was superior to monocropping in reducing legume diseases (Table 2). The low severity (incidence) of disease in the intercropped legumes was attributed to:

- Inoculum transfer being made much more difficult by the presence of alternating rows of legumes and cereals.

- Wind velocity reduction, reducing pathogen spread.

- Reduction in spread of pathogen by rain splash (Keswani and Mreta, 1982; Katunzi et al., 1987).

- There was a varietal difference in disease reaction in legumes when they were intercropped with cereals. This suggests that varieties react differently to disease under the two cropping systems, and as such they have to be bred/selected to suit them (Katunzi et al., 1987).

**Weed Studies and their Control**

Studies on weed-crop competition and weed control in intercropping systems initiated at Ilongo (Morogoro) in the late 1970s and early 1980s, and recently at Lyamungu show that:

- Intercropping resulted in less harvestable weed dry matter than monocropping, demonstrating that intercropping is more effective in controlling weeds (Mugabe et al., 1982). These results seem to agree with those of Evans and Sreedharan (1962) who observed that intercropping had a greater competitive advantage over weeds caused by high population pressure provided by the component crop species together.

- Crop spp. combinations in the intercrops had a significant effect in suppressing weeds. For example, bulrush millet as opposed to maize and sorghum, was most effective in controlling weed growth in an intercrop system (Mugabe et al., 1982).
- The efficacy of herbicide varied according to the rate of application, weed species, the ecology (mainly soil and moisture regime) of the area and crop species combinations used (Anon. 1980; Matowo and Mmari, 1988).

- Due to phytotoxic effects from several herbicides tested on legumes, particularly those applied post-emergence, no suitable herbicide was found. Eight herbicides were tested at different rates. The herbicides used were alachlor (Lasso 480), bentazon (Basagram 480), linuron (Afonal 50), metolachlor + metabromuron (Galex 500), illoxn (Illoxan 28), pendimethalin (Stomp 330) and atrazine (Gesarprim 500).

Breeding

The need for developing specific genotypes of crops for intercropping has long been recognized by several researchers (e.g. Finlay, 1976, Francis et al., 1976). Nevertheless, little work has been undertaken in Tanzania.

The first attempts in the selection of crop genotypes suitable for mixed or intercropping were at the Faculty of Agriculture, Morogoro during the mid to late 1970s using crop varieties initially recommended for sole cropping systems. Recently the screening of legume cultivar lines for use under mixed cropping systems was initiated at Uyole, Ilonga and Lyamungu Research Centers. The findings show:

- Significant cropping system by genotype interactions suggesting that different genotypes may have to be recommended for different cropping systems in order to maximize yields of both crops (Jakobsen, 1980; May and Misangu, 1982; Makena and Doto, 1982). The climbing legumes tended to do better than the bush types (Jakobsen, 1980) although in recent studies at UAC and Lyamungu bush type beans recommended for monoculture have been found to be as good under mixed cropping provided that plant density is increased to double that of the climbing types (Mkuchu et al., 1987).

- Depending on the type of crop combination involved, the low yields recorded with the legume component have been associated with the reduction in crop yield components, notably number of branches per plant, productive pods per plant, seeds per pod and 100 or 200 seed weight, caused by greater competition for space, light and nutrients from the cereal crop (Mwambene, 1977; May and Misangu, 1982; Makena and Doto, 1982).

- In the case of cereals that tiller (such as sorghum and millets), low tilling, short stature genotypes, (less than 2.0 m tall) with rapid and vigorous early seedling growth were superior in performance in mixed cropping systems because such genotypes allow more light to reach the low-lying legume crop. Slow growing cereal genotypes, on the other hand, tended to be choked by the legume and this led to a drastic reduction in yield of the cereal crop (Mwambene, 1977).

Intercropping Research Involving Trees (Agroforestry) and Crotalaria

Pioneer studies to investigate the possibility of intercropping food crops (maize, beans and sorghum) with trees were initiated at Sokoine University of Agriculture by Maghembe and Redhead (1978). Initial results with Eucalyptus melliodora when intercropped with maize, beans and sorghum separately, on clean weeded and from the intercrop (Nadar, 1982). A review of work done in this field revealed three studies, but with conflicting findings:

- Work carried out by the UAC farming systems team on intercropping maize with beans showed that intercropping resulted in the lowest gross margin (i.e. monetary return) compared to monoculture although Land Equivalent Ratio analysis showed about an 18% advantage of the intercrop over the monocrop system (Kirway, 1986).

Other independent studies by Mbuya et al., (1987) and Katunzi et al., (1987) at Lyamungu and Morogoro respectively showed that:

- Gross and net benefits between sole crop and intercrop may vary considerably depending on the proportions of component crops and their prices (Mbuya et al., 1987). Although intercropping had a higher production investment than monoculture, its pronounced yield advantage resulted in higher net benefit.

- The higher monetary returns from intercropping are attributed to the higher combined yield of the associated crops than the yield of either crop alone (Katunzi et al., 1987).

Economic and Social Implications

One of the advantages of intercropping under smallholder conditions is that of profit maximization, from the sale of crops

Intercropping Research Involving Trees (Agroforestry) and Crotalaria

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unweeded plots encouraged further investigation using other tree species. Those selected were *Eucalyptus camaldulensis* (which is suitable for fuelwood and poles) and *Leucaena leucocephala* (*Leucocephala*) to investigate the effects of intercropping maize in tree rows. Comprehensive results are yet to come.

Such agroforestry systems (defined by King *et al.*, 1978) as those land use systems and technologies where woody perennials--trees, shrubs, palms, bamboo are used on the same land management unit as agricultural crops and/or animals, either in the same spatial arrangement or temporal sequence), can greatly increase fuelwood production as well as food income, shelter and sustainability (Vahaye, 1988). Actually, agroforestry in Tanzania is not new, it is practised extensively on the slopes of Mt. Kilimanjaro, Kagera and Mbeya (Rungwe) where land use methods combine domestic animals, perennial crops (coffee) with annuals such as yams and melons. *Grevillea robusta* and *Cordia abyssinica* are used as shade trees over coffee and banana in Kilimanjaro (Maghembe and Redhead 1982). The system allows permanent sustained agriculture and has protected those areas from soil erosion for many years. Though this system has existed for a long time no quantitative research information is available.

Studies on intercropping maize and crotalaria have been initiated at Uyole Agriculture Center, TARO Mingano and Ukiriguru. At Uyole, an attempt was made to evaluate a) the legume N contribution to maize when grown in association, b) the best seeding pattern and c) whether it can suppress weeds at the critical period of weed competition in maize. Broadcasting and seeding crotalaria in alternate rows at planting and after a first weeding with and without N and P fertilizer in a full stand of maize (44,444 plants ha⁻¹) were studied for two seasons at four locations in the Southern Highlands. Results indicated that seeding crotalaria in alternate double rows of maize was the best option (Temu, 1987). Broadcasting the whole plot or seeding in alternate single rows complicated harvesting because the maize rows were inaccessible. Crotalaria suffered weed competition initially due to its slow growth in high elevation cool areas. Supplemental N at 100 kg N ha⁻¹ to maize was necessary in the association since the N contribution by the legume was inadequate to meet the high N demand by maize. However, when crotalaria is ploughed under as green manure a nitrogen saving of 80-100 kg N ha⁻¹ is possible, as confirmed in earlier trials at Uyole (Temu, 1986).

**Future Work on Intercropping Research**

In order to improve intercropping systems in Tanzania, Karel and Ndongururu (1980) reviewed and pointed out several areas that required research effort. These included the screening of suitable genotypes or crop varieties for intercropping, choice of crops suited for intercropping, plant population and planting geometries which will favour rapid ground cover to reduce weed and moisture competition and minimize soil erosion, fertilizer use, disease and pest complexes in intercropping systems and their control, and economic analysis of the system.

From the highlights presented in this paper, evidently agricultural scientists have researched on some of those areas and have come out with some practical results that could be put forward as recommendations to improve the system. However, research intensification in all areas not yet tackled is required. In addition it is worthwhile to add the following studies to the list:

i) Intercropping research needs to expand to include the most widespread crop combinations as described earlier.

ii) Herbicide use under intercropping systems.

iii) Light and water use efficiencies in intercropping situations.

iv) Interaction effects on various management factors in polyculture systems.

v) More studies on economic and social implications of the system.

**Acknowledgements**

The authors are grateful to Drs. W.Y.F. Marandu and D.G. Lyimo for their very useful suggestions and assistance during preparation of the paper. Also the management of Uyole Agricultural Center for their permission to attend the Workshop and present the paper.

**References**


Table 1. Mean grain yield (g/plot) for soybeans.

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Planting schedule (weeks)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Monoculture</td>
<td>1400a</td>
<td>1397a</td>
<td>1075b</td>
<td>1097b</td>
<td></td>
</tr>
<tr>
<td>Soya/maize</td>
<td>1447a</td>
<td>752b</td>
<td>307c</td>
<td>272c</td>
<td></td>
</tr>
<tr>
<td>Soya/millet</td>
<td>1035a</td>
<td>497b</td>
<td>87c</td>
<td>72c</td>
<td></td>
</tr>
</tbody>
</table>

Mean grain yield (g/plot) for maize and finger millet

<table>
<thead>
<tr>
<th>Intercropped with soybeans</th>
<th>Planting schedule (weeks)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>+1</td>
<td>Mono-check</td>
</tr>
<tr>
<td>Maize</td>
<td>1890a</td>
<td>2695a</td>
<td>3025</td>
<td>3212</td>
<td>4085</td>
</tr>
<tr>
<td>Millet</td>
<td>995a</td>
<td>1843a</td>
<td>2225</td>
<td>2290</td>
<td>2660</td>
</tr>
</tbody>
</table>

a = mean significantly differs from respective monoculture check.

Table 2. Disease Index (at 6 WAP) and mean yields of green gram (kg ha⁻¹) and cereal under different cropping systems

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Disease Index</th>
<th>Yield (Kg ha⁻¹) Greengram</th>
<th>Cereal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greengram</td>
<td>7.9a</td>
<td>157.7a</td>
<td>-</td>
</tr>
<tr>
<td>Greengram/sorghum</td>
<td>6.4a</td>
<td>73.3b</td>
<td>481.7</td>
</tr>
<tr>
<td>Greengram/millet</td>
<td>6.0a</td>
<td>57.2b</td>
<td>362.4</td>
</tr>
</tbody>
</table>

Figures followed by the same letters are not significantly different (P = 0.05) by Duncan’s Multiple Range Test.
Intercropping Research Experience in Zambia

Aggrey M. Mwaipaya, Cropping Systems Agronomist, Msekera Regional Research Station, P.O. Box 510089, Chipata, Zambia

Introduction

Located within the semi-arid tropics, Zambia experiences a unimodal rainfall distribution pattern during November to April, a short cool and dry season during May to July, and a warm to hot dry season during August to October. Three ecological regions (regions I, II and III) are recognized, based mainly on rainfall. These represent areas receiving mean annual rainfall of 500-800mm, 800-1,000mm and >1,000mm respectively.

Zambia has an undulating topography in both the plateau and the valley areas. Soils form pockets of shallow, poorly drained rangelands, to deep and well drained arable expanses. Some very low fertility status, leached and acid soils, developed over schist (quartz-mica variety) and similar parent materials in the high rainfall region also occur.

From several diagnostic surveys, it has been established that in the traditional Zambian subsistence farming sector local open-pollinated maize cvs have always been planted together with local legumes. The diagnostic survey clearly indicated that intercrops vary according to local dietary preferences and ecological conditions, and that combined yields tend to be generally very low, mainly the result of late planting, irregular weeding and haphazard spatial arrangements of the component crops on soils of low fertility status. The surveys also established that disease and insect management is either untimely or not practised at all.

Problems

From diagnostic surveys carried out in parts of Zambia, three major problems were identified concerning intercropping:

\begin{itemize}
  \item Intercrop yields in the subsistence mixed cropping systems were generally very low.
  \item Labour constraints were experienced during labour peak periods associated with land preparation, planting and weed management.
  \item Subsistence farmers were hesitant to adopt soybean production, despite a vigorous campaign to popularize the crop.
  \item Groundnut plants developed large numbers of pods when grown in the high rainfall leached soil areas.
  \item Soybean cultural practices were still new and the crop was not readily used for food by farmers, mainly due to its processing requirements.
\end{itemize}

Causes of Low Intercrop Yields

Possible causes of low intercrop yields in the subsistence mixed cropping systems include:

\begin{itemize}
  \item Local crop cvs. of maize, sorghum, millet and beans used in intercrops were of low yield potential.
  \item Optimum intercrop plant density and spatial arrangements were not known.
  \item Intercrop planting time was not properly synchronized to reduce species competition and maximize complementarity.
  \item Chemical fertilizers were not available in time due to cash constraints and logistical problems.
  \item Insect and disease control were not practised.
  \item Time spent at school by younger farm family members reduced the amount of family labour available during critical farm operations. As a result, late maturing local and hybrid crops were often planted late.
\end{itemize}

Research Strategy

Based on survey data, it was considered appropriate to first improve agronomic management practices of intercrops, before embarking on breeding. Foremost, the suitability for the combining of different crop plants as intercrops had to be determined experimentally, through on-station studies. These were competition studies on important cereals (maize and sorghum) and legumes (groundnut, field bean and soybean).

Underlying this approach is the desire to develop possible agronomic intercropping technologies as a priority, according to economic and location advantage. Optimum intercrop plant density and spatial arrangement would then be established for each crop combination, starting with simultaneous planting of component crops and later investigating possible advantages of relay cropping. It was decided to include legumes in intercropping for reasons of fertilizer economy. Insect and disease control practices would also be undertaken, if and when necessary.

By developing an intercropping research programme in this way, it is hoped that the apparent yield effects of labour shortage during critical farm operations would be minimized and general crop management improved.
Research Highlights

To determine whether significant combined intercrop yield advantages were possible under the prevailing labour shortfall during critical operations, the National Intercropping Research Team started working with hybrid cereal and better yielding legume cvs., paying special attention to improved intercrop management techniques. Undoubtedly, out of a wide range of research studies on legume cvs. carried out in Zambia, the studies of maize/field bean (Zea mays/Phaseolus vulgaris); maize/soybean (Glycine max (L) Merr.) and maize/groundnut (Arachis hypogaea), are by far the most significant.

These experiments were conducted at the Copperbelt Regional Research Station, Mufulira (12° 37'S, 28° 09'E; elevation 1243 masl), during 1980/81, 1981/82 and 1982/83 cropping seasons with 1250mm, 963mm and 1411mm of rainfall, respectively. With regard to maize, SR52-(a narrowly adapted single cross hybrid in the 700 FAO maturity group, mean height of 2.25m)- was used in all the three experiments conducted.

Zambia considers maize an important staple food crop, and equally important is the field bean. This is clearly reflected in the maize/bean intercrop combinations under research in most provinces (Table 1).

Maize/Bean

From on-station research it appears that the symbiosis formed between bean genotypes and native soil Rhizobium strains is not sufficiently effective to satisfy the N requirements of the plant. Indications are that nitrogen deficiency is limiting bean production in many areas of Zambia. The need to improve or select both bean genotypes and Rhizobium strains to obtain the best combination of both symbionts was identified.

Maize/Groundnut

In highly leached soils of the high rainfall areas (Region 1), groundnut often suffers from pops. During groundnut pod-formation and pod-fill phases, the plant experiences a shortage of calcium. Furthermore, even after application of 2000kg ha\(^{-1}\) of fine dolomitic lime at the start of an experiment, continued occurrence of some pops, two seasons later, strongly indicated the need for application of lime from sources richer in calcium.

Intercropping two maize rows on the flat followed on every third by a groundnut ridge row - rows at 75cm spacing - gave the most stable combined yield of 55 bags maize with 4.5 bags groundnut ha\(^{-1}\) (Mwaipaya, 1984; Table 4). Better still, planting groundnut two weeks earlier - third week of November - than maize, improved both the maize and groundnut component yields. From this result it appears that of the two species, groundnut was less competitive for plant nutrients.

Maize/Soyabean

Despite the slow adoption rate of the new soybean crop by small-scale resource-limited farmers in Zambia, the crop's potential N-fixing ability and residual fertility benefits to following cereal crops has been firmly established. However, direct transfer of the biologically-fixed N by soybean to the maize intercrop during the same season (1982) was not evident, using the N-15 isotope dilution method at the National Irrigation Research Station, Mazabuka.

At the Copperbelt Research Station, Mufulira, intercropping twin soybean rows between maize rows gave yields slightly better than intercropping triple soybean rows by replacing every third maize row. The two intercropping alternatives achieved combined yields of 53 bags maize with 11 bags soybean and 47 bags maize with 13 bags soybean ha\(^{-1}\), respectively (Mwaipaya, 1984). Financial returns per hectare differed only marginally (Table 3).

Other Crop Combinations

Sunflower (Helianthus annuus) groundnut intercropping at Msekera Regional Research station, Chipata (Region II), has consistently shown promise.
## Treatment Index for Tables

### 1. Maize/Bean

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Sole maize planted in rows 1 meter apart at 25 cm between plants, on flat.</td>
</tr>
<tr>
<td>(b)</td>
<td>Sole maize planted in check rows, on flat.</td>
</tr>
<tr>
<td>(c)</td>
<td>Sole dwarf bean planted in rows 50 cm apart at 8 cm between plants, on flat.</td>
</tr>
<tr>
<td>(d)</td>
<td>Maize as in (a) with twin dwarf bean rows between maize rows, on flat.</td>
</tr>
<tr>
<td>(e)</td>
<td>Maize as in (a) with three dwarf bean plants between maize plants, in common rows on flat.</td>
</tr>
<tr>
<td>(f)</td>
<td>Maize as in (a) with 3 climbing bean plants between maize plants, in common rows on flat.</td>
</tr>
<tr>
<td>(g)</td>
<td>Maize planted in check rows with 4 climbing bean plants around each maize check row station.</td>
</tr>
<tr>
<td>(h)</td>
<td>Maize planted in check rows with twin dwarf bean rows between maize check rows, in one direction (observation, 1982/83 only).</td>
</tr>
</tbody>
</table>

### 2. Maize/Soyabean

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Sole maize planted in rows 1 meter apart at 25 cm between plants, on flat.</td>
</tr>
<tr>
<td>(b)</td>
<td>Sole soybean planted on flat in rows 50 cm apart at 5 cm between plants.</td>
</tr>
<tr>
<td>(c)</td>
<td>Maize and soybean; such that as in (a) every third maize row replaced by 3 soybean rows.</td>
</tr>
<tr>
<td>(d)</td>
<td>Maize check rows with 1 soybean row between maize rows in both directions.</td>
</tr>
<tr>
<td>(e)</td>
<td>Maize as in (a) with twin soybean rows between maize rows.</td>
</tr>
<tr>
<td>(f)</td>
<td>Maize as in (a) with 5 soybean plants between maize plants, in common rows.</td>
</tr>
</tbody>
</table>

### 3. Maize/Groundnut

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Sole maize planted in rows 1 meter apart at 25 cm between plant stations, on flat.</td>
</tr>
<tr>
<td>(b)</td>
<td>Sole groundnut planted in ridge rows 1 meter apart at 10 cm between plants.</td>
</tr>
<tr>
<td>(c)</td>
<td>Maize on flat and groundnut in ridge rows; every third row a groundnut ridge row, one meter row spacing.</td>
</tr>
<tr>
<td>(d)</td>
<td>Maize and groundnut planted in common ridge rows 1 meter apart; 4 groundnut plants between maize plants.</td>
</tr>
<tr>
<td>(e)</td>
<td>Maize in check rows on flat with mounds of 4 groundnut plants at space intersections.</td>
</tr>
<tr>
<td>(f)</td>
<td>As (c) but row spacing at 75 cm (observation, 1982/83 season only).</td>
</tr>
</tbody>
</table>
Reference


Table 1. Intercropping research arising out of diagnostic surveys.

