International Workshop on Intercropping

International Crops Research Institute for the Semi-Arid Tropics

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Foreword

Farmers in the developing world have been growing two or more crops together on the same piece of land for many centuries. In India, as many as 84 different crops are used in mixed cropping, but seldom do we find more than four at a time, and a relatively simple mixture of only two or three crops is most common.

The main consideration for mixing crops together is to reduce the risk of failure. The farmer reasons that if several crops are grown at the same time, at least one will survive to harvest. But there are other reasons too. Frequently one can find short-duration and long-duration crops in the mixtures. This helps spread labor needs more evenly. Food crops are usually mixed with cash crops to help ensure both sustenance and disposable income. Cereals and legumes are often mixed, probably more for dietary reasons than for any beneficial effect that the nitrogen-fixing powers of the legumes convey to the associated cereal crop or to a subsequent one. The crops may be grown as random mixtures but in India they are generally grown as intercrops with a few rows of one component regularly interspersed with a few rows of another.

Although research on intercropping may have started to provide an understanding of why the farmer used such mixtures, and to help improve his productivity in ways relevant to his practice, it has now been shown that intercropping may have several advantages over sole cropping. It appears to make better use of the natural resources of sunlight, land, and water. It may have some beneficial effects on pest and disease problems, although the overall results are somewhat inconclusive. The advantage of mixing a legume with a nonlegume to save on the use of nitrogenous fertilizers has already been mentioned. These advantages show up as ultimate benefits in yield, and increases of as much as 70% over a sole crop on the same piece of land have been recorded. One must enter a caveat, however, in that the methods for indicating such yield benefits are open to questions and criticisms.

Intercropping is a practice most common among small farmers and where farmers have least access to irrigation. Thus, for ICRISAT, with its mandate to work particularly for small dryland farmers with low-factor environments, intercropping is of particular interest, and a substantial effort is being made by the Institute to understand and improve this method of crop production. The research is done within the larger context of our Farming Systems Research Program in recognition of thefact that any cropping system has relevance only within a system of farming and within the social, economic, and technical constraints with which farmers must live.

This Workshop brought together many scientists interested in intercropping. The proceedings represent a state-of-the art summary and should be of substantial interest to other researchers in the field. However, because intercropping has substantial absolute advantages over sole cropping — even at high input levels— and because so many farmers use the practice, the proceedings should also be of great interest to development agencies, institutes, and services. If intercropping is indeed a more efficient and environmentally sounder practice than sole cropping, it is time that governments, agricultural infrastructure and services, and financial institutions take cognizance of the facts and help farmers expand their intercropped areas. It is obvious from current trends that this will lead to a major change in the thinking and direction of such agencies and their staff.

L. D. Swindale
Director General

Opening Session

Chairman: R. C. McGinnis

Chairman's Opening Remarks

R. C. McGinnis*

I believe the last significant workshop that we have had internationally on this subject was held in Morogoro in Tanzania in 1976. And at that time it was obvious that there was a great deal of experimentation going on in the field of intercropping in general. But the results clearly indicated that a lot of the data that was coming forward was not as crisp and sharp as it could have been and there were very many wide gaps in our knowledge. For example, I can recall considerable debate as to whether intercropping was good or bad, and whether it increased or decreased yield per unit area and these are very serious questions. I think a great deal of additional experimentation has gone on since then and the direction and design of the experiments have changed, so that the data that is now being generated is probably even more meaningful than it was at that time.

The objectives of this workshop of course are simply to find out the state of the art at the present time, to identify major gaps in research programs and in our knowledge, and then to try to bridge the major gaps in the research programs. I hope that you have an enjoyable and profitable conference.

* Director for International Cooperation, ICRISAT.

A Scientific Approach to Intercropping Research

R. W. Willey*

Abstract

A scientific approach to intercropping research is outlined with reference to the ICRISAT program. For the purposes of the Workshop, intercropping is defined as any cropping system where there is a significant amount of inter-crop competition. Compared with sole cropping, the possible yield advantages of intercropping are defined as (1) higher yields in a given season, and (2) greater stability of yield in different seasons. Considering higher yields in a given season, three different objectives are defined: (a) where the combined intercrop yield must exceed the yield of the higher-yielding sole crop, (b) where intercropping must give full yield of a "main" crop and some additional yield of a second crop, and (c) where the combined intercrop yield must exceed a combined sole crop yield. Assessment of the yield advantage in these three situations is discussed. Especially for the third situation, some advantages and disadvantages of the land equivalent ratio are presented. Some other competition functions are also briefly reviewed.

The general areas of intercropping research are defined. In the crop physiology area, the need for more studies on growth patterns and resource use is suggested. In the agronomy area, some plant population work is presented to illustrate the kind of detailed, scientific approach that is possible in intercropping research. The need for more work in the areas of yield stability, the role of legumes, and weeds, pests and diseases is emphasized.

In this opening paper on intercropping, I want to try to do three things. First, as the title suggests, I want to outline a suggested scientific approach to intercropping research; in its simplest terms, this means a rational approach based on scientific principles which will give us the best chance of getting the answers we believe we need. Second, I want to say something about the ICRISAT intercropping program: I shall do this by using some of the ICRISAT work to illustrate the suggested scientific approach. Third, I want to highlight those areas of research most in need of attention and most likely to reward greater research efforts; I would hope that some of these will get particular consideration during our workshop discussions. But I make no apology for the fact that, at this stage in the workshop, I am largely raising questions and making no serious attempt to provide answers.

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First of all, I would like to explain our use of the term "intercropping." There is now quite an extensive array of terms available to describe the various systems where two, or more, crops are grown together on the same area of land. These terms usually attempt to distinguish between systems on the basis of such factors as spatial arrangement. But in this instance we are simply trying to focus on what we believe is the characteristic feature of all these systems, which is that, in contrast to sole cropping, there is competition *between* crops. In other words, compared to the *intracrop* competition of sole crops, there is the added complexity of *inter-crop* competition. For the purposes of this workshop, therefore, we can assume that "intercropping" includes any system where there is a significant amount of *intercrop* competition.

The importance of intercropping in farming practice has long been recognized, but it is only very recently that it has awakened real interest among research workers. The main reason for this is undoubtedly the increasing evidence that intercropping can provide substantial yield advantages over sole cropping. To date, these advantages have mainly been identified as higher yields in a given season, and it is no doubt this form of advantage that will occupy most of our attention during the next few days. But it has also been suggested that intercropping may give greater stability of yields over different seasons and that this is the primary reason for its prevalence in farming practice. This latter aspect has been badly neglected and later in our program we have tried to focus some specific attention on it. I will also be mentioning it again later. But the real importance of these advantages, whatever way they are expressed, is that they are achieved not by means of costly inputs but by the simple expedient of growing crops together. Thus, intercropping may offer a very genuine way in which the poorer farmer can benefit at least as much as the better endowed one.

