INTERCROPPING
in semi-arid areas

Report of a symposium held at the
Faculty of Agriculture, Forestry
and Veterinary Science,
University of Dar es Salaam,
Morogoro, Tanzania,
10-12 May 1976

Editors:
J.H. Monyo, A.D.R. Ker,
and Marilyn Campbell

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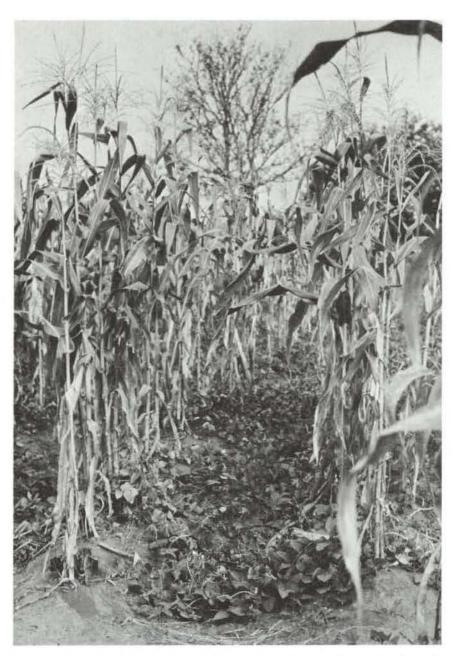
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Farmer's field near Ibadan, Nigeria, showing intercrop of cowpea under maiz

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Foreword

Intercropping is the mixing or interplanting of a number of different crops on the same piece of land, at the same time. It is almost universally practiced by small farmers in most tropical countries, but, in spite of this, agricultural research workers in the tropics have generally tended to neglect the complicated intercropping systems and to concentrate on research on one crop at a time, as is done in temperate regions. Recommendations based on the results of this research were then made to the small farmers so that they might improve their crop yields. The farmers almost invariably rejected these attempts to impose alien single-crop systems on them, and continued their own traditional intercropping practices.

Subsequently, a very limited amount of experimental work on intercropping began to indicate that not only was the total production usually considerably greater from intercropping plots than from the same crops grown on separate parts of the same plot, in pure stand, but that intercropping offered considerable additional advantages to the farmer: it reduced the risk from failure of one crop; it helped control weeds and therefore minimized labour requirements at peak seasons; it protected the soil from the deleterious effects of exposure to sun and rain; and there is some evidence that it reduced the incidence of certain pests and diseases.

Therefore, in 1972, discussions took place between the staff of the Faculty of Agriculture, Forestry and Veterinary Science of the University of Dar es Salaam at Morogoro, Tanzania, and Dr Hugh Doggett of IDRC, concerning possible support for intercropping research at the University. In 1973, the Faculty began research in the IDRC-supported project, and later in the year, Richard Finlay, an IDRC advisor, was appointed to help with the project. Most of the staff members and students in the faculty were involved in the project, under the leadership of Dr John Monyo, Head of the Crop Science Department, and good progress was made on the study of the intercropping systems that could be practiced under Morogoro conditions.

Therefore, in collaboration with IDRC, the faculty decided to organize a symposium on intercropping to share the results of their research with other scientists working in the same field, and to exchange information and research results generally.

Some 88 participants from Mauritius, the Sudan, Ethiopia, Kenya, Uganda, Tanzania, Botswana, Zaire, Nigeria, the Cameroons, Liberia, India, England, and Canada attended the symposium, which was held at Morogoro in May 1976, and the papers presented are summarized in this report.*

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*Those who are interested in obtaining complete copies of the papers are requested to write to the respective authors at the addresses given in the *List of Participants.*

Professor David Norman of Sir Ahmadu Bello University, Zaria, Nigeria, and Dr Hugh Doggett of ICRISAT and IDRC summarized the conclusions of the symposium, which may be found at the end of this report.

The need for a clearinghouse for the exchange of information on intercropping, including the regular publication of a newsletter, was emphasized during the discussion.

The warm hospitality and excellent arrangements provided by the Executive Secretary of SISA Mr A. N. Mphuru, and later by Dr C. L. Keswani (who was mainly responsible for the conference arrangements after the departure of Mr Mphuru in early March for further studies in the United States) were greatly appreciated by all the participants at the symposium.

A. D. R. Ker
Program Officer
International Development Research
  Centre
Dakar, Senegal

Addresses
to the
Participants

Welcoming Address

A. M. Hokororo
Chief Administrative Officer, University of Dar es Salaam, Morogoro, Tanzania

It gives me much pleasure to welcome you all to the Faculty of Agriculture, Forestry and Veterinary Science of the University of Dar es Salaam. This is one of our young faculties in the university and, because of the nature of its work, is situated in a rural setting away from Dar es Salaam, which we hope has not inconvenienced you.

During your stay here members of staff of this faculty will present results of their work on intercropping and share with you their experiences. It is my belief that you will feel free to comment on our work and criticize any aspect of this work.

With regard to the work itself (which has been made possible through a grant from IDRC, for which the university is grateful), I have been told that the faculty has been examining the productivity of various crop combinations. The view was adopted right from the start of the project that the productivity of this type of cropping system could be improved by empirically screening for high-yielding genotypes that nick well in mixed cropping. There is also need for a better understanding of the processes responsible for the attributes of mixed cropping. This would enable our scientists to design better cropping systems for the peasant farmers. From the data collected over the past three seasons we are beginning to understand the complexity of this kind of cropping system. It is hoped that from the papers presented to the symposium it will be possible to develop a strategy on how best to tackle this intricate problem in the future.

Finally I would like to wish you successful deliberations and a comfortable stay in Tanzania.

It gives me great pleasure to welcome the Principal Secretary of the Ministry of Agriculture, United Republic of Tanzania, Mr A. Mushi to open the Conference on behalf of the Hon Mr J. S. Malecela, Minister of Agriculture.

Opening Address

Hon Mr J. S. Malecela, M.P.
*Minister of Agriculture, United Republic of Tanzania**

It is indeed an honour and privilege for me to have been invited to open your Symposium on Intercropping for Semi-Arid Areas. As you are no doubt aware, agriculture is the mainstay of Tanzanian economy and the Tanzania government has given it priority so that all farmers can increase food production for better human nutrition and for export. We are all aware of the fact that there are several parts of the tropics where water in the form of rainfall or irrigation is not sufficient and that for such areas we have to breed drought-resistant crops. There are several parts of Tanzania where rainfall reliability is poor and in these areas farmers who grow crops such as maize consistently fail to get a good harvest. We are asking such farmers to grow drought-resistant crops such as sorghum, millet, and cassava. We are aware of the fact that we need protein-rich crops also, and the growing of cowpeas, chick-peas, pigeon peas, and other legumes is being encouraged. I am very pleased to note that you wish to exchange ideas on traditional methods of growing the above crops and to look for ways of assisting farmers in increasing production.

Turning to the main subject of your symposium, intercropping as a cultural practice is widely used by peasant farmers in many parts of the tropics. It is therefore fitting, and indeed opportune, that we have gathered here today scientists from different parts of the world with the relevant tropical experience to critically assess the scientific basis of intercropping. This type of culture has been described variously as primitive, uneconomic, and unscientific. Despite that grim picture painted by agricultural extensionists, the peasant farmer has persistently used mixed cropping for his subsistence and sustenance. In some cases it has been extended to cash crops such as coffee–banana intercropping in various parts of East Africa.

If from your deliberations you should find convincing evidence for or against this type of practice it is my hope that you will suggest ways and means of getting the message to the farmers. Mere resolutions will benefit no one unless a strategy for implementing them is also instituted.

The developing nations are striving for the highest level of productivity in agriculture as our economy relies on it. The costs of production are, however, escalating. There is therefore a great need to reduce the burden on the small farmers who constitute the largest part of the farming community in the tropics. If this burden can be lessened by adopting intercropping on a more scientific footing, then spare no efforts

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*Presented by Mr A. Mushi, Principal Secretary, Ministry of Agriculture, on behalf of the Hon Mr Malecela.

in seeing to it that the intercropping message reaches the farmers. If, however, there is need to move away from this practice then the urgency is even more imminent.

While considering this type of farming, cognizance should be taken of national aspirations in mobilizing the people to become more productive. There may be situations where land is a problem; in others, the trouble may be associated with lack of organized large-scale farming where land is plentiful. The possibilities or otherwise of mechanizing mixed cropping and the problems associated with crop protection in intercropping for the large-scale farmer should also be borne in mind.

I am pleased to note that this conference is a joint venture between the University of Dar es Salaam and the International Development Research Centre (IDRC), Ottawa, Canada. I wish to express my thanks to IDRC for showing interest in small farmers in the developing world.

I understand too that the results that will be discussed at the conference accrued from Phase I of the project, and that Phase II, which started in July last year, is also being funded by IDRC. It is particularly pleasing to know that it is IDRC's intention to help local scientists in the developing countries develop their research capabilities by working on problems that have a vital role to play in their economies. I find this very encouraging. Most of the money given as aid to the developing countries flows back to the donor countries largely as cheap raw materials in return for expensive industrial goods. Here we have a situation where the donor wishes that the money granted and the knowledge gained should be for the benefit of the recipient country.

I wish you a good conference and hope that at the end of Phase II we should be even better equipped to tackle the problems confronting peasant farmers in the semi-arid tropics.

With these few remarks, I have the pleasure in declaring your symposium open.

Summaries
of Papers
Presented

An Appraisal of Some Intercropping Methods in Terms of Grain Yield, Response to Applied Phosphorus, and Monetary Return from Maize and Cowpeas

Y. A. Sudi, H. O. Mongi,[1] A. P. Uriyo, and B. R. Singh

Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Morogoro, Tanzania

This project aimed to evaluate some intercropping methods in relation to grain yields of maize and cowpeas, their response to applied phosphorus, and monetary return per unit area.

In the intercropping experiment, applied P significantly affected the grain yield of maize under both mono- and intercropping conditions, but not of the intercropped cowpeas. The intercropping methods had significant effects on the cowpea yield. At a particular rate of applied P, the yield of maize was the highest and that of cowpeas the lowest under the late between-row intercropping. Planting cowpeas between maize rows at the same time was the most economical intercropping method as it gave 33.6% higher monetary return than the monocropped maize. Sowing maize and cowpeas in the same hole gave an increase of 29.2% over the monocropping, which, although less than between-row intercropping, could be more convenient to farmers because it may save time and labour.

Fertilizer P affected the soil inorganic N content significantly. Its magnitude increased appreciably under the intercropping conditions. It was thought to be due to stimulative effects of P on nodule development and rhizobium activity. Furthermore, the symbiotically fixed N probably was excreted from nodules in the soil, leading to increased inorganic N content.

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[1]Present position: Director, Uyole Agricultural Centre, Mbeya, Tanzania.

Rhizosphere Populations in Intercropped Maize and Soybean

T. H. M. Kibani, C. L. Keswani, and M. S. Chowdhury

Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Morogoro, Tanzania

A rhizosphere is a region of contact between plant roots and soil from which plants obtain their nutrients and in which each plant exerts its particular effect on the soil by stimulating or inhibiting the growth of microorganisms. Similarly, it is also possible that microorganisms in the rhizosphere may have effects on the growth and yield of the plants. Rhizospheres of different plants harbour different microflora, and the quantitative and qualitative nature of the microflora depends on the age of the plant, the depth of the root system, and the physiological and nutritional status of the plant (1).

Gantotti and Rangaswami (2) have suggested that the rhizosphere microflora in association with the roots of growing plants plays a vital role in improving soil structure. Gerretsen (3) described the enhancement of nutrient uptake by plant roots under the influence of microflora and observed that under sterile conditions without bacteria the uptake of phosphate proceeds at a lower rate than in the presence of bacteria. The rhizosphere of maize contains bacteria capable of releasing phosphorus from its compounds (3, 4).

Several studies have been done on the influence of microflora on the growth and yield of crop plants (5, 6, 7), but these studies involve monoculture conditions. Shantaram and Rangaswami (8) studied rhizosphere microflora of mixed crops using sorghum (*Sorghum vulgare* Pers.) and sunhemp (*Crotolaria juncea* Linn.) under greenhouse conditions.

This study dealt with rhizosphere and nonrhizosphere fungal and bacterial populations of soybean (*Glycine max* (L.) Merr.) and maize (*Zea mays* L.) under intercropped and monoculture conditions. Since both crops were grown simultaneously in intercropping, it is hypothesized that root exudates from either of the crops may have effects on the rhizosphere microflora and consequently on the availability of nutrients to plants. Therefore, an attempt was made to assess the microbial population in the rhizosphere and nonrhizosphere soils of maize and soybean under intercrop and monoculture conditions and its relation to crop yield under field conditions.

Results showed that the rhizosphere microbial population was greater than the nonrhizosphere microbial population. Maize intercropped with soybean showed an increase of 1.10 and 9.19% fungal and bacterial populations in its rhizosphere, respectively. Unlike maize, soybean showed a decrease of 11.74% of fungal population and an increase of 3.52% in bacterial population in its rhizosphere. Intercropping increased the bacterial R:S ratios of maize and soybean whereas fungal R:S ratio showed a decrease in both cases when compared to monoculture conditions. Yields of maize increased by 33.97% in intercropping compared to monoculture, whereas

yields of soybean decreased by 51.14% compared to monoculture. *Rhizopus microsporus* was predominant in the rhizosphere soil of maize under both farming systems, and *R. microsporus* and *Aspergillus niger* were predominant in the rhizosphere of soybean under intercrop and monoculture, respectively. *A. niger, Penicillium variable*, and *A. terreus* were predominant in the nonrhizosphere soil of maize and soybean under both cropping systems.