<table>
<thead>
<tr>
<th>Province</th>
<th>Intercrops</th>
<th>Location</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>Maize/bean</td>
<td>OF</td>
<td>LER, MV, FE</td>
</tr>
<tr>
<td>Copperbelt</td>
<td>Maize/bean</td>
<td>OS</td>
<td>LER, MV</td>
</tr>
<tr>
<td></td>
<td>Maize/groundnut</td>
<td>OS</td>
<td>LER, MV</td>
</tr>
<tr>
<td></td>
<td>Maize/soybean</td>
<td>OS</td>
<td>LER, MV</td>
</tr>
<tr>
<td>Eastern</td>
<td>Maize/bean</td>
<td>OF, OS</td>
<td>LER, MV</td>
</tr>
<tr>
<td></td>
<td>Maize/groundnut</td>
<td>OS</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Maize/cowpea</td>
<td>OS</td>
<td>LER</td>
</tr>
<tr>
<td></td>
<td>Maize/pigeon pea</td>
<td>OF, OS</td>
<td>LER</td>
</tr>
<tr>
<td></td>
<td>Cotton/groundnut</td>
<td>OS</td>
<td>LER, MV</td>
</tr>
<tr>
<td></td>
<td>Sunflower/groundnut</td>
<td>OS</td>
<td>LER</td>
</tr>
<tr>
<td>Luapula</td>
<td>Maize/bean</td>
<td>OF</td>
<td>MV</td>
</tr>
<tr>
<td></td>
<td>Maize/soybean</td>
<td>OF</td>
<td>NV</td>
</tr>
<tr>
<td></td>
<td>Maize/groundnut</td>
<td>OF</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Cassava/bean</td>
<td>OF</td>
<td>NV</td>
</tr>
<tr>
<td>Lusaka</td>
<td>Maize/cowpea</td>
<td>OF</td>
<td>FE</td>
</tr>
<tr>
<td></td>
<td>Maize/bean</td>
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<td>LER</td>
</tr>
<tr>
<td></td>
<td>Maize/sunflower</td>
<td>OF</td>
<td>FE</td>
</tr>
<tr>
<td>Northern</td>
<td>Finger millet/bean</td>
<td>OS</td>
<td>LER</td>
</tr>
<tr>
<td></td>
<td>Maize/bean</td>
<td>OS</td>
<td>LER</td>
</tr>
<tr>
<td>Northwestern</td>
<td>Maize/bean</td>
<td>OF</td>
<td>LER, MV</td>
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<tr>
<td></td>
<td>Maize/groundnut</td>
<td>OF</td>
<td>LER, MV</td>
</tr>
<tr>
<td>Western</td>
<td>Maize/cowpea</td>
<td>OF, OS</td>
<td>LER</td>
</tr>
</tbody>
</table>

Key: OF = On-farm  LER = Land equivalent
      OS = On-station  MV = Monetary value
      NV = Nutritional value  FE = Farmer evaluation
      L = Labour
Table 2. Maize/bean grain productivity and financial returns, Copperbelt Research Station, 1980-83.

<table>
<thead>
<tr>
<th>Experiment (treatment)</th>
<th>Yield kg/ha (LER)</th>
<th>Combined LER</th>
<th>% contribution to yield advantage</th>
<th>Financial return in Zk/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Bean</td>
<td>Maize</td>
<td>Bean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize/field Beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a)</td>
<td>4729 (1.00)</td>
<td>Nil</td>
<td>1.00</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>4869 (1.06)</td>
<td>Nil</td>
<td>1.06</td>
<td>+6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>Nil</td>
<td>736 (1.00)</td>
<td>1.00</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td>3703 (0.73)</td>
<td>328 (0.46)</td>
<td>1.18</td>
<td>+11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e)</td>
<td>4495 (0.93)</td>
<td>236 (0.32)</td>
<td>1.25</td>
<td>+19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(f)</td>
<td>4460 (0.95)</td>
<td>362 (0.49)</td>
<td>1.44</td>
<td>+29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g)</td>
<td>4672 (1.00)</td>
<td>250 (0.33)</td>
<td>1.33</td>
<td>+25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h')</td>
<td>5735 (0.76)</td>
<td>522 (0.58)</td>
<td>1.34</td>
<td>+19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand mean (a-g)</td>
<td>4488 (0.95)</td>
<td>319 (0.43)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Level of significance
NS

SE +0.20%

CV 17%

Pooled Error df 12

*Results from 1982/83 season only; comparison with yields pertaining to that season.*
Table 3. Maize/Soybean grain productivity and financial returns, Copperbelt Research Station, 1980-83.

<table>
<thead>
<tr>
<th>Experiment (Treatment)</th>
<th>Yield kg/ha (LER)</th>
<th>Combined LER</th>
<th>% contribution to yield advantage</th>
<th>Financial return in Zk/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>Soybean</td>
<td>Maize</td>
<td>Soybean</td>
</tr>
<tr>
<td>(a) Maize/soybean</td>
<td>5491 (1.00)</td>
<td>Nll</td>
<td>1.00</td>
<td>Nll</td>
</tr>
<tr>
<td>(b) Nil</td>
<td>1659 (1.00)</td>
<td>1.00</td>
<td>Nll</td>
<td>Nll</td>
</tr>
<tr>
<td>(c) 4265 (0.76)</td>
<td>1219 (0.73)</td>
<td>1.49*</td>
<td>+25</td>
<td>+24</td>
</tr>
<tr>
<td>(d) 4364 (0.82)</td>
<td>479 (0.29)</td>
<td>1.11</td>
<td>+8</td>
<td>+3</td>
</tr>
<tr>
<td>(e) 4767 (0.90)</td>
<td>1035 (0.64)</td>
<td>1.55**</td>
<td>+32</td>
<td>+23</td>
</tr>
<tr>
<td>(f) 2998 (0.48)</td>
<td>687 (0.40)</td>
<td>0.89</td>
<td>Indistinguishable</td>
<td></td>
</tr>
</tbody>
</table>

Grand mean (a-e) 4377 (0.80) 1016 (0.61)
Level of significance (P=0.01)
SE +0.254
CV 21.7%
Pooled error df 10

Table 4. Maize/groundnut grain productivity and financial returns, Copperbelt Research Station, 1980-83

<table>
<thead>
<tr>
<th>Experiment (treatment)</th>
<th>Yield kg/ha (LER)</th>
<th>Combined LER</th>
<th>% contribution to yield advantage</th>
<th>Financial return in Zk/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
<td>G. Nut</td>
<td>Maize</td>
<td>G. NUT</td>
</tr>
<tr>
<td>(a) Maize/groundnut</td>
<td>5301 (1.00)</td>
<td>Nll</td>
<td>1.00</td>
<td>Nll</td>
</tr>
<tr>
<td>(b) Nil</td>
<td>1263 (1.00)</td>
<td>1.00</td>
<td>Nll</td>
<td>Nll</td>
</tr>
<tr>
<td>(c) 3561 (0.68)</td>
<td>467 (0.39)</td>
<td>1.07</td>
<td>+4</td>
<td>+3</td>
</tr>
<tr>
<td>(d) 3443 (0.62)</td>
<td>407 (0.33)</td>
<td>0.95</td>
<td>Indistinguishable</td>
<td></td>
</tr>
<tr>
<td>(e) 4662 (0.85)</td>
<td>226 (0.18)</td>
<td>1.03</td>
<td>+2</td>
<td>+1</td>
</tr>
<tr>
<td>(f) 4940 (0.73)</td>
<td>361 (0.24)</td>
<td>0.97</td>
<td>-2</td>
<td>-1</td>
</tr>
</tbody>
</table>

Grand mean (a-e) 4242 (0.80) 591 (0.47)
Level of significance NS
SE 0.12
CV 11.55%
Pooled error df 8

*Results from 1982/83 season only; comparisons with yield pertaining to that season.
Intercropping Research in Zimbabwe: Current Status and Outlook for the Future

M. Notarajan and E.M. Shumba, Agronomy Institute, Department of Research and Specialist Services, P.O. Box 8100, Causeway, Harare, Zimbabwe

Abstract

Intercropping of annual food crops is not widely practised, even by smallholders, in present day Zimbabwean agriculture. Although some attempts to promote intercropping of cereal grain crops with legumes were made in 1981, experimentation to evaluate this practice vis-a-vis sole cropping did not start until mid-eighties. Currently, several units of the Department of Research and Specialist Services are conducting research to compare intercropping systems with sole crops for their productivity and stability of production. Some work to specifically look at its usefulness in pest, disease and weed control is being initiated. The intercropping research programme in Zimbabwe is thus very young. Since sole cropping is the most common method of crop production currently, the practice of intercropping may not be considered as an alternative unless it is proved to be clearly more advantageous than sole cropping under the agro-ecological conditions in which the smallholders operate.

Introduction

Intercropping is practised by smallholders in a number of ways and for a variety of reasons all over Africa, central and south America and parts of Asia. With the advent of modern input-intensive agriculture, this was discouraged as a backward practice typical of subsistence and less productive agriculture. However, the persistence of peasant farmers with intercropping in some countries, despite efforts to discourage it, and evidence from research that it can be a productive and useful practice under certain situations, has renewed the interest of researchers on this practice all over the world since the mid seventies.

Current Status of Intercropping in Zimbabwean Agriculture

It is not clearly known how common the practice of mixed cropping was in the pre-European agriculture in Zimbabwe. Reid (1977) in his article about the early agriculture of Matabeleland and Mashonaland refers to mixed cropping among some of the agricultural practices of nineteenth century Zimbabwe. If mixed cropping was in fact a common practice in the traditional agriculture, then extension has been very effective in discouraging it over the years. Now, monocropping is predominant even in peasant agriculture in Zimbabwe. Intercropping, it is generally felt, is practised in only small isolated patches, where pumpkins or cowpeas are often seen planted in the cereal crops. However, one does come across other types of intercropping such as the planting of maize rows in a groundnut crop. Mixed planting of finger millet or bambaranuts with maize, and upland rice with groundnuts are some other examples of intercropping that are seen on some farms, though on a limited scale.

Recent Attempts to Promote Intercropping

Some of the recent attempts to promote intercropping in Zimbabwean agriculture were made in the 1981-82 crop season following a diagnostic survey conducted in Chivi communal area. This survey revealed the need to increase the quality and quantity of dry season cattle feed and it was envisaged that some additional legume fodder can be obtained by planting leguminous crops between cereal rows. Simple farmer managed trials conducted during that year using velvetbean, dolichos, soybean and cowpeas as intercrops showed that the cereal yields (maize in particular) were reduced by intercropping, though the total dry matter production from the system was higher than when the cereal was monocropped. Farmers also indicated that the intercrops were more difficult to weed. The need to conduct some research on intercropping under controlled conditions at research stations was thus felt. However, this experimentation only started in 1986.

Research on Intercropping in Zimbabwe

Several units in the Department of Research and Specialist Services have, either in the past or currently, been involved in conducting research on the intercropping of annual food or forage crops. These are the Farming Systems Research Unit, Lowveld Research Station, Grasslands Research Station, and the Agronomy Institute. Work by these units is discussed in some detail later in this paper. The plant Protection Research Institute of the department intends to develop a comprehensive project on the influence of intercropping on major pests and diseases of crops commonly grown in the communal areas of the country. A study on the impact of intercropping of maize with beans or cowpeas on several species of plant-parasitic nematodes has already been started.

Some work on intercropping of maize with cowpea has been started during the 1987-88 crop season in the Department of Crop Science at the University of Zimbabwe.
Research on the intercropping of perennial crops such as coffee has, however, been going on for a long time in the country. The Coffee Research Station of the Department of Research and Specialist Services has been conducting work on growing legume cover crops between coffee rows as a substitute for the traditional practice of mulching, since 1971 (Clowes, 1973). In later years, grain legumes such as soybean and sugar bean were tried as intercrops in addition to the pasture legumes, in young or ratoon coffee plantations. The objective was to provide both in-situ mulch and grain. The effect of these cover and intercrops on coffee production is still being studied.

**Farming Systems Research Unit**

Work on intercropping by this unit started in 1987-88 as a sequel to the observations made at Chivi. A trial with a maize-cowpea combination was conducted on sandy soil at Makoholi Experiment Station (mean annual rainfall about 650 mm), which represented the semi-arid environment of Chivi. The objectives of the trial were to explore cereal-legume proportions so as to minimize yield reduction in the cereal, and to study the effects of total population pressure on performance of the intercrop in this dry environment. The results showed that under the conditions of Makoholi in that year, there was no grain yield advantage by combining the two crops although the total dry matter production was higher in the intercrop. There was a significant reduction in the cereal yield when intercropped.

**Lowveld Research Station**

Some work on relay cropping of maize and sorghum with grain legumes such as soybeans, cowpea and pigeon pea and cereals such as pearl millet, sorghum and maize was initiated in 1984-85 and was repeated during 1985-86. Since the relay crops were planted at physiological maturity of the main crops, there was hardly any effect of these on the latter. Pearl millet, cowpea and pigeon pea performed reasonably well when the late rains were favorable whereas the others were not at all successful as relay crops. Relay crops performed better following maize than after sorghum.

Intercropping work at this station, which represents one of the driest environments in the country characterized by a mean annual rainfall of less than 600 mm and mean monthly evaporative demands exceeding mean monthly precipitation even during the rainy months, started in 1986-87. The crops studied were maize and sunflower. Interplanting of these crops was compared with mono and relay cropping. The results showed that while intercropping performed better than monocropping, the highest yields were obtained with relay cropping of sunflower after maize.

**Grasslands Research Station**

The Veld and Pasture Section of this station initiated a study in 1986-87, on intercropping three legumes, lablab (*Lablab purpureus*), cowpea and pigeon pea in maize. The objective of the study was to explore the possibility of improving the feeding value of maize residues with hay produced by the intercropped legumes. These three legumes, selected out of the twenty evaluated in an observation trial in 1985-86, were sown between maize rows planted 90 cm apart, five weeks after the maize was planted. While the yield of maize was not affected by intercropping, the performance of all the legumes was rather poor (Clatworthy and Nziramasanga, 1987). The study, after a break of one year, is proposed to be continued with some modifications.

**Agronomy Institute**

The Agronomy Institute, though situated in Harare, conducts its research at a number of experimental stations and on-farm sites located to represent three ecological zones of Zimbabwe, where arable cropping is important. Research work on intercropping by this institute started in the 1986-87 crop season and later expanded in the following year. The combinations being studied are as follows.

**Cereal-coupea intercropping**

The objective of research with this combination is to produce some additional yield of cowpea, a grain legume whose leaves, pods and seed are used in the local diet, without reducing the cereal yield. The work on the maize-cowpea combination started in 1986-87 with three treatment factors, namely, cowpea variety, cowpea sowing time in relation to that of maize, and cowpea within-row spacing. The experiment was conducted at experimental stations and as a researcher managed trial at six on-farm locations. The trial turned out to be too complicated for on-farm situations, and the treatment factor, planting date of cowpea, was difficult to impose under rainfed conditions in that dry year. Results showed that while staggered planting of cowpea one month after the maize could help keep the maize yield unaffected, cowpea yield itself was low as an intercrop. Simultaneous planting in this dry year, reduced the maize yield drastically at some sites. A sequel of this trial in 1987-88, did not have planting date as a treatment factor, but an attempt was made to reduce competition from a simultaneously planted cowpea to maize by reducing the row proportions and component population of cowpea. Sorghum was included as an additional and, for some sites, more appropriate, cereal. This trial is being repeated during 1988-89 without any further changes.
A second trial on maize-cowpea combinations examined five plant types of cowpea (differing in duration and canopy spread), and spatial arrangements aimed at reducing competition to maize while giving cowpea a better opportunity to grow. This trial was conducted at two research stations, Makoholi (rainfall: about 650 mm during the crop season, and soil type: coarse sand or coarse sandy loam) and Kadoma (rainfall: about 980 mm during the crop season, and soil type: clay loam), representing two contrasting environments in terms of moisture availability. The results indicated that in the dry environment of Makoholi IT82D-889, the compact and short duration genotype, was found to be more suitable than the spreading types which caused considerable depression in maize yield. In a favorable environment at Kadoma, the growth of maize was so good that very early and compact genotypes were suppressed and genotypes such as TVX 3236 with a relatively longer duration and greater spread performed better.

Some work on interplanting cowpea between the rows of maize to study its usefulness in smothering weeds has been started by the weed research team of the Agronomy Institute in the current crop season.

**Intercropping groundnut with other crops**

The objective of the trial was clearly to try and exploit the physiological advantage by intercropping crops with contrasting canopy heights. The components used were comparable to groundnut in their importance as food or cash crops and are grown commonly by the smallholders in a sole crop situation. During 1986-87, in an exploratory study, three row proportions each of maize-groundnut and sunflower-groundnut were studied on sandy soils. Based on the results of the study, two of the three row proportions (one row of maize or sunflower to two or three rows of groundnuts) were chosen for further study in 1987-88. In the first year of the study all the intercrops were of replacement type, with the total population pressure not exceeding that of the sole crops. Since the plants of the taller component (maize in particular) did not respond to additional space in the intercrops as much as expected, an additional factor of within-row spacing was included in the second year trial to study the consequences of a higher plant population pressure on yield advantages under different moisture environments.

Maize-groundnut intercropping forms a part of yet another study which was started in 1987-88 to compare the productivity, over a four year period, of three cropping systems options for a farmer growing both maize and groundnut. This study compares continuous monocropping, continuous intercropping and alternating the two crops in a two-year rotation cycle, at four levels of nitrogen fertilizer input.

**Intercropping with slow-growing multi-purpose crops**

This study, started in 1987-88, examined the feasibility of growing a long-duration and slow-growing pigeonpea as an intercrop in other crops that are commonly grown in the communal areas, in such a way that the yields of these crops were not affected. It was envisaged that pigeonpea can either be grown to seed or cut for forage as seen appropriate by the farmer. Pigeonpea was planted in single rows alternating every two rows of either maize or sunflower in such a way that both the component crops are maintained at full sole crop optimum plant population. It was also grown with groundnut in a three groundnut to one pigeonpea row proportion by sacrificing every fourth row of groundnut.

As expected, the pigeonpea did not interfere with the growth of maize and sunflower to cause any significant yield reduction in these crops at the two sites where the experiment was conducted. But the groundnut yield was considerably reduced by intercropping, necessitating the need for its full population and adjustment in row proportions. This trial is being repeated with modifications during the 1988-89 crop season.

**Preliminary investigations on intercropping bambaranuts in maize**

Bambaranuts are grown in the communal areas for family consumption or for sale in the local markets. Being a legume, it is shown to leave substantial residual nitrogen for the following crops. However, this crop is not grown on a large scale as a sole crop. An attempt was made during 1987-88 to study its suitability as an intercrop in maize. Because of the exploratory nature of the study, a systematic design was used to cover a range of row proportions of the two crops with minimal use of land and resources. This trial is being repeated during 1988-89.

**Intercropping research on other miscellaneous combinations**

Two other intercropping studies were initiated with either a cereal or a legume as one of the components. The first is a study to see if the insecticidal sprays given to cotton, and its initial slow growth can be used to advantage to produce a seed crop of cowpea. The initiative for this trial came from the International Institute for Tropical Agriculture (IITA) and the Agronomy
Scope for Intercropping Research in Zimbabwe

In many countries of eastern and southern Africa mixed cropping is actively practised by smallholders and there is a clear need for research to improve or modify this practice to enhance crop production. Zimbabwe is in a way unique in the region, because monocropping is the most predominant cropping system, even in smallholder agriculture in the country. Under these conditions, unless there is clear evidence of its superiority as a better practice either in terms of overall productivity, yield stability, or sustainability over time, intercropping need not be seen as an alternative to the current farmers' practice. Intercropping research in Zimbabwe may therefore be restricted to evaluating the usefulness, if any, of this practice vis-a-vis sole cropping, under the agroecological conditions prevailing in the country. This need becomes more important when one considers the sudden enthusiasm in some extension personnel to demonstrate the 'usefulness' of intercropping based on the experiences elsewhere, under altogether different circumstances.

It is envisaged that a systematic survey to collect information on the extent of intercropping in the country, the farmers reasons for intercropping, current management practices in intercrops and the levels of productivity from them, will be conducted to provide a conceptual framework within which the current intercropping research efforts can be assessed.

Acknowledgements

The authors wish to acknowledge Drs. P. Muchena and I.K. Mariga for the information on intercropping research in the Plant Protection Research Institute and the Department of Crop Science, University of Zimbabwe, respectively. The information on the intercropping work by Lowveld Research Station and Coffee Research Station has been put together from the summary annual reports of these stations. The intercropping trials of the Agronomy Institute are now conducted under the programmes run by Mrs T.M. Nleya, and Messrs. G. Zharare, P. Mafongoya, D. Mataruka and S. Mabasa. Their help in providing information about the trials is appreciated. The authors thank the Director and Assistant Director (Crops) of the Department of Research and Specialist Services for their support.

References


Sustainability Issues with Intercrops

Session 6

Charles A. Francis, Professor, Department of Agronomy, University of Nebraska, Lincoln, NE, 68583-0910, USA

Abstract

Intercropping systems have been developed for a number of complex biological, economic, nutritional, and social reasons. We know that these systems represent a perceived optimum strategy for producing food and income under some of the most difficult of farming situations where resources are limited. The importance of the many factors which influence management decisions in intercropping systems have not been studied in detail, nor have their multiple interactions been quantified successfully by those in research or extension. Conventional wisdom suggests that multiple species in the field each year -- whether intercropped, relay cropped, or sequentially cropped -- make more efficient total use of resources, provide a more varied food supply and income source, and present less risk of failure to the farmer than monoculture systems in the same region under the same conditions. Limited experimental evidence appears to support the hypotheses of efficient resource use and of reduced risk with intercrops. There is greater production stability of dissimilar crops together in the field, just as diverse natural ecosystems persist over a range of different climatic conditions from year to year. Based on limited research plus the observations that low-resource farmers insist on preserving complex mixtures of crop species, it could be concluded that intercropping systems provide greater potential than monoculture for sustained production of food and income, especially in regions of limited resources.

Introduction

Intercrop yields and income sustainability are key issues which face farmers and decision makers in research. Much of our total resource has been dedicated to improving productivity of monoculture systems, with the implicit assumption that high yields and most efficient resource use will be achieved by exploiting single crops during each growing season. Yet increasing numbers of scientists are questioning whether this direction is the only potential route to increased and sustained food production?