In the case of higher yields in a given season, it is usually suggested that the major ways in which they can be brought about are (1) better use of resources, (2) less incidence of pests, diseases, or weeds, and (3) improved N economy when a legume is present. The first of these is now well proven and is probably the most important; it is certainly the most widely applicable. But evidence for the last two effects is much less definite. Although there are well authenticated cases of less incidence of pests or diseases, there are equally well authenticated cases of greater incidence. And it is still not really established whether the presence of a legume in an intercropping situation confers any benefits that cannot be gained just as easily from a sequence of sole crops. These two latter aspects clearly need more research effort and, again, we have tried to focus on them later in the program.

Before we consider advantages in more detail, however, it may be well to remind ourselves that there can be disadvantages of intercropping. There may be possible difficulties in the practical management of intercropping, and actual yield decreases may occur because of adverse competitive effects (Ahlgren and Aamodt 1939; Donald 1963; Harper 1961), allelopathic effects (Rice 1974; Risser 1969), or possibly greater incidence of pests or diseases (Pinchinat et al. 1975). But these adverse situations should never be used as a general argument against intercropping; rather, they should serve to remind us that one of the more fundamental objectives of intercropping research is to identify those situations which are beneficial and those which are not.

Assessment of Yield Advantages in a Given Season

Although few scientists would now dispute that there can be advantages of intercropping, there is still often confusion about what constitutes an advantage and, in any given situation, what the exact magnitude of the advantage is. This is because it has not always been appreciated that different intercropping situations may have to be assessed by different criteria. I would suggest that there are three basic situations:

1. *Where combined intercrop yield must exceed the yield of the higher-yielding sole crop.*

   This is the criterion that has traditionally been used for assessing grassland mixtures (van den Bergh 1968; Donald 1963), and it may be appropriate for assessing mixtures of very similar crops, or mixtures of genotypes within a crop. The criterion is based on the assumption that unit yield of each component is equally acceptable and, therefore, the farmer's requirement is simply for maximum yield regardless of which crop it comes from. It is not always appreciated, however, that it also assumes that growing only the higher-yielding sole crop is a practical alternative to growing both.

2. *Where intercropping must give full yield of a "main" crop plus some additional yield of a second crop.*

   This criterion may often apply where the primary requirement is for some essential food crop, or, at the other extreme, for some particularly high-value cash crop. It is a very well recognized situation in India, but largely ignored in international literature.

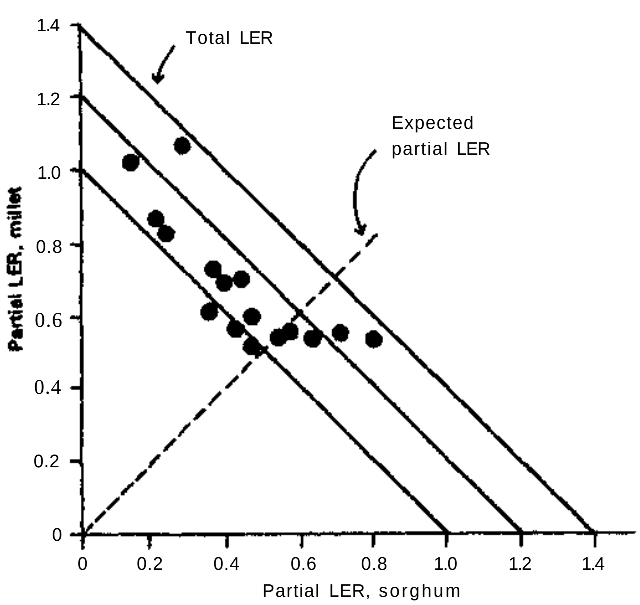
3. *Where the combined intercrop yield must exceed a combined sole-crop yield.*

   This criterion applies where a farmer needs to grow both (or all) the component crops — e.g. to satisfy dietary requirement, to spread labor peaks, to guard against market risks, and so on. The basis for assessment must then be whether intercropping provides more yield than growing the crops separately. An important point here is that the combined intercrop yield need not necessarily exceed the yield of the higher-yielding sole crop.

Recognizing these different criteria is important for two reasons. First of all, it helps to ensure that research on a given combination is focused on treatments which are likely to be relevant in farming practice. Second, it should ensure that yield advantages are assessed in valid, quantitative terms which are appropriate to the situation being considered. On this latter point, the first two situations above are relatively straightforward: in situation 1, the quantitative advantage is the extent to which the combined intercrop yield exceeds the yield of the higher-yielding sole crop; in situation 2, it is the yield of the "additional" second crop. But situation 3 has very often presented problems because it is not immediately apparent (and even now not universally agreed) what proportions of sole crops the combined sole crop yield should be compared with. It was emphasized sometime ago (Willey and Osiru 1972) that it was often invalid to make this comparison on the basis of *sown* proportions (e.g., 1 ha of 50:50 intercrop compared with 0.5 ha of each sole crop) because competition in the intercrop situation usually produces a final *yield* proportion different from the sown proportion. Comparisons effectively based on yield proportions are now commonly made using the land equivalent ratio (LER), which, in its simplest form, can be defined as the relative area of sole crops that would be required to produce the yields achieved by intercropping. As is now well known, LER values of less than 1, equal to 1, or greater than 1 indicate, respectively, a yield disadvantage, no difference, or a yield advantagefor intercropping; thus an LER of, say, 1.20 would indicate a yield advantage of 20%.

At ICRISAT, we use the LER term a good deal — both for any individual components (partial LER) and for the combined intercrop yield (total LER) — because it puts different crops, or situations, on a comparable basis; also, in addition to giving a measure of the yield advantage, it can be used to indicate competitive effects. As an example, Figure 1 illustrates two different types of intercropping experiments. Figure 1a shows all combinations of four genotypes of pearl millet x four genotypes of sorghum grown in alternate rows; for any given combination, comparison with the "total LER" lines shows the overall yield advantage,

a. Four millet x four sorghum genotypes (ICRISAT 1977)



b. Population response in maize/bean intercrops (Willey and Osiru t972)