Although there were some qualitative and quantitative differences in fungal populations in intercropped and monoculture conditions, there seems to be no relationship between these parameters and yield in either maize or soybean.

Intercropping for Increased and More Stable Agricultural Production in the Semi-Arid Tropics

B. A. Krantz, S. M. Virmani, Sardar Singh, and M. R. Rao

Farming Systems Research Program, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India

In the semi-arid tropics with non-mechanized harvesting, intercropping is possible and usually highly desirable; however, there is a dearth of basic agronomic and physiological information on the interaction of two or more species in intercropping systems. Likewise, the agronomists have failed to encourage breeders to develop genotypes that would be especially adapted to various intercropping situations.

There is a vast potential for improved conservation and utilization of natural resources by intercropping and many avenues for research to capitalize on this potential. As much as 50 or even 100% increases in yield from alternate-row cereal–pigeon pea intercropping systems over that of "shared" cropping systems have been obtained in experiments at ICRISAT.

Proposals for a systems analytic method have been made for estimating available water for crops over the growing season using climatological, water balance techniques. Such an estimate for a given soil–climate situation, when compared with the water demand of crops or their varieties at different phenologic stages, gives a reasonable first approximation, regarding their suitability in a given situation. Hyderabad has been taken as an example and some fitting of crops of various durations and characteristics have been shown for three simulated soils having 50, 150, and 300 mm available water storage capacities in the root profile. The studies showed that a short-duration crop of pearl millet intercropped with a long-duration indeterminate crop of 130–150-day castor would suit a low-water availability situation. In the case of medium-water availability soil situations, a medium 90–100-day crop intercropped with a 130–150-day crop of pigeon pea would suit. Similarly, in the case of high-water storage soil situations, a 100-day maize crop intercropped with 150–180-day pigeon pea would suit best. The technique that yields a quantification of soil–climate situation for assumed water environment for crop growth is amenable to computer analysis. With this type of model, it should be possible to quantify the natural resources for any given region and be better able to match cropping systems to the resources available.

Possible approaches are also given to the development of the needed basic agronomic and physiological information of various crops species and genotypes for optimizing intercropping patterns. By using computer simulation techniques on cropping systems information and rainfall and soil data, it should be possible to match alternative cropping systems for optimum utilization of the present or the potentially improved natural resources of a given area. This initial sorting should greatly reduce the number of crops and cropping combinations that need to be investigated to evolve alternate improved and economically viable farming systems for any given region.

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Cropping Systems Research: the Scope and Strategy for Research in Crop Combinations Based on Experience of Previous and Current Studies

B. N. Okigbo

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Recently there has been a resurgence of interest in the study of intercropping in Africa because of (1) a realization that research aimed at improving the existing cropping systems must be based on the understanding of the mechanics, economics, advantages, and disadvantages of the traditional systems that we desire to change and improve; (2) the disappointing response of most African farmers to improved technology of food crop production systems based on sole cropping transplanted from temperate largescale cropping practices with its attendant high energy and capital requirements and risks; (3) the impact or the potentialities of multiple and relay cropping systems work at the International Rice Research Institute based on modifications and improvement of current intensive traditional cropping systems in Taiwan and Indonesia, which significantly increased yield per unit area; (4) the recently recognized fragility of agroecosystems of single varieties of crops grown in sole culture over wide areas of land either with respect to the dramatic buildup of pests and diseases in the "green revolution" areas of Southeast Asia or the widespread devastating epidemic of southern corn blight in the United States where 90% of the corn crop carried a common source of cytoplasm; and finally (5) the recent general concern about the environment and interest in integrated pest management pioneered by ecologists who maintain that mixtures in traditional cropping systems constitute ecologically more stable production systems than large areas of single uniform varieties grown in pure culture. This paper reviewed past and recent studies in intercropping in tropical Africa as a basis for the consideration of the scope, strategy, and methodology in research on cropping combinations and sequences.

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Mixed Cropping Research at the Institute for Agricultural Research, Samaru, Nigeria

E. F. I. Baker and Y. Yusuf

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Because agricultural research in developing nations has been conditioned by cropping systems of the more developed countries, little attention has been paid to indigenous cropping systems, in particular mixed cropping systems of subsistence farmers. Most re-search has been directed to increasing production under sole cropping (a predominantly temperate system) instead of asking how to increase production under mixed cropping (the dominant system of tropical subsistence farmers). It is the lack of knowledge of the principles underlying mixed cropping that has prevented the application of improved technology to these farmers.

Although research with mixed crops has been done at this Institute over the past 25 years, albeit intermittently, little progress was made until the findings of Norman (10) that not only is labour used more efficiently but also that returns are less variable from year to year from mixed cropping than from sole cropping. Recognition that mixed cropping is based upon sound economic sense, and is far from being an unsophisticated form of agriculture, led to renewed research at the Institute.

Current research has been directed to answering one question. "Is mixed cropping intrinsically higher yielding than equivalent sole cropping?" As a baseline to answer this question we took a 3-year mixed cropping rotation common to the area around the Institute.

Experiments with the 1st year break, mixtures of a 1:1 ratio of millet and sorghum, showed that yields of both were higher when grown in mixture than when grown alone. This occurred because the different canopy structure formed by mixing a fast-growing early millet with a short, late sorghum allowed better light utilization early in the season when millet was taller than sorghum, and later when the millet had been harvested. It was also demonstrated that adding maize to the mixture gave even greater returns.

For the 2nd year, when the "gicci" system of intercropping cereals with groundnut is practiced, experiments demonstrated that the reduced yield of groundnut, because of competition from cereals, was more than compensated by yield of cereal. This mixture consistently gave returns 30% higher than equivalent sole crops.

In the final year cotton is sown relay within cereals. This is done because farmers are unable to devote time to land preparation for cotton, being more concerned with weeding and harvesting early cereals to end the "hungry gap" after a long dry season. Cotton, consequently, is sown late and within the cereal. Yields are poor. We have demonstrated that rather than sow cotton late within cereal, thus reducing the period of overlap, cotton should be sown under cereal as early as possible, sowing date having a far greater effect on yield than period of overlap.

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These and other mixed cropping experiments have demonstrated that the subsistence farmer has developed a highly sophisticated system of cropping based upon good economic sense. We feel that the answer to the question is an unqualified "yes" and now intend moving to high input mixed cropping. Particularly we intend looking at the part played by nitrogen fixation by legumes within mixtures and the possibility of growing continuous legume crops within mixtures of various other crops. We also intend investigating rearrangements of the cereal component to give yet higher populations, possibly

by closing up rows and sowing double rows to facilitate mechanization. We have already initiated lysimeter studies to investigate water use by high populations in mixtures.

Finally, preliminary studies have shown that trifluralin is selective in cotton, castor, okra, groundnuts, soybean, sunflower, and tomatoes; chlorbromuron is selective in soybean, maize, and sorghum; and linuron is selective in millet, maize, cowpea, cotton, soybean, and groundnuts. The last is being developed as a herbicide for use in millet/sorghum and cowpea mixtures.

Crop Production Practices in Intercropping Systems

R. C. Finlay[1]

Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Morogoro, Tanzania

At the beginning of an intercrop research production program, it is important to identify quickly those factors that in combination increase agricultural production in terms of both quantity and quality.

It is suggested that an interlinked three-tier system be established involving: (1) studies on research fields; (2) experiments in village research-extension demonstrations; and (3) production data collection by sampling in actual farm conditions.

The purpose is to establish a testing

and information network that will be self-checking. Priorities are established in meaningful terms within the real crop production sector. Data on the research innovations under development in the farmers' environment are continually being generated, analyzed, and corrected. These are all linked through field research studies, village research-extension experiments, and farmers' recommendations from within their own farming systems. The entire program is based on a recommendation-generating crop production system set within the framework in which the innovation is to function.

[1]Present address: Plant Science Department, University of Manitoba, Winnipeg, Man.

Effects of Crop Combinations and Planting Configurations on the Growth and Yield of Soybeans, Millet, and Sorghum in Intercropping

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The types and choices of crops grown in intercropping depend on physical factors (soil conditions, temperature, moisture regimes), social factors (personal tastes, traditions), and economic factors (market prices and transport). However, a legume has almost always been included in the intercrop, the major ones in Tanzania being groundnuts, beans, cowpeas, and pigeon peas.

Although the yields of one or both crops in the intercrop have been shown to be lower than their respective pure stands (12, 13) the combined yields from the intercrop have been higher than the yields of either crop as a monoculture (13, 14, 21, 22) and the cash returns have been greater from the intercropping (15, 20). This lower yield has been attributed to competition for light and nutrients (16).

To obtain the highest possible yield from mixed cropping, natural competition for light, nitrogen, water, and possibly space and CO_2 should be reduced to a minimum. However, nitrogen and water are not easily manipulated since they depend on cost and climatic conditions, respectively. Light competition can be minimized by selecting a suitable plant type or planting date (17). Since cereals and root crops are more important than grain legumes from the farmers' point of view, legumes that are not aggressive and do not reduce yields of the staples are preferable. In soybean, the short-duration determinate types have decided advantages over long-duration indeterminate types (18).

Total productivity is a basic consideration in evaluating crop combinations. Based on yields from several repeated trials, crop combinations can increase land productivity from 30 to 60% over monoculture cropping (19). Millet and sorghum grow well in the drier regions of Tanzania, and although soybean is a recently introduced crop into Tanzania peasant farming, it is expected to occupy a prominent position as a foodstuff in the near future because it has a high protein content.

A field experiment was conducted at the Faculty Farm, Morogoro, Tanzania, to find out the influence of crop combinations and planting configuration on the growth and yields of soybeans (cv Improved Pelican) in intercropping with sorghum (cv Dobbs bora) and millet (cv Serere composite). There were seven treatments, which included: soybeans, sorghum, and millet grown in pure stand; sorghum and soybeans grown within a row and alternate rows; sorghum and millet within a row; and millet–soybeans within a row with a total plant population of 111,110 plants/ha. The growth and yield data collected included days to 50% flowering, plant height, number of tillers/plant, number of pods/plant, panicle length, dry mat-

ter/plant, grain yield/hectare; grain yield was converted into land equivalent ratio (LER).

The results indicated that only the plant height of sorghum was significantly different in the different treatments. Millet tillered more than sorghum. The number of pods per plant of soybeans and the panicle lengths of both millet and sorghum were not significantly different, whereas dry matter accumulation per plant was significantly different between pure stands of sorghum and its intercrops. The same trend was observed in soybeans, whereas the grain yield of millet was unaffected regardless of cropping systems. LER obtained in intercropping varied from 1.04 to 1.44, compared to pure stand at 1.0.

Intercropping with Sorghum at Alemaya, Ethiopia

Brhane Gebrekidan

Ethiopian Sorghum Improvement Project, College of Agriculture, Diredawa, Ethiopia

In Ethiopia, sorghum, which is the second most important food crop after tef, is grown both at high altitudes along with such cereals as wheat, barley, and tef, and at low altitudes where virtually no other crop thrives. In the high altitude areas, sorghums are seldom grown in pure stands but in mixtures with other crops. The most important area of highland sorghum areas in Ethiopia is the Chercher Highlands in the eastern part of the country, where sorghums are grown in mixture with maize (*Zea mays* L.), chat (*Catha edulis*), beans, and sweet potatoes, the most common combination of crops being sorghum–maize–beans (23, 24). At planting time the typical farmer mixes sorghum and maize seeds in equal proportion by volume and to this mixture he adds one-fourth of the mixture volume of beans. The entire mixture is broadcast over the prepared seed bed and covered using either an oxen plough or a shovel-like hoe. Since the sorghum seed is much smaller than either the maize or bean seeds, this typical mixture of seeds gives a higher proportion of sorghum plants. The maize crop is normally harvested green in the soft- to hard-dough stage of seed formation and consumed or marketed as maize on the cob. The maize stalks are also removed while still green and fed to livestock. The beans are also normally pulled long before the sorghum is cut, thus giving the sorghum plants much wider space after seed formation for good panicle and seed development.

Farmers in the Chercher Highlands attribute several advantages to mixed cropping as compared to pure stands of the component crops. Through mixed cropping the farmer is provided with food for his family and feed for his livestock over a longer period of time compared to a pure culture. In the mixture mentioned above, the maize is normally consumed first, then the beans, and finally the sorghum. This system of farming also provides a sort of insurance against poor harvests. If the rains are optimum all the three crops develop sequentially and complementarily but if the rains are below normal the farmer pulls out the appropriate component of the mixture to fit the seasonal rainfall situation. The mixture also provides the farmer's family with more balanced nutrition, and such cropping also enables the farmer to spread his family labour more efficiently. The beans mixed with the cereals must also help in maintaining soil fertility. This advantage is specially noteworthy because the application of fertilizers in field crops is seldom practiced in the Chercher Highlands. Pest and disease prevalence must be minimized under mixed cropping rather than under pure culture of a single crop. Under these mixed cropping systems the stratifications of plant heights and foliage densities at various heights certainly help minimize soil erosion. Last, but not least, farmers feel that they get higher economic returns through mixed farming.