A recent publication, “Enhancing Agriculture in Africa” (Office of Technology Assessment, 1988), notes that agricultural systems in Africa which were once sustainable, today no longer meet the increased demands for food and income. The report suggests that high priority be placed on:

- environmental, economic, social, and institutional sustainability;
- assurance that resource-poor agriculturists benefit from development assistance;
- local participation of women and men farmers as well as technical people in planning and implementing projects; and
- sound natural resource management for the future.

How does intercropping as a specific type of crop culture help to meet these objectives, and how does this differ from what is offered by monoculture? Before this can be discussed, it is essential to define “sustainability”. This has become difficult because of our lack of consensus on the time frame of reference, the projected availability and cost of resources, and how technology will be used and by whom in agriculture. More simply put, we would need to agree on “sustainability of agricultural production” under what conditions: costs of fossil fuels, acceptable limits on environmental disturbance, health and safety issues for humans and other species, and for how long? Clearly, a consensus would be difficult.

Harwood (1989) suggests an overview or umbrella definition of sustainable agriculture as “an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use and a balance with the environment that is favorable both to humans and to most other species”. Although this is a useful philosophy and a conceptual definition within which to work, it is necessary to be more explicit about what practices and systems fall under this umbrella.

In a practical research-based extension program in Nebraska, we have used an operational definition of sustainable agriculture as “a management strategy which helps the producer to choose hybrids and varieties, a soil fertility package, a pest management approach, a tillage system, and a crop rotation to reduce costs of purchased inputs, minimize the impact of the system on the immediate and the off-farm environment, and provide a sustained level of production and profit from farming” (Francis et al., 1987). There is a need for local adaptation of terminology and programs, of diversity in approach, and of creativity in planning for the future. Yet these definitions give us a place to begin.
Biological Sustainability

Conventional wisdom in ecology suggests that natural ecosystems are relatively stable because of their genetic/biological diversity. Some authors (for example Goodman, 1975; Loomis, 1984) question this relationship, failing to find clear evidence that diversity always makes a system more stable in nature. The left hand side of Figure 1 shows a range in biological diversity occurring in natural ecosystems (Francis, 1986). These are all climax vegetation patterns, and represent an evolution to some degree of stability or sustainability of plant species in specific climatic conditions.

A parallel situation for diversity (and assumed stability) in cropping systems is shown in the right hand side of Figure 1. The most diverse systems are those employing dozens of species in shifting cultivation or the 10- to 15-crop mixtures typical of the tropical forest zone of West Africa. The least genetically diverse are those of monoculture maize or wheat in temperate regions. The susceptibility of such monocultures to disease problems is illustrated by the Irish potato famine, and by the attack of Southern corn leaf blight in the U.S. (Adams et al., 1971). Having described this range of genetic diversity in cropping systems, what can we conclude about their sustainability?

Results which demonstrate stability in a statistical sense are difficult to find. Experiments in Colombia with maize and beans in 20 environments (Francis and Sanders, 1978), and in India with sorghum and pigeonpea in 94 environments (Rao and Willey, 1980), suggest that intercropped cereal/grain legume crops were more stable than monoculture. Table 1 shows both higher yields and lower coefficients of variation from the intercrops than from sole crops of the cereals and legumes (Smith and Francis, 1986). Data from many of the same sorghum/pigeonpea trials are shown graphically in Figure 2 (from Mead, 1986). All points above the line with slope 1.00 demonstrate overyielding by the intercrop system. Relative yield totals for the intercrop were determined by assuming a price ratio of 1.8:1 for pigeonpea/sorghum, the relevant ratio in India during the time of the experiments. From this scarce data, we can tentatively conclude that intercrops are more stable, and thus more potentially sustainable in a biological sense, than their contrasting sole crop alternatives.

Economic Sustainability

Potential economic stability or sustainability of cropping systems is even more difficult to predict or analyze than biological stability. In addition to the variable and unpredictable climate, factors such as input costs, prices received at harvest, interest rates and numerous other “externalities” to the farm become involved. Effects of the interactions of three factors (maize yields, bean yields, and relative price ratio of bean/maize) are shown in Figure 3. Three monocrop bean yield levels (4, 3 and 1.2 t/ha) and three intercrop bean yield levels (2, 1.2, and 0.4 t/ha) represent maximum experimental yields, average experimental yields, and average on-farm yields of climbing beans. Maize yields were the same in monoculture and intercropped with beans in these trials. Bean/maize price ratios from 1 to 8 were plotted, representing the range occurring in Latin America at the time of the trials. Net income was highest for monocrop beans at all price ratios above 3, assuming highest experimental yields; income was highest at all ratios above 4, assuming average experimental yields. When average on-farm yields were assumed, the intercrop advantage extended up to a price ratio of more than 7; this indicates a rational economic basis for limited resource farmers to continue with the intercrop system.

Further evidence of why farmers use intercrop systems is shown in the economic summary in Table 1 with the data from Colombia and India. With intercropped maize/bean, the probability of income greater than 0 is 0.92 and probability of income above CP10,000/ha is 0.73; these are higher than the corresponding probabilities with either monocrop. Intercropped sorghum/pigeonpea had probabilities of 1.00 and 0.66 of producing income greater than 250 Rs and 3,250 Rs/ha, respectively; both were higher than monocrops of the component species. Mead (1986) illustrated the economic risk of monocrop sorghum versus intercrop sorghum/pigeonpea in graphic form as shown in Figure 4; for example, if there is 0.5 probability of return from sorghum less than a specified level d', the corresponding probability of lower return from the intercrop would be less than 0.25. There is a critical need for more quantitative evaluation of risk involved with different types of technology intervention, both in monocrop and in intercrop systems.

Research Agenda for Sustainable Intercropping Systems

The concept of farming systems research described by Gilbert et al. (1980) has been widely implemented in one form or another during the past decade. This approach has been an attempt to resolve some of the irrelevancies of research recommendations which were listed by Collinson (1982); he maintains that current research results often are not applicable because:

- a prescriptive tradition of improved management practices passed from researcher to extension specialist to farmer often ignores the real constraints and farm to farm variation which characterizes limited resource farmers;

...
• an isolation of researchers on the experiment stations from their farmer clients makes it difficult to understand the real circumstances under which results will be applied; and

• a near-complete reliance by researchers on biological/grain yield per unit area rather than economic and other criteria used by farmers makes it difficult to communicate about “improved” systems and practices.

Success in the application of farming systems research methodology has been highly variable, often due to continued focus on the discipline-specific approaches brought to a project by team members. It has been difficult for scientists trained in specific subject matter areas to develop a concept of how their specialities fit into the total system. Yet an appreciation has developed about the complex nature of farming systems, and there is greater awareness of the difficulty of introducing single components of technology without considering the impact on the larger system. There is growing concern about the nutritional, social, and political implications of cropping system decisions.

This has provided an impact on the research agenda with regard to intercropping systems used by farmers. The more communication has improved between research personnel and those in the field, the greater the appreciation of what systems are being used and why farmers insist on preserving diversity of crops and income sources. This has broadened the perspective of the research community, and certainly accelerated the search for appropriate technologies for limited resource farmers (Francis, 1985). There has been a rapid increase in the number of journal publications on intercropping during the past decade. The interest shown by technical people at workshops and symposia has been even more spectacular, as shown by the number of special meetings organized by national programs and the international centres with focus on intercropping.

Some of the specific areas in sustainable agricultural systems where more research is needed have been listed by Miller (1988) as a result of a planning session in Raleigh, North Carolina. Since many of these are relevant to intercropping, the list of research priorities has been edited for presentation here:

1) alternative nutrient sources and nutrient cycling
   -- information base on legumes and organic wastes
   -- nutrient cycling processes and efficiencies
   -- role of rhizosphere and associated organisms

2) cropping systems research
   -- information base on rotations and practices
   -- tests of cover crops, tillage, chemical impacts
   -- intercropping alternatives

3) alternative weed control strategies
   -- cultural factor effect on competition and populations
   -- weed ecology and biology
   -- biological control of weeds

4) alternative disease and nematode management strategies
   -- effects of cultural practices on microorganism balance
   -- methods to favour indigenous antagonists and biocontrol
   -- improved genetic resistance/tolerance to pathogens

5) alternative insect management strategies
   -- ecology of cropping systems as they influence insects
   -- methods for cultural and biological control of insects
   -- improved genetic resistance/tolerance to insects
   -- understanding regional insect pest dynamics

Future research strategies for intercropping need to take into account information which is already available, both from the research stations and from farmers. There is a large body of knowledge on biological principles of crop growth and productivity, interaction with environmental factors, and stability of yield. Even though much of this has been developed in monoculture systems, there is direct application of most information to intercropping systems. Our challenge is to find out which of the information is relevant and how it can be applied efficiently. There is an even greater need to continue our emphasis on interdisciplinary research and on research/extension/farmer interaction to develop methods and systems which will help to improve productivity of intercropping systems. These are among the most important current issues relating intercropping to sustainability of food production systems.

References


Table 1. Yield stability of intercropping patterns based on multiple experiment analyses

<table>
<thead>
<tr>
<th>Cropping pattern</th>
<th>Yield kg/ha</th>
<th>CV</th>
<th>Total income CP/ha</th>
<th>CV</th>
<th>Probability of an income ≥ Y/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maize and climbing bean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize monoculture</td>
<td>4,986</td>
<td>23.6</td>
<td>1,944</td>
<td>242.5</td>
<td>0.65</td>
</tr>
<tr>
<td>Bean monoculture</td>
<td>2,941</td>
<td>29.4</td>
<td>16,061</td>
<td>88.2</td>
<td>0.80</td>
</tr>
<tr>
<td>Maize and beans</td>
<td>6,114</td>
<td>22.9</td>
<td>16,521</td>
<td>60.0</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>Sorghum and pigeon pea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum monoculture</td>
<td>3,208</td>
<td>47.0</td>
<td>3,208</td>
<td>-</td>
<td>0.95</td>
</tr>
<tr>
<td>Pigeon monoculture</td>
<td>1,446</td>
<td>42.7</td>
<td>2,892</td>
<td>-</td>
<td>0.91</td>
</tr>
<tr>
<td>Sorghum and pigeon pea</td>
<td>3,856</td>
<td>39.0</td>
<td>4,473</td>
<td>-</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Note: CV = coefficient of variation; Y = variable yield per hectare; Rs = Indian rupees; CP = Colombian pesos.

*a* Twenty-trial analysis in Colombia, 1975-78 (Francis and Sanders 1978).

*b* Ninety-four-trial analysis in India, 1972-78 (Rao and Willey 1980).
Figure 1. Spectrum of genetic diversity in natural ecosystems and cropping systems.

Figure 2. Bivariate plot of intercrop return against solecropped sorghum return for 51 experiments.

Source: S.P. Singh, All-India Coordinated Sorghum Improvement Project, unpublished data.
Figure 3. Net income from three cropping systems at different field bean/maize price ratios with different field bean yields.


Figure 4. Relative risk graph (risk of an intercrop yield return less than \( d \) plotted against the risk of a sorghum solecrop yield return less than the same value, \( d \).
Sustainability of Cereal-Legume Intercrops in Relation to Management of Soil Organic Matter and Nutrient Cycling

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Introduction

Objectives
Sustainability has become one of the major targets in farming systems research. Inter-crop combinations of cereals and legumes offer some obvious attractions as systems with potential for sustainability.

Sustainability in a farming system is characterised by high efficiency of internal resource use. In terms of the soil resource this can be achieved through conservation of soil organic matter (SOM) and efficient nutrient cycling. Whilst this may occur in natural systems, in agricultural cropping systems cultivation and the removal of regular harvests acts to deplete soil nutrient and SOM reserves. It is possible to supplement nutrients by addition of inorganic fertilisers to obtain a required level of yield, but the cost of such intervention to the small scale farmer is often unacceptable, particularly as fertiliser requirements rise. There can be no substitute for SOM, and continued cropping with little return of organic residues usually results in degradation of soil physical and chemical properties.

Inter-cropping represents a system whereby these losses can be reduced to some extent by the return of biomass to the soil. In the cereal/legume system such returns include green manure (or mulch) and/or residues (including roots) from the nitrogen fixing legume. The system therefore has the potential to conserve N, recycle nutrients and to preserve SOM.

It is our objective in this paper to review the potential of cereal-legume intercrops in this respect and in particular to suggest some research priorities for evaluating the potential for developing sustainable systems.

Sustainability as a framework for research
Sustainability in a farming system must be viewed in a holistic manner - not only in terms of internal (natural) resources but also with respect to market relations and other socio-economic requirements. Many definitions of sustainability have been given (see Francis, this volume) but the scientist will view sustainability primarily in productive terms. Dumanski (1984) has given a working definition in suggesting that 'sustainable production is measured not by total output in a short unit of time, but by the average output over an infinitely long time period (generations), which can be sustained without depleting the renewable resource on which production depends.' This immediately raises a number of important issues with respect to the measurement or assessment of sustainability.

a) The time scale. The concept of sustainability has an axiomatic time dimension to it, but we can immediately ask 'sustainable for how long?' Infinity is somewhat excessive but the target is scarcely worthwhile if only a few seasons are envisaged. We suggest that the time scale for assessment should be determined by climatic considerations. Many tropical climates, particularly at the drier end of the scale, are characterised by considerable inter-season variability. In many cases there is also a cyclical pattern with groups of wet years followed by groups of dry years. A sustainable system should be able to persist through the full range of such cycles.

b) Average yield versus yield variation. The concept of sustainability implies a notion of an 'equilibrium yield' (in its turn presumably implying a productive system in equilibrium). Aspirations to absolute maximum yields may be sacrificed in order to stabilise this equilibrium. The yield will nonetheless vary from season to season, but the concept of sustainable stable equilibrium assumes that the amplitude of oscillation will be small. This constrains with the much higher risk associated with maximal yield systems where 'boom or bust' responses may be seen in response to a fluctuating environment or economy.

The key assessment for sustainability is thus not 'what is the mean yield in an average year' but 'what is the extent of variation of yield in response to a typical range of fluctuation in the environment (or the economy) of the region'.

c) The concept of renewable resources. Odum (1984) distinguished between systems in terms of the extent to which they are externally controlled (e.g. by input regulation) as opposed to internal control by feedback mechanisms (Fig 1). Agricultural systems are typical extreme versions of the former case but a target of increased sustainability will include changing the system to greater internal control in such areas as nutrient cycling. We assume however that realistically the target will be to reduce input subsidy to a minimum - not to attempt to exclude it entirely.

These three components of Dumanski's (1984) definition have significant implications for the type of research necessary for assessment of sustainability.

Monitoring over long time periods of state variable change within the systems is essential to assessment of sustainability. Greater predictive value is likely to be achieved, however, from experimentation, in
which the response of key variables is assessed in relation to a range of treatments (stresses, perturbations) characteristic of the range of environmental and economic fluctuation to which it is likely to be subjected.

Selection of key variables moreover, should be directed more at internal regulatory processes rather than merely at output:input ratios.

In seeking to devise sustainable systems a word of caution may be extracted from the ecological literature. Holling (1973) has distinguished between 'stability' and 'resilience' as ecosystem characteristics which may have evolved under contrasting environments. Stability, characteristic of relatively constant environments, resembles the pattern of behaviour sought in our diagram of sustainability - a system which deviates little from an equilibrium (of for example production) in relation to a normal range of disturbance or stress. A resilient system may show very wide fluctuations however, but retains the capacity to recover even after extreme disturbance. The danger on selection for stability is that the extreme event (the 100 year drought or collapse of the economic subsidy system) can completely destroy the system.

Whether some degree of resilience should or could be built into sustainable agroecosystems is a matter worthy of some consideration.

In this paper we confine our discussion of soil fertility to nutrient cycling and SOM dynamics. Because of the N fixing ability of legumes, N has dominated research on nutrient cycling. The amount of N fixed and the distribution within the plant are consequently well documented. The fate of N in residues however is not so widely covered, whilst the study of dynamics of other nutrients within cereal-legume inter-crop systems has been largely ignored. Other aspects of soil fertility, such as soil physical structure and water regimes, are equally worthy of discussion but space does not permit.

**Nutrient Cycling**

Ofori and Stern (1987) have reviewed aspects of nutrient cycling in cereal-legume inter-crops. Fig 2 illustrates some of the major flux pathways for N in the plant-soil system of a cereal-legume intercrop. The focus on biologically-mediated processes is in accord with the conclusions of the preceding discussion on research needs into sustainability, i.e. it emphasises the need to consider the modes of internal regulation.

**Nitrogen budget**

Although study of specific flux processes will give the greatest insight into the way in which sustainability of soil fertility can be achieved, nutrient budgeting establishes an essential quantitative framework. Ofori, Pate and Stern (1987) working in South Australia on irrigated systems, drew up an N budget for a maize/cowpea intercrop which included above-ground seed yields, return of residues and inputs of fixed and fertiliser N, but did not account for losses of N through leaching, denitrification or volatilisation; there was also no measurement of N in root biomass. In the absence of fertiliser they found that the amount of N fixed in above-ground biomass of cowpea balanced with the amount of N removed in cowpea seed. Thus with the removal of N in maize seed, the system was in deficit (Fig 3). Considering the contribution of N from root biomass by decay and nodule slough they used Peoples et al. (1983) estimate of 12% N in below ground parts of mature cowpea and found this relieved the N deficit but did not remove it. As the cowpea received only 53-69% of its N from N₂ fixation, the remaining N requirement must have come from soil reserves.

Harvesting of cereal grains results in large losses of nutrients, particularly N, from the system. Cereal residue is often removed from fields and this may also need to be considered in nutrient budgets. Such residues are known to contain high amounts of N, P and K (e.g. 90% of plant K in sorghum, Poulain 1980) which could make a significant contribution to the nutrient cycle. Yamoah et al (1986) also found that when using prunings of Flemingia and Cassia to achieve optimum maize yields in an agroforestry system, external sources of N were required, although N remaining in Cassia prunings after maize harvest was high.

N-fixation is potentially the major source of N in inter-crop systems. The amount of N fixed by legumes depends on the species and cultivar used; the number of nodules; their size, longevity and bacterial strains; the conditions of growth and management of the crop; soil available water and soil nutrient status. Legumes can have specific soil requirements which must be satisfied before they can nodulate. Many legumes do not nodulate for the whole season and the longevity of nodulation is greatly influenced by soil moisture, with nodule shedding resulting when soil water deficits occur. The amounts of N fixed thus vary greatly and figures presented by Nutman (1976) show that many tropical herbaceous legumes have great potential in this respect (e.g. cowpea 73-354, chickpea 103, groundnut 72-124, pigeon-pea 168-208 and soyabean 55-168 kg/ha).

It is clear however that not all legume crops fixing N will enrich the soil. There is a tendency for grain legumes to reduce soil N and legumes grown for leaf to increase
it. Indeed only rarely will a legume intercrop be grown solely as a soil ameliorant - instead it is favoured for grain and/or fodder and these products are removed with a resulting loss of nutrients from the system. The distribution of N within a legume can vary with species and cultivar and with the stage of plant development. Minchin et al. (1978) found that 48-65% of total plant N occurs in the seeds of four cowpea cultivars; harvesting of legume grain therefore has important implications for the N budget. In contrast only 5-6% N has been found to occur in roots and nodules (Minchin et al. 1978) while Peoples et al. (1983) found that 12% of final N of mature cowpea plants was recovered in below-ground parts. Russell (1973) reports 90% of N from the nodules of peas and vetches was transferred to the tops before the plant died but that subtropical summer forage legumes such as velvet beans, lespedza and kudzu retain 20-30% fixed N in their roots. The contribution of root residues to N enrichment of soil may therefore be highly variable and both species and site specific. It has been suggested that if fodder cowpea was harvested at the stage of maximum noduleation this could result in all fixed N being left in the soil (Singh 1983) although presumably at the expense of the fodder quality. Eaglesham et al. (1982) observed that estimates of actual amounts of N fixed can be deceptive. They showed that although soyabean fixed more N than cowpea, soyabean caused a greater net N depletion because of sequestering a greater fraction of N in the grain.

Work to date has concentrated on N but other nutrients need consideration. The budgets of other nutrients are not augmented like that of N by fixation, consequently a greater deficit of these might be expected within an intercropping system without fertiliser additions. Most workers agree that intercropped mixtures extract more nutrients from the soil than a single stand (Agboola 1980) and experiments at Ibadan University have confirmed the high rates of K and N removal in inter-crops. This increased nutrient consumption makes soil fertiliser evaluation complicated.

**Direct intercrop transfer of nutrients**

According to Reddy et al. (1983) the benefits of a legume intercrop, with respect to N, are direct transfer of N from legume to cereal during the current inter-crop, as well as the residual effects when fixed N becomes available to rely on sequential crops after senescence of the legume and decomposition of residues. It has been suggested that direct transfer occurs by excretion of N from legume nodules representing an immediate source of N to the cereal. This is however controversial and needs clarification (Willey 1979). Eaglesham et al. 1981 demonstrated some transfer of fixed N from cowpea to maize using $^{15}$N but Reddy et al. (1983) could not detect transfer from groundnut to an associated crop. Transfer of other nutrients such as P might occur by mycorrhizal ‘bridges’ (Newman 1989).