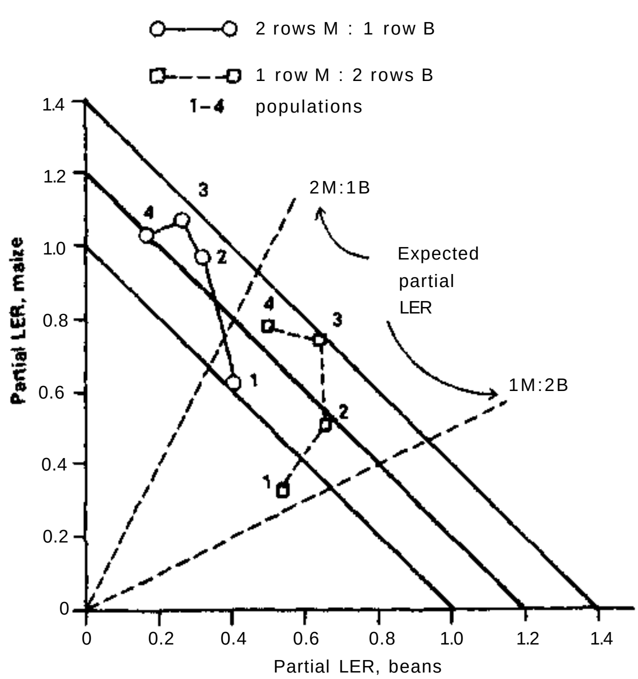


Figure 1. Land equivalent ratio diagrams.

and comparison with the "expected partial LER" line shows the degree to which either component is dominant. Similarly, Figure 16 shows that, for each of two arrangements of maize/beans, the maximum yield advantage occurred at population 3, and maize became increasingly dominant as population increased. A point to remember when presenting intercropping data using LER, however, is that, since LERs only indicate relative effects, some indication of absolute yield levels is also needed; a statement of the sole-crop yields used as the basis for calculating LERs will normally suffice.

However, LERs essentially indicate the physiological efficiency of intercropping compared with sole cropping. Thus, there may sometimes be problems in relating LER advantages into meaningful practical terms at the farmer's level. These problems arise because the proportion of sole crops with which the combined intercrop yield is effectively compared is determined as a *consequence* of intercrop competition; this exact proportion may therefore be something of a "theoretical" concept rather than a realistic cropping alternative for a farmer who has to decide his proportions of crops at sowing time (Willey 1979). Furthermore, when considering different LERs — e.g., from a range of experimental treatments — it may be unreasonable to assume that the different proportions of crops which they indicate are all equally acceptable to a farmer (Mead, personal communication). Some of these aspects will arise again later in the workshop.

Some comment must also be made here about the use of such "common denominators" as protein, energy, digestible nutrients, or monetary value as a means of putting different crops on a comparable basis. These aspects can be quite useful, and certainly when considering monetary value intercropping must, in the final analysis, be assessed in economic terms. However, it must be appreciated thatthe use of these factors in no way eliminates the need to satisfy the basic criteria given above. Considering monetary value, for example, in situation 1, the monetary advantage is the amount by which the value of the intercrop exceeds the value of the higher-value sole crop. In situation 2, it is the value of the "additional" second crop. And in situation 3, it is the amount by which the value of the intercrop exceeds the value of the *combined sole-crop yield.* Thus, this last calculation is analogous to that of the LER; as an example, if LER for yield is equal to 1.25, the monetary advantage must be the value of the extra 25% yield. It can be written:

Monetary advantage = Value of combined intercrop yield x (LER - 1)/LER

Although LER is now an accepted way of expressing yield advantages, this type of calculation does not seem to have been used to express monetary advantages. Usually, the value of an intercrop has been compared with the same sown proportions of a sole crop, or, perhaps more often, with the value of the higher-value sole crop. And yet, if, as defined in situation 3, we are concerned with a situation where the farmer requires *both* crops, then growing only the higher-value one is *not* a valid alternative.

Before leaving this section, it may be pertinent to point out that there are a number of other functions that can express competitive abilities of components and/or yield advantages. These functions have largely been formulated in ecological work or in research on pasture mixtures, but they may deserve a little more consideration in intercropping. These have been defined and discussed elsewhere (Willey 1979) and are only briefly referred to here. The first three below are all based on relative yields (partial LERs); they were originally proposed only for "replacement" population situations, but if their yield-per-plant form is converted to a yield-per-area one (Willey 1979), they probably have wider applicability. *The Relative Crowding Coefficient* (de Wit 1960) indicates relative competitive abilities and the existence of an advantage (though not readily the magnitude of the advantage): *Aggressivity* (McGilchrist 1965) indicates competitive abilities: *Reciprocity* (McGilchrist and Trenbath 1971) indicates yield advantages (this last is in fact simply LER-1). Of these three, the relative crowding coefficient may be of most interest: it was used by Hall (1974) in a grass/legume situation to determine the efficiency of use of a given nutrient; it has also been suggested that it should allow the prediction of competitive effects, though a recent examination of some intercropping data was not very promising in this respect (Willey 1979). A rather different function is the *Competition index* (Donald 1963); this determines competition between components in terms of equivalent plant numbers, and it also indicates the existence of a yield advantage. However, although it is a useful concept, sole crops are required at a range of plant populations to estimate the equivalent plant numbers, so its use in practice may be limited.

Areas of Research

Research workers in many fields seem to be identifying an increasing number of research areas relevant to intercropping, and there is certainly no difficulty in finding areas in which useful research can be done. But the rapid proliferation of intercropping research has brought its problems, and there can be difficulties in deciding what the real priority areas are and how they should be combined into an overall, coherent approach. At ICRISAT, we have developed our approach by regarding any given intercropping combination simply as a "crop"; by this we mean that, despite its complexity, intercropping is still a community of plants that are competing with each other and using growth resources to produce some desired yield. Using this approach, we find we have, in effect, defined an "intercropping improvement program" that bears many similarities to the kind of program that is so often defined for sole-crop improvement. This should hardly surprise us when we consider that, if we are ever to have any influence on intercropping at the farmer's level, we need to have exactly the same kind of information that we have always felt necessary with sole crops.

For our present purposes, we can list our ICRISAT research under five broad headings:

1. Crop physiology
2. Agronomy
3. Yield stability
4. N fixation by legumes
5. Plant protection

You will be hearing more detail about the last two aspects later in the workshop, so I am only going to comment on the first three at this stage. But I must point out that, bearing in mind our role as an International Institute, our general objectives may be rather broader than those of many other programs. We can state these as being (1) to identify and understand the basic relationships that are most likely to provide a scientific basis for improvement, and (2) to develop methodologies and approaches that will be helpful to intercropping work elsewhere.