Alemaya is a typical place in the Chercher Highlands where highland sorghums dominate the agriculture of the region and mixed cropping is the stan-

dard practice of the average farmer. The altitude is about 2000 m and the annual rainfall is about 860 mm, coming in a bimodally distributed pattern with the small rains peaking in April and the big rains reaching the highest level in August. Planting is normally done toward the middle of April with harvest at the end of December. This means the crop season for sorghum is as long as 9 months. With the bimodal distribution of the rains, some farmers pull out the beans that have been planted at the beginning of the small rains and put in another crop of beans at the beginning of the big rains in July. This planting of the second bean crop often coincides with the cultivation of the maize and the sorghum.

The objectives of the experiments at Alemaya were to ascertain to what extent the advantages attributed to crop mixtures in the Chercher Highlands were true or not. An additional objective of the investigation was to determine the optimum combination of crops to give the highest economic return under a peasant farming system of the Ethiopian sorghum highlands. It was also the intention of this investigation to compare early and late-maturing sorghum varieties for their fitness in an intercropping system.

The trials conducted in 1974 involved three sorghum cultivars, one from each of the late, intermediate, and early maturity group of sorghums for Alemaya, and two different species of legumes, a haricot bean cultivar and a local cowpea. Another intercropping experiment in 1975, at the same location, involved the two late and intermediate sorghum cultivars and the haricot bean used in the 1974 trial, an early maturing maize, and a standard soybean cultivar.

The 1974 trial showed that the late sorghum cultivar, Alemaya 70, and the intercropped haricot bean cultivar Ethiopia 10 gave a total yield of 58 q/ha compared to 50 q/ha for the best pure stand of sorghum and 20 q/ha for the highest yielding legume pure stand. The highest yields were realized when both the sorghum and the bean were planted simultaneously early in the crop season. In 1975, the highest grain yield of 80 q/ha was obtained with the pure stand of Katumani maize when planted early. The best yield from an intercropped plot, 58 q/ha, was again obtained from Alemaya 70 and Ethiopia 10 with early planting of both the sorghum and the bean. This compared with 38 q/ha for the best pure stand of sorghum, Alemaya 70. Pure stand of Ethiopia 10 gave only 20 q/ha of bean yield as in 1974.

The overall results of the two years show that although the economic advantage of intercropping over a sole crop was not impressive, the best combination of intercropping in the Chercher Highlands appears to be to use a late-maturing sorghum and an early maturing legume (having neither a spreading nor aggressive habit), both planted early.

Studies on Mixtures of Maize and Beans with Particular Emphasis on the Time of Planting Beans

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Recent comprehensive studies have shown considerably higher yield advantages from mixtures as compared to pure stands. For instance, Andrews (20) reported large advantages from mixtures of late-maturing sorghum with finger millet and cowpea, which were attributed to the long growing season that allowed the interplanting of crops of very different maturity periods. At Makerere, mixtures that involved short-term annual crops (maize and beans, sorghum and beans) have outyielded their pure stands by up to 38 and 55% respectively (21, 22). A major conclusion that emerged from the Makerere experiments was that mixtures probably gave higher yields because they were able to utilize the environmental resources much more efficiently than pure stands.

The real physiological mechanism by which the physical environment may be better exploited by mixed crops is not well understood. There are basically two possibilities: firstly, mixtures may achieve better spatial use of resources because of more efficient canopy structure or rooting pattern. Secondly, they may achieve better temporal use of resources because different growth cycles of the component crops combine to give an extended period of efficient resource use.

So far little research attention has been directed to determining the relative importance of these two effects. A number of experiments were therefore carried out at Makerere, the main objective of which was to examine the importance of different growth cycles in the productivity of mixtures.

Like the maize and beans experiment reported earlier (21), a "replacement series" of pure maize, two-thirds maize/one-third beans, one-third maize/two-thirds beans, and pure beans was used at three plant populations and at three dates of planting beans. The maturity periods of the maize and beans were 120 and 85 days, respectively. A high level of nitrogen was again applied to eliminate the effect of nitrogen transfer from the beans.

Yields of the mixtures were up to 25% higher than could be achieved by growing the two crops separately. These advantages of the mixture decreased markedly with delayed planting of the beans. For instance, at population 3 for the mixtures, which consisted of two-thirds maize/one-third beans, the yield advantages decreased from 20% when beans were planted the same time as maize to only 2% when the beans were planted 4 weeks after.

It is concluded that differences in maturity periods of the component crops were probably the major factors contributing to the yield advantages in these mixtures.

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Intercropping of Cassava with Vegetables

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Various investigators have shown that the mixtures for traditional cropping systems have higher total productivity than pure stands of any of the individual crops in the mixtures (20, 21, 22, 25). Incompatibility between mixed cropping and some modern agricultural techniques is the reason most often given for not fostering mixtures. Wilson (26), however, contends that many traditional mixed cropping systems could be modified to accommodate some of these techniques. Thus there is no need to base the development of new cropping systems in the tropics solely on pure stands.

In various parts of West Africa where cassava is an important staple, it is a major component of the mixed cropping systems. Vegetables are usually minor crops in such systems, but increases in the vegetable component can significantly improve the nutrition of the people of the area (27). There is, therefore, a need to increase the vegetable component of these systems.

The results of one of a series of experiments on vegetables in a cassava-based cropping system for the humid tropics were as follows.

With the aid of irrigation one crop of cassava was intercropped with three crops of vegetables in the sequence tomato–okra–French bean, and the highest yields were produced when the cassava rows were 2 metres apart. Cassava had no apparent effect on the performance of the tomato, but suppressed the yields of okra and French bean, the second and third crops respectively. The land equivalent ratios showed that the cassava–vegetable intercropping was more efficient than pure cropping of cassava alone or any of the vegetables.

The poor performances of okra and French beans may be due to the zero tillage method used, as these crops have been found to perform better on tilled than on nontilled land.

In regions where cassava is the staple, the diet is sometimes low in essential vitamins, minerals, and protein. Increasing the vegetables in the diet would overcome the vitamin and mineral deficiency and supply a reasonable amount of protein (27). To increase the available vegetables the production must be increased. This could be achieved through an intercropping system in which production of the major staple is maintained.

Some Aspects of the Productivity and Resource Use of Mixtures of Sunflower and Fodder Radish

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Initial studies at Makerere University (Kampala, Uganda) showed that maize–beans and sorghum–beans mixtures were capable of using growth resources more effectively than pure stands, producing yield advantages up to 38 and 55%, respectively (21, 22). These results must have been achieved because resource use by the component crops was to some degree complementary rather than purely competitive. Since the beans had a much shorter growth period than the cereals (85 days compared to 120 days) this complementary effect could have occurred because: (1) the component crops were using resources at different times; or (2) the component crops were using resources in rather different ways or from different parts of the environment.

The relative importance of these temporal and spatial aspects was examined in subsequent experiments (28) by delaying the sowing of the beans so that the growth patterns of the component crops were more closely synchronized. In maize–beans mixtures, advantages declined from an average of 23.0% for simultaneous sowing to an average of 6.3% when the beans were sown 1 month after the maize; in sorghum–bean mixtures the comparable effect was a decline from 33.1% to 10.6%. Similar results were obtained when maize was grown in mixture with an early (85 day) or a late (120 day) soybean variety. With

the early soybean variety an average yield advantage of 21.6% was achieved; with the late variety, which matured at the same time as the maize, the average advantage was only 6.5%.

From these and other Makerere experiments it was concluded that the greatest potential benefits of mixtures were likely to be where there was greatest scope for combining crops of very different growth patterns. Conversely, it was thought that advantages of mixtures were likely to be very small where component crops had to have similar growth patterns. This latter restriction may often exist in, for example, highly developed agriculture when mechanization dictates that component crops cannot be sown or harvested at different times. It was with this latter situation in mind that a series of experiments on sunflower and fodder radish was started at Reading to investigate the possible advantages of mixtures in which component crops were sown and harvested together.

Perhaps the main finding of these experiments was the importance of temporal resource use by the mixtures, despite sowing and harvesting component species together and despite the relatively short growing period. Of the particular resources involved in this effect, light was probably a major one because of the large temporal difference in leaf area development between the species. This lends further support to the earlier Makerere conclusion that mixtures are likely to give greatest yield advan-

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tages where components of different growth patterns can be combined.

With regard to spatial resource use, the important finding was perhaps not so much that there was any single effect of major importance but that there was some evidence of several effects. In particular, there was evidence that the root systems of the mixtures could have been more efficient in taking up water, an effect that may have been partly responsible for the large yield advantages in the very dry season of 1973. There was also evidence that when nitrogen was limiting, mixtures gave greater uptake. Improved nutrient uptake by mixtures has been suggested for the less mobile nutrients, but these results indicate that this may also be possible for nitrogen.

Preliminary Results of Intercropping Trials in Zaire with Maize and Certain Legumes

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Practically without exception, maize farms throughout Zaire are planted on raised beds, about 40–50 cm high with an interbed (interrow) spacing of approximately 1 metre. Maize hills usually consist of two to four plants at about 50 cm spacing along the bed. Even amongst the most progressive farmers, this laborious practice of hoeing-up beds for maize culture exists.

Following harvest, farmers put the current season's maize fodder together with various weeds and other crop residues (squash vines, tomato vines, peanut tops) on the surface of the ground in the bottom of furrows between the current season's beds. These furrow bottoms become next year's beds, and the residues, mainly maize fodder, act as the new year's fertilizer supply.

Although the system as described above seems ingenious on the one hand, because (1) the raised beds would improve soil drainage if drainage were a problem; (2) owing to the raised culture, each maize plant probably has access to more topsoil than on flat culture and thus more fertilizer via the mineralization of organic matter; and (3) the system provides a means of putting under next year's fertilizer supply, viz., the maize fodder, other crop residues, weeds, etc.; on the other hand, there are at least as many arguments against the system as for it. In the first place, growing maize on poorly drained areas should be avoided, particularly since the maize crop is very sensitive to "wet feet," especially in countries like Zaire where there is no squeeze due to land pressure, either to a lack of arable land or the privilege of being able to farm it. Secondly, preparing such beds requires tremendous quantities of human physical energy; energy that could be spent on much more productive things. Though farmers will often say that flat culture is much more work than their traditional farming method, the bold fact remains that insofar as land preparation is concerned, such is just not the case in spite of the fact that any method of land preparation using the hoe prior to planting is by far the hardest phase of maize farming. That weeding, sidedressing, and hoeing-in of fertilizer urea are viewed as extra work in flat culture by farmers is another matter that should not be confused with land preparation, and the farmers need to be taught and convinced that their failure to weed or sidedress fertilize their maize fields, as they traditionally do not do, is not in their best interest, though at present, they often simply view the practice as unnecessary or unprofitable expenditures of work and money. Thirdly, little benefit is actually derived in terms of nitrogen and phosphorus from using last year's maize fodder as the fertilizer source for next year's maize crop. The extremely wide C:N in dry maize stalks adds but a trifle of useful fertilizer elements and therefore the fodder is also of little or no value in contributing to soil humus either.

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Since the use of raised beds will doubtless be in practice for years to come, a trial was conducted to evaluate the effectiveness of maize stalks as the fertilizer source now generally used by many maize farmers in Zaire. Additionally, the potential of *Crotalaria caricea* and *Vigna unguiculata* intercropped with maize was anticipated to augment the following year's maize yield when used as a crop residue like maize fodder is now used by farmers.

All cropping systems studied in the trial were done with and without fertilizer and with and without crop residues.

Important highlights from the results reveal that:

(1) fertilized plots highly significantly outyielded plots that received no fertilizer;

(2) plots that received maize stalk residues or those intercropped with a legume (*C. caricea* the previous year 1973–74 and *V. unguiculata* during the season for which the results are presented, viz., 1974–75) highly significantly outyielded plots that received no residues or legume intercrop;

(3) plots intercropped with a legume highly significantly outyielded those plots that were not legume intercropped, but received only maize fodder residues.

(4) plots intercropped with a legume on the same day as maize was planted significantly outyielded plots where the legume was planted after maize. (N.B.: For the 1973–74 season, *Crotalaria* was planted 19 days after maize sowing, and for the 1974–75 season, *Vigna* was planted 12 days after maize sowing.)

Thus far the results of the still-ongoing intercrop trials on two soil types are very encouraging, particularly on yellow clay soil. Maize yields are clearly augmented dramatically when maize is grown on ridges that were furrows grown to a legume the previous year. The trial has also shown that *C. caricea* competes too severely with maize if planted at the same time as maize whereas the converse is true when *V. unguiculata* is the legume intercropped with maize.

Effects of Maize Height Difference on the Growth and Yield of Intercropped Soybeans

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For real benefits to arise from intercropping, crops must achieve a satisfactory balance in their competitive ability. Little work has been done on interspecific competition as it relates to intercropping, and further work in this field is essential before intercropping can be fully understood and more advanced intercropping practices developed.

McLeod and Mott (29) showed that various combinations of pasture grasses and legumes gave a response varying from mutually beneficial to mutually depressive and this same variability is certain to occur with different intercropping combinations. It is therefore essential to find which combinations of crops are the most satisfactory. Equally important is the task of finding which morphological characteristics are desirable for plants being intercropped.