**Decomposition of crop residues**

The main pathway of conservation of nutrients is through the return and decomposition of crop residues. Crop residues also represent a major resource for the small scale farmer. Manipulation of the fate of the nutrient released by residue decomposition is thus a target for improving the nutrient use efficiency of cropping systems.

The rate of decomposition is regulated by two categories of factor; the physico-chemical environment (P) and the intrinsic character of the residue, i.e. its resource quality (Q). In tropical climates the temperature is generally favourable to high rates of decomposition and soil moisture availability is the key P determinant. In seasonal environments in the tropics the wetting of residues on or in the soil is the usual trigger initiating decomposition. Periods of within-season drought may slow or halt these two processes of decay and nutrient release but generally speaking the rate of these two processes will, from this point on, be related to the quality of the residue.

Characteristics contributing to high-Q (and thus fast decay and nutrient release) are high content of N and other nutrients and of readily metabolised sugars and low content of lignin, polyphenols and other biostatic or recalcitrant compounds (Swift, Heal and Anderson 1979). Figure 4 shows the pattern of decomposition of two types of cowpea residue.

This demonstrates that whilst nutrient release patterns often follow decomposition rates, they may differ markedly for high and low quality resources. In high-Q resources release may occur very early by a combination both of leaching and mineralisation by microbial activity. In low-Q resources however nutrient is usually immobilised in microbial tissues and only released later in the time course of decay. Low-Q resources may indeed starve the surrounding site by uptake and immobilisation of N by the decomposer organisms. The timing of nutrient release may be predicted by either the C:N ratio or the lignin:N ratio (Swift et al. 1979; Berg and Staff 1981; Melillo et al. 1983).

The main biomass returned to the soil in the inter-cropping system will be legume leaves (green manure or mulch) or true residues (stalks, stems, whole plant) following senescence, together with the roots of both legumes and cereals. Above ground cereal residues may also be returned but are often removed for other uses.
Generally legumes are considered a high quality residue in that they have a high N and low lignin content and as such may be expected to decompose rapidly. However the maturity of the legume leaf is also known to affect its resource quality with older leaves being of lower quality. Also the N content of different components of the legume plant is known to change through the season.

Information on rates of decomposition of legume residues is not abundant. Attention is focussed towards the root residues as it has been considered that mineralisation of root residues and sloughed off nodules from N fixing plants contribute most to soil available N (Trimble and Shapton 1937, quoted by Walker et al 1954; Agboola and Fayemi 1972; Ruschel et al 1979). As discussed in section 2.1 the N content of roots is not always high and so rates of decomposition are variable. Russell (1973) observed that plants with extensive root systems, such as lucerns and clovers, which are continually sending out new roots leave more N in the soil than crops with restricted root systems, such as peas and beans.

Pandey and Pendleton (1986) found that the decomposition of soyabean green manure occurred rapidly and N became available in soil 7-10 days after incorporation. Yamash et al (1986) determined rates of decomposition of Gliricidia, Flemingia and Cassia in agroforestry systems and found that the former decayed completely in 120 days and released all or most of its N for crop use, whereas the latter two decayed more slowly. Kang et al (1981) reported a very rapid decomposition of Leucaena leaves due to their low C/N ratio. Nnadi and Balaubaraman (1978) observed that N content and the rate and amount of mineralisation of tropical grain legumes varies among species and even cultivars.

The contribution of cereal residues needs consideration, since although stalks (stover) may be removed or returned, roots are always left in the soil. Above ground cereal residues represent low resource quality material and are only available at the end of the season when soil moisture is limiting. Their decay rate is low and there is a tendency to immobilise nutrients. Nutrient release is therefore only likely to occur in the succeeding season.

Mixtures of cereal and legume residues should decompose at intermediate rates but there seem to have been no experiments investigating this.

Partitioning of nutrient released during decomposition
N and other nutrients released during the decomposition of crop residues are partitioned between a number of pathways (Fig 2). The balance between these pathways is the key to regulation of the nutrient use efficiency of the system. These include:

a. Entry to the soil mineral pool and direct uptake by the plant (Fig 2, fluxes 3 and 8)

b. Retention in the soil during synthesis of soil organic matter (Fig 2, fluxes 3 and 4); or, in the case of cations, on the exchange coloids; the latter is dependent of the presence of SOM, except in the case of soils with a significant component of active clay fraction

c. Losses from the soil through leaching (particularly prevalent for anions such as $\text{NO}_3^-$), denitrification or volatilisation (Fig 2, fluxes 5, 6 and 7). The extent of these losses varies greatly and is affected both by soil conditions (moisture content, pH etc) but also by the 'competition' with the other pathways above; these aspects have been discussed for tropical soils by Grimme and Juo (1985) but most of our information still comes from temperate zone studies.

Clearly the target of an effective system of soil management is to maximise return of nutrient to the plants via pathways (a) and (b) and to minimise (c). This is the basis of the discussion of the remaining sections.

Soil Organic Matter Dynamics

The key role of SOM in maintaining soil fertility needs no emphasis. The amount of SOM in the soil is a balance between the rate of synthesis and the rate of decomposition. Conversion of land to agriculture usually leads to a decline in the equilibrium level of SOM due to a decrease in the former (as a result of decreased organic input) and an increase in the latter (largely due to tillage operations).

The retention of organic residues offers a means of retaining or re-establishing a higher SOM equilibrium. SOM is synthesised as a by-product of the decomposition of crop residues. A proportion of the C and N of the residues is by this means retained in the soil (Fig 5, Ladd and Amato 1985). These workers followed the decomposition over 8 years of a mixture of tops and roots of *Medicago littoralis* (C:N, 15:1) incorporated at a field site in South Australia. They reported that 30% of legume $^{14}\text{C}$ remained in the soil as organic residue after 0.3 years declining to 11% after 8 years. Net mineralisation of legume N occurred concurrently but after 0.3 years, two thirds of N remained in the soil as organic residue, declining to one third after 8 years.

The fraction of SOM formed may be relatively constant for materials of similar quality, but the time scale may differ in different climates (Fig
SOM is not a homogeneous material; the nutrient cycling model shown in Fig 2 divides it into four fractions with differing rates of turnover (and hence of nutrient release by mineralisation). The active pool is subdivided into live microbial biomass and a variety of relatively easily metabolised materials such as dead microbial cells and extracellular microbial products with short turnover times. Most of the immediate source of nutrient is obtained from this pool. The other two pools are both chemically more recalcitrant and physically more protected (e.g. by clay). Most models of soil nutrient dynamics agree on the inclusion of these pools although details may vary (e.g. Jenkinson and Rayner 1977; Parton et al 1987; Van Veen, Ladd and Friesel 1984; Paul and Juma 1981). Fig 5b shows the proportion of C and N entering microbial biomass and its rate of turnover relative to the less active pools as illustrated by the experiments of Ladd and Amato (1985) referred to previously.

Van Faassen and Smilde (1986) argue that sustainability may be disrupted if there is too much reliance on active SOM to provide immediate soil fertility. The higher the relative contribution of active SOM to nutrient flow, the greater and faster the loss in soil fertility when supplies of fresh organic material are neglected. They imply that active SOM is in this respect analogous to inorganic fertiliser in behavior i.e. that interruptions in supply will upset the system. The importance of the less active SOM fraction is therefore apparent and of considerable importance to the target of sustainability. This has been illustrated by Kang and Duguma (1985) who point out that, where agroforestry prunings help build up stable SOM fractions, an overall improvement of soil productivity results.

**Nutrient Use Efficiency**

A number of models have been developed which formulate the interactive nature of the factors determining the efficiency of nutrient supply to plants. Although a great variety of factors influence the flow of nutrient to plants fundamentally the problem resolves into a synchronisation in time and space of the demand of the plant for nutrients with the supply of those nutrients by the soil system. Sources of information for cereal nutrient demand over the season are good and demand curves can be readily modelled (Fig 6). The uptake of minerals varies with both species and cultivar as demonstrated by Poulain (1980), but nutrient acquisition is usually more rapid than dry weight increase.

Nutrient supply represents a combination of availability from both residue decomposition and SOM mineralisation. McGill and Myers (1987) have pictured soil mineralisation capacity in a simple way by a soil moisture times temperature predictor, comparing it with plant demand as simulated by relative growth (Fig 6). They predict that in some environments synchrony in time will be relatively good (Fig 6a) but others may be characterised by a marked asynchrony (Fig 6b). The situation in reality is likely to be more complex than this. For instance the N released from high Q residues may provide a benefit by immediate synchronisation with demand, or by replenishing the SOM pool in such a way as to boost the availability in later seasons.

Nutrient release from organic residues may have three fates:

a. Nutrients released during the current inter-crop giving immediate benefit to the cereal crop. This is most likely to occur where decomposition is rapid from high resource quality inputs. For example prunings with high N content in agroforestry systems provide a nutrient resource for current crops (Yamoah et al 1986, Kang et al 1981). Nutrient release from residue decay at senescence is, however, less likely to benefit an associated cereal crop both because of delayed input and lower-Q.

b. Nutrients available to relay or sequential crops. There is evidence that benefits from legumes may be greater for cereals in a succeeding season than for current season cereals. Singh (1983) demonstrated an increase in yield and N uptake in wheat which followed a legume inter-crop reducing the need for inorganic N by 30-84 kg/ha. Agboola and Fayemi (1972) found that cowpea and calgo did not benefit an early maize crop but acted as an important source of N for later crops, possibly as a result of root decay and nodule slough. They suggested that legumes cannot benefit associated crops during the same growth period. It is possible however that short season legumes can transfer N to an associated longer season crop through mineralisation of dead roots.
c. Slow sustained release after conversion to SOM-N. Ladd and Amato (1985) report on experiments which demonstrate this in a rotational system. They estimated recoveries of 14N from the legume M. littoralis, residues of which were left to decompose for 5-8 months before sowing with wheat. The total recovery (crops plus soil) of applied N generally exceeded 90%, but the majority of residue-N recovered in soil after wheat cropping was in SOM. A common feature of their experiments was that, irrespective of wheat yields, the N released from decomposing legume (M. littoralis) residues constituted only a minor fraction of the available N pool. Their figures show that 50kg of applied legume N contributes only 10% of the N in the first wheat crop and the availability of N is halved for the succeeding wheat crops. Despite the high total recoveries demonstrated, N from residues contributed only a minor percentage to the available N pool. They conclude that the main value of legumes in rotations (and presumably in inter-crops) lies in their ability to maintain or increase soil organic N.

The efficiency of nutrient transfer by these pathways and the synchrony of nutrient release with plant demand, are affected by a variety of factors:

a. The proximity of cereal roots to nutrient source;

b. Plant use efficiency (it cannot be assumed that a cereal can utilise all available nutrients, for instance Kang et al (1981) state that even though large quantities of N can be harvested in Leucaena prunings, the efficiency of utilisation of that N by maize is low compared to from N fertilizer);

c. The susceptibility of the system to nutrient loss by leaching, denitrification, volatilisation or erosion. (These are influenced by prevailing rainfall and soil conditions; if nutrient release coincides with rain, large losses of nutrients might result, particularly if soil conditions which promote leaching, prevail);

d. The capacity of soil to store nutrients (clay and organic colloids provide exchange sites and can retain released nutrients and microbial biomass).

Management of Soil Fertility

We attempt to show here how the principles outlined above can be manipulated by management practices in order to achieve two targets: improved nutrient use efficiency and higher SOM status. Management recommendations must be practicable and lie within the reach of the small-scale farmer. We concentrate on three possible practices; manipulation of crop residues; tillage; and utilisation of fertiliser inputs.

It has been shown above that nutrient release from legume manures or residues can benefit both associated and sequential crops. Whether these two types of benefit are exclusive has not been considered. The residual benefit may be due to delayed release of available nutrients from slowly decomposing residues or to efficient retention in the soil of earlier released nutrients. With an understanding of these nutrient release processes and their controlling factors, it should be possible to manipulate these processes through management with an aim to better synchronise nutrient release with plant demand, thereby improving the efficiency of nutrient cycling. Table 1 outlines some of the potential management options together with the variables affecting and determining the practice and the outcome. These options can be reduced to the following; the type of organic input utilised; the timing of its application; the state and form in which it is incorporated (e.g. moisture content and particle size); and its location on or in the soil. The latter two aspects are determined by tillage practice, the former by the range of residues available.

Residue type and state

The amount and type of biomass returned to the soil in the intercropping system will be dictated by the choice of crops i.e. by the harvest requirements of the system. Ideally all 'non-harvest' plant components should be available for return to the soil. This is often not the case, however, for example in areas where there is a firewood shortage, as in the Mossi plateau, Upper Volta, residues are used for fuel (Sedogo 1981). There is also a demand in many parts of the world for residues for animal feed e.g. stems of groundnuts and cowpeas are used for feed in the Sudano-Sahelian region (Gigou et al 1985), maize stover in Zimbabwe (Swift et al 1989). Other losses of residue might include use for construction; residue quality may also be changed by additional management practices such as composting or burning.

We cannot therefore assume that all residues from the inter-crop system are available for return to the soil. The residues produced from the system will include legume leaves (as green manure or mulch) and/or legume true residues which are stalks, stems, whole plants and roots which are available following plant senescence. Cereal residues might include stalks, husks and roots. Nutrient which is removed from residues may however be returned as manure or after composting.
From the discussion of decomposition rates above it is clear that the high N/low lignin resources typical of legume systems can provide rapid release N and this may synchronise with peak plant demand. As with fertiliser, however, a single readily available input may be inefficiently utilised and subject to losses through leaching with nutrient deficits resulting later in the growth period.

The value of low quality resources may be in the provision of a slow but sustained supply of nutrients which will enrich the soil and benefit sequential and succeeding crops. When residue quality is low, the decomposer microorganisms themselves assimilate the released nutrients (and when these are insufficient will also use existing soil nutrients) thereby temporarily removing them from the system. In effect, this can act as a store since the nutrients are released again once decomposition ceases and the microbial biomass decays. By controlling immobilisation, through manipulation of the quality of the input, the release of nutrients might be regulated. The advantages of this might be seen in storing nutrients from the end of one season to the beginning of the next.

Immobilisation increases the labile pool of SOM (by increasing the microbial biomass) and so transfers mineralisation and nutrient control to this pool. Van Faassen and Smilde (1985) calculated that for annual sorghum residues it can take almost a year before net immobilisation of mineral N turns to net mineralisation. In contrast, the immobilisation period was just one month following annual additions of cotton residues with lower C:N.

This highlights the potential value of mixed residues. Combinations of high and low quality resources should enable the timing of nutrient release to be regulated and so provide both immediate and sustained nutrient supplies. The interaction between the residues in terms of mineralisation and immobilisation, decomposition and SOM synthesis can also be manipulated to influence the nutrient storage capacity of the soil.

The pattern of nutrient release from the residue will also depend on its state and form at the time of utilisation. Some features of this have already been mentioned, the age of the residue, the potential for mixing, precomposting or manure conversion. Each of these alters the Q and thence the nutrient release pattern. The rate of decay can also be influenced by the residue moisture content at the time of incorporation irrespective of soil moisture status. Read (1982) in a study investigating the effect of placement of Leucaena pruning on decomposition rate showed that dried prunings had a longer half life than fresh prunings whether buried or applied on the surface (Fig 7). Nonetheless he could find no difference in maize yield from application of fresh compared to dry material.

The size of the particles at incorporation will also affect the rate of decay. This may be particularly important for low-Q resources. Thus maize stover that has been chopped up or milled will have a quite different decomposition pattern to whole stems. This may not be a particularly viable option because of the labour cost but it applies in particular to roots where the system of tillage will affect the size of the root residues as well as their location.

Timing of residue input
The requirement to synchronise nutrient release with plant demand is too simple, since plant demand will change through the growth period. It is important therefore to provide sustained nutrient release for the whole growth period but also to anticipate the occasions for peak demand. The principles of fertiliser use might be drawn upon here.

Timing of inputs for sustained improvement requires detailed investigation for prediction of maximum benefits. The timing of inputs (to achieve synchrony) within a current season will be dictated to a large extent by legume growth periods and whether they can provide a green manure of benefit to the cereal. Timing of inputs can be more flexible in agroforestry systems, although often pruning is done to reduce shade rather than provide nutrients. Yamoah et al (1986) found that a single application of Gliricidia prunings was insufficient to meet maize N requirements for the season. A second pruning, 66 days after planting was necessary to meet the requirement. Storage of green manure or prunings in a dry state might be considered as an option, as can composting of single or mixed residues.

Soil moisture conditions are known to influence decomposition rates. Timing of inputs should therefore be related to the moisture conditions. If irrigation is available manipulation of moisture as a management practice for residues as well as for crops is possible.

Location
Manipulating the spatial distribution of residues may represent an easy and effective management option for regulating nutrient release. Residues ploughed in decompose more rapidly than those left on the surface. Fresh Leucaena prunings were shown by Read (1982) to have their half-life reduced by 50% when buried as compared with decay at the surface (Fig 7). Deep incorporation may however displace residues from the root zone of early growth and thus result in a dislocation of demand and supply.

Use of fertilisers
Although priority should be given to increasing the efficiency of intercrop systems by using the potential of fixed N, it is evident that
fertilisers do have a complementary role in the system in meeting the nutrient deficits, as demonstrated by Ofori, Pate and Stern (1987). Work has concentrated on determining the minimum fertiliser rates required to achieve optimum cereal yields in inter-cropping systems (Pandey and Pendleton 1986; Nair et al. 1979). One phenomenon of N fertiliser use in cereal-legume intercrops is the apparent suppression of nodulation at high N levels. Rao et al. (1987) recorded suppression of legume yields with increasing N fertiliser. Eaglesham et al. (1982) report that although there are benefits from cowpea and soyabean at low mineral N, no benefit occurs at high mineral N levels due to inhibition of nodulation. Eaglesham et al. (1981) also conclude that N excretion from the legume only gives significant benefit to associated crops in conditions of low N.

In some cases however nitrate fertilisers were found to increase both nodulation and yield. Ezedinma (1964) demonstrated this for cowpeas in Nigeria. Evidently there is a need to establish under what conditions high N levels suppress nodulation and to determine a threshold at which this occurs. A balance needs to be obtained between this threshold and the advantages of fertiliser N applications in relieving the N deficits discussed in Section 2.1.

Whilst fertilisers may be seen in terms of their immediate benefits to crops, a greater efficiency of return may be achieved by interaction with residues. Low-Q residues will tend to immobilise fertilisers and prevent massive losses associated with early, unsynchronised, application. This combination with the residues may act to accelerate decomposition by stimulating decomposer organisms.

Research Priorities

Research targeted on the development of sustainable systems must clearly involve some long term monitoring. The choice of variables for such monitoring should go beyond those of yield and also focus on key processes regulating the stability of nutrient cycling and other system properties. The Tropical Soil Biology and Fertility Programme (TSBF) has made proposals for 'minimum data sets' of such variables (Swift 1987; Anderson and Ingram 1989).

More rapid insights to the potential for sustainability may be gained from experimental studies. It is suggested that the selection of experimental designs be based on the answers to two questions:

1. What are the key determinants (processes or variables) of sustainability?
2. How do these determinants respond to stress or disturbance?

The answers to these questions and the selection of a research agenda will, to a considerable degree, be site and system specific but, with relation to the role of soil fertility in sustainability, the following are proposed as a guideline to potential contributions:

1. The essence of sustainability is to attain a high efficiency of nutrient cycling and conservation of SOM. This cannot be achieved by concentration on the short-term fate of applied or fixed-N. There is a need to develop management systems which provide nutrient both for immediate requirements and for long-term stability.
2. There is however little understanding of soil processes involved in yield promotion. There is a need to divert the focus of research away from continuous empirical trials to investigations of mechanisms.

3. The potential for managing processes such as decomposition by manipulation of the timing, state, type and amount of residues should be given high priorities e.g. by investigation of:
   a. Value of legume leaf materials for green manure as a function of species, cultivar, time of harvesting etc.
   b. Value of legume root residues as a function of N content at time of harvesting, maximum nodulation, etc.
   c. Rates of residue decomposition as a function of residue quality, methods and place of application, size etc.
   d. Value of legume and cereal residues both alone and in mixes, both in terms of immediate returns to plants and in improving SOM status.
   e. Products of decomposition; pathways of nutrient release to available N, unavailable N, lost N, immobilisation.
   f. Products of decomposition; SOM pools, SOM as a nutrient reserve.

4. Investigation of 2 and 3 above provides the mechanistic background for developing predictive models and practical recommendations for improving nutrient use efficiency by synchronising nutrient release and plant uptake. For example by optimum combinations or type of residues; optimum timing and method of application; optimum soil conditions (particularly moisture); optimum fertiliser applications; optimum length of cereal and legume seasons; optimum harvesting regimes.
5. Factors affecting N losses from soil.