Crop Physiology

In crop physiological work, we seek to understand how yield advantages can occur. Experiments take the form of detailed growth studies with very frequent sequential measurements of total dry matter, partition of dry matter, leaf-area index, and rooting patterns, This enables us to plot growth patterns over time to determine how component crops compete with each other and how they complement each other. A further, vital aspect of this work is the detailed monitoring of resource use: total light interception is integrated over time using tube solarimeters; soil moisture is measured (by the staff of the Environmental Physics subprogram) using neutron probes; and nutrient uptake is determined from the growth samples. Later, we hope to show that crop physiology can be a particularly rewarding area of research and one which is likely to repay greater attention. We should recognize, however, that there are limits as to how far crop physiologists can, or should, go in this very complex field. This is where we urgently need to capitalize on the expertise of other disciplines, especially ecology, where the detailed study of plant competition and resource use is long established. I have no doubt that the talks we have scheduled later in this workshop will help us to do this.

Agronomy

The agronomic studies seek to understand how, in practice, intercropping yields can be maximized. For our present purposes, these studies can be divided into three categories:

1. Plant population/spatial arrangement relationships
2. Effects of nutrient fertility and water regimes
3. Identification of genotypes

As an example of our approach, I will consider only one of these areas, that of plant population and spatial arrangement. I am choosing this one because it is an area in which we are investing considerable effort but to which we will not be referring later. While taking this example, I would like to stress that our starting point for intercropping research is usually our existing knowledge of sole crops. At the very least, therefore, we must ensure that we are using this knowledge to the fullest, and, to date, it is doubtful that we have really done so. At the same time, we must never allow traditional sole-crop concepts to be a constraint, and we must be prepared to broaden these concepts as the special circumstances of intercropping demand it.

The responses of intercrops to plant population and spatial arrangement are just as important, and deserving of the same detailed study, as those of sole crops. Not surprisingly, however, they are rather more complex. For sole crops, plant population and spatial arrangement aspects are relatively straightforward: plant population defines the number of plants per unit area, which determines *the size* of the area available to the individual plant; spatial arrangement defines the pattern of distribution of plants over the ground, which determines the *shape* of the area available to the individual plant.

For the intercropping situation, and considering plant number first, both *total population* (sum of all components) and *component population* (each component) have to be distinguished. The main problem here is that, in terms of the plant population "pressure" on resources, a single plant of one crop is seldom directly comparable with a single plant of another crop (Willey and Osiru 1972). This can be overcome by regarding optimum populations of sole crops as comparable. If they are taken as 100, component populations can then be expressed on a simple relative basis — e.g., a simple intercrop treatment having half the sole-crop optimum of each of two components is expressed as a 50:50 component population. Any intercropping situation can be defined like this, and not just those belonging to a replacement series; for example, an important practical situation such as a full sole-crop population of one crop plus half the sole-crop population of another is simply described as 100:50.

With regard to spatial arrangement of intercrops, two factors have to be distinguished. The first factor is *the proportional areas* allocated to each crop at sowing time. Often, the proportional areas are directly related to component populations; thus, if a 50:50 component population is achieved by having equidistant alternate rows, proportional areas will also be 50:50. However, this direct relationship does *not have* to apply, and component populations and proportional areas can be varied independently. Frequent examples of this occur in Indian intercropping research where a "main" crop is grown at full sole-crop population, but its spatial arrangement is manipulated to leave space for an additional intercrop.

The second factor is how proportional areas are arranged with respect to each other. This is usually a matter of how "intimately" the crops are mixed. Thus, an intercrop with a proportional area of 50:50 can be arranged as (1) alternate plants within the row, (2) alternate rows, or (3) alternate "double" rows, and so on.

Perhaps the main objective of population/spatial arrangement research should be to quantify the responses to these different factors, and to avoid as far as possible the "confounding" of effects that has so often occurred in experiments to date. A simple approach being used a good deal at ICRISAT is to select appropriate spatial arrangements (usually row arrangements) and to examine at each of these a factorial combination of a range of populations of each component. This allows estimation of (1) the response to total population, (2) the response to population of either component at a range of populations of the other, and (3) the effect of different spatial arrangements on these population responses.

But one of the problems with this approach is that designs rapidly get very complex, and experiments get very large, much more so than in sole-crop research. Thus, much more thought may have to be given to experimental designs. A possibility here is the use of systematic designs. At ICRISAT, we have used a number of these, ranging from a simple sequence of row arrangements (e.g., a sequence of 1:1,1:2, 1:3, etc.) to more complex ones incorporating factorial combinations of row arrangement, total population, and component populations. Our commonest design has been to assign populations of one component to main plots and to systematically vary populations of the other within each of these, the whole possibly being repeated for different row arrangements. Figure 2 illustrates some of the data from a safflower/chickpea experiment of this type. It can be seen that, in the 1:1-row arrangement shown, advantages were maximized with a high chickpea population but only a moderate, and fairly critical, safflower population. The critical safflower population was thought to be related to a possible beneficial effect of shade on chickpea growth (an effect that has been observed in the chickpea