Maize (*Zea mays*) of two heights was intercropped with soybeans (*Glycine max*) to study the effect that variation in maize height had on the intercropped soybeans. Differences in height between the tall and short maize were not substantial at any stage of the experiment. There were no significant differences in soybean height between the tall and short maize. The percentage of lodged soybean plants at 60 days after planting was not significant either. The maize grain yield was greatly affected by the level of fertility and spacing but there was no overall difference between the tall and short genotypes. The legume in the short maize gave a higher grain yield than in the tall maize. The yield of soybeans under the short maize was 17% higher than in the tall maize. The number of days taken to reach the 50% flowering point and physiological maturity (as measured by 50% leaf drop) in the soybean crop did not differ significantly between the tall and the short maize plots. These two factors, however, appeared to be insensitive in their response to differences in competition. The proportion of soybeans in the combined maize–soybean yield was similar in both the tall and short maize (0.122 and 0.153 respectively). The only component of soybean yield that was greatly affected by the differences in maize height was the number of pods per plant. The proportion of pods attached to branches was 0.28 in the tall maize and 0.30 in the short maize. This was significant at the 5% level of probability.

The choice of whether to use tall or short maize when intercropping with soybeans is obviously an important one, as experimental results show that even slight differences in height affect soybean yield. The cereal spacing and the level of fertility also appear to be important in achieving a proper competitive balance between the cereal and the legume. Fisher (30) also concluded that to have one crop completely dominating another would decrease the benefits accruing from intercropping.

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Intercropping as a Means of Producing Off-Season Tomatoes during the Hot Summer Months in the Sudan

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The tomato is an important vegetable crop that is used daily by almost every family in big cities in the Sudan as a salad crop or in the local stews. Commercial production is limited to the winter months (October–March) because during the hot summer months (April–July) the tomato fails to set fruit. Research had indicated that the hot dry winds and the low relative humidity are the major factors contributing to this phenomenon of fruit-set failure.

Many crop husbandry practices were introduced to overcome this problem. However, in the "Alafoun area" near Khartoum intercropping tomato with pigeon pea modified the environmental conditions and enabled the production of tomatoes during the hot summer months, thus saving hard currency that used to be spent in importing tomatoes during that period.

Development of Cowpea Ideotypes for Farming Systems in Western Nigeria

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Western Nigeria has three main types of vegetation, namely savannah to the north, mangrove swamps to the extreme south, and rain forest and deciduous forest between them. Except in the mangrove swamps, farming is done mainly by peasants with characteristic small holdings, shifting cultivation, and mixed cropping. Larger size farms under sole cropping are managed by literate farmers and government agencies. All farms are rainfed.

The cowpea crop is grown mostly in the second season beginning in September. During this season, rainfall and daylength are diminishing. Traditional varieties are mostly prostrate, indeterminate, and appear to be suited to competition in mixed cropping systems. For the larger farms adopting monoculture, a more erect and uniform-maturing type plant suitable for mechanical harvesting is more useful.

Attempts have been made to develop high-yielding, uniform-maturing cowpea varieties for the farming systems highlighted above. Such plant types have yet to be tested under mixed farming as practiced by farmers. For monoculture, the upright habit with fewer branches has been found suitable. The question of optimum yield level of the crop is unresolved. Progress in this area in terms of physiology, leaf display, partition of dry matter, etc., are still in the rudimentary stage. The best breeding methods to obtain yield have not been found. Only the traditional breeding methods have been adopted as yet, though some good results have been obtained.

Cereal–Legume Breeding for Intercropping

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At Morogoro in the cereal–legume variety testing and improvement program, the genetic material has been tested in three ways.

A range of our best cowpea and soybean varieties was tested in monoculture and in mixture with three standard cereals: a dwarf sorghum, a tall bulrush millet, and the local full season maize variety. We examined the genotype–mixture interaction along with other important factors such as insecticide spraying in cowpeas and the use of inoculum in soybeans.

A wide range of maize material was then tested with our standard soybean variety. In 1976, in addition to maize, we are testing 50 sorghum varieties and the Morogoro bulrush millet composite (in an $S_1 — 10 \times 10$ lattice yield trial). Cowpea, green gram, and sesame breeding lines are also being tested this season in yield trials under monoculture and intercrop conditions. Growth and development parameters and yield components are being examined for differences.

The third method used is diallel analysis, in which superior cultivars of different species are tested in mixtures for compatibility. Differences have been observed within and among species. If less competitive species, such as low-growing legume varieties in a mixture, are put under severe competition stress by taller cereals, their tendency is toward a low mean yield. Varietal differences for such legumes are more easily measured under milder forms of competition where error means tend to be larger. The importance has been noted of plant stand, height, leaf number and size, and the proportion of the high-yielding component in our mixtures. We are developing appropriate selection criteria from these studies for use in the breeding program. This program is an integrated part of production in the cropping system, which, in turn, must be tailored to local farming systems.

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Cowpea as an Intercrop under Cereals

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The predominant cropping practice in the lowland tropics of Africa consists of growing crops in mixtures, in which the life cycles of the components overlap completely or partially. One of the commonest systems involves grain legumes such as cowpea or groundnut planted under cereals such as sorghum, millet, or maize (31). Steele (32) suggests that cowpea may have come from its supposed center of origin, Ethiopia, to the West African semi-arid zone as part of such a cereal–legume farming system. At present, cowpeas in the savannah are planted 1–2 months after sorghum and millet have become established, flowering toward the end of the rains, and maturing into the dry season (33).

Although some agronomic and physiological studies have been carried out on cowpea as an intercrop with cereals (13, 30, 34, 35), the work so far has emphasized the cereal crop in the mixture and has not focused on cowpea varietal differences in response to intercropping. Measurements of the physical environment under which the cowpea is growing are also lacking, particularly with regard to light levels encountered by the legume in such mixtures. In studies over 3 years at IITA, the light environment under several maize canopies, the effect of shade on cowpea growth and yield, and the influence of maize intercropping on yield of both crops were investigated.

Light levels reaching the ground at maize (*Zea mays*) row spacings of 75 or 100 cm were insufficient to allow vigorous growth of cowpea (*Vigna unguiculata* L. Walp.) beneath the canopy. The same situation occurred at 150 cm spacing if cowpea planting date was delayed 1 month after the maize. In two shading experiments, cowpea dry matter production was reduced by 50% at flowering by 50% shade levels. Shading in the vegetative period caused erect cowpea genotypes to lodge, reducing yield by 46%. A prostrate cultivar was much less affected by the same treatment, although shading after flowering reduced yield by 50% in this cultivar. Mixed cropping trials of maize and cowpea caused yield reductions of both components in the mixture, with the cowpea most affected. Planting of cowpea at the same time as the maize, and using a climbing cultivar of cowpea had the least detrimental effect on cowpea yield. The climbing cultivars caused increases in lodging of maize and lowered maize yields more severely than erect or spreading cultivars.

These intercropping experiments point to large gaps in our knowledge of legume–cereal interactions. Foremost among these is the question of the nutrient-supplying power of the legume. Although Agboola and Fayemi (35) found that mung bean could benefit associated crops in the same growing season, no such evidence was found for cowpea. The increased maize yield when grown with Prima cowpea indicates that such effects are worth investigating further with a range of cowpea cultivars. Although competition of the associated crops for nutrients and for water has received attention in the temperate areas (36), further work is required on this aspect in tropical regions.

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Selection Criteria in Intercrop Breeding

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Intercropping or mixed cropping, like plant breeding, is an ancient practice. However, selection in natural plant communities began long before people began domesticating those species that they valued. This same selection practice has continued today but with different emphasis and intensity due in part to scientific advances. Few varieties of that special group called "standards" a few years ago are still accepted as such today.

Plant scientists, as they attempt to observe and describe a phenotype found in an intercropping environment, may slowly come to realize that this completely integrated and complex genotype was once a product of natural selection. It is also important to realize that in a mixture most traits such as height and yield are quantitative rather than qualitative.

The effects of genotype × environment interactions in a plant breeding program with help of biometrics have been incorporated into quantitative genetic theory in terms of variance components. In the future, as superior mixed populations in the form of gene pools are created from superior families and hybrid combinations, the breeder will be required to use such genetic theory in the development of his breeding system. These random mating populations will require direction using selection pressures, a system modeled on controlled fast-stream evolution.

If we are to help revolutionize the cropping system called "intercropping"

through plant breeding, then the best mechanism at our disposal yet developed for handling such a complex phenomenon would be a cyclic system involving a population improvement approach (37). New techniques and criteria for selection urgently require development. Investigations should begin on existing cropping systems within the existing farm environment with due consideration to present practices founded on hundreds of years of trial and error research, but investigated in the light of future developments. Therefore, existing systems should be studied in a more positive manner — with every intention of improvement.

Selection Alternatives

At Morogoro, we are only beginning to examine the system as a whole rather than as individual components. Any system, as complex as mixed cropping tends to be, is usually studied first on the basis of individual components. Although yield is made up of many traits, selection for yield alone will not provide acceptable mixtures. A cereal crop is generally tall and high yielding in relation to a legume, which is relatively short (except for pigeon pea). If such a mixture was selected only on the basis of kg/ha, then the cereal would have a definite advantage. The legume, however, has a higher food value and market price.

We therefore need to decide on what basis will mixtures be formed: (1) nutritional basis; (2) economic basis; (3) crop production basis; or (4) a mixture of all three.

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In population improvement programs we need to decide which traits should be considered and how much weight should be given to each.

Selection Indices

One method that has been developed and found to be the most efficient in improving several quantitative traits at the same time is index selection.

Pesek and Baker (38) have developed a modified selection index method, based upon desired genetic gains rather than the older methods that required that the relative economic weight of traits be calculated. They believe that the main requisites for using index selection are quantitative data, estimates of genetic parameters, and a statement of the goals of the program. Here, we come full cycle — how much effect has genetics had on crop production in comparison to improved agronomy practices in African countries? Even if the genetics is sound, but our selection criteria are based on economically unimportant traits, are we likely to have any real impact?

In mixed cropping we are not only directly involved in the improvement of economically important species, but also economically important mixtures of those species.

Crop Value Index

At the International Rice Research Institute the mixed cropping program has developed a ratio that is used for comparison purposes between a crop in a mixture with its yield in monoculture under similar management levels to determine productivity levels (39). This ratio is termed the "land equivalent ratio" (LER), in which the optimum monoculture population is used for comparison.

On any given area of land, any combination of crops as monoculture can be grown as a certain percentage of that area. It would be more satisfactory to compare our optimum intercrop combi-nations to optimum monocrops on the same land area with the same level of management and inputs. Productivity is then calculated on the basis of yield in kg/ha in addition to economic and food value returns.

At Morogoro, we are developing an index system that is termed the "crop value index" (CVI). This involves converting all our important food and cash crops that we believe will do well in mixtures, into a usable numerical form. The true worth of an intercrop combination has to be weighed and assigned a value.

The performance of mixtures can therefore be measured and examined in terms of alternatives. Such a procedure is of value only if there are competing species available. Each available species must compete for a place and a percentage in the mixtures. This procedure has no further real improvement value once the optimum mixture is attained. As the problem of the availability of data is overcome and the number of parameters needed to fully specify the real situation has been tested, then computer simulation will be an invaluable tool.

If the nutritional well-being of people who live in semi-arid areas is a major prerequisite for development, then nutritional values must be combined with crop production targets — quality combined with quantity. The nutritional values of different production mixtures are measurable.

A crop value index must therefore be based on some form of economic function developed from real situation data. The total inputs required for the production of a certain mixture must be balanced against the returns in terms of real benefits to the farmer. Additional labour inputs or any new innovation involving capital inputs has to be carefully examined in the development process if we are to develop a truly useful improved technology. For this reason, any new innovation must be early field tested under the actual prevailing production

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conditions — within the framework of the complete farming system.

The location specificity of some mixtures requires that research be conducted and data obtained from different ecological zones to test the range of their usage and in isolating environmental and other inherent responses.

As we now assemble and update our information on cropping systems research under actual production conditions (37), unimportant traits in the system can be discarded. A statement of goals formulated on the basis of real situations can be clearly written. A program of action based on resource capabilities can then be implemented.

Alternative Mixtures

In semi-arid regions there are only a certain number of plant species producing the major share of plant food in the diet containing carbohydrates, protein, and fats. At Morogoro we work on four cereals: sorghum, bulrush millet, finger millet, and maize; three legumes: cowpeas, green grams, and pigeon peas; and three oil crops: sesame, sunflower, and soybean (also a legume, high in protein). Root crops are extremely important in the tropics and even more important in semi-arid areas. How much carbohydrate can cassava or sweet potato produce in an acceptable form mixed with groundnut or another legume to compete with the best high lysine, tryptophan maize hybrids? How will these two systems compare on an input–output basis using the CVI approach?

Breeding Program

With the statement that the goals of the program be based on well-researched data, working priorities must be established within the framework of available resources.

An intercropping program is based on improving economically important factors in terms of nutrition combined with crop production. This is accomplished within a total cropping system combined with improvement through selection cycles in which important traits are improved together rather than moving one component at the expense of another. We now have a program in which breeding objectives are defined in the form of production targets. No selection criteria experiment can predict the limits of selection (40). Any single trait selection, as pointed out above, is unlikely to succeed. The complexity of mixtures and breeding within them probably means that progress in our understanding the limits to selection will be rather slow. The chief advantage we have for beginning intercropping breeding research at this time is the modern computer with all the potential of simulation. We can continue building new and better models as data become available and then testing the individual assumptions we need for further application.