6. Direct transfer of nutrient from legume to cereal roots.

7. Role of inorganic fertilisers in meeting budget deficits but not suppressing nodulation.

8. Role of SOM in promotion of soil physical properties; and water regimes.

9. Role of soil fauna in regulating residue decomposition and soil physical structure.

Whilst the state of understanding of the regulation of nutrient cycling in intercrop systems still requires a good deal of improvement by means of fundamental research this does not obviate the potential for the trial of potential management options for sustainable soil fertility as outlined in the section on Management of Soil Fertility. The TSBF programme has advocated a dual approach to soil fertility studies (Fig 8) involving both 'strategic' (fundamental) and 'target' (management orientated) research. The utilisation of mechanistic simulation models, and ultimately of knowledge based ('expert') systems provides a means of rapidly generalizing from these research initiatives (see also Thornton's paper in this volume). Such a research programme is essentially multi-disciplinary and holistic in approach and combines both on-station and on-farm research. We believe that an integrated research agenda of this type is essential for the development of a predictive understanding of sustainability issues.

References


### Table 1. Factors regulating amount and timing of nutrient release and potential management options

<table>
<thead>
<tr>
<th>Target variable</th>
<th>Controlling variable</th>
<th>Modifying variables</th>
<th>Management options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition rate</td>
<td>Resource Q</td>
<td>Species/cultivar, Plant parts returned, Fresh or dry, Maturity</td>
<td>High RQ-quick release, Low RQ-slow release, Mixed residues, Store residues</td>
</tr>
<tr>
<td></td>
<td>Soil moisture, Soil temperature</td>
<td>Climate, Availability of irrigation</td>
<td>Moisten soil or synchronise application when moist</td>
</tr>
<tr>
<td></td>
<td>Method of incorporation</td>
<td>Tillage practice</td>
<td>Incorporate or leave on surface</td>
</tr>
<tr>
<td>Timing of residue input</td>
<td>Species/cultivar</td>
<td>Residues available</td>
<td>Green manure available before residues</td>
</tr>
<tr>
<td></td>
<td>Planting dates</td>
<td>Climate, Species/cultivars</td>
<td>Organise legume planting date so residues available at most appropriate time</td>
</tr>
<tr>
<td>Immobilisation</td>
<td>RQ, C: N microbial biomass, Soil fertility</td>
<td>Residues available</td>
<td>Where low RQ use fertilizer N to prevent immobilisation or use immobilisation as storage system</td>
</tr>
</tbody>
</table>
Figure 1. Internal and external control of natural and agro-ecosystems.

Note: Regulation of nutrient cycling and other processes in natural and agricultural ecosystems. Regulation in the natural ecosystem is internal by a process of feedback between components such as the plant and decomposition subsystems. In agricultural systems internal feedback regulation is largely lost, being replaced by control through management manipulations, including those of input and output (modified from Odum, 1984).

Figure 2. Major pathways of nitrogen flux in the plant-litter-soil system of a cereal-legume intercrop.
No added fertiliser N-(NA experiment)

Above-ground residues returned to soil

Harvested as seed

Cowpea 60.2
Maize 46.4

Fixed from atmosphere

Cowpea 58.8

Cowpea 89.5
Maize 65.9

Total in shoots

Cowpea 30.7
Maize 65.9

Net balance in soil from cropping system

-47.8

Fertiliser N added (25 kg N/ha) - (NL experiment)

Above-ground residues returned to soil

Harvested as seed

Cowpea 68.0
Maize 50.8

Fixed from atmosphere

Cowpea 73.0

Cowpea 107.9
Maize 87.6

Total in shoots

Cowpea 39.9
Maize 27.8

Net balance in soil from cropping system

-29.8

Applied as fertiliser

Cowpea 1.8
Maize 4.6

Uptake from fertiliser

Cowpea 33.1
Maize 83.0

Uptake from soil

Unused fertiliser

19.6

Figure 3. Nitrogen budgets for maize/cowpea intercrops without (NA) or with (NL) added nitrogenous fertiliser (kg N ha⁻¹) (Otori, Pate, and Stern 1987).
Figure 4. Nutrient dynamics during decomposition of crop residues. The pattern of weight and nitrogen loss is shown for residues of high (leaf) and low (stem) resource quality for a cowpea (*Vigna unguiculata*) crop at Ibadan, Nigeria (Swift, unpublished data).

Figure 5a. Decomposition of isotope-labelled material in soils located in contrasting climatic regions. The diagram shows the residual C and N incorporated into SOM after the initial rapid period of decomposition (Ladd and Amato 1985).

Figure 5b. Formation and decline of isotope-labelled biomass C and N during the decomposition of 14C, 15N-labelled plant material (Ladd and Amato 1985).
Figure 6a. Synchrony of soil mineralisation (Moisture x Temperature Index) compared to relative crop growth (yield) for wheat at Hyderabad in the semi-arid tropics (McGill and Myers 1987).

Figure 6b. Asynchrony of soil mineralisation (Moisture x Temperature Index) compared to relative crop growth (yield) for wheat at Narayen in the Darling Down of Queensland, Australia (McGill and Myers 1987).

Figure 7. Decomposition of fresh and dry leucaena prunings applied as mulch or buried in soil with time (Read 1982).

Figure 8. Components of an integrated approach to research on soil fertility.
Bunda College of Agriculture, University of Malawi

College faculty are charged with the responsibility of implementing the National Bean Research Program. The National Bean Program is coordinated through the National Agricultural Research Council. The research strategy being followed seems to be somewhat isolated from the rest of the research system and from the needs of farmers.

Through discussions among workshop participants and researchers two important issues surfaced. The first is in relation to the seed industry and the second relates to the linkage between research and extension.

Some of the problems in the seed industry are: a) breeder seed is given free of charge to the seed producing agency, b) arbitrary pricing policy, c) un-restricted export while the internal demand is not met, and d) seed target clientele is not well identified, that is, seed is not directed to the areas to which the variety is adapted. These problems impose serious constraints to the adoption of improved varieties.

Although informal communication channels exist between research and extension, there was no evidence of well established mechanisms that allow a rapid and continuous flow of information to the farmer. Again, the approach/strategy being followed imposes constraints to the adoption of new technology.

In the experimental plots at Bunda College, participants saw trials of maize/bean intercropping and bean breeding.

Q. It was observed that climbing beans were staked in pure stand while that was not a practice of the farmer.

A. True, what was being done here was not practised by the farmer. Farmers usually grow climbing beans with maize.

Q. Participants were informed that local collections of bean landraces were obtained from farmers and these were used in selection for high yields, and adaptability over a wide range of environments. The question that then arose was, why should bean landraces which the farmer had selected for specific adaptability be screened for wide adaptability?

A. These landraces were selected for higher yields and other traits such as pest and disease resistance.

Q. What was the mechanism of release for superior varieties?

A. After screening for three seasons over several locations, those varieties suitable for release were handed over to a variety release committee. The varieties were given to the Seed Company of Malawi for multiplication for sale, but the price of certified seed was found to be very high and hence it did not benefit the farmers.

As an alternative, farmers were contracted to multiply seed themselves which they sold to the farmers cooperative for marketing at acceptable prices.

Q. The team noticed that unlike in most maize/bean intercropping agronomy and breeding trials, there was a very low level of pest incidence; a situation very unlikely in the farmers fields. What was the reason for this low level of pest incidence?

A. Pest incidence levels varied throughout the growing season and at the time of this visit the pest incidence levels were low (no control measures had been taken).
Q. What types of beans did farmers grow?

A. The type of beans grown by farmers were very much dictated by market prices where mixtures fetched lower prices than pure lines.

**Adaptive Research Trial in Farmers Field**

The team was received by WCC Mughogho, agronomist with the Lilongwe Adaptive Research Team and the farmer Mr G. Kalungwe. Mr Mughogho indicated that beans were not very adapted to the Lilongwe Plains so the on-farm trials also included maize/soybean intercropping. There was another reason for the choice of soybean. It was noticed that in this area, many children were malnourished and the soybean was expected to improve the protein intake of these children. The soybean was also a source of livestock feed. The trial was at the third season of evaluation.

The team was informed that intercropping was popular with farmers because of land and labour scarcity. Maize/legume intercropping was done such that the maize yields were not significantly reduced by the legume association.

Discussions whilst visiting this on-farm trial indicated that there may be little relation between the research being carried out and what may be the real problems faced by the farmers. Some participants expressed concern in the way on-farm research objectives appear to be set and the criteria used to establish them. However, most discussion just covered the one trial visited: other participants thought that the on-farm research was well targeted and the objectives well set.

Q. Was weeding done by the farmer and if so how was it ensured that weeding was done uniformly and as quickly as possible?

A. The adaptive team explained to the farmer the need for proper management of the trial (e.g. weeding to be as uniform as possible and done within a short time). Results from the trial had shown little variation within site but large differences between sites.

Q. Why did the farmer plant one bean/hill?

A. The farmer said he did not have enough seed otherwise he would normally plant three seeds/hill.

Q. Out of the total farm area, how much was devoted to sole maize and how much to maize-bean intercrops?

A. Three acres were devoted to sole maize and one acre to a maize-bean intercrop.

Q. Why was only one acre intercropped?

A. The farmer said that his other pieces of land gave low yields of beans.

The team was informed by the adaptive researchers that the farmer used to grow pure stands of maize and legumes but due to influence from agricultural workers, he had adopted intercropping.

Q. Why was the intercrop trial on the station fertilized especially after groundnuts? Maize hybrid yields on the station were reported to be high (approx. 8 t/ha) while the farmers average was 1.2 t/ha.

A. The on station trial was a control and the trial was replicated outside the station on several farmers fields where farmers used some fertilizer.

Q. How popular are your maize hybrids with the farmers?

A. The hybrids are very popular with farmers but there has been a constraint in the supply of hybrid seed. The station breeds maize hybrids, composites and synthetics.

**Visit to Chitedze Research Station**

Dr P. Sibale, Head of Chitedze Station, gave a brief introduction of the station, its soils, rainfall and temperature data and research work being done there. The planting pattern on the station was organized around a rotation of groundnuts and maize.

All workshop participants were favourably impressed by the facilities, organization and management of Chitedze Research Station. All the trials visited were well managed.

Through discussions among participants and station researchers it became evident that there is little coordination among maize scientists and bean scientists, resulting in what some participants labeled as the “trivial pursuit approach” in solving problems faced by farmers who practice maize and bean intercropping.

Q. Why was the intercrop trial on the station fertilized especially after groundnuts? Maize hybrid yields on the station were reported to be high (approx. 8 t/ha) while the farmers average was 1.2 t/ha.

A. The on station trial was a control and the trial was replicated outside the station on several farmers fields where farmers used some fertilizer.

Participants were also informed that the on-farm trials were being conducted jointly with the adaptive teams.

Q. How popular are your maize hybrids with the farmers?

A. The hybrids are very popular with farmers but there has been a constraint in the supply of hybrid seed. The station breeds maize hybrids, composites and synthetics.
Preliminary trials were done on the station while elite materials were tested in the National Maize Variety Trials over several locations in the country.

Discussion in the plots at Chitedze was cut short by a rain storm.

Overall Comments
The field tour offered participants a good overview of the type of intercropping research being carried out on station. All participants commented on the excellent management of the trials visited. It was also evident that those research officers in charge of these trials were very enthusiastic about their work.

Communication channels among researchers in the maize and bean programs should be formalised and mechanisms for the exchange of information be established. The same can be said about communication between on station and on-farm researchers and extensionists. Joint planning sessions should be implemented to improve the objectives and orientation of the process of generation and transfer of technology.

Chitedze Research Station

General Information
Chitedze Research Station is the largest agricultural research facility in Malawi. Other main Department of Agricultural Research (DAR) centers in Malawi are Bvumbwe and Makoka in the Southern Region and Lunyangwa in the North.

Chitedze station was established in 1948 and occupies 480 ha, some of which are used for physical infrastructure and woodlots. It is situated 16 km west of Lilongwe on the Lilongwe - Mchinji road; Latitude 14°S, Longitude 33° 45'E at an elevation of 1097 meters above sea level.

Soils
The soils are typical of the Lilongwe plain, which is the main area for production of maize, tobacco and groundnuts in Malawi. The soils are derived from gneisses and granulites and form a catena of sandy clay loams over dark red sandy clays, becoming yellowish red on gentle slopes; dark brown with impeded drainage (lateritic outcrops) to grey mottled clays as the lower "dambo" areas are approached.

Weather
Rainfall is around 1000 mm per year, with 85% falling in the period December to March on approximately 65 days. The highest maximum temperature (30.6 °C) occurs in October, and the lowest 23.9 °C in June and July. The highest minimum is 17.9 °C in December and the lowest, 7.3 °C in July, with an average minimum throughout the year of 13.3 °C. Daily sunshine ranges from 4.9 hours in February to 9.6 hours in October, with an average of 7.4 hours.

Staffing
The current staff for Chitedze Research Station stands at 51 Scientists, 27 Technical Officers, 66 Technical Assistants and several field hands. These numbers exclude personnel in administration and farm management. Of the 51 Scientists, just seven are expatriates attached to various projects supported by MARE/USAID and the World Bank. Twenty-two of the 44 Malawian scientists are on long-term offshore graduate training.

Research Organization
Agricultural Research in DAR is organized into seven commodity groups, each of which may have several commodity research teams. The commodity groups and teams are:

1. Cereals Commodity Group
   - Maize Commodity Team
   - Rice Commodity Team
   - Wheat and Barley Commodity Team
   - Sorghum and Millets Commodity Team

2. Grain Legumes, Fibres and Oilseeds Commodity Group
   - Groundnuts Commodity Team
   - Cotton Commodity Team
   - Other Grain Legumes Commodity Team
   - Beans Commodity Team
   - Oilseeds Commodity Team

3. Livestock and Pastures Commodity Groups
   - Large Ruminants Commodity Team
   - Small Ruminants Commodity Team
   - Monogastrics Commodity Team
   - Pastures Commodity Team

4. Horticulture Commodity Group
   - Vegetables and Spices Commodity Team
   - Tropical Fruit Commodity Team
   - Temperate Fruit Commodity Team
   - Coffee Commodity Team
   - Cassava and Sweet Potatoes Commodity Team

5. Adaptive Research Commodity Group
   - Eight adaptive research teams, one team in each Agricultural Development Division (ADD)

6. Soils, Land Husbandry and Engineering Commodity Group
   - Soils Commodity Team
   - Crop Storage Commodity Team
   - Farm Machinery Commodity Team
   - Agroforestry Commodity Team
The fifty-one scientists based at Chitedze Research Station are deployed in 19 of the commodity teams outlined above.

**Intercropping Research**
The bulk of the research work at Chitedze is geared for monoculture. Intercropping research at Chitedze is done by a section within the Maize Commodity Team. This responsibility has temporarily been assigned to a scientist working in the Wheat and Barley Commodity Team. The scientist collaborates with various scientists on the station during the planning and implementation of intercrop research work.

The Adaptive Research Teams carry out the bulk of intercropping research in DAR. This work is conducted on farmers' fields in the ADDs.

**Other Research Organizations Resident at Chitedze**
The SADCC/ICRISAT Groundnut Programme is housed at Chitedze. Their research mandate is regional, and they do not carry out any intercrop research work.

The Eastern and Southern African Research Network on Root and Tubers Research, supported by IITA, is also based at Chitedze. They do not carry out research on intercrops.
**Discussion on Papers Presented**

**Session 1**

**Chairman's Comment (W.R. Stern)**

The take home message from this Session is that there is infinite potential for intercropping research but researchers need to avoid trivial pursuit and make sure that priority problems related to intercropping by farmers are addressed.

**Questions to C.A. Francis**

**M. Swift (Comment).**

You mentioned the possible link between diversity and stability (and hence sustainability). Ecologists now cast some doubt on this link, and indeed in some instances diversity may be a product of instability. We should not assume therefore, that by increasing diversity, even to the limited extent it is possible in our agricultural systems, we will necessarily increase stability.

**C.A. Francis (Response).**

Recent writings in ecology do suggest greater stability in natural ecosystems. We suspect that well designed intercrops will usually be more stable as a total system than most monocultures. There are very few absolute monocultures in nature, and that should tell us something.

**R. Mead (Comment).**

In your paper a 'small' experiment means one with three or four factors, not small in the conventional sense (one or sometimes two factors). I believe four factors is right.

**J.K. Ransom (Question).**

You mentioned several times in your presentation that as research attempts to address more complex issues, interdisciplinary teams of scientists are needed. Is there any research or information being developed on how to make teams work? Too often the interactive process between researchers breaks down.

**C.A. Francis (Response).**

There have been few studies of how teams work, nor do I suspect that most teams would welcome this. Such a situation is unfortunate! We should be willing to look at ourselves and have others study our teams to learn about how they work and how to improve research. One publication is, *Enabling Interdisciplinary Research*, by Martha Garrett Russell (1982), University of Minnesota Miscellaneous Publications.

**R. Arias (Question).**

How should farmers participate in the research process and in the transfer of results?

**C.A. Francis (Response).**

That would depend on where we are in the world and which farmers we are dealing with. In the USA for example, farmers have helped agricultural researchers avoid the trivial pursuit syndrome, especially in respect of relevance of the work.

**R. Arias (Question).**

In adaptive research what is the real role of the researcher?

**C.A. Francis (Response).**

The researcher has a vital role to play in research on intercropping in spite of how much the extension specialist and farmer do in this process. Those in research can bring technology and new information into the process, can provide methodology, and can help show technically how some of the components fit together.

**F. Kisyombe (Comment).**

Another important role for the researcher is to study the farmers' current intercrop practice. Information from such studies will help researchers to plan their experiments. This is particularly a role of social-economists.

**B. Zambezi (Question).**

How can we involve women in adaptive research when men make decisions in most cultures?
C.A. Francis (Response).

Obviously, the woman’s role in agriculture and farming is extremely culture specific. However, I think we have grossly ignored the importance women play in most farming systems and what they have to offer in improving system productivity. Not only must women implement many of the changes and new technologies, they can also contribute to development of new methods as full participants. Women may, in fact, be more sensitive to total system performance, risk avoidance, nutrition and long term sustainability.

M. Omunyin (Question).

How can researchers make their methods respond faster to farmers’ problems?

C.A. Francis (Response).

We need to be very concerned with how long research takes. That is why research and extension priorities are important. Are there agronomic solutions that are faster than breeding solutions? Can we learn from other regions or countries? Are there some short term and other long term solutions? We should take more care to consider the time frame for our research.

Questions to D Yiwombe

M.S. Reddy (Question).

Malawi is regarded as one country in the region where a lot of intercropping research has gone on (at Chitedze, Bunda etc.). Have messages from this research not worked or have they not been communicated to farmers?

D. Yiwombe (Response).

There has been a lot of research but little of it has been passed to extension. We do not know, for example, which are the most useful crop combinations for farmers to grow.

M. Omunyin (Comment).

Shortage of labour has tended to make farmers set their own priorities. Hence farmers are often averse to adoption of new technologies especially in intercropping, which tends to be labour intensive.

D. Yiwombe (Response).

Here in Malawi there is insufficient data on the labour requirements of intercrops; we have no specific recommendations.

F. Ofiri (Comment).

There appears to be a break of communication between researchers and extension officers on intercropping in Malawi in recent times. Please comment on this?

D. Yiwombe (Response).

In the past researchers tended to believe that what they were doing was the best (i.e. good research), and they did not listen to extension or to farmers. This has now changed and there is now a better relationship and interaction between researcher, extension and the farmer. Adaptive Research teams have been set up to develop and improve this linkage. We now see considerable change in attitudes especially in how researchers see things.

D. Manda (Comment).

In terms of intercropping we do have a lot of land intercropped in Malawi. But current technologies have not come from research. Researchers are now learning from farmers. With recent increases in human population there are more areas with small land holdings. Intercropping has been developed to maximise use of small land holdings. We from research are now trying to understand these systems and how they work.

Session 2

Question to A.R.C. Low

I.M. Mharapara (Question).

During formal and informal surveys do farmers give truthful answers or what they expect the interviewer wants to hear. If the latter, what can be done to prevent this?

A.R.C. Low (Response).

Getting answers farmers think you want is always a danger in informal and/or formal surveys. The danger can be minimised by being aware of the problem. In informal surveys questions can be repeated in different ways to get at what actually happens. Doing the interviews in farmer fields is another way of ensuring that you get answers consistent with what you see. For example, if the maize is very yellow the farmer cannot easily claim he applied the recommended fertilizer.
Questions to J Woolley

M. Swift (Question).

There seem to be at least two explanations for the differences between on-station and on-farm conclusions, that is, (1) failure to identify farmers' constraints e.g. in the spacing trials you mention or (2) site specific factors (the phosphate trial where rainfall variation may play a role). What is the relative frequency of these two curves?

J. Woolley (Response).

(1) All solutions tested in these spacing trials were identified on the basis of a simple diagnosis and planning process. In the particular case of the spacing change, I should mention that farmers themselves were consulted from the time the original technology was proposed until they saw it at harvest time in the second year trials with larger plots.

(2) It is time that the station should not be regarded a priori as being different from the farms. In the cases presented, the treatment x (station versus mean of farms) interaction was always greater than the treatment x (between farms) interaction.