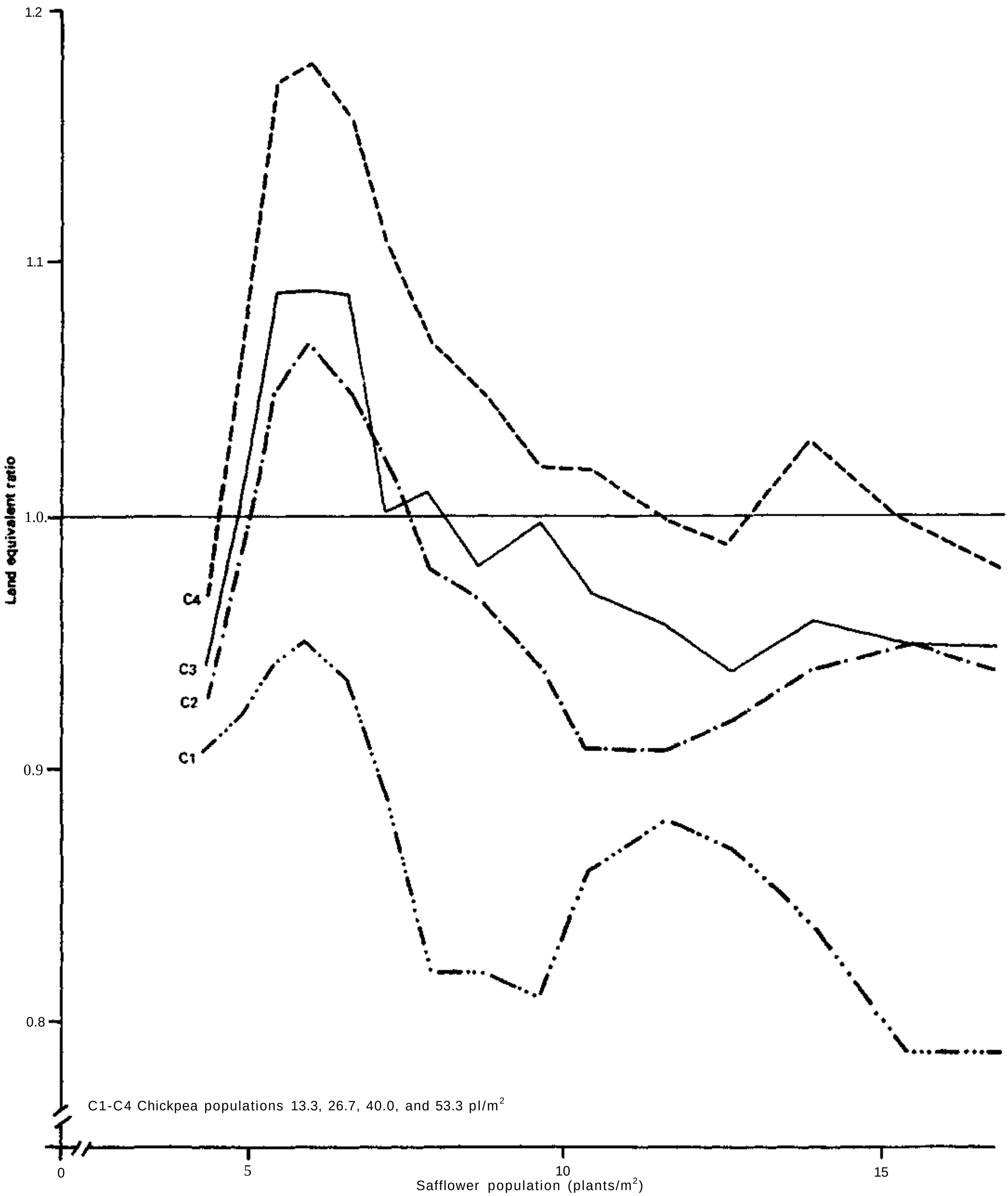


Figure 2. Effects of plant population on total LER of chickpea Isafflower intercropping in 1S: 1C row arrangement.

physiology work at ICRISAT); thus, too low a safflower population provided insufficient shade, and too high a population provided too much competition. This reasoning was supported by the lack of a yield advantage at 1-safflower:2-chickpea row arrangement, where chickpea was clearly shaded much less.

One further aspect of population research which should probably receive more attention is the use of quantitative relationships to describe the yield responses. These have been quite widely used in sole crops. Ideally, they can help in understanding the responses, and they can help achieve maximum predictability from minimum data. These tend to be most useful in an experimental situation where there are practical restrictions on the number of treatments that can be examined, so their use might prove even more rewarding in intercropping research than in sole-crop research. To examine these aspects, some examples of fitted curves are shown in Figures 3 and 4: in all cases, the reciprocal relationship of Holliday (1960) has been used. (This is based on a quadratic regression of the reciprocal of yield-per-plant against population; it has been suggested that this is one of the better relationships used for sole crops (Willey and Heath 1969)].

Figure 3 shows total yield (the components being combined on a relative basis) fitted against total population. It can be seen that the intercrop responses are described just as well as the sole-crop ones— in fact, in most cases slightly better. Figure 4 shows the same data where the yields of the individual components are fitted against their own component popula-

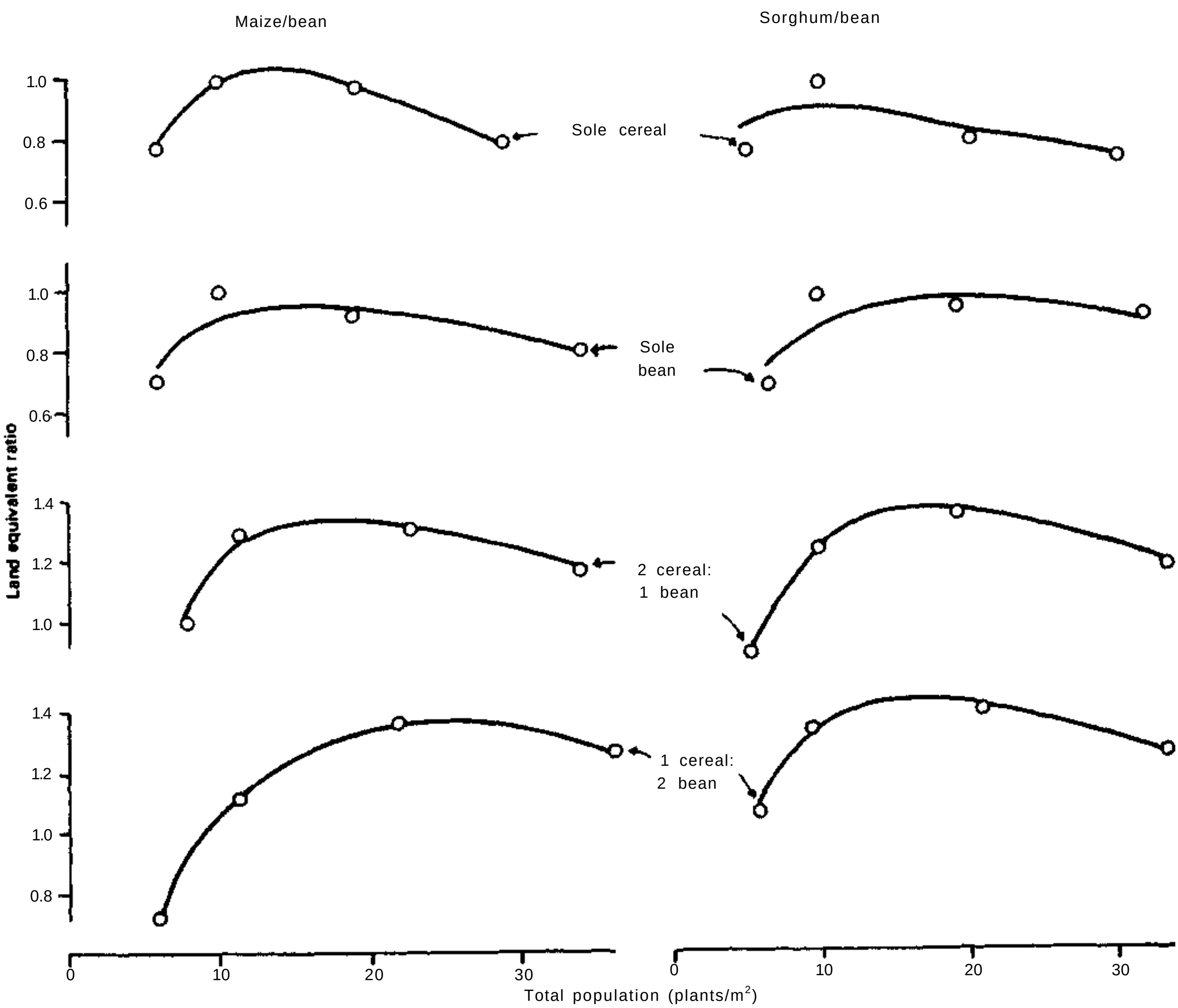


Figure 3. Total population responses for ceReallbean intercropping (fitted after Holliday 1960).