Our breeding program works on the principle of expected gains rather than observed gains. We are required, therefore, to predict responses. Heritability must be accurately measured for all our important traits. As heritability is a measure of ability to differentiate among genotypes (41), it must be interpreted as interrelated to the total gain in the complete system. The phenotypic variance will change, depending on which environments are used for testing (5). If progress is to be made, we must standardize our testing procedures and select a standard range of testing sites over a range of ecological zones (41). We can then generate the data that is so important and not now available. Such a program for breeding and testing (37) and agronomical research (42) has already been proposed.

Selection Traits

Those traits that are qualitative rather than quantitative will require special care in using any of our recurrent selection breeding procedures. The benefits of

polygene accumulation, for example disease and insect resistance, may be lost if simple inherited gene combinations in the population mask their efforts. The problems of height and maturity in our own studies on sorghum population breeding methods are compounded by the effects of a few genes on the quantitative gene combinations.

Important components of mixtures and the important traits of each will have to be compared in combined monoculture and intercropping experiments if we are to use the monoculture information already accumulated. The validity of heritability of certain traits will not change although the relative importance of these traits certainly may. New interactions that are unique to mixtures will have to be identified and their importance ascertained. When working within a complete integrated type of cropping system such as intercropping, we must learn through research experience how to deal with complex interacting factors such as variation of genotype among species and changes in environment, time of seeding and planting, maturity and harvest, levels of management and inputs. First, we must deal with problems of scale, then other factors such as time and space. Techniques, even unorthodox in nature, require rapid development. Sample size, in time and space, requires immediate investigation, not only for yield data, but for economic and ecological effects on a short- and long-term basis. The importance of root interactions and leaf number, size, and placement may require the development of root sampling techniques and a system of stratified leaf sampling. The management of all these factors offers new challenges. Perhaps the great challenges for researchers in semi-arid areas of Africa are finding permanent solutions to the problems of soil fertility and water management. How quickly progress is made may depend on our success in achieving interdisciplinary participation at each stage of our investigations. It should also be remembered that the most important component for selection in any breeding program is the plant breeder.

Experiments with Maize–Bean and Maize–Potato Mixed Crops in an Area with Two Short Rainy Seasons in the Highlands of Kenya

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In the tropics, there is good evidence of better returns to land area from mixed crops than from pure stands of their components (43). The objective of mixed cropping research at the University of Nairobi since 1972 has been to examine whether the same would be true under our conditions and, if so, to ascertain the mechanisms by which the crop mixtures utilized the factors of growth more completely or more efficiently.

In one experiment, maize–potato mixtures yielded less than the pure stand comparisons in two seasons and were no different in a third. Maize–bean mixtures were not significantly different in two seasons, significantly worse in one low-rainfall season, and significantly better in one relatively high-rainfall season. A second experiment indicated that even in the season when maize–bean mixtures showed an advantage, this could be explained by the higher population pressure in the mixtures rather than the intrinsic value of mixing the species. Light measurements suggested that mixtures could be more efficient in light interception. Soil–water profiles toward the end of the cropping season showed the capability of maize–bean mixtures to extract water more completely from the rooting zone.

Since the finding of no intrinsic value of mixed cropping at Kabete contrasts markedly with other African work, most especially with that of Willey and Osiru (21) in Uganda, an attempt is being made in the current season to confirm the finding with maize–bean mixtures in a replacement design. In the west of Kenya where rainfall is usually not a major limiting factor, advantages from mixtures comparable with the Uganda results appear to occur with some consistency (45), although they are small if the maize crop is a high-yielding one. If for any reason, the maize is prevented from developing its full yield, the beans can produce a very useful yield without further reducing maize yields. In conjunction with the Kabete results, this suggests that mixed cropping does have an insurance value under most conditions but not necessarily where the major risk is from drought. Under these conditions, maize yields may be reduced more than can be compensated for by the beans.

An original objective of the Kabete work was to study interactions between cropping systems and the physical environment, particularly light interception and water use. At the time, it was assumed that the mixtures would out-yield the pure stands and the aim was to find out how this might come about. Since the yield results were not as expected, it is perhaps not surprising that the data collected suggest that any differences are small.

Light interception was measured with the silicon photocells, banked to give spatial integration, described by Fisher (44). Interception was increased both by

increasing plant density and by mixing the crops. Even in high-density, high-yielding crops, maize has a rather low light interception during the time when these measurements were made, which approximately corresponds to the reproductive and filling phases of the beans. Greater efficiency of light utilization might therefore be expected from the mixtures if beans could utilize the light not intercepted by maize. These considerations, however, become rather academic if competition for water is ever a major factor.

The general finding for soil–water extraction is illustrated by data on soil–water content for 1 Aug 1973 after a dry period following the long rains. Potatoes and beans had already been harvested but the maize was not yet mature. In the upper soil layers, there was no difference between maize, potatoes, and their mixed stands, but in the subsoil, the maize lowered water content significantly more than the potatoes. The mixed plots were not significantly different from either pure stand. Beans lowered topsoil water content more than maize, which no doubt accounts for the severe competitive effect of beans on maize in a poor season. The soil under maize–bean mixtures was also drier than under pure maize. In the subsoil, the water content under mixtures was significantly lower than under either pure stand. It seems probable that rapid water extraction from the topsoil by the beans that establish a closed canopy more rapidly than maize, forced the maize in mixtures to exploit water from deeper layers than was necessary in pure maize stands. Nevertheless, the mixtures were not higher yielding than pure stands, so that in this season, the more efficient water extraction of which the mixture appears to be capable was apparently not of benefit.

Pest Control in Mixed Cropping Systems

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At Morogoro, preliminary research on the problems of intercropping have included the ecological analysis of the insect pest management in intercropped and monoculture crops, estimation of insect pest populations and their damage in different crop combinations, incidence of diseases in intercropping and monocultures, and now, the design of pest management techniques for use in mixed crop ecosystems.

In any discussion of the factors that operate in bringing about insect population changes in mixed or single crop ecosystems it is important first to point out that climate sets the arena in which all the other biotic factors interact. For example under conditions at Morogoro, and indeed in other parts of East Africa, the timing and duration of rainfall influences the time and severity of insect pest and disease attack, causing annual fluctuations in yields. This is best illustrated by the damage caused to cowpea (*Vigna unguiculata* L. (Walp.)) by *Ootheca bennigseni*. The initial *Ootheca* infestation in cowpea fields arises from beetles emerging from dry season aestivation. At Morogoro if the main rains come early in February or March and if the rainfall distribution for the rest of the season is even, the emergence of beetles is spread over the entire season and cowpeas are less seriously damaged, though this also depends on the size of the aestivating population. If, on the other hand, the main rains are delayed, no beetles emerge during the drought period in February and March. The entire population emerges over a shorter period in April and May, resulting in a distinct population peak. Under such circumstances *Ootheca* becomes an important pest causing considerable defoliation of young cowpea seedlings.

Although the purpose of pest management is usually the reduction of pest numbers, the ultimate goal is to reduce yield loss. Consequently, the stability of mixed cropping systems can result from their ability to maintain yields despite pest and disease attack. This can be achieved by growing mixtures that have a "spare capacity" or are able to compensate for damage caused by pests. Indeed, the agronomic success of many mixtures depends upon the plasticity of their component crop plants. The fact that a sorghum–cowpea combination gives a 20% increase in yield over sole cowpea, or almost 1 1/2 times the yield of sole sorghum, is partly the result of each crop's ability to compensate for reduced populations. This occurs through an increase in the number of pods per plant, and an increase in the grain yield of the sorghum (46). Clearly, if one crop is badly damaged by insect attack, a second crop may to some extent compensate for the resulting loss in yield. Alternatively, where the level of pest attack shows fluctuations over the growing season, the most susceptible stages of crop development may be protected by adjusting sowing time. Where this is not feasible, as for instance with long duration crops, resistant varieties or resistant crops, such as cassava, can be grown.

When making decisions concerning the characteristics of his cropping system, the farmer has to make pre-emptive pest management decisions, in the sense that he necessarily has to make such decisions before pest attack occurs. Under these circumstances, he will design a system according to his prediction of the dimensions of pest attack that will occur. Apart from its pest control or tolerance properties, however, cropping systems can be designed that increase the farmers' ability to adjust to pest attack. For instance, the inclusion of short duration crops that can be left to ripen, such as maize and groundnuts, gives the farmer increased management flexibility (14). In addition, the form of the cropping patterns adopted will affect the feasibility and efficiency of any chemical control measures required. Apart from the technical problems of applying chemicals, the need for their selective use is particularly critical in mixed crops. Indeed, widespread application of broad spectrum chemicals may destroy the innate pest control properties of the system.

As for the future, the integration of conventional pest control measures in mixed crop systems is critical. Research emphasis needs to be placed on screening chemicals for low toxicity to natural enemies, reevaluating application dosages, and applying insecticides at times when the susceptibility to pest attack is greatest. At the same time, research should be carried out to ensure that the recommendations made will be compatible with the requirements of the cropping system.

Research in many African countries has, until very recently, largely ignored staple food crops and traditional, mixed cropping systems. In the drive to produce more food, these systems have an almost untested potential for increasing yields. As attempts are made to realize this potential, an increasing effort will be required to reduce losses caused by pest attack. The challenge for applied entomologists lies in utilizing the innate pest management properties of these systems that have stood the only valid test of ecological management — their persistence over time.

Measuring Plant Density Effects on Insect Pests in Intercropped Maize–Cowpeas

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One of the several advantages ascribed to 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 the crops are grown separately. Intercropping, in which one or more crops are cultivated between another crop in a regular pattern, is the form of mixing that should provide the maximum opportunity for any such advantage to operate.

Two main effects of intercropping on pests are described by Irvine (47). Many photophilic pests avoid short crops when they are shaded by taller crops; usually the shade crops are trees, but even comparatively short crops, such as cocoyam (*Xanthosoma sagittifolium*), which reaches a height of 1–2 m, can be used to shade and protect the early stages of taller crops (for example, cacao) from pests. The second effect claimed is that flying pests cannot spread so easily through intercropped farms.

If either, or both, of these factors operate when cowpeas and maize are intercropped, it would explain the popularity of this cropping pattern with peasant farmers in the Morogoro area. For cowpeas are recognized as a low-yielding crop in the absence of pesticides, mainly from the heavy damage caused by three groups of insects: leaf-eating galerucid beetles (especially *Ootheca bennigseni* Wiese), sucking bugs (mainly coreids and pentatomids), and pod-boring caterpillars (especially *Maruca testulalis* Geyer (Pyralidae) and *Laspeyreysia ptychora* Meyr. (Eucosmidae)) (48).

It is reasonable to expect that both of these intercropping effects, and possibly some other factors that might affect the pests, would be directly related to the density of the crops. Thus, preliminary investigations of the influence of maize–cowpea intercropping on cowpea pests were made in 1975 and 1976 within a systematic spacing design in the shape of a fan. Ideally, this design would permit the preferred habitat of each pest to be revealed by the distribution of its population and the damage; and the yield at each plant density would be the product of the interactions between plant growth and the damage caused by the whole pest complex in that microenvironment.

The fans in this experiment had 16 radii and 16 arcs (Fig. 1), providing a gradient of spacings between 29 × 29 cm and 98 × 98 cm. A locally selected cowpea variety SVS-3 and maize hybrid 512 were grown in monoculture and intercropped in alternate rows, with two replicates treated with pesticides and two untreated.

The spraying program for the protected plots was designed to control all pests. Twice weekly applications of DDT in the first 5 weeks after emergence was followed by a side-dressing of carbofuran granules. Pod pests were treated with endosulfan and phosphamidon twice weekly.

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Fig. 1. The fan design (256 plants, arranged in 16 radii and 16 arcs), either monoculture or two crops (as illustrated) in alternate radii.

The fan design has several advantages in this type of investigation; it is compact and therefore several cropping patterns can be included in a small area; the pests are presented with a gradient of micro-environments over a short distance; and the closely spaced plants at the apex are easily accessible for study. But the results obtained need to be examined cautiously since several inherent features of the fan could distort the normal behaviour and affect the distribution of both pests and their enemies. The "funnel" effect itself, created by the continuous narrowing of the plant spacing, can influence insects by presenting choices not found in a uniformly spaced field. Other distortions come from the smallness of the plots. Edge effects might be operating over several of the outer rows that have been included in the calculations. Also the close juxtaposition of sprayed and unsprayed plots can produce abnormally heavy pressure on the protected plants from pests leaving the unprotected plots.

The movements of *O. bennigseni* were probably detected more easily with a fan than an orthodox plot design. But the modifying effect of the fans on insects' behaviour needs to be investigated in fans alongside plots with uniformly spaced crops (and also in a year with more typical pest populations) before some of these results are taken further. This comparison is being tested this year (1976).

Probably most of the conclusions made in this paper are relevant to small farms. Closely spaced cowpeas intercropped

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with maize was the most successful combination in unsprayed fans during the *O. bennigseni* onslaught in 1976, and the similar method used by some local farmers of growing cowpeas in clumps between maize hills has also been successful this year.

Intercropping is less attractive in large mechanized farms, and a different strategy might be more appropriate. Since most preflowering damage is caused by the adult *O. bennigseni*, which has a univoltine life history, crop damage should be reduced if a superabundance of food is provided, for example, by planting perhaps 20 ha of cowpeas. The sucking bugs, which have a single generation within the cropping season, could also be swamped by a large area of cowpeas. In contrast, *Maruca testulalis*, which passes through several generations during the cowpea season, has a high capacity for increase, and would become a major pest unless the level of control achieved in 1975 could be improved, possibly through an integrated control program (49).