W.R. Stern (Question).

I was interested in the data on on-farm and on-station research. (1) Was this time consuming and did it require extra effort? (2) How many other individuals or groups have used this approach?

On the whole it seemed to me to be an important diagnostic tool.

J. Woolley (Response).

(1) In fact the trials designed for farms were part of a real on-farm research program, although it is true that this particular program worked on many different priority topics. The extra effort was in the planting of trial crops on-station.

(2) In preparing these data for publication, we did search for other examples. The few we have found were in papers or reports which did not deal specifically with this issue.

A. Sutherland (Question).

As 75% of results from on-farm agronomy experiments were different from on-station, is it possible to better simulate farmers' conditions on research stations or should more agronomy research be conducted on-farm?

J. Woolley (Response).

Beans are a crop very affected by environment, so the results might not be as contrasting in some other crops. In other experiments we compared results from an infertile field on the station where yields were similar to farms. Even so, under 50% of the results were correct for farms. I believe that the effort expended in finding suitable conditions for simulation on station is usually greater than that for running trials on a few representative farms.

A.F.E. Palmer (Response).

We recommended on-farm research where the aim of the trials is to derive production recommendations for variety, fertilizer application etc. in order to test technology under the circumstances of the target group of farmers. Such technology is not "untried" but without doubt certain answers are better obtained under on-farm conditions.

M. Swift (Question).

You have raised the question of evaluation or assessment measurements for intercrop systems. Has any consideration been given to using an index of nutrient use efficiency as a comparative measure? This has an advantage because of its relationship to sustainability.

R. Kirkby (Response).

Measurement of nutrient use efficiency in evaluating intercrops has seldom been used. More commonly, yield measurements become indicators of efficiency of nutrient uptake or extraction (e.g. complementary rooting systems that better capture an early flush of nitrogen). I agree that this is an issue deserving of more attention in the development of technology that will be long-lasting.

Questions to N Govinden

I.M. Mharapara (Question).

What fertilizer practices are used in the sugar cane/potato and sugar cane/maize intercrops which have enabled sugarcane yields to be maintained?
N. Govinden (Response).

The cane and its intercrops are fertilized separately. The cane receives its requirements, and the intercrops theirs. At present, the general recommendation is to fertilize the intercrops at the same level as sole crops, that is on a per plant basis. Further research is now in progress. It consists of fine-tuning the system by working out the optimum levels of nutrients in the mixtures. Such aspects as competition and complementarity in nutrient use and residual effects are being examined with the use of labelled nitrogen. The nitrogen contribution of groundnuts to sugar cane is also being studied.

F. Ofori (Comment).

In view of the varying duration of potato, maize and groundnut as intercrops in sugar cane, time seems to be an important factor in the assessment of advantages of intercropping. It will be worth using the ATER index suggested by Hiebisch and McCollum (1981) at Raleigh, North Carolina, USA.

Questions to J Davies

I.K. Mariga (Question).

Are there any characteristics observable in bean pure stands that can help one narrow down or select varieties or lines that are worthwhile to test in cereal/bean intercropping?

J. Davis (Response).

In general, vigour (competitive ability) should be selected, especially early vigour.

N.M. Mwania (Question).

In the work you describe selection of bean varieties for intercropping seemed to emphasise only growth characteristics and grain yield. Did farmers show bean preferences relating to palatability and cooking characteristics, or even grain colour?

J. Davis (Response).

In the trials preferences for grain type were deliberately excluded since we wanted to learn farmers' opinions on plant type characteristics related to suitability for their cropping systems.

A. Mwaipaya (Question).

At what stage in the breeding programme can we start selecting plants for intercrops under intercropped conditions?

J. Davis (Response).

It is only worth selecting in the early generations under intercropping when the efficiency of selection is improved by doing so. Otherwise it is better to identify desirable traits, consult farmers, then test on-farm.

B.T. Zambezi (Question).

How many times were the single hill experiments conducted? Are you not undersampling the maize genotype if it is open-pollinated?

J. Davis (Response).

The single hill experiments were conducted over two seasons. The maize was open-pollinated and the procedure used may undersample the maize population, but it is adequate for selecting beans.

A. Sutherland (Question).

In the CIAT breeding programme have efforts been made to select varieties according to weed suppressing qualities?

J. Davis (Response).

No deliberate effort has been made yet to select varieties which are more competitive with weeds. It is likely that such varieties would need to be heavily branched.

F. Ofori (Comment).

In the maize/bean intercrop experiments described, there is incomplete temporal separation of the component crops at maize maturity because light seems to be an important factor limiting bean growth. There will be no below-ground competition because the maize is dead!

M. Omunyin (Comment).

There is need to extend the farmers participation in the selection of adapted germplasm for intercrops. This should include the seed grain colour and cooking time tests (in addition to field vegetative observations).
R. Mead (Comment).  

Selection based on deviations from regression will be considerably affected by choice of the regression line.

**Question to J Ransom**

A. Sutherland (Question).

Was there any evidence during your study of weed control in intercropping that legumes are used by farmers to suppress weeds?

J.K. Ransom (Response).

My comments are based primarily on experience in the mid to high elevation environments of Eastern Africa. I assume that since farmers expend considerable labour to plant legumes, and since the presence of legumes increases the amount of labour needed for the first weeding (compared to monoculture maize), that the use of an intercrop to suppress weeds is not a significant objective of the farmer, at least for the first weeding.

**Session 3, Part 2**

**Questions to A Mkandawire**

A. Abebe (Comment).

Fertilizer is becoming unaffordable by many farmers. It would be good to study the use of inoculant as a way of allowing legumes to produce more nitrogen, particularly in intercropping beans with cereals.

A. Mwaipaya (Comment).

In cases where there is one crop of the intercrop (in this case beans) per growing season, then ATER equals LER for unimodal rainfall areas where the season is too short for a second bean intercrop. These two measures differ only in cases where there are two crops of the intercrop (beans) per growing season because ATER brings the benefit of an increase in bean yields, but it also tends to inflate the proportion of the yield figures.

**Questions to C Rweyemamu**

Z. Semgalawe (Question).

You mentioned that in future you are planning to move your trials into farmers fields, but at the same time you said that at the moment the same trials are being conducted by the FSR team of Sokoine University of Agriculture. I wonder how much cooperation there is between your team and the FSR team? Otherwise you may end up duplicating efforts.

C. Rweyemamu (Response).

We do plan to take the trial to farmers fields this year but at the same time there is a plan to have a multidisciplinary approach with the FSR team.

A. Mwaipaya (Comment).

In intercropped maize/groundnut and maize/soybean studies using labelled N\textsuperscript{15} in Zambia during 1981/82, there was no evidence of direct transfer of biologically fixed nitrogen by the legumes to the cereal. In your presentation you indicated that there was direct benefit in the form of biologically fixed nitrogen from beans to maize.

A. Mkandawire (Response).

True, there are many prospects of using organic sources of nutrients e.g. animal manure (instead of chemical fertilizers)? Fertilizers are becoming expensive and farmers may have to revert to other sources of nutrients. Is this a priority area for research?

C. Rweyemamu (Response).

The benefit achieved from maize may have been due to an increase in plant population density rather than from biologically fixed nitrogen. Since other agronomic parameters were not measured in the study, the yield advantage cannot be attributed to biologically fixed nitrogen.

O.T. Edje (Comment).

In the maize/bean intercropping system where beans are in the same row the yields of maize were reduced but yields of beans increased. We also had the same experience but when beans are in between rows of maize, lower bean yields were obtained because beans were not fertilized. But in years where there is drought, this was not experienced. As a result it is not clear whether the increase in yields of beans where beans are on the same row is due to the added fertilizer or not.
Question to R Arias

D.C. Munthali (Question).

Rweyemamu's work at Sokoine Agricultural University has shown that a maize/beans intercropping system where beans are planted in the same hole as maize was the most superior arrangement with the greatest advantage. This observation agrees with what farmers do in Malawi. However, your arrangements did not include that one. Perhaps you should include this arrangement in your studies in Ghana.

R. Arias (Response).

Cowpeas are to be maintained at 100% population because they have a higher economic value in Ghana than maize.

W.R. Stern (Comment).

The research effort should be commensurate with the return from any expected increase in productivity. Referring to the title of this session, "Development of an intercropping research programme and component research" we should beware of undertaking research that is too detailed for the task in hand. Research should be undertaken at various levels but the ultimate aim should be to meet the particular need of farmers. Taking fertilizer research as an example, is there a need to develop nutrient selection indices when the need is to overcome major nutrient deficiencies? Is there a need to undertake studies in host parasite relationships when there is a need to control a pathogen or an insect pest? Where detailed work is required, perhaps it ought to be contracted to groups that have the time and resources to undertake such detailed work. The local research programme needs to be tailored to the immediate needs.

Session 4

Questions to A.R.C. Low

M. Omunyin (Question).

Which types of objectives should be achieved through on-farm research and which ones through the station or away from the farm?

A.R.C. Low (Response).

When trials go on-farm versus on-station must depend on the stage of experimentation and whether researchers have confidence in the nature of the technical response. As soon as that question is answered and the researcher wants to test whether the innovation is useful to farmers then there is need to get onto farm. In respect of intercropping vs. a pure crop this may need to be earlier in research since answering the technical interaction questions may be more difficult to do well on experimental stations. These may change when we take the treatments to the farm.

A. Sutherland (Question).

Leaving out a sole plot treatment in southern and eastern Africa presents a problem because all crop recommendations are for monocropping and there is need to test the validity of these recommendations against the intercrop treatments being tested on farm. What should researchers do in this case?

A.R.C. Low (Response).

The one situation where a sole crop plot can be justified is where the sole-intercrop comparison is needed either because the change from or to intercrops may become a recommendation, or because politicians need convincing. But actually very often the objective of the research is to modify existing intercrops. One has to think very hard about the value of pure crop plots in these cases.

A. Sutherland (Question).

Sole crop treatments may be necessary in cases where the extension recommendations only apply to monocropping, or is this not so?

A.R.C. Low (Response).

Yes, if thinking of changing from or to an intercrop. But we have seen in Malawi (especially) trials whose objective was to test modifications to existing intercropping which have sole crop plots included because that is the standard practice and how else can we measure LER? Where the objective is to make modifications to intercrops one has to question very hard whether a sole crop plot is justified in on-farm trials.

O.T. Edje (Question).

If you are in a situation where farmers realise the importance of intercropping but government policy through extension workers discourages intercropping, should you not include sole cropping for comparison?

A.R.C. Low (Response).

It is helpful to include a sole crop in such a situation in order to test, and if necessary revise, existing extension
recommendations - even to say that in some cases an intercrop is better than a sole crop.

R. Mead (Comment).

Another point to consider is that variability of sole crop yields and of intercrop yields is usually not the same, hence analysis requires transformation or separate analyses.

Questions to R Mead

A. Sutherland (Question).

If sole plots are a problem or are not statistically comparable because of variance, how can economic analysis of such plots be carried out?

R. Mead (Response).

The problem is in the assessment of precision and significance. Calculation and comparison of economic measures is possible and I think, not sufficiently variable to cause precision problems.

C.N. Murithi (Question).

What do you recommend to be the standard experimental plot size for economic trials (e.g. quantification of labour for planting, weeding, harvesting) in intercrops?

R. Mead (Response).

Different plot sizes are required for different forms of measurement. I cannot give sizes without visiting the sites and seeing plots of various sizes in experiments.

J.M. Bokosi (Question).

What type of designs and treatments would give/reveal appropriate information about an intercropping system like a maize-bean association where, as is mostly the case in Malawi, the bean crop is planted as a mixture?

R. Mead (Response).

This is a treatment design question and the question needs to be a more precisely formed before we can define an appropriate structure. I would need to sit down with the questioner and get more detailed information.

Questions to J Woolley

L. Dadi (Question).

In site selection, consideration of slope and taking samples of soil was suggested. Do you think this can be practical where resources and expertise are limited?

J. Woolley (Response).

It is difficult to get results on soil analyses before planting trials. Slope and soil data were examples. The main point made was that the recommendation domain for each type of solution will be defined according to certain descriptions, whose range of variation we can estimate. The sites chosen for trials should fit within typical ranges for the area. The descriptions might be very simple, of a type which can be measured without any sophisticated apparatus.

L. Dadi (Question).

In doing on-farm experiments it is suggested to change the farmers who cooperate with the researcher over cycles. Would you elaborate on the advantages and disadvantages of this approach?

J. Woolley (Response).

For the early stages of on-farm research where a few farms are used to obtain results for the domain, it is important to change the sample of farms each year to avoid persisting in the same biases of the sample.

N.M. Mwania (Question).

What are your experiences in on-farm trials when you provide the inputs or when farmers are asked to provide the inputs themselves?

J. Woolley (Response).

In most stages of on-farm research, the researchers provide the experimental inputs. Most on-farm research programmes talk of some sort of semi-commercial testing as a final research stage in which the farmer compares just one new practice or set of practices side-by-side with his or her traditional practice to find out whether the new technology can be managed by the farmer and is compatible with the rest of the system. In Latin America, we never succeeded in arranging semi-commercial trials in which the new input was recommended to farmers and it was left to them to see if and how much they applied. Instead we had to supply the input. Maybe it is more realistic to consider conducting a survey of farmers who had semi-commercial trials the following year, to see how many continued
using the input. Non-experimental inputs are usually supplied by the farmer in most trials.

I.M. Mharapara (Question).

In on-farm variety trials with a series of entries is it wise to allow farmers to retain the seed?

J. Woolley (Response).

In trials with many entries, we usually exchange the produce of the different plots for the same amount of grain of a well-known local variety. This is especially true if some are not well-known seed types for the market or consumption or if we need to multiply the seed for use in future trials in a self-pollinating crop. However, farmers often take or request small amounts of seed. We must recognise that we cannot restrict the movement of varieties, lines, or ideas which we take on-farm. We should be glad about this; it fits in with the idea of more flexible recommendations and of each farmer choosing what suits him or her best.

Session 5 Part 1

Question to M.S. Reddy

C.A. Francis (Question).

You mentioned a number of alternative biological measures related to nutritional value. Even though laboratories may not be available for detailed analysis, could we assume values of protein, lysine, methionine, or other constituents from prior knowledge of each crop? My impression is that differences thus calculated among systems will be far greater than within crop variation as a result of system or agronomic treatments.

M.S. Reddy (Response).

Yes, it should be possible. But lack of the required information in the literature is still a drawback. Very few researchers are using these techniques in Africa.

Questions to O.T. Edje

N. Govinden (Question).

In your conversion of bean into energy, i.e. 1420.4 J/100 g edible portion of seed, has not the protein already been converted to energy? If so, is it not double use to interpret energy and protein in the sense of your paper?

O.T. Edje (Response).

The table from Platt (1962) seems to indicate that the protein had not been converted into energy.
I.M. Mharapara (Question).

I believe intercropping is biologically inefficient whenever there is competition between the component crops. Should we then not help the farmer define his domain more specifically to be able to allocate his resources more precisely rather than intercrop.

O.T. Edje (Response).

There is a large body of evidence to show that intercropping is a more efficient resource use system than sole cropping. Perhaps then, the question does not arise.

I.M. Mharapara (Question).

Please comment on risk and whether we should move from intercropping to sole cropping.

O.T. Edje (Response).

Evidence shows that the combined yield of intercrops is generally higher than those of sole crops. It is when we researchers have poor crop combinations that we reduce yield.

Questions to A.R.C. Low

D.C. Munthali (Question).

In Malawi and possibly other African countries, beans are probably more used (on a daily basis) by the farmer when leaves are plucked as a vegetable. How would you put a price on the farmers' daily pluckings? - which may be a strong reason why the farmer intercrops. It seems to me that you have assumed that the farmer grows the bean for the seed. When should this economic analysis be done?

A.R.C. Low (Response).

Yes, all useful production should be valued. Economic analysis has tended not to do a very good job at this in the past.

A. Sutherland (Comment).

In the example given, which is quite typical of maize/bean intercropping results in the region, the logical recommendation would be to put more fertilizer on crops for home consumption and less on crops for the market, whereas the official policy in most of the region is to supply fertilizer as credit to produce maize for the market. Economic analysis cannot assume a free market situation but must also take account of national policy as well before a crop recommendation can be made.

A.R.C. Low (Response).

Economic analysis has been applied to sustainability issues using the technique of discounting future streams of costs and benefits to present values. That way current large (but decreasing) benefits can be compared with smaller initial but constant benefits.

Session 5, Part 2

Question to F.W. Kisyombe

I.K. Mariga (Question).

Does it mean that we have to do many simple cereal/legume experiments rather than compound ones (including one cereal and several legumes) if legume data are to be included in the ANOVA?
In sustainability issues two often conflicting assessments occur. Social (community) net benefits vs individual net benefits. Something may be good for the society in the long term but not attractive for the individual in the short term. If it is clearly shown that there are long term benefits, then prices, subsidies, taxes, etc have to be used to persuade individuals to undertake these things in the short term.

Special Session

Question to L. Ngwira

F. Ofori (Question).

The LERs for maize/cowpea were very low and this I presume was due to no cowpea seed yield. What was the cause of this?

L. Ngwira (Response).

Cowpea yields in the experiment at Chitedze were low due to insect pests. Insect damage on cowpea is often severe at Chitedze because that station is at a higher elevation (1200 masl) than where cowpeas are suited.

Question to L. Dadi

R. Kirkby (Question).

Could you expand on the reasons for selecting your treatments in the on-farm maize/bean trial, as you mentioned not all treatments had been tested previously on-station.

L. Dadi (Response).

In the Bako area, draft power and labour shortages were major constraints so the treatments were selected to not require additional inputs for intercropping haricot beans and to not change maize weeding management since farmers considered maize as the major crop. The intercropping treatments were planted when interrow cultivation was done for maize.

Questions to A.E.M. Temu and N.M. Mwania

A. Negasi (Question).

Why does crop protection come in the third stage? Is that because there is no problem of crop protection with the current intercropping pattern that farmers employ?

A.E.M. Temu (Response).

Pest control came third after agronomy and breeding simply because entomologists and pathologists started slightly later to tackling pest problems in intercropping systems. It does not imply that the current intercropping systems in Tanzania have a low incidence of pests.

L. Dadi (Question).

In areas where intercropping is practised and farmers already use a certain intercrop plant population and spatial arrangement, do you think farmers will adopt a new spatial arrangement and intercrop density unless you adequately addressed the cause of the problem in the first place?

A.E.M. Temu (Response).

There has been no problem in the adoption of a technology by farmers, whether in a sole or intercropping situation as long as that technology has proven its worth. My long experience in the Southern Highlands of Tanzania confirms this.

M. Omunyin (Comment).

Farmers find it difficult to adopt new plant arrangements incompatible with traditional set ups, especially if they have implications for labour use. This is the case for the central province of Kenya.

N.M. Mwania (Response).

If a new technology component e.g. fertilizer application, is being introduced and is acceptable to the farmers, they might be willing to change their planting patterns. Where intercropping is a new practice farmers tend to adopt the planting patterns demonstrated to them.

Questions to M Natarajan

C.L. Rweyemamu (Question).

In Tanzania cotton is not to be intercropped with any crop to avoid contamination of cotton fibres at harvest. What is the situation in Zimbabwe?

M. Natarajan (Response).

Since the cowpea that we used is of very short duration, and will be harvested long before the bolls start forming, I do not think contamination of cotton fibre will be a problem at all in the system I have mentioned.

D.D. Yiwombe (Comment).

It is difficult for a smallholder farmer to spray his cotton if it is densely intercropped with cowpeas.

I.K. Mariga (Comment).

Intercropping cotton with cowpeas would not work for Zimbabwe since the small-scale farmers emphasize the use of cowpea foliage as a relish and the
pesticides used in cotton are extremely poisonous, making the eating of cowpeas an unsafe practice.

C.L. Rweyemamu (Comment).

I think intercropping cotton with cowpeas can be achieved when the appropriate varieties of the two crops are used e.g. cotton variety IL 74 and cowpea variety "vuli" are currently in use in Tanzania.

C. Chanika (Question).

Stability of yields in low rainfall areas with one crop favoured by the farmer and another not, seems difficult to achieve. Can you comment?

M. Natarajan (Response).

The system we tried was of a replacement type. So population pressure in the intercrop was not more than in sole crops. But in a dry year when the maize fails at least the farmer can harvest some food from the other crops.

O.T. Edje (Question).

Why was the pigeon-pea crop in the sunflower/pigeonpea intercrop regarded only as a fodder crop and not for both seed yield and fodder?

M. Natarajan (Response).

In fact the pigeon-pea was grown to maturity. Since at present there is not much interest in pigeon-pea grain, I was only mentioning a possible alternative use.

C.L. Rweyemamu (Question).

If intercropping is not a very popular cropping system in Zimbabwe as you have just mentioned, why do researchers in Zimbabwe want to put a lot of emphasis on this work?

M. Natarajan (Response).

Intercropping is not very common with farmers at present, not because it is not popular with farmers, but because it has been discouraged by extension for many years. If we can show that it is a more productive and/or stable system, it can be easily adopted by the farmers.