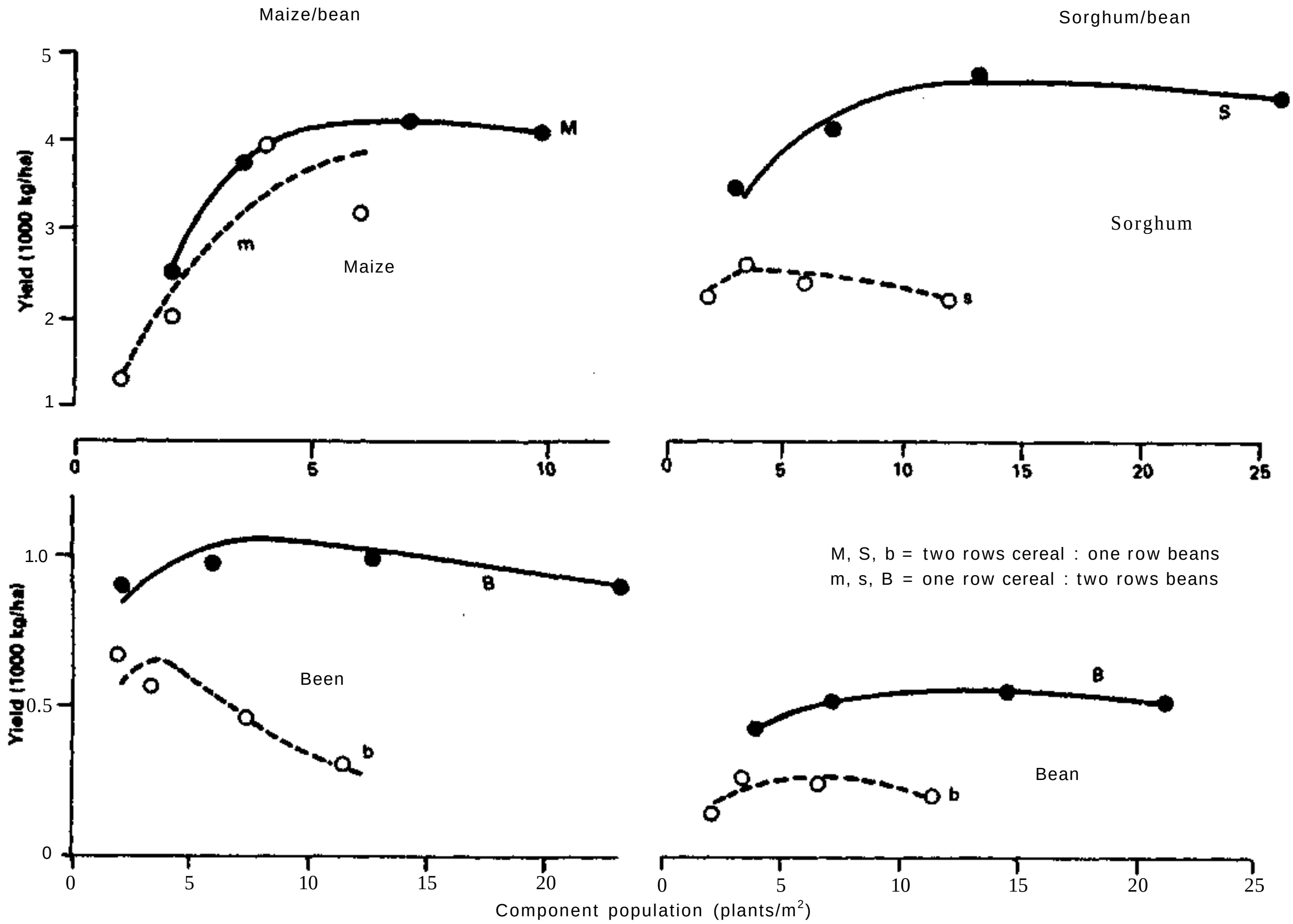


Figure 4. Component population responses for cereallbean intercropping (fitted after Holliday 1960).

tions. Here it might be expected that a dominant component, which tends to show a population response not unlike a sole crop, might be more accurately fitted than a dominated component, which often appears to have a much modified, population response (Willey 1979). However, in all cases, both the components are described equally well: in fact, most ofthe curves are such a good fit that this technique would seem to be very promising. It could be very helpful, for example, in obtaining a better estimate of the higher population which is so often thought to be required in intercropping; with this particular relationship the optimum population is estimated as $\sqrt{a/c}$, at which value the estimated maximum yield is $1/(2\sqrt{ac} + b)$.

Finally, this would seem an appropriate place to emphasize the need for a greater statistical input in intercropping research. As seen above, experimental approaches are likely to become more complex, and the help of statisticians is needed both to plan these and to get maximum value from the data produced. It is also no longer acceptable for an intercropping research worker to have to do much of his analysis on a calculating machine because computers are only programmed for sole-plot analyses; hopefully, this is a situation that will soon be rectified.

Yield Stability

The main physiological basis for greater stability of yield in intercropping is that if one crop fails, or grows poorly, another component can compensate, and such compensation cannot occur if crops are grown separately. This is an additional effect from that of just "spreading risk" by growing two crops, because this latter effect occurs whether crops are grown together or not. A further stabilizing effect could occur if intercropping gave greater yield advantages under stress situations because this might help avoid low yields in adverse seasons. A similar effect could occur if intercropping reduced the incidence of pests or diseases because this again could help to avoid low yield situations.

Whatever the mechanisms might be, however, there is still considerable doubt as to what the degree of improved stability can be, or indeed whether it actually does occur. Where stability has been examined in experimental data, the evidence for greater stability has at best only been marginal (Trenbath 1974b; Daniel 1955; Willey 1979). But a serious limitation to date has been that the situations examined have usually had very similar component crops. Where bigger differences between components occur, which is much more likely to be the case in farming practice, the improvement in stability could be much greater. We will, of course, be hearing more up-to-date evidence on stability later in the workshop. This will not only be from experimental data, but also from data at the farmer's level. I'm sure those papers will leave us even more convinced of the need for more research on stability, not just in terms of collecting the basic information but also in terms of how we should analyze and interpret it.