Even if losses from a large field of cowpeas were low, huge pest populations might be created that would pose a serious threat to cowpeas in the following year, and it might only be possible to escape heavy losses by large-scale cropping in alternate years.

Effects of Spraying on Yield of Cowpeas Grown in Monoculture and under Maize, Sorghum, or Millet

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Part of the intercropping program at Morogoro involves studying the effect of crop combinations on the population and behaviour of the main insect pest species of cowpea, one of the legumes chosen for intercropping in this program. When the studies first began in 1970 the most important insect pests were thought to be the sucking bugs, such as *Acanthomia* spp. and *Nezara viridula*, because of their numbers and the damage they caused to pods. It later became apparent that other pests may also assume importance in some years causing considerable damage to the crop.

At Morogoro the leaf-eating and flower-infesting insects are four Coleopteran species, namely *Ootheca bennigseni, Systates* sp. *Lagria villosa, Coryna kersteni*, and the striped bean weevil, *Alcidodes* sp., whose adults and larvae damage the plants by girdling and boring the stem at ground level. Other minor pests that feed on the foliage and flowers include *Empoasca* sp. and the thrip, *Taeniothrips sjostedti. Ootheca* is probably the most important economically as it sometimes causes devastating damage to young cowpea plants.

The important coreids infesting cowpeas and other grain legumes include *Acanthomia horrida, A. tomentosicollis, Riptortus dentipes, Mirperus jaculus, Anoplocnemis curvipes*, and several other lesser

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important species. The pentatomid, *Nezara viridula*, occasionally causes considerable damage to cowpeas, though it breeds very little on cowpeas. These heteroptera probably form the most important group of the insect complex in Morogoro as they fly into the fields at the time of flowering from alternative host plants and feed by sucking on young pods. In the case of the coreids, both the adults and the nymphs that are bred in the crop feed on the pods. As well, although experimental evidence is scanty, the sucking bugs *Acanthomia* spp. and *N. viridula* in particular have been implicated in the transmission of a fungus, *Nematospora coryli*, into the developing seeds, which also contributes to the damage.

Recently the spotted pod borer, *Maruca testularis* Gey, appears to have assumed importance. The larvae feed on the growing points, flower buds, flowers, and green pods. Infested pods can be distinguished by the presence of a feeding hole plugged by frass. Young pods are often wholly destroyed by larvae feeding on pods near the penduncles. As the pods mature and begin to ripen they are attacked by a less important pest, *Cydia (=Laspeyresis) ptychora* (Encosmidae). The larva infests the cowpea pod just before the crop is harvested, causing extensive damage to the seeds.

During 1973 an intercropping experiment was laid down using maize, sorghum, and millet as the main cereal crops

combined with 18 varieties of cowpea. The results obtained indicate that the population of *O. bennigseni* built up rapidly from about the 3rd week and was highest in plots that were planted to cowpea in pure stands (monoculture). The population on cowpeas under sorghum and maize was more aggregated. It is suggested that the presence of a nonhost plant such as maize between cowpea plants impedes the movement of adult beetles from one plant to another, causing them to be more aggregated than when the cowpea plants form a continuous cover. A similar pattern of distribution of the coreid bugs was obtained.

With regard to damage the situation was complicated by the fact that cowpeas grown under sorghum, maize, or millet produced fewer flowers and pods probably due to shading. Except for cowpea grown in and under maize, spraying significantly increased the number of pods per plant. With cowpeas grown under maize, spraying the local variety with endosulfan three times during flowering and pod development had little effect, and on the basis of these preliminary results we would not recommend spraying cowpeas grown under maize.

Possible Relationship Between Intercropping and Plant Disease Problems in Uganda

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It is generally believed that intercropping is advantageous with respect to disease control on peasant farms. It is thought that the rate of development of a disease epidemic would be reduced if a crop susceptible to one disease was intercropped with another that was resistant to that disease for the following reasons:

(a) The distance between susceptible plants would be increased in a crop mixture. However, this by itself would have little practical significance for compound interest diseases (sensu Van der Plank), which are normally airborne, where the distances involved would be covered in a short time by spores. But it would be important for simple interest diseases that are normally soilborne and where the soil would act as a barrier to the movement of pathogens.

(b) The foliage in the case of airborne diseases would act as a trap for the spores and therefore would reduce the number of propagules available for infecting the susceptible crop.

(c) The nonsusceptible host would provide an environment hostile to the development of the disease on the susceptible plants.

Disease in crop mixtures could be reduced as a result of a process of "pathogen filtration." But this would not happen if some of the component crops suffer from the same disease.

Crop mixtures would tend to increase the relative humidity of intercrop and hence to increase the risk of diseases that are favoured by high relative humidity.

Hence, in a crop mixture there are two conflicting phenomena controlling the disease level in the intercrop: pathogen filtration and high relative humidity. Experimental data are required to show which of these processes is stronger.

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Attempted Control of Virus Incidence in Cowpeas by the Use of Barrier Crops

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Field experiments conducted at Ikenne, Ibadan, and Eruwa, Western State (Nigeria) in the late seasons of 1973 and 1974 compared cowpea virus situations in cowpea monocultures with cowpeas either protected or intercropped with maize, rice, or soybeans. Sprayed plots had fewer (though not significant at the 5% level) infected plants than unsprayed plots. Intercropped cowpeas had fewer infected plants than any other treatment. Ife Brown (Irawo) cowpea yields were greatly improved by spraying with an insecticide in monoculture over unsprayed checks or the intercropped or protected plots. Many of the intercropped and protected plots produced little or no yield. There were more mouldy and unmarketable pods and grains from the unsprayed and protected plots than from sprayed plots (70%, 100%, and 2% respectively). Sprayed plots were more uniform in flowering, pod set, and pod ripening.

Induced Resistance to Bean Rust and Its Possible Epidemiological Significance in Mixed Cropping

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Resistance induced by infection with a nonvirulent race of a pathogen, or with an alien rust fungus, and which is effective against subsequent infection with a virulent race has been recognized for over 20 years (50, 51). Yarwood (51) found that bean rust (*Uromyces appendiculatus* (Pers.) Ung.) uredospores induced resistance in sunflower leaves to infection with *Puccinia helianthi* Schw. and vice versa. Johnston and Huffman (52) reported induced resistance to *P. recondita* Rob. ex Desm. in wheat following inoculation with *P. coronata* Corda var. *avenae* Fraser & Ledingham. Resistance was expressed as a reduction in the number of pustules. Similarly, Littlefield (53) induced resistance to *Melampsora lini* (Ehrenb.) Lev. in flax by inoculation with *P. graminis* Pers. and *P. recondita*.

Although the underlying mechanism of this cross-protection phenomenon has received much attention (50, 52, 53, 54, 55), its possible epidemiological significance has only recently been realized. Johnson and Allen (56) suggested that induced resistance might play a role in the resistance of multiline varieties, and Allen (57) noted that a similar effect could occur in crop mixtures.

Results from seedling tests on induced resistance to bean rust showed that such resistance may be induced by additional inoculation with wheat yellow rust (*Puccinia striiformis*) or maize rust (a mixture of *P. sorghi* and *P. polysora*). Such induced resistance can delay and reduce sporulation resulting from infection with virulent races. The resistance may be conferred irrespective of whether the inducing inoculum is applied 24–48 hours before, simultaneously with, or 48 hours after the virulent challenge inoculum.

It is suggested that such effects of induced resistance could retard the development of rust diseases in the field, particularly in legume–cereal intercrops.

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A Limited Objective Approach to the Design of Agronomic Experiments with Mixed Crops

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Most authorities agree that mixed cropping of annual crops in tropical regions is a more efficient means of using available land area than are pure stands. However, agronomists will need to ascertain what the optimum management is for a given crop association in a given environment, i.e., they will need to study the agronomy of mixed crops.

The scientific method of isolating a number of subsystems of a complex system for study when applied to mixed cropping would involve studying a mixture of two crops, arranged in a more clearly defined geometric pattern than is common in traditional agriculture. This approach is valuable (*a*) because as the interactions of two crops are understood, it becomes possible to extrapolate this understanding to the more diverse systems; (*b*) although the small farmer will not easily be persuaded to abandon his practice of mixed cropping, he is capable of improving his system to make use of technological innovations such as improved varieties and fertilizers.

In Kenya, the small farmer is moving toward planting associations of only two crops, with at least one of these crops in rows. Food cropping is now dominated by a single crop association, maize–beans, with hybrid maize and fertilizer being used and the maize planted in rows.

This apparently successful compromise has been worked out on the farm, not in the research stations, even though much extension effort has been expended to persuade the farmer to abandon his mixed cropping. It is a hopeful sign that even as research agronomy moves toward accepting for the time being the inevitability of mixed cropping, so the farmer is himself evolving a simpler system that can more easily be studied and further improved by the scientific method.

Even though it may be desirable to optimize the indigenous mixed cropping system rather than to replace it, an association of only two crops is a more difficult system for which to define optima than is a pure stand because the number of agronomic variables is multiplied by mixing the crops. Thus the fairly simple factor of time of planting of a pure stand becomes complicated if one must consider all the possible combinations of time of planting of the two crops relative to each other as well as to the cropping season. The same argument can be applied in different forms to the factors plant density, plant arrangement, fertilizer application, tillage practice, and all aspects of crop protection. In short, we cannot design practicable experiments that accommodate all possible variables.

A frequent response to this dilemma has been to isolate one of the factors, and this has been done for the factor plant density by Evans (14), Willey and Osiru (21), Osiru and Willey (22), and Huxley (58). Evans (59) has studied fertilizer responses in mixed crops, and J. O. Owuor of the University of Nairobi

plans to examine the effect of relative times of planting in maize–bean mixtures. However, the factor selected for study may not be the most important one for immediate optimization.

An alternative approach is to concentrate attention on one of the crops rather than one of the factors and to attempt to optimize the management of this crop as it is grown within the mixture. This approach, though of limited objective, has advantages where two conditions apply. Firstly, one of the two crops must be known to be competitively aggressive over the other. It is not intended to suggest that aggression is always a feature of one crop in a mixture, only that where aggression does occur, the approach might be useful. Aggression in mixed cropping is identified by the capacity of one crop to maintain yields almost unaltered whether or not the competitively recessive crop is present, with all else, including the density of the aggressive crop, being equal. In good rainfall seasons maize is highly aggressive in maize–bean mixtures at Kabete but is not in poorer seasons (60).

The second condition is that the optimum management of the aggressive crop in pure stand should have been well researched. There is as yet no reason to believe that the optimum management of an aggressive crop is very different in mixture than in pure stand, certainly not sufficiently different to justify the adoption of separate recommendations for the two systems. It becomes counterproductive if the steady progress achieved with one crop is jeopardized at the farm level by a confusion of issues brought about by the mixed cropping controversy. Nobody realizes this more clearly than the better Kenyan small farmer who has frequently adopted recommendations for maize derived from research with pure stands, even though he persists in interplanting beans. He has undoubtedly benefited and it is unhelpful if this fact is ignored,

whatever view is held of the relevance of research done in pure stands.

Since all the problems of mixed cropping cannot be solved in a single experiment, it is a valid interim research strategy to accept the recommendations for an aggressive crop provided that these are scientifically determined, even if in pure stand. The research objective then becomes one of optimizing the agronomy of the recessive crop while holding the aggressive one constant. For many crop associations, this is a more urgent requirement than determining, for instance, the optimum plant arrangement for the mixture. When it becomes known which agronomic factors are most important for the recessive crop in the mixture, then is the time to vary the agronomy of the aggressive crop in combination with the important factors of the recessive.

To illustrate this approach, an experiment was carried out at three sites (Kitale, Kakamega, and Kisii) in western Kenya (45). The preconditions for the usefulness of the approach were ideally met. The maize was already known to be aggressive at two of the sites (61) and the agronomy of maize had been studied in some detail (62, 63, and annual reports of the National Agricultural Research Station, Kitale). In contrast, almost no research had been done with beans, even in pure stand. The strategy was therefore to accept the maize recommendations, which meant the use of a hybrid variety, planted as soon as practicable after the beginning of the rains, at a spacing of 75 × 30 cm. A generous but economic application of phosphorus was placed in the planting hole and a similar topdressing of nitrogen applied around the maize plants. The beans were interplanted with one row between each maize row, and pure stands of both maize and beans were included for comparative purposes.

At none of the three sites was there a statistically significant effect of bean

cultural treatment on maize yield, and at two sites where comparison was possible, the mixed crop maize yields were not significantly different from pure stands. Thus the maize was certainly aggressive over the beans whose yields at the different sites varied between 17 and 73% of pure-stand yields for the first time of planting and between 0 and 29% for the second planting. The bean yields clearly indicated the overriding importance of the relative time of planting factor in maize–bean mixtures. The response to fertilizer was not significant at any site and, even at Kitale, the magnitude of the response was not great enough to meet the cost of fertilizer. There was little difference between 10- and 15-cm spacing in the row and certainly, the spacing factor is of little importance relative to time of planting. Thus by the design of an experiment with limited objectives, immediately useful results have been achieved without confusing the maize recommendations that have contributed to some improvement in maize growing over the last decade on the small farms of the area. For future research, it is clear that time of planting is the factor to concentrate on to define the optimum strategy for the small farmer faced with a peak labour requirement at the onset of the rains.