M.J. Swift (Response).

I agree that our target should be at an intermediate level of structure. It would be foolish to expect to construct a fully 'closed' agricultural system but we can certainly hope to improve on the very 'open' nature which characterizes most current agricultural systems.

A. Sutherland (Question).

What is the state of knowledge on the role of termites in the recycling of nutrients and movement of organic matter in Eastern and Southern Africa? Should they be controlled by chemical sprays?

C.A. Francis (Response).

In fact the termite colonies go deep into the soil, and some species are useful in bringing up nutrients from below. In the eastern plains of Colombia the entire area is 'turned upside down' to a depth of several metres due to termite action over 50-88 years according to one calculation.

C.A. Francis (Response).

Different fauna have differing ecological roles varying from crop pests (which may require control) to humivorous species which promote the physical and chemical status of soil and are thus worthy of encouragement. One of TSBF's objectives that we have not mentioned in our paper is to develop methods for managing soil fauna for improved soil fertility.

O.T. Edje (Comment).

The importance of anthills for soil improvement has long been recognised by farmers. A review paper on this aspect was published recently from the
University of Zimbabwe. In Malawi farmers use soil from anthills for crop production, including in tobacco production.

M.J. Swift (Comment).

Soil from termite mounds, originally from subsoil horizons, is commonly higher in clay and cation exchange capacity, hence its value as a 'fertilizer'.

Questions to M.J. Swift

C.A. Francis (Comment).

It would seem appropriate to close the "information cycle" by taking farmer/extension experience after applying an expert system and management option and feeding this back into the pool of heuristic (farmer) information. Likewise, much farmer information and our observations on the farm lead to ideas for careful testing and increase scientific information.

M.J. Swift (Response).

This is of course correct. Although I have represented the transfer of information as a directional flow, it is of course an interactive, cycling process. The expert system should act as a powerful means of integrating the information and will be an updating tool as well as a management tool.

C.A. Francis (Question).

We know that P is rapidly fixed in many soils, thus P will perhaps not be available no matter how synchronous the release from crop residue and weeds. Is soil P status and equilibrium more important than the synchrony you describe?

M.J. Swift (Response).

Yes P is not the best example with respect to the concept of synchrony. N, which is a biologically mediated element, is much more appropriate. Nonetheless, where P availability is critical tight synchrony with biologically derived P may have an effect.

W.R. Stern (Question).

Are there any particular measurements or sets of simple measurements that can indicate the health of the system?

M.J. Swift (Response).

The TSBF programme has proposed a minimum data set of site characterisation variables which can act as a 'diagnostic tool' in this respect. This is published by CAB International as a Handbook of Standard Methods. It is worth commenting however, that it is essential to make such diagnosis on a comparative basis, both spatially and temporally.

R. Kirkby (Comment).

One place to start implementing the approach advocated by Professor Swift is with improved procedures for diagnosis of an existing system. The rest of us should be ashamed that all too often it has been left to the anthropologist to identify farmers methods for recycling nutrients. In the densely populated highlands of Eastern Zaire, for example, it took an anthropology PhD student living closely with farmers, to discover that they are consciously managing soil fertility during the crop season by harvesting early weed growth, sorting out "useful" species, drying them and later, reapplying them as fertilizer to the most demanding crop species.

J. Chumo (Question).

Are there differences in the rates of decomposition of various legumes? If so, what legumes have a sufficiently fast rate of decomposition for P to be available for plant growth early in the season?

M.J. Swift (Response).

As commented before it is more appropriate to consider N in this respect. Some examples are given in the written paper but in general terms 'woody' legumes will decompose more slowly than those with 'softer' tissue. What is appropriate for any given cropping system is however somewhat site-specific. This does not however contradict our claim that with sufficient information we should be able to develop models with sufficient predictive power to use as management tools.

B.T. Zambezi (Question).

I refer to the graph that showed availability (release) of nutrients from organic matter as related to the timing of plant demands for nutrients. Is this perhaps one of the reasons why we get a decline in yield on late planted crops?

M.J. Swift (Response).

It should be one of several reasons. A particular situation would be early rain sufficient to initiate mineralization, followed by a dry spell which inhibits plant growth. This could result in a nutrient flush which is lost to the crop at the subsequent onset of rain because root systems are not yet established.
Sessions 1 and 2

Group 1

Issues:

1. How to create an awareness of the multiplicity of factors involved in intercropping research among researchers, extension, farmers, research administrators - factors such as varieties, climate, soils, crops

Need to use a multidisciplinary approach -- diagnose the problem and identify key factors and key players to assist in planning the intercropping research.

2. How to promote effective communication and interaction among:
   - different disciplines
   - national and regional organizations
   - farmers of both genders

Need an institutional base to formalize linkages between different disciplines.

Members of the group need to have similar levels of training/education to permit interaction. People of different disciplines can talk to each other if they know a little about each other's activities. The institutional arrangement should be endorsed by the establishment.

Frequent group meetings needed to consult and organize activities.

Place researchers and extensionists together to encourage communication.

3. What are the possible contributions of different disciplines, biological and social?

Depends on the understanding of the people concerned and their willingness to cooperate. Working together is important.

Each participant can bring a different perspective to the team, and this helps to build strong intercropping research programmes.

Group 2

Issue:

1. Identify relevant intercropping methodologies including:
   - Contribution of farmers

Farmers' can contribute by:

- Helping identify problems and causes
- Assist in description of farming system and understanding interactions within it
- Evaluating results from OFR
- Time required for research

Research time can be reduced by:

- Simultaneous coordination of OSR with OFR
- Distinguish clear roles for research and for extension
- Place for simulation modeling
- Work within system framework
- Do simultaneously with experiments
- Helps identify appropriate component research

Group 3

Issues:

What should be the criteria for evaluating intercropping systems and prioritizing research programmes?

Depends on the understanding of the people concerned and their willingness to cooperate. Working together is important.

Socio-Economic Factors:

- Nutritional requirements of the farmer.
- Net income stability.
- Feeding value for livestock -- e.g. in the dry season cereal stover mixed with legume residues.
- Labour feasibility and costs.
- Land tenure systems -- e.g. where land is freely owned, a farmer is likely to take good care of his land.
- Government policy -- some policies may promote or discourage intercropping.
- Risk -- stability of yields.

Group 4

Issue 1. Role of farmer surveys and farmers' participation in planning intercropping research and shortening delivery time.
Farmer surveys are very important in planning intercropping research. They are necessary to:
- identify and prioritize problems, define or redefine trial approach (treatment design),
- identify possible interactions between treatments and other factors, identify target groups and hence, define recommendation domains.

Farmer participation helps during the planning stage in various ways:
- Farmers are more aware of their problems than anybody else and this helps in identifying problems and assigning priorities.
- Ensures that real needs are addressed.

Farmer surveys and farmer participation speed up delivery time by:
- Firstly, helping ensure that the research done is on target. This avoids having to re-do part of the research because important issues were missed.
- Secondly, ensuring the recommendation given is more complete because more aspects are covered.

**Issue 2.** When should experiments be done on-farm as opposed to on-station? What balance should be established between the two?

The following factors influence the choice:
- the nature of the solution being tested. Usually, if there are technical questions where the answers are not yet evident, better to start on-station. If it is a question of replacing a farmer variety with a supposedly higher yielding one, then go on-farm.
- the interaction between the treatments and farmers. If farmer participation is necessary, then on-farm trials become obligatory. For example, testing whether a treatment reduces labour inputs.
- the number and complexity of treatments.
- the availability of resources to do the job. In terms of trained personnel, transport etc.
- degree of control needed to ensure valid results.

Because of the number of factors involved and the interactions between factors and also with the farmers' environment, there is a need for more on-farm research in intercropping than in sole cropping.

Two other important issues:

a) Having more on-farm trials does not necessarily mean increasing delivery time. In many instances, some on-farm trials can be done simultaneously with on-station trials.

b) There is also always the possibility, in cases where resources are too scarce to do on-farm trials, of enlisting farmer 'participation' by bringing farmers to stations to examine, criticize and evaluate certain specific trials.

**Group 5**

**Issue 1.** How to prioritize the objectives of the farmer in intercropping?

Farmers' Objectives are to:
1. achieve maximum productivity (income or subsistence) from dominant crop component, yield from subordinate as a bonus.
2. minimize risk of crop failure.
3. make more efficient use of land
4. make more efficient use of labour
5. conserve the soil
6. maintain crop diversity, temporally, spatially, nutritionally
7. protect against pests, diseases and weeds

**Issue 2.** How to achieve a balance between farmers' objectives and those of government and of researcher?

A good researcher's objectives are the farmer's objectives.

Government objectives reflect farmers' needs balanced by wider considerations e.g. food security, foreign exchange earning.

Mechanisms of prioritizing objectives should be a balance between farmers, extension and research, as in OFR.

**Group 6**

**Issue** How can the influence of extension on farmer responses be reduced during surveys?

1. Research and Extension should function as a team during
2. Give training in advance, if possible, to extension staff on interview methods and sampling.
3. Extension workers should select farmers jointly with research.
4. Sample from a list of farmers/villages.
5. Ensure other team members speak the local language.
6. If possible get extension staff from other areas to participate in surveys.
7. Give more attention in training on how to ask questions.
8. Develop a critical mass of researchers and extension staff with experience in informal surveys.

Sessions 3 and 4

Group 1

*Develop guidelines for appropriate experimental designs specific to problems common to cereal/legume intercropping trials. Consider both on-station and on-farm trials:*

1. Every experiment has to be considered individually but the following factors must be considered to maximize precision.
   a) Plot size
   b) Blocking structure
   c) Number of treatments

2. For any treatment comparisons that are necessary to answer questions which are important to the experimenter there should normally be at least a 4 fold replication (explicit or implicit).

3. a) Consider a minimum plot size for each component and the minimum size for the intercrop should be the largest of these minimums (try not to let the plot size get bigger than this).
   b) In a situation where a particular treatment requires machinery or equipment which can only be applied to plots larger than this minimum, a split plot design will often be appropriate.

4. Plots in a block should not be more than 30 m apart. Should not have more than 12 treatments in a block. For more treatments than that maximum, incomplete block designs are necessary. Different blocks can be as far apart as considered realistic within a recommendation domain.

5. a) In a typical on-station experiment with between 45 and 60 plots there should normally be about 20 d.f. allocated to treatment comparisons. This will usually imply 3 or 4 treatment factors.
   b) With on-farm trials treatment factors will usually be fewer.

Other Points:
- If trial is too large for farm then block onto different farms.
  - First determine treatment design, then arrange blocks.
  - The number of replicates, taking into account explicit and implicit replication, does not normally need to give more than 29 d.f.
- Blocks are not equal to replicates, so plan on-farm experiment location and distribution within and across farms according to blocking needs and land availability

- Group 2

*Develop guidelines for planning and implementing on-farm cereal/legume intercropping trials to assure relevance and acceptance. Include:*

a) **Complexity of trials**

Depends on Research Objectives
- Type of Trial
- Type of Information

Highly complex trials e.g.
- Variety Selection
- Fertilizer Levels

Less Complex trials e.g.
- Verification
- Socio economic + Operational information
- Single issue trials can have more farmer involvement.

Is an inverse relationship between complexity of a trial and number of farmers that are involved.

b) **Relations of trials to total farm enterprises**

This is a problem in resource economics.
It is almost impossible to deal with all the interactions.

Important to collect farm characterization data through Surveys and Experimentation.
There are no precise prescriptions, rather a framework of things to remember.
c) Involvement of farmer and researcher

No neat solutions

Need clear definition of what we want -- regular meetings

d) Relative importance of biological, operational and socio-economic responses

Depends on objectives of trial.

e) Proper use and time sequence for exploratory, levels and verification type trials. How to speed up the research process?

Imaginative short cuts:

Surveys are quicker than On-farm experiments
Start with on-farm trials?
Allow more farmer participation at the start
Brainstorm every year
Use path analysis in relation to research adoption

3. Planning

This should be in consultation with as many disciplines as possible in the early stages.

Leadership needed to coordinate the planning efficiently.

Plans should be consistent with government policy.

Ensure that planning is consistent with available resources such as manpower, finance, and facilities.

There should be a balance between flexibility and rigidity.

Policy makers need to be involved as well as extension workers.

4. Implementation

Need to define the roles and responsibilities of those involved in running the research.

Need to make decisions about data storage and accessibility to all members of the research team.

Decide on who is going to run station trials and on-farm trials. Sometimes the same group may be involved, but this needs to be clarified.

Decide which research activities need to be done on research stations e.g. variety development, and which activities need to be done on-farm e.g. cultivar evaluation, etc.

Need to define extension role in the implementation of the programme.

5. Analysis of research data and compilation of reports should involve all members of the research team.

Group 4

Provide guidelines on opportunities for varietal development of maize/legume intercropping combinations, and include at what point should varieties be tried on-farm for intercropping performance.

A. At International level

IARC's cannot be expected to develop site and situation specific varieties. They should continue to breed for adaptation to different agro-ecological zones. Additionally, they must place greater emphasis on trials related to intercropping e.g. maturity of component crops, plant height and vigor, leafiness, lodging, broad resistance to pest and diseases, husk cover and nitrogen fixation ability.

B. At National level

1. National programmes are responsible for developing site and situation specific varieties. At the national level breeders have to select and adjust varieties to suit their needs.

2. More emphasis should be placed on other desirable traits besides yield.

3. Breeders need to be more sensitized to cropping systems and practices by having more interaction with social scientists and getting the community involved with the station work.
4. National programmes should ensure they receive the appropriate germplasm from IARC's.

5. Cereal and legume breeders have to work closely together.

6. The initial variety selection has to be done on the station for reasons of efficiency and logistics.

7. Later when comparisons between materials are needed experiments must be done in mixed stand vs. pure stands.

8. It is desirable to have comparison trials in target areas at several locations and over several seasons.

9. On-farm trials must be researcher managed with maximum involvement of the farmers, especially in evaluation and feedback.

10. Breeders need to sample variability in individual situations and to keep abreast of changes.

Other comments:
Because bush and climbing beans differ in their response to intercropping, climbing beans need to be evaluated in intercropping at an earlier stage.

There is merit in allowing farmers to make selections in intercropping trials.

Timing of the move to on-farm trials should be flexible. Breeding is not a straight-line progression from station to farm. Farmer inputs needed at the beginning of breeding, to help define objectives, criteria etc.

Group 5

Given the tremendous variation in potential cereal/legume intercropping combinations, what guidelines are needed to determine the biological factors that should be researched, and to what level of detail should solutions be developed vs. what should be left for farmers to "fine tune"?

Objective: to increase productivity of traditional practices without losing intrinsic balance nor acceptability of the system.

Strategy: to assess the biological factors that constitute constraints on combined yield in the intercrop and appraise opportunities for their alleviation by making adjustments to the system.

Research Goals:
1. Assess priorities among biological factors as yield constraints in the traditional system.

2. Determine what alterations in those priorities might result from potential agronomic changes e.g. plant population, spatial/temporal arrangements, variety substitution.

3. Determine chief factors that underlie changes in prevalence/severity of pest, pathogens and weeds with intercropping systems.

4. Identify opportunities for the effective manipulation of the crop association so as to decrease biological constraints below the economic threshold and so achieve a biologically balanced system.

5. Identify those stresses not adequately regulated by agronomic and/or genetic manipulation alone, and seek opportunities for their alleviation by other means at appropriate levels of input e.g. hand weeding, Rhizobium inoculation.

6. On-farm evaluation of prototype adjusted systems.

Level of detail: OFR vs. OSR

1. On-farm characterization of systems and diagnosis of agronomic constraints.

2. On-station investigation of causes underlying constraints, and identify potential for alleviation.

3. Researcher managed OFR with farmer participation, to evaluate potential improved systems.

4. "fine tuning" in farmer managed OFT

5. Modelling can be a useful tool once cause and effect are understood for each pest/disease.

Group 6

Develop guidelines for the important elements of on-farm intercropping experiments, giving more detail in the case of elements and situations specific to intercropping. Among these include guidelines for determining whether and when to include sole crop treatments.

Task 1. Identify things that can be studied in on-farm trials

- Content of trial should be relevant to farmers problem as identified in diagnostic surveys
- Trial content to depend on differences between research station and off-farm conditions.

- Elements to be studied:
  - Variety
  - Planting methods and dates
  - Plant population and spacing
  - Fertilizer applications time, methods, and rate
  - Weed management
  - Pest and disease
  - Soil type and fertilizer status
  - Rainfall
  - Yield (grain and TBM)
  - Labour measurements
  - Consumption preferences
  - Farmer evaluations
  - Farmgate prices

**Session 5 and 6**

**Group 1**

*Assuming there is a need for applied research programmes to address more specifically the topic of sustainability, develop guidelines for the roles and operational principles of:*

- National Agricultural Research Systems (NARS)
- Regional Organizations
- International Agricultural Research Centers (IARCs)

Guidelines:

**A. NARS**

1. Coordination needed between national agricultural research stations and universities and other non-governmental research organizations that are involved in research and development.

2. Coordination of departments within the national research organization and development of well laid-out guidelines for both short-term and long-term undertakings for sustainable agriculture.

3. Roles:

   **A. NARS to:**
   - Identify problems
   - Prioritize problems
   - Formulate programmes
   - Conduct applied research

   **B. Universities and specialized research institutes to conduct basic research oriented towards the identified problems.**

   **C. Liaise closely with extension organizations.**

**B. Regional Research Centers**

1. Assist in facilitating specific research efforts in the interest of member nations.

2. Assist in:
   - Training
   - Interaction of scientists through workshops, conferences, seminars, publications etc.
   - Canvassing for funds for projects of regional interest.

3. Need to be:
   - Well informed
   - Quick to respond
   - Seen to be fair

**C. IARCs**

1. Provide:
   - germplasm
   - literature
   - support and consultation for research efforts especially in basic studies (expertise and equipment)

2. Provide specialized training to be done:
   - in country
   - in region
   - Headquarters or global

3. Provide international forums for information exchange.

4. Inter-center coordination within a region is needed to avoid duplication and strengthen efforts especially in the case of intercropping.

5. Provide advice on research policy and operational structure conducive to sustainable agriculture.

**Task 2.** Whether and when to include sole crop treatments

Depends on the objective of the trial. May be necessary to convince policy makers, extension and researchers.

Sole crop treatments are necessary for certain types of experiments e.g. involving entomology and pathology

Sole crop plots to be included where monocropping is:

   a. Practised
   b. Recommended
   c. Proposed

May not be possible (even if necessary) where intercropping is clearly the farmers' preference and land is in short supply.

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Session 5 and 6

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Group 2

Provide guidelines on how to compromise the need for production vs. sustainability for smallholder farmers in land scarce environments and the impact on research and extension agendas.

Guidelines:

1. For diagnostic purposes, key issues for measurement are:
   i. Nutritional and infant mortality status.
   ii. Source of food: whether coming from the system internally or from external sources.
   iii. Soil degradation
   vi. Changes in biological diversity
   v. Changes in soil fertility, especially soil nitrogen

2. Goals should be set from the start: i.e. whether
   i. short term sustainability or
   ii. long term sustainability

A diagnostic guideline could be as follows:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Closed System</th>
<th>Open System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrient levels</td>
<td></td>
<td></td>
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<tr>
<td>Weeds</td>
<td></td>
<td></td>
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<tr>
<td>Fertilizer</td>
<td></td>
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</tr>
<tr>
<td>Etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Conflict in sustainability issues:
   i. Population pressures
   ii. Political pressures

4. In order to improve short term goals the following measures were brought forward:
   i. better communication between research and extension.
   ii. proper diagnosis of the farmer's problems to leave more time to work for long-term goals.

Group 3

Provide guidelines for identifying resources that could be utilized to promote more sustainable agricultural production systems and how they could effectively be used for energy, etc.

Guidelines:

1. Help to look at resources at different levels e.g.
   - Field
   - Farm level (individual farm)
   - Beyond the farm (community)

2. The list of resources to be examined includes:
   - Crop residues
   - Soil organic matter
   - Nitrogen fixation
   - Animal manures
   - Rainfall
   - Indicator species (vegetation that indicates soil fertility or otherwise)
   - Natural predators
   - Soil microflora/fauna
   - Farmer and family labour
   - Outside labour - e.g. extended family systems
   - Animal power
   - Ground water - e.g. for small-scale irrigation such as vegetable crops in dambos (small valleys)
   - Communications - roads which enable the farmer to transport produce to market.

3. Assign priorities to the resources.

4. Because of the wide range of resources it may be necessary to develop a flow chart and show the interactions.

5. How the resources are utilized will vary from farmer to farmer - e.g. crop residues may be grazed in situ or they may be collected and fed to cattle in the pen, or they may be incorporated into the soil.

Group 4

1. Develop general guidelines for deciding which analysis/evaluation techniques are appropriate in different types of trials.

2. Apply these guidelines to the following example, listing the most appropriate techniques and indices and why selected.