Considering the collection of information on stability, one obvious way would seem to be to compare sole-crop and intercrop performance in a wide range of environments, preferably over different seasons. We have tried to do this in a limited way at ICRISAT, but I would like to suggest that the setting up of some joint multilocational experiments across different countries is something this workshop should very seriously consider. These should be seen initially as a means of determining the degree of stability actually provided by intercropping; but eventually they could provide a means of testing promising intercropping practices to ensure that those which are eventually recommended to the farmer are at least as stable as his existing ones.

What Combinations Do We Work On?

Although I have left this section until near the end, deciding which combinations to work on is usually one of the first problems an intercropping research worker is presented with. Early intercropping research often examined quite a large number of combinations because a basic question being asked was whether there was any evidence at all of yield advantages. However, in much of our present research, there is probably a need to focus on a few combinations which we can recognize as likely to be the most promising; this is especially so where we wish to carry out more detailed work to gain a better understanding of intercropping. In many situations, these combinations can be chosen on the basis of which combinations are important in local farming practice. At ICRISAT, where we have a rather wide mandate, our reasons for choosing particular combinations have to be somewhat different. Currently, we are concentrating mainly, but not exclusively, on four combinations. These are based on all five ICRISAT crops and have been chosen to represent the more important characteristics of typical intercropping situations (see Table 1). The two main combinations (sorghum/pigeonpea and pearl millet/groundnut) represent very different intercropping situations on our two major soil types; the subsidiary ones cover important additional aspects of postmonsoon cropping on stored moisture (sorghum/chickpea) and the intercropping of very similar crop types (sorghum/millet). These combinations also represent situations requiring the use of different criteria to assess yield advantages.

An important feature of handling these combinations has been the adoption of "standard" treatments that represent the best preseason estimate of optimum row arrangement and plant population. For example, the two rows of sorghum: one row pigeonpea with 100% population of each crop was designed to achieve the "full" sorghum yield (i.e., equivalent to sole crop) and maximum additional pigeonpea yield which farmers usually require from this particular combination. Conversely, the millet/groundnut treatment was designed to give the best balance of competition between the crops. These "standards" have been used wherever row arrangement and plant population have not been experimental variables, and they have helped to maintain comparability among different research areas.

Operational Evaluation of Intercropping

While the advantages of intercropping seem to

Table 1. Representative intercropping combinations receiving major emphasis at ICRISAT.

Soil	Characteristics	"Standard" row arrangement and component populations
Vertisol		
Main combination Sorghum/pigeonpea	Growing periods very different. Cereal/late maturing legume. Objective to produce 100% sorghum yield + additional pigeonpea. "Additive" populations. Typical of Indian semi-arid tropics.	2 rows sorghum: 1 row pigeonpea 100% sorghum + 100% pigeonpea
Subsidiary combination Sorghum/chickpea	Growing periods similar. Cereal/low-growing legume. Grown on stored moisture.	
Alfisol		
Main combination Pearl millet/groundnut	Growing periods not very different. Cereal/low-growing legume. Objective to produce balance between crops and higher yield than growing both crops separately. "Replacement" populations. Typical of West African semi-arid tropics.	1 row millet: 3 rows groundnut 25% millet: 75% groundnut
Subsidiary combination Sorghum/pearl millet	Similar growing periods. Similar crops. No legume component. Objective to produce higher yields than higher-yielding sole crop.	1 row sorghum: 1 row millet 50% sorghum + 50% millet

become increasingly attractive it is as well to remember the possible disadvantages referred to earlier. Perhaps the one most often quoted in the past has been the practical difficulty of handling intercropping, especially where some degree of mechanization is involved. At present, this may not be a very serious constraint for the subsistence farmer of the developing tropics, but it could assume greater importance with the development of improved practices. Now that there are many intercropping combinations where advantages are well proven in' small experimental plots, there is an increasingly urgent need to examine these under conditions nearer to the farmer's situation. A first step in this direction is the use of large plots to determine, on an operational scale, whether we can satisfy the practical requirements of the individual component crops as satisfactorily as if they were sole-cropped. Some of these aspects havealready been studied for a number of years at ICRISAT and this work will be presented in detail later. It is also an area worthy of consideration for other intercropping programs.

Session 1
Agronomy

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D. J. Andrews (India)
Rajat De (Brazil, West Africa)
N. G. P. Rao (East Africa, Genotypes)

Rapporteurs:
M. S. Reddy
M. Natarajan
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Management Practices for Intercropping Systems

Rajat De and S. P. Singh*

Abstract

Intercropping is an age-old practice of the traditional systems of agriculture in the underdeveloped parts of the world. Proper management of the intercropping systems could play a determinant role in making a success of these systems. Choice of crops which have to be grown in an intercropping system plays a vital role in this regard. Growing crops of dissimilar growth patterns, such that the peak periods of growth do not coincide, would ensure optimum productivity of the two crops growing in association. For long-duration crops with an initial, slow growth rate, solar energy utilization can be optimized by interpfanting a quick-maturing crop. For crops with an initial, fast growth rate, such as pearl millet and cowpea or mung, staggering the time of planting avoids mutual competition. Changing the planting geometry may avoid shading. Keeping the plant population constant and altering row orientation for paired or trebled row plantings offers more space for accommodating the companion crops. Both under dryland and irrigated systems, greater water use efficiency of intercropping systems has been recorded. Weed and pest incidence is considerably reduced in an intercrop.

Intercropping (or mixed cropping) of two or more crops is an age-old practice in India, especially under rainfed conditions. The practice aims to (1) insure against total crop failures under aberrant weather conditions or pest epidemics, (2) increase total productivity per unit land area, and (3) equitably and judiciously utilize land resources and farming inputs, including labor. The traditional practice consists of either broadcasting seed of two or more crops together or sowing a few lines of intercrops between the rows of the base crop. One obvious limitation of these mixtures is the reduced population of both the crops and their apparent productivity except when cooperative interaction exists between the components. With the availability of crop cultivars of varying duration and growth rhythms, appropriate plant-protection technology, and appropriate fertilizer practices, the aim of intercropping is now more toward augmenting the total productivity per unit area of land per unit time by growing more than one crop in the same field.

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Better utilization of environmental resources is the prime objective.

An attempt is made in this paper to anah/ze the agronomic management practices that may be necessary for the success of intercropping systems. The idea is not to review the existing literature on intercropping but to focus attention on the basic concepts related to successful intercropping systems.

Crop Compatibility

When two crops are to be grown together, it is imperative that the peak periods of growth of the two crop species do not coincide. Crops of varying maturity durations need be chosen so that a quick-maturing crop completes its life cycle before the grand period of growth of the other crop starts (Saxena 1972). Schematically, it can be depicted as in Figure 1. In this example, the base crop does not start its grand period of growth before 60 days, within which period the companion crop matures.