A secondary but rather interesting finding from this experiment emerged rather by accident than by design. Maize yields at Kisii were low because of a combination of late planting, hail damage, and disease. It was nevertheless at this site that the advantages of mixing over pure stands were greatest, though it must be remembered that total production was lowest. In fact, the sites could be arranged as in the table below in decreasing order of land equivalent ratio (LER), a measure of the degree to which the mixed crops gave a higher return to land area than the pure stands. This arose because where maize yields are lowest, the beans were most capable of developing a worthwhile yield in mixtures. On most small farms, maize yields are lower than on the research stations for reasons that are to some extent beyond the control of the farmer. Clearly, if this is so, the advantages of mixed cropping are considerable.

	Pure maize yield (quintals/ha)	LER
Kitale	84	1.08
Kakamega	52	1.24
Kisii	27	1.87

$$LER = \frac{\text{maize yield in mixture}}{\text{maize yield in pure stand}}$$

$$+ \frac{\text{bean yield in mixture}}{\text{bean yield in pure stand}}.$$

Systematic Spacing Designs as an Aid to the Study of Intercropping

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Although intercropping and relay cropping are widely practiced in the tropics, particular systems are usually highly location-specific (64). As compared with sole cropping, socioeconomic benefits are often better established than are ecological or technical ones (44) and this is sometimes due to comparisons being made at different total plant populations (21). Indeed, the exploitation of environmental resources will be highly dependent not only on crop combination but also on plant population. Furthermore, the interaction between these two factors may well vary depending on the time and magnitude of the particular environmental components involved and the stages of plant development achieved, so that ecological benefits are apparent in some instances from intercropping (21) but not in others (43, 44). A more fundamental approach is likely to sharpen our understanding of the value of intercropping more rapidly than just a proliferation of empirical trials, particularly as the number of variables involved is so large and their interactions so complex. Experiments involving systematic spacing designs could well assist here (58).

Both the extent of between-component competition and within-component interference can be tested by using a replacement crop series within a systematic spacing design (e.g., a "fan"). The theoretical results of such a trial were discussed by comparing the *actual* yields of the individual crop components used in such a design with their *predicted* yields, the latter based on the sole crops grown over a wide range of plant populations using the same design.

Thus, for a mixture, both the best crop ratio and spacing to optimize yield per unit area of harvested parts, calories, protein, or cash, can be predicted from the results of a few preliminary experiments that provide the yield/plant population response curves of the components, and the extent to which these are altered in mixtures. It is then possible to compare this with the maximum sole crop returns for each component grown at its optimum plant population. The results of combining crops with different types of sole-crop yield/plant population response curves were then outlined.

Future Directions of Intercropping and Farming Systems Research in Africa

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Valuable experience has been obtained in the intercropping studies at Morogoro and elsewhere, but further research is needed both in intercropping and multiple cropping, and particularly into the development of improved farming systems for semi-arid areas.

Small farmers in areas of high potential have been successful in developing highly intensive farming systems adapted to heavy population pressures, but in general, farmers in the semi-arid areas have not been so fortunate, and major problems of low crop yields, soil exhaustion, and erosion are occurring.

A two-pronged approach is desirable, with initial surveys of the most severely affected areas by interdisciplinary teams, followed by pilot-scale trials on the farmers' land.

This approach would need to be supported by backup work on research stations, with perhaps some emphasis on integrated small farming systems, particularly for analysis of economic problems.

Developing Mixed Cropping Systems Relevant to the Farmers' Environment

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The decision as to which crops are grown in a particular area is determined not only by physical or biological factors (water, temperature, radiation, evapotranspiration, and soil conditions), but also by social (personal tastes, tradition, ethical code, etc.), economic (prices, ease of transportation, compatibility with the farming system, etc.), or political factors (marketing boards providing marketing channels, stable prices, etc.), which determine the farmers' choice.

A number of factors also influence the cropping system, which can be defined as the way in which crops are grown. These include tradition, level of technology (power source, improved seed varieties, use of inorganic fertilizer, etc.), resource availability (land, labour, capital, managerial skill), the farming system, and the physical environment (temperature, water availability, etc.). Increasingly, attention in recent years has been focused on investigating these systems for two major reasons:

(1) There has been increasing frustration that the farmers have often not accepted improved cropping systems that have resulted from research by agricultural scientists. As a result a conventional wisdom has developed that, by introducing improved technology into cropping systems that already generally prevail in the area, it will require a less dramatic change on the

part of the farmer and will therefore increase the probability of the improved technology being adopted under practical farming conditions.

(2) There has been increasing recognition of the fact that indigenous cropping systems used by farmers have often evolved over a number of generations and represent some sort of balance with the "total" environment, which consists of both technical (i.e., biological and physical) and human (i.e., social and economic) elements. The technical scientists, in particular, have recognized that a closer study of these indigenous cropping systems may potentially be important in evaluating prospects for increasing production as a result of introducing changes that take into account the underlying principles, particularly those of a technical nature.

Traditionally, increasing agricultural production has emphasized two dimensions: expanding area and improving the yield of individual crops. However, recent research has increasingly emphasized a third dimension, time, which involves increasing the yield per unit of area per year. The time available for crops to grow on a given piece of land in any one year will depend fundamentally on temperature and water availability. It is obvious that in tropical and subtropical areas water availability is the more limiting factor. It would therefore appear that this variable is a key factor in determining the cropping system under indigenous small farming conditions (65, 66).

Semi-arid areas in the tropics are characterized by an arid[2] season of 5–10 months and an annual rainfall from approximately 500 mm to about 1500 mm (67). The length of growing season in the area, therefore, ranges from about 80 to 200 days. With such a constraint, multiple or double cropping is in general not feasible unless reliance is placed on supplementary or complete irrigation systems. Therefore, in semi-arid areas if the farmer wants to grow more than one crop on a piece of rainfed land in 1 year the only way is by means of crop mixtures.[3] Crop mixtures or mixed cropping in the context in which it is used in this paper is the growing of two or more crops on the same piece of land in the same season so that plants of at least one crop are associated with plants of another crop for a substantial period of time (68). There are two types of crop mixtures: intercropping in which one crop is either sown with or after another crop and harvested before it; and, interplanting, when one crop is sown shortly after another and also harvested after it. As water availability becomes more limited in terms of monthly duration (i.e., toward the lower limit of the growing season mentioned above), the range of crops or varieties that can be grown becomes less, thereby forcing the farmer steadily toward a sole cropping system.

The objective of this paper is to briefly outline the type of approach that will be required to develop and assess the suitability of improved cropping systems of relevance to small farmers in semi-arid areas. Consideration will be mainly confined to elements that fall outside the realm of physical and biological factors, as social and economic factors tend to be even more location-specific than physical and technical factors.

Relevancy of Indigenous Cropping Systems in Northern Nigeria

An analysis of the indigenous cropping systems in two areas of northern Nigeria demonstrated quite clearly the dominance of crop mixtures under indigenous conditions in the semi-arid areas of Nigeria, because the cropping systems being used are relevant or adapted to the total environment.

At the risk of oversimplification it is suggested that the total environment can be divided into the following components:
(1) Technical element
(2) Human element:
  (a) Outside farmer's influence — infrastructural support systems, which in the developing world are often funded and manned by government.
  (b) Under farmer's influence — the farming system he adopts taking into account (1) and (2a) above, and his own resource limitations (i.e., quantity and quality), attitudes, etc.

Some examples illustrating that indigenous cropping systems in northern Nigeria reflect adaptation to each of these elements are discussed in the following sections.

(1) Physical element

The farmers' cropping systems indicate an appreciation for the rainfall limitations and possible complementary relationships between the growth cycles of different crops. This is reflected in the practice of growing crops in mixtures to make the most of the limited growing season, in the changes of the significance of planting densities and ratios of different crops to fit the physical environment, and the overwhelming popu-

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[2]An arid month is one in which the potential evapotranspiration exceeds precipitation.

[3]In semi-arid areas with growing seasons near the upper limit (200 days), relay cropping (i.e., where crops overlap for only short periods) is, of course, also sometimes possible.

larity of certain crop mixtures such as the millet/sorghum mixture in the Zaria area.[4]

(2) Outside farmer's influence — infrastructural support system

Because of limited financial and manpower resources and the large numbers of customers (i.e., farmers) dispersed over big areas, many parts of northern Nigeria lack in terms of quantity and/or quality the factors that would be necessary to provide an adequate infrastructural support system to encourage the adoption of much of the improved technology at present available. The basic elements of the infrastructural support system, assuming that an improved technology is available that is profitable and dependable in its return, are:

(i) The convincing element that involves an input by extension staff and perhaps the explicit provision of a market for the product produced (e.g., marketing board, minimum price, etc.).

(ii) Since most types of improved technology cost money, ensuring that farmers have the necessary financial resources at the required time in order to purchase it.[5]

(iii) Ensuring the improved inputs required for the adoption of the improved technology are distributed in sufficient quantities to the right places at the right time.

Since in both the Sokoto and Zaria areas, extension staff are in short supply (i.e., one per 2500–3000 farmers), institutional credit sources are lacking,

and the input distribution system (largely confined to inorganic fertilizer) is invariably inadequate, farmers have adopted indigenous cropping systems that have evolved over generations and are adapted to the situation. These require little in the way of improved inputs[6] and consist of methods already well known within the village. The lack of reliance placed by the farmers on infrastructural support systems is further exemplified by their growing a number of crops to insulate themselves against the vagaries of the market.

(3) Under farmer's influence

The farmer is faced with limited resources (i.e., land, labour, capital, and management), both in terms of quantity and quality, that he combines into a farming system that he feels will best fulfill the goal or goals he has set himself. However the infrastructural support system can influence this, for example:

(i) By changing the quantities and qualities of the resources. An efficient improved input distribution system provides the basic prerequisite for adopting improved technology, whereas, under certain circumstances, the existence of an institutional credit program, supplementing other sources of investment funds (e.g., savings, borrowing from friends, relations, etc.), can help provide the financial resources needed for purchasing them. Such funds can also provide funds for hiring labour,[7] or

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[4]These two crops have been shown to have complementary growth cycles and much experimental work has been carried out on this mixture under experimental conditions (68, 69, 70).

[5]With certain types of improved technology this may imply the need for an institutional credit program to make adoption possible.

[6]This can be deduced by examining the difference between the figures for average value of production per hectare and the net return per hectare when labour is not valued.

[7]The types of improved technology usually considered to be most relevant to the small farmer, such as fertilizer, improved seed, etc., usually result in substantially increased labour requirements, particularly in harvesting the increased yield. With sole crop sorghum it was found for example that the labour requirements increased by 69% when improved technology was used (71).

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increasing its productivity (e.g., mechanization, herbicides, etc.), obtaining more land, etc. Finally an extension input provides an opportunity for teaching the farmer how to manage the improved technology.[8]

(ii) Because of (i) above, it can influence not only the way the crop is grown (i.e., level of technology) but also in some instances what crop(s) are grown and the degree to which they are grown. An infrastructural support system providing the possibility of some assured market or support price may produce cropping and farming systems significantly different from that which would result in the absence of such a program.

For farmers in the Sokoto and Zaria areas, the low level of infrastructural support systems has resulted in them having very limited resources largely unmodified by external influences. Since their incomes are low, their actual level of living is at the same level or only slightly above that required for subsistence (72). As a result a profit maximization goal is likely to be severely constrained by a security goal that will inhibit risk taking. However, the growing of crops in mixtures under indigenous technological conditions was consistent with both these goals. Consequently, farmers will be interested in maximizing the return to the most limiting factor. Lack of capital and managerial expertise with reference to improved technologies are of course limiting factors to most farmers under indigenous technological conditions. However, whether land or labour is more constraining is to some extent a function of population density and soil quality. For farmers in the Zaria area, where fallow land still abounds, labour, especially during the peak period, is likely to be more limiting than land. In the Sokoto area, where there is little fallow land, land is likely to be more of a constraint than labour. However, the notion of growing crops in mixtures in both the Sokoto and Zaria areas is better for all farmers no matter whether they are faced with a land or labour constraint. Whether or not this apparent consistency would be true under improved technological conditions is not certain and should not be assumed to be the case.

(4) Conclusions concerning relevancy

The above remarks have indicated that the test of relevancy of a cropping system goes far beyond that of adapting it to the physical environment to one embracing, in addition, adaptation to the human environment. The interdependencies within this framework are recognized since analysis of the former determines whether or not the cropping system can technically be grown, whereas the analysis of the latter will determine whether or not it will actually be grown. In other words, the physical environment provides the necessary condition, whereas the human environment provides the sufficient condition for the presence of a particular cropping system.

There is no doubt that scientists have recognized the technical advantages of growing crops in mixtures. Many, however, have perceived the idea of relevancy mainly in physical terms,[9] whereas relatively few perhaps have accepted the challenge of defining rele-

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[8]This is not meant to imply that the farmers' managerial expertise is very limited. They do in fact possess considerable expertise with reference to farming under indigenous technological conditions but a lack of exposure to improved technology obviously limits their initial capacity to efficiently manage the latter.

[9]One can hardly blame individuals for confining themselves to this. The sheer complexities of working with crop mixtures compared with sole crops even just in terms of the technical elements precludes consideration of other elements.

vancy in both physical and human terms.