Example: Target farmers: grow maize/beans intercrops, consume both crops in a 10:1 ratio, sell small surplus of beans in a good year, feed residues to livestock. Trial - on-farm trial of 6 promising bean genotypes of different growth habits, under a uniform maize crop. (6 treatments, 3 replicates, and 4 locations).
General guidelines for analysis/evaluation:

Variety trials:
- no need to consider costs
- use relative prices (price ratios)
- involve farmers in evaluation on station and on-farm
- check which varieties farmers would like to test, as well as their ranking on station

Farmer managed trials encourage differences between the environments

Cropping systems and agronomic trials:
- Where sole crops are important, analyze returns on cash basis and/or area basis (LER), but not using bivariate approach.
- involve farmers in evaluation
- analysis should take into account relative importance of the crops to the farmer

In the example given, the following assumptions were made:

1. Bean varieties are more or less acceptable to the farmer in terms of consumer acceptance e.g. palatability, grain shape and color, processing time, etc.

2. No control is contemplated in design so it is assumed that bean varieties previously have been compared with local check and/or the surrounding field is checked.

3. Farmer expects maize yield to be unchanged by introducing a new bean variety.

4. Management of trial (farmer or researcher) and use of same or different maize varieties will not affect analysis.

The evaluation (analysis of the trial):
- Neighboring farmers should visit the trials to assess management of the varieties - e.g. labour time, rank them, indicate which they would like to test.

- Evaluation of grain weight and stover weight at harvest for both maize and beans.

- Compare the maize yields with bean grain yield using “Churchill” diagram -- i.e. graph of bivariate analysis; see Mead in this volume.

- Analyze each separately and calculate monetary value of output for each treatment.

- Compare maize grain yield with local output of grain and stover using “Churchill”.

- Analyze the cost of the seeds.

- Analyze within each farm, and use means to compare across farms in terms of grain yield, management etc.

Researcher evaluation of On-farm trials:
- Relevance of trial to local farming system
- Timeliness of sowing
- Size of trial: farm size
- Level of experimentation

Evaluation indices:
- Improved productivity: yield measured by some combination of absolute yield, LER (with caution), and economic value of crop components. Use of sole crop plots justified in an area wherein intercropping being eroded by extension advice, or where it shows promise to replace sole cropping.

- Maintained acceptability: components assessed by on-farm survey and on-station farmer participation. Indices are flavor, quality, grain color / size / processing / cooking time, storability, crop duration (vis a vis land/labour).

- Maintained stability: of crop performance, and sustainability of the system itself. Levels of stress tolerance of varieties, contribution of crop association to maintenance of soil structure and fertility.

Group 5

Provide guidelines for identifying indices or other methods for evaluating intercropping trials, both on-station trials and on-farm trials, to ensure the evaluation focuses on farmer production objectives.

Farmers production objectives revisited:
- Crop productivity
- Risk avoidance
- Food, fuel, and fodder supply
- Income
- Efficient use of land and labour

Group 6

Provide guidelines on how to determine the extent farmers are concerned about grain and crop by-products production, nutrition, economic values or other sociological/anthropological factors in their intercropping enterprises and how this would influence the evaluation and interpretation of intercropping trials.

1. Review literature where available. Things like different crop combinations should be looked at.
2a Conduct informal surveys, by going to the farmers and asking them questions. The survey should:

* focus on the importance of intercropping in the existing system
* What crops are grown
* Assess the objectives of the farmer
* Look at various ways the crop residues are utilized
* What are the major crops

Guidelines for informal surveys have been developed/revised. They should not go beyond the description of the system.

2b Where resources are available conduct formal survey to identify and quantify problems.

3. Conduct trials in the farmers' fields based on the diagnostic survey.

4. Involve the farmers to evaluate trials:

   Discuss contents of the trial with the farmer. Tell him about the size and duration of the trial. Small plots may be more readily accepted by the farmer.

   Explain the treatments to the farmer before setting up the trial in the field and make necessary adjustments according to their preference.

   - Involve farmer evaluation during the growing season.

   - Involve farmer evaluation during and after the harvest including cooking, storage and marketing.

5. Conduct adoption studies after a certain period

   - This will provide positive and negative feedback on the technology.
Summary of Issues and Guidelines for On-Farm Experimentation With Intercrops

Introduction

This summary draws on presentations and discussion during the Workshop. Emphasis is on concepts and methods for on-farm adaptive intercrop research and little attention is paid to specific intercropping experimental factors, such as genotypes, weeds, fertilizer and plant spatial arrangements. Some of the points made here did not enjoy unanimous endorsement at the Workshop.

Most intercropping research has been conducted on experiment stations with the aim of proving or understanding the efficiency or advantage of intercropping systems, or of designing new systems on the basis of biological principles. However, experiment station trials often make poor predictions of the best varieties, fertilizer rates and application methods, population densities, and sometimes disease control techniques for use by smallholder farmers in their intercrops.

Much intercropping research should aim to offer farmers improvements on their existing intercropping systems. To do this, more research should be conducted on-farm using a production problem orientation. Most of the general issues and techniques related to farmer orientated on-farm intercrop research are similar to those for other forms of on-farm agronomic research. There are however some aspects that differ. These special considerations, rather than the similarities, are emphasized here.

Formulation of Intercropping Research Programmes

Farmer focus and on-farm research
Much previous intercropping research in E and S Africa (and elsewhere) was in the form of isolated experiments with limited biological objectives, conducted within commodity programmes and generally on-station.

In spite of the large amount of intercropping research done, very few appropriate intercropping recommendations to extension and smallholder farmers have emerged from that work. Intercropping systems are complex and there are myriad opportunities for fine-tuning the system, but most will not be acceptable to farmers. Because several technology factors are involved together and are likely to interact strongly with the farmers' environment, a higher proportion of on-farm experiments in an intercrop research programme than in sole cropping may be justified. Most intercropping experiments should be very adaptive in nature.

Intercropping research needs a higher level of farmer involvement than does most other forms of research. This is due to local agro-ecological adaptation and because of farmers' multiple objectives in intercropping.

Thus more appropriate formulation of intercropping research programmes is vital.

Organization of intercropping research
To ensure good technical content and the relevance of proposals to farmer needs, research policy makers, researchers from several disciplines and extensionists need to interact effectively at various levels.

Social and economic scientists have a large role to play in ensuring the relevance of intercropping research to farmer needs.

Because of the complexity in intercropping research much can be learned from success and failure elsewhere -- information networks are useful.

Intercropping research might be organized in the form of interactive working groups made up of members from several commodity and disciplinary teams, rather than as separate dedicated intercropping teams.

An intercrop combination can often usefully be treated as a "commodity" of several component crops together rather than have the ideas, treatments and recommendations developed for each component separately.

Problem orientated intercropping research should follow the established process of diagnosis, planning, experimentation, evaluation and replanning, and dissemination.

During implementation of a problem orientated intercrop research programme close interaction between on-station and on-farm components, and with extension, is vital.

Diagnostic Procedures

Most intercrop research has emphasized the comparison of biological yields in experiments, yet intercropping experimentation relevant to smallholders first requires our understanding of farmer problems and needs. This is the role of diagnosis.
Aims of diagnosis
Similar diagnostic procedures apply as in other forms of farmer problem orientated research. Aims remain to understand farmer circumstances, describe farmer practices, identify farmer problems and examine causes of the problems identified, and develop some tentative ideas on target groups of farmers, all in close interaction with the farmer. But since intercrops are more complex (involving two or more crops, possibly staggered planting times, different spatial arrangements etc) then diagnosis of problems may require additional socio-economic as well as deeper technical insights. Frequently surveys underestimate the importance of associated secondary or "subordinate" crops such as legumes. Care is needed to examine these fully often justifying multi-visit surveys.

Farmer objectives
A major aim of diagnosis is to learn the farmers objectives in intercropping. There will usually be several and they may include biological and socio-economic reasons:

- spread requirements for labour over time
- reduce risk of crop failure
- improve output stability over seasons
- increase yield per unit land area e.g. to maintain yield of a staple (often cereal) crop and produce some yield of a subordinate (often grain legume) crop.
- provide a greater range of secondary outputs e.g. legume leaves as relish, residues for livestock, stems for roof thatch
- comply with government/extension policy

It is unlikely that all the farmer objectives, nor their ranking, are immediately obvious to the researcher, so some investigation is needed.

Farmer resources
It is also important to learn about the resource requirements of the farmers current intercrop practices, particularly labour, since most intercrops are labour intensive.

It may be relevant to devote more time to assessing the sustainability implications of current farmer intercropping or other practices, with a view to developing intercropping experimentation that has a sustainability perspective.

This may involve assessing resources and their use at several levels e.g. the field level, whole farm level and community level.

Resources to evaluate include:
Crop residues, soil organic matter, nitrogen fixation, animal manures, rainfall, farmer and family labour, non-family labour, animal power, ground water (for small-scale irrigation), household waste.

Followup diagnosis
Followup diagnosis during on-farm experimentation is likely to be even more necessary with complex intercropping technologies. There may be more of a role for surveys and monitoring in farmers fields and less of a role for exploratory trials in intercropping diagnosis.

Planning Intercrop Experiments
General
The process of planning on-farm intercrop trials is the same as for other on-farm agronomic trials. Planning uses the information generated during diagnosis to develop appropriate targeted experiments.

On-farm experimentation with intercrops can be complex and expensive. Thus on-farm experimental programmes with intercrops need to be carefully planned and justified.

Because of the greater complexity with intercrop trials, a systematic approach to developing clear objectives and related appropriate treatments becomes more important than ever. Then the analysis and interpretation of results becomes easier and more productive.

Good information generated with farmer participation in the diagnosis will help ensure the planned experiments address farmer needs. Feedback from farmers on experiment proposals before the trials are implemented is very useful for intercrop trials.

Experimental factors and treatments for intercrop trials
There has been relatively too much research on plant population density and spatial arrangements of intercrop component crops to the detriment of other aspects relevant to smallholder farmers such as fertilizer use, weed control and pest control.

When identifying possible technologies as solutions for inclusion in intercrop trials it is important to know whether we are considering:

1) changing one or more components of an existing intercrop, or

2) changing the cropping pattern (i.e. replacing sole cropping with intercropping or intercropping with sole cropping).

In problem orientated on-farm intercropping experiments we are usually looking at 1) i.e. changes to components of an existing intercrop. Some general concepts for such trials are:
- We need to test new technology against current intercrop practices employed by the farmer,
- New technologies for testing should not differ in too many ways from the current farmer practice if they are to stand a good chance of adoption,
- We must be clear about farmers’ current objectives for intercropping and ensure new treatments for testing are compatible with those objectives, and with resource levels of farmers. For example, with weeding work it will be important to know the timing of labour bottlenecks using current weed control methods in order to think about modified weed control technologies that might reduce the problem.

Care is needed when planning on-farm intercrop trials on the basis of yield benefits or Land Equivalent Ratios (LER) obtained from on-station trials. Benefits may disappear on-farm. For example, there are doubts about the technical performance or biological advantage of intercrops in some semi-arid areas.

Complex changes to intercropping systems may be difficult for farmers to accept. These changes may require more institutional support (e.g. training from extension) than sole crop technologies.

Sole crop plots vs. plots of farmer practice
In many on-farm intercrop experiments sole crop plots are not needed.

The number and type of sole crop plots required depends on the objectives of the trial. Most on-farm intercrop trials aim to see how best to grow intercrops, or to modify current intercrops, not to determine whether intercropping has biological advantage over sole cropping. Here we need to think very carefully if any sole crop plots are needed at all.

Usually the important comparison is between the new technology and the farmer’s current intercrop technology, so far more important than plots of sole crops are plots of the farmer practice. This is especially true in adaptive verification trials.

Generally we only need to think about calculating LERs (and so include sole plots) if land is a clear limiting resource and if farmers intercrop mainly to increase the efficiency of land use. Where sole crop plots are needed for LERs these do not need to be randomised and grown on plots in the experiment. They can be obtained from sole crop areas near the experiment.

Sole crops may be useful to convince policy makers, extension staff and other researchers.

In on-farm trials, it may be impracticable to have plots of sole crops where intercropping is clearly the farmers’ preference and land is in short supply. The farmer may regard plots of sole crops as wasteful.

**Experimental designs and treatment structures**
Good experimental design is even more important in intercrop experiments on-station or on-farm, than for sole crop experiments.

Underlying principles of design are no different for intercropping than for other areas of field crop experimentation.

Design of any agronomic (intercrop) experiment consists of 3 stages:

1) Identification of experimental plots and variation between them, followed by control of variability through blocking.

2) Identification of objectives of experiment and selection of treatments to provide answers to the questions proposed—develop treatment structure.

3) Join chosen treatments to the structured set of experimental units.

In intercrops we may need larger plots, both because of the need to have sufficient plants of all the component crops and the need for larger guard areas. The minimum plot size for the intercrop should be the largest of the minimum plot sizes for each of the component crops.

Some special designs have been developed for on-station intercrop experiments. Systematic (e.g. modified fan) rather than randomized designs should often be useful for on-station work on spatial arrangements in intercrops where many spacing treatments will be combined factorially with other factors. In these designs the plant density or spatial arrangement changes slowly from row to row across a plot, meaning that guard rows are usually not necessary. Statistical analysis of systematic designs is different, involving fitting a response function of yield on the factor that varies in each systematic plot.

Factorial treatment structures with several factors included are important for efficient intercropping research to develop technologies because there are many more possible factors to consider, but standard on-farm research practices of keeping trials as simple as possible still apply.

Therefore, with on-farm intercrop trials there is greater need to consciously restrict the trial to a few variables and/or levels of a variable. Appropriate choice of treatments is thus more critical than ever.
Many existing intercrop trials (on and off station) with two or more experimental factors use a split-plot design, but usually this is not the most appropriate design. Split plots are inefficient and should only be used where it is not possible to apply a treatment to a small plot e.g. if large-scale machinery is needed.

Instead of split-plots confounded designs or incomplete factorial treatment sets may be useful in intercropping where we often have conflicting requirements to have several factors included but to also have small blocks.

Output comparisons
During planning some tentative decisions about how the trial will be analyzed and assessed need to be made to help decide on the types of data to be collected during trial implementation.

The most meaningful and generally useful output comparison for the farmer is usually total output from one or more experimental intercrops and total output from the farmers existing crop, with output expressed as monetary values or nutritional value (calorie output). Choice should depend on the uses the farmer puts the output to. Where the farmer sells at least some of the output to a formal or informal market (usually the case), or if the farmer buys some of one or more of the crops, then monetary value (or net income) is most appropriate. Thus monetary value is the best measure of output for most adaptive verification intercrop trials.

Farmer assessment
Given the multiple objectives farmers have with intercropping there is a more important role for farmer participation in intercrop trials and in their assessment. Opportunities for farmer assessment during trial implementation need to be planned for.

Implementing Intercrop Experiments

Principles of farmer and site selection, and field plot layout and technique for intercrop experiments on-farm are all similar to those employed in sole crop experiments.

The main difference relates to the increased complexity of the trial when two or more crop species are combined. This means more care and work is needed when implementing the experimental treatments and in managing non-experimental variables. There will often be additional data to collect.

Analysis and Interpretation of Intercrop Research

Form of analysis and interpretation
Methods for evaluating on-farm intercropping trials will depend on the reasons farmers have for intercropping, especially the balance between market vs. subsistence orientation:

If the farmers' aim is improved productivity with emphasis on sale of output, then interpretation should focus on yield outputs of the test intercrop technologies, probably finally as combined monetary values.

If test technologies have potential for producing outputs for home consumption, and especially if the technologies are germplasm, then farmer acceptability for flavour, leaf quality, grain colour/size/processing/cooking time, storability, crop duration in relation to labour and land, need to be assessed through farmer surveys. If stability of performance is paramount then evaluation needs to take into account the levels of stress tolerance of component varieties when grown in a crop association.

Measuring biological outputs
Before the productivity or efficiency of intercropping systems can be assessed the basis on which outputs are measured and to be compared needs to be decided upon.

Evaluation of intercrop practices should be in terms of the most limiting resource or production factor. In E and S Africa this is often labour and only sometimes land.

Evaluations can be made on many different bases e.g. whole plant dry weight, grain dry weight, or plant constituents like fat, calorific values, protein, fodder yields for feeding animals, or on net income. Character(s) used will depend on the objectives of the research and what is useful to the researcher and the farmer.

A whole series of indices have been developed to combine output data (usually biological yields) to assess biological advantage of intercrops and competitive aspects of components of intercrops. These have been extensively used in more basic intercropping research on-station. The most important indices of biological advantage are the relative yield total and the LER. In most cases these indices are inappropriate on-farm.

Reasons why farmers intercrop are usually multiple- only one may be to intensify the use of land. Therefore LER may often not be useful, so often there is no point in calculating it.
Simple value indices such as money, protein or dry matter are usually the most relevant for on-farm intercrop trials.

**Statistical analysis**

No single form of statistical analysis will be appropriate to all forms of intercropping data.

In more basic technology generation intercrop experiments, sometimes done on-farm, data structures will be complex with different forms of yield information available for different sub-sets of experimental units.

A basic aspect of statistical analysis in intercrops is to obey the principle of comparing like with like. If yields are measured in different units, or over different time periods, or for different species then comparisons will not be valid.

Several forms of analysis are possible: Analysis of each crop yield separately; Multivariable (Bivariate ANOVA) analysis; Analysis of crop indices (e.g. LER, monetary values).

Bivariate analysis of variance is a powerful form of analysis that does not lead to loss of information. This involves the joint analysis of the pairs of yields for two crops intercropped on a set of experimental plots.

In on-farm research the multiple products or outputs from an intercrop may be most meaningfully evaluated together since farmers will be interested in the total worth of all useful outputs from different intercrop systems. However, it is easy to do misleading statistical analyses using indices.

In adaptive or verification OFR the most useful index is monetary value. This is done by converting the output (may be other than grain yield) from each component crop to monetary units according to market values and summing these for all component crops on a per plot basis, giving monetary units per hectare. These values are then subjected to an ANOVA in the same way yields might be analysed. Monetary values have practical meaning for most farmers.

Comparisons of biological efficiency through LERs are not valid for different crop combinations. When calculating LERs we must make sure the divisors are constant for all the values to be compared.

Comparison of LER values within an analysis of variance is usually valid provided that a single set of divisors is used over the entire set of intercropping plot values. Questions about the precision of LERs are usually not important.

**Agronomic interpretation**

General principles are the same as for other on-farm trials but interpretation can be much more complex because of complex interactions and several output variables.

**Socio-economic assessment of outputs**

Many relevant evaluation criteria in intercropping may be socio-economic rather than related to agronomic performance per se. Thus, farmer evaluation is very important.

Farmers should be fully involved in the assessment/evaluation of on-farm adaptive intercropping trials, with less emphasis on conventional statistical methods. Rather than develop complex statistical measures and procedures to cover multiple objectives, a qualitative evaluation involving farmers is often more cost effective. Also, measurement of all the relevant outputs from intercrops can be very difficult while farmer assessment will integrate the outputs important to the farmer.

Assessment can be done through a survey of farmer opinion on the benefits of the intercropping technologies under test on-farm, using an open-ended questionnaire.

Farmers may be interested in evaluating the technology on any of the following grounds:

- compatibility with farmer objectives in intercropping
- outputs appropriate
- labour implications
- effect on timing of operations
- cash implications
- risk implications
- land implications
- relationship with decision making in household
- effect on household food supply
- availability of required inputs

The questionnaire may involve basic information on the farmer and the trial, treatment by treatment evaluation by the farmer, ranking of treatments by the farmer and general comments made by the farmer.

**Economic analysis and interpretation**

An economic analysis of trials is essential if the researcher wants to check whether the technical responses are sufficiently attractive economically for farmers to adopt the tested technology. This will be an important objective with data from adaptive on-farm intercropping trials.

Relative comparisons of economic gains and losses will depend on the nature and objective of the trial. We can consider three situations in intercropping trials where gain/loss comparisons are different:

a) Comparison of output gains, caused by incremental changes in the levels of a key input, with the extra cost of each unit of input.
b) Comparison of different combinations of intercrops given a fixed level of inputs.

c) Comparison of different combinations of inputs for a given level of output.

Comparisons 1 and 2 will be relevant where the objective of the trial is to make modifications to existing intercrops. Comparison 3 will usually be relevant where a sole crop is being compared to an intercrop.

Standard considerations before meaningful economic analyses can be done apply equally for intercrop trials: i.e. inclusion of the farmer's current practice, data from sites representative of farmer conditions, non-experimental variables at current farmer levels and real costs and benefits to the farmer used, not market prices or researcher yields.

With intercrop trials it is generally best to do the economic analysis on the weighted value of the crops combined, reflecting farmers aims and objectives. This means a statistical analysis will have to be done first on the combined monetary values as indicated earlier.

If market values of the crops within the intercropping system vary greatly during the season, then evaluate the treatment effects in the experiment over a range of market price rates.

For analysis/evaluation of variety intercrop trials there is little need to consider costs. Price ratios between component crops can be used, and evaluation by farmers should occur early in variety development i.e. on-station as well as on-farm.

Feedback to commodity/disciplinary research needs to reach a wider audience than results from sole crop research because of the multi-commodity nature of the work.

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