Sugarcane is an initially slow-growing crop for the first 80 to 90 days. Since sugarcane is generally planted in rows 1 m apart, a considerable land area remains vacant for these 3

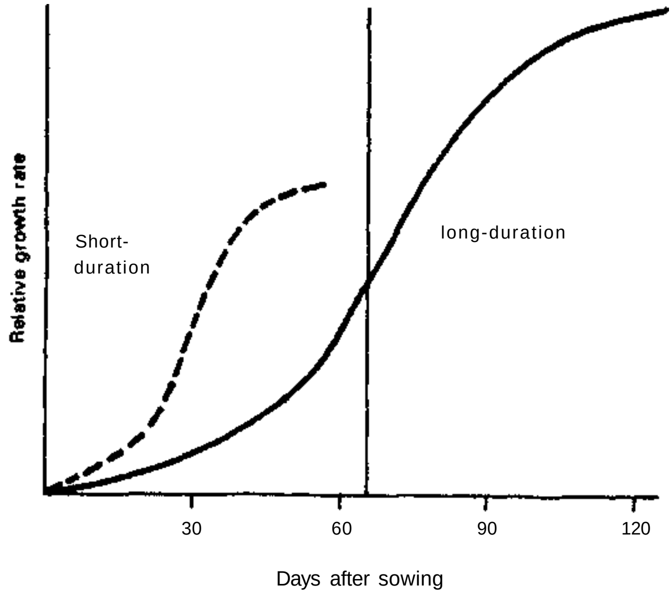

Figure 1. Difference in growth pattern of long- and short-duration crops growing in association.

months. The incident diffused solar radiation measured by a pyrheliometer and recieved at the ground surface in a sugarcane field which was grown alone and intercropped with mung, cowpea, and dwarf castor (Ganguly and De, unpublished) is presented in Table 1. At the end of a 70-day period, the proportion of incident diffused solar radiation of that received on bare ground was 82% in a crop of sugarcane grown alone while intercrops of mung (*Vigna radiata*), cowpea (*V. unguiculata*), and castor (*Ricinus communis)* reduced this value to 60, 57, and 48%, respectively, indicating a better utilization of solar energy. Sugarcane, therefore, is an example in which short-duration crops maturing in 80-90 days can be advocated. Aiyer (1949) recommended vegetable crops for intercropping with sugarcane, while Arakeri et al. (1956) found lucerne good for this purpose. Gill (1963) made an exhaustive review of intercropping experiments with sugarcane in different parts of the country. He concluded that although intercrops at times reduced the yield of sugarcane, there was no adverse effect of the companion crops on its juice quality. He has recommended field peas (*Pisum sativum*), chickpea (*Cicerarietinum*), and rapeseed (*Brassica campestris*) as suitable intercrops for sugarcane under north Indian conditions. Kanwar (1975) recommended mung, sunflower, and okra (*Abelmoschus esculentus*) as suitable intercrops for autumn-planted sugarcane in the Punjab region, while Wankhede and Parashar (1975) found cotton to be a suitable intercrop for spring-planted sugarcane.

Table 1. Incident diffused solar radiation at the ground surface of various intercropping systems with sugarcane.[a]

Cropping system	Incident diffused solar radiation[a], cal.cm^{-2} day^{-1} at:		
	60 days	70 days	95 days
Fallow land (near cropped area)	594 (100)	631 (100)	342 (100)
Sole-crop sugarcane	574 (96)	518 (82)	247 (69)
Sugarcane + mung	565 (94)	380 (60)	227 (66)
Sugarcane + cowpea	453 (76)	357 (57)	198 (58)
Sugarcane + dwarf castor	463 (73)	304 (48)	202 (59)

a. Figures in parentheses denote the radiation as a percentage of that incident on fallow land.

For sorghum, grain legumes such as cowpea, mung, black gram (*V. mungo*), or groundnut (*Arachis hypogaea*) are the recommended intercrops which do not generally affect sorghum yield but help in obtaining additional returns (Ayyangar and Ayyar 1942; Dey et al. 1958). Often, sorghum yields increase when grown in association with mung, black gram, cowpea, or groundnut (Kaushik 1951; Bodade 1964). On the other hand, Chandravanshi (1975) reported that intercropping grain sorghum with soybean (*Glycine max*) at Indore resulted in a reduction in yield of grain sorghum. Perhaps soil-moisture stress was responsible for this reduction.

For maize, soybean is a compatible companion crop for the Kangra valley of Himachal Pradesh (Sekhon and Bedwa 1953). Inthe plains of Punjab, soybean or black gram increased maize yields by 2000 to 4000 kg/ha when grown in association (Narang et al. 1969). Singh et al. (1973) and Roquib et al. (1973) reporte'd an increase in maize yields when grown in association with soybean or mung.

Pearl millet is a quick-tillering and fast-growing crop that attains full canopy development within 20 to 30 days of seedling establishment. Pal (unpublished) noted thatthe yield of pearl millet did not suffer in association with groundnut, black gram, soybean or castorbean. But the yields of companion crops were very drastically reduced. Batra et al. (1973) intercropped pearl millet with a long-duration cultivar of pigeonpea (250 days) and noted that the pigeonpea made very little growth till the pearl millet was harvested. Thereafter, the pigeonpea crop picked up growth and gave good yields.

For an initially slow-growing crop like cotton, short-duration and fast-maturing crops of mung, black gram, groundnut, or guar *(Cyamopsis tetragonoloba)* would appear to be compatible companion crops. But, there are variable reports on the effects of intercropping cotton with these crops. While Anjaneyulu and Rao (1956) and Rao and Murthy (1965) reported reduced cotton yields when grown in association with groundnut, Kairon and Singh (1972) found increased cotton yield when intercropped in a 1:1 ratio with mung. Kairon et al (1975) assigned these beneficial effects to an addition of 23 kg N/ha to the soil by the mung crop.

Venkateswarlu (1969) tried various short-duration grain legumes with pigeonpea and found cowpea to be the best companion crop forpigeonpea in peninsular India. Blackgramor cowpea (Saraf et al. 1975), soybean (Saxena and Yadav 1976) and groundnut (Roy Sharma et al. 1975) have been reported to be suitable intercrops for pigeonpea. Maintenance of an optimum ratio of 1:1 rows of pigeonpea and mung at 22.5 cm row distance was found most remunerative by Giri and De (1978).

Planting Geometry

Sowing crops in the normally recommended uniform row distances would afford little or no opportunity for accommodating a companion crop. On the other hand, a modification of a planting pattern of the base crop would make intercropping feasible and often remunerative. Keeping the plant population per unit area of the base crop constant, no deviation in its yield has been noted by altering the orientation of the rows (De et al. 1978). Maintaining a