Even where human elements have been considered it has often been assumed that an adequate infrastructural support system will be present to provide the appropriate modifying influences on factors under the farmers' control, thereby creating conditions suitable for the adoption of the improved cropping system. Unfortunately the infrastructural support system that is usually assumed to be present is at a fairly high level (e.g., high levels of improved inputs, possibility of credit institutions to provide funds for their purchase, complex technologies sensitive to timing, therefore necessitating high concentrations of extension staff to impart to the farmers the managerial expertise necessary for its successful adoption, etc.).[10] For many semi-arid areas, including large parts of northern Nigeria, this is not a reasonable assumption for the near future and therefore less complex and more flexible cropping systems with lower demands on the infrastructural support systems need to be designed. If adopted, the potential impact in the long run could be substantially greater than those requiring substantial infrastructural support systems that might give spectacular returns but will only be able to be provided to and adopted by a small proportion of the population.

Framework for Cropping Systems Research

A simplified framework for undertaking cropping system research, and one designed to develop improved cropping

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[10]This has been encouraged to some extent by many of the scientists being trained in the high income countries where such elements are taken for granted and by the fact that professional recognition has often in the past been on the basis of spectacular changes. To achieve these, strong infrastructural support systems are essential.

systems that are relevant to the "total" environment, can be summarized as follows[11]:

(a) Achieve an understanding of the present methods of production and the constraints the farmer faces and feels are most restrictive. This information can be obtained mainly by social scientists hopefully supplemented by information collected by extension agents.

(b) Obtain some idea of the present and proposed programs of government with reference to infrastructural support. This information can be obtained through communication with government and from work carried out by social scientists, particularly with reference to the effectiveness of infrastructural support systems operating at present.

(c) Take into account information arising from (a) and (b) above in the development of improved cropping systems that will therefore consider both technical and human elements. This ideally would involve multidisciplinary research teams consisting of both technical and social scientists.

(d) Undertake as much as possible of the adaptive research on farmers' fields even prior to drawing up final recommendations. This encourages constant attention being paid to the problems of adapting the proposed cropping system to practical farming conditions (i.e., relatively low soil fertility, the problems of fitting it into the farming system, lack of experience and expertise of farmers in managing the new cropping system, etc.).

There is of course nothing new in the proposal. Indeed the international centres are basically following such an approach. Unfortunately, however, be-

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[11]A more sophisticated schema was developed at a recent cropping systems workshop in the Philippines and is presented elsewhere (73).

cause of more limited finances and manpower, few national research centres are able to mount such a program.[12] However, it would appear that a program approximating this approach is absolutely essential if cropping systems are to be systematically developed that are relevant to the "total" environment. One such possibility is:

(1) To commence with trying to improve one or a very limited number of cropping mixtures that are already popular under indigenous conditions in the area.[13]

(2) In designing the research program examine the possibility of working at two assumed levels of infrastructural support systems. One at the advanced level would assume that the provision of the infrastructural support system is such that there is a possibility of substantially changing the farmers' methods. The other at the intermediate level would assume that the infrastructural support system is poorly developed and therefore improvements would have to be introduced into a farmer's environment that is little influenced by external forces. Such improvements would give a dependable return, would not involve a high cash investment, would demand only low levels of improved inputs, would be easy to adopt, and would not involve radical changes on the part of farmers. Crop mixtures because of their dominance in semi-arid areas form an ideal base for the development of intermediate level recommendations. Obvi-

ously it is not reasonable with intermediate level practices to expect that there will be such a high payoff as at the advanced level practices but it is suggested that in terms of relevancy this approach has potentially a much greater impact on the economy. The problem of working with more than one crop at the same time is that the improved system that evolves is liable to be complex (e.g., timing and rates of application to different crops in the mixture) and subject to a high degree of managerial expertise. The skill on the part of the researcher lies in simplifying it so that it can easily be adopted under practical conditions. At the present time the bulk of the work on crop mixtures should be undertaken to obtain intermediate level recommendations (i.e., low infrastructural support systems).

(3) In terms of assessing the relevancy of the improved crop mixtures to the actual farming environment it is essential that they be tested under practical farming conditions. Testing should not simply be restricted to collecting information on yields[14] but in addition should involve collecting and analyzing information to provide documentation on:

(a) what was suggested by the research workers in terms of timing of operations, levels and types of improved inputs to use, planting densities, etc.;

(b) the labour profile through the growing season as a result of following the suggestions with particular emphasis on labour peak periods;

(c) the cash flow profile involved in following the suggestions;

(d) an assessment of the complexity or ease of following the suggestions (i.e., managerial expertise required);

[12]Especially at one point in time; for example, much of the recent work on crop mixtures at the Institute for Agricultural Research, Ahmadu Bello University, has been undertaken by one person, an agronomist, who is also involved in substantial administrative responsibilities.

[13]For example, much experimental work has been carried out on the popular millet/sorghum mixture at the Institute for Agricultural Research, Ahmadu Bello University.

[14]Or for that matter value of production or net return (i.e., excluding labour) per hectare. Much experimental work on crop mixtures goes no further than these.

(e) the level and dependability of the yields of the different crop constituents as a result of following the suggestions;

(f) assessment of the improved crop mixture in terms of:

(i) deviations from the suggestions given in (a) above and an analysis of the reasons; these could well be linked with (b), (c), and/or (d) above;

(ii) level and dependability of the profit, and return to the more limiting factor (e.g., land or labour particularly during the labour bottleneck period)[15];

(iii) its compatibility with the over-all farming system adopted by farmers.[16]

Such information hopefully would provide guidelines as to whether further changes in the proposed improved crop mixture should be considered and whether a reappraisal of the infrastructural support system required is necessary. As far as possible, work at the experimental level should be undertaken concurrently with the adaptive research at the farmer's level to provide a feedback of information that can be incorporated in research work at the former level.

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[15]Labour, when viewed on a seasonal basis, is in fact more often a more limiting factor than land in many semi-arid areas and yet analysis is seldom couched in terms of the former factor.

[16]A useful starting point is to consider any differences the improved crop mixtures exhibit compared with the indigenous crop mixture and an assessment of the importance of them considering both the benefits and problems.

Assessment of Innovations in Intercropping Systems

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There is a widespread complaint that small farmers in tropical Africa fail to adopt innovations produced by research. A farmer normally adopts innovations because they provide benefits to him that exceed their costs, but these net benefits to the farmer are seldom assessed. There is a need to project the costs and benefits within the farming system of an innovation before it is developed and to assess costs and benefits of recommended innovations. Many research-produced innovations require fundamental changes in the farming system. These changes can be assessed by farm planning methods that indicate the impact of innovations on the whole farm plan and on overall farm profits. The Morogoro Intercropping Project is largely concerned with relatively small changes in farm operations designed to fit in easily with the existing system. The net benefit of these changes can best be assessed by methods akin to partial budgeting that focus on comparing changes in benefits and changes in costs. Close cooperation with scientists is required in choosing relevant areas to examine for innovations, and intimate knowledge of the farming system is required if all costs and benefits are to be identified.

Summary
and
Conclusions

We should view farmers as our customers in that we researchers are producing a "product" (i.e., technology) suitable for them. With reference to this two points arise:

(a) Since in most semi-arid countries governments do not force farmers to change, it is of paramount importance that research workers produce a "product" that is relevant to the needs of farmers. Otherwise, due to the voluntary nature of changing, farmers will not buy and utilize the "product."

(b) Unlike a commercial firm, the benefits of research undertaken in governmental or pseudogovernmental institutions do not accrue to the individual research worker but to the society as a whole. In addition the costs of the research are also met by the society rather than the individual research worker. Therefore, research work is usually accountable to society, which usually has a short- rather than long-run time horizon and is also very cost conscious.

The basic problems with research on mixed cropping are that it is a very complex area to investigate and, as a result, is very expensive and time consuming to undertake. In addition, in many areas it was, until recently, and often still is associated with subsistence or backward agriculture and therefore was considered incompatible with a modern agriculture. It is therefore not surprising that organizations such as IDRC have had to take a lead in financing work on mixed cropping.

However, this places an important obligation on us to continuously ask ourselves the question: are we using our limited manpower (time) and financial resources available for research in mixed cropping in the most efficient manner, in order to derive practical results in the shortest possible time?

Variables Involved in Mixed Cropping

We have had sessions on: soil management and fertility; crop combinations; plant breeding and crop physiology; pests and diseases; experimental methods; and economic and social aspects of intercropping.

We all, of course, appreciate that a large number of variables influence the physical yield of sole crops and that this becomes considerably more complex in a mixed cropping situation because of the possible interactions involved. For example, papers given at this workshop have included consideration of the following variables and

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their interactive relationships:

> different crops and varieties;
> different planting times, plant populations, and crop arrangements;
> different fertilizer rates, types, and methods of application;
> different levels and methods of controlling pests, diseases, and weeds.

It is obvious that the number of possible experiments that could be undertaken are infinite. Obviously we cannot afford the luxury of undertaking them indefinitely. Since we are increasingly becoming accountable for maximizing the returns from our limited research resources, it would be opportune for the symposium to consider two points:

(*a*) Have some general principles emerged from the papers given at the symposium? Professor Huxley expressed the opinion that there was perhaps a valid conventional wisdom emerging. Or, as Dr Wein suggested, have we been too concerned with the end result (i.e., yield) and not sufficiently concerned with an analysis of how that yield was obtained, which would presumably result in the derivation of general principles? Alternatively, is there too much location specificity in a mixed cropping society to permit general principles to emerge? There would appear to be merit in the participants discussing this issue and recording the general principles if in fact they have emerged.

(*b*) Arising out of (*a*) above, can duplication and repetition of experiments be avoided? Can this also be minimized by a systematization and coordination of ongoing research? What has surprised many of us at the symposium has been the large number of individuals and institutions involved in crop mixture research. This is most encouraging. However, what has also emerged is the tremendous inequality in the distribution of research resources ranging from those places with high levels of support, such as the international institutes and Morogoro (where IDRC has been so supportive), through intermediate levels such as Samaru and Ibadan, to those where resources appear to be rather more constrained, such as Makerere, Khartoum, Nairobi, and Alemaya. The statement by Dr Ker indicating that IDRC would be willing to consider requests from individuals for research support, is to be welcomed, particularly where individuals are working largely on their own. However, there are at least three other possibilities of overcoming to some extent the inequitable distribution of research resources, economizing on the use of research resources, and maximizing the return from ongoing research:

(i) Through better communication by the circulation of papers and the occasional staging of workshops on specialized topics.

(ii) For the symposium members to delineate the research priorities to emphasize where resources are limited. Are there critical variables that should always be looked at, or are the problems of mixed cropping too location-specific to arrive at such generalizations?

(iii) To seriously consider the possibility of coordinated work on mixed cropping between different institutions. There would appear to be a "critical mass" of research resources necessary for looking at all facets of crop mixture research. Through such coordination individuals working in more constrained circumstances would be able to increase the productivity of their research.

Relevance and Evaluation

In terms of relevance, a number of individuals have quite rightly emphasized the importance of looking at the farmer's environment and comparing the results of mixed cropping using improved technology with this environment. At the same time there appears to be a great deal of research aimed at maximizing the physical potential of the mixed cropping system. The question arises as to whether such an approach is always necessary to develop "packages" that are relevant to the practical farming situation. It is suggested that greater coordination between technical and social scientists could help in evaluating improved mixed cropping systems and assessing their relevance to practical farming conditions.

The evaluation of mixed cropping systems has perhaps been the most disappointing part of the symposium. It is suggested that a great deal more attention needs to be paid to this subject, which could perhaps usefully form the basis of a future workshop. Evaluation starts with a consideration of the physical characteristics into which the mixed cropping system would fit but does not end in terms of physical yield, land equivalent ratios, etc. Some participants went beyond this to consider social and economic facets and the way the proposed mixed cropping system would fit into the farming system as a whole. This would involve a consideration of both the flows (i.e., over time) as well as the stocks of resources used in undertaking the proposed mixed cropping system. Evaluation, therefore, goes far beyond looking at the level and dependability of return per unit area to include consideration of labour, capital, etc. Baker has shown in work published elsewhere that it is quite feasible for technical scientists to look at improved technologies in terms of inputs other than land. The most important criteria on which to judge the viability of the proposed mixed cropping system will, of course, be somewhat location-specific.

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The traditional agriculture inherited by the peasant farmer was designed to raise sufficient food for himself and his family in a situation where very little else was required. There were no taxes, no school fees, no goods for purchase, low population levels, and little pressure on the land.

Death control, costs of a country-wide government organization, education, and material needs of Western civilization have changed all this. The farmer now has to produce a lot more from continued use of the same piece of land.

As researchers, we have to ask ourselves: Is the intercropping technology that we have developed thus far sufficiently superior to that already used by the farmer? We need to look at what the farmer is doing, and why he is doing it.

The farmer has tried many possibilities during the last thousand years, but we may be able to bring in new crops, new crop varieties, new ideas of cropping patterns from other countries. The main possibilities for improvements are new varieties, oxen power and improved implements, fertilizers, and weed control.

Improved varieties often involve a redistribution of total dry matter production so that much more of it is grain. This gives the farmer an immediate yield increase without additional inputs. On this can be added simple agronomy practices, provided the new varieties are responsive, which they must be. Only then can we think in terms of farming systems.

However, population pressure is increasing and time is running out. Increased production per unit area is essential, and governments will be faced with the hard decision on whether these changes can be induced by persuasion or whether state control is necessary to make the farmer adopt new ways.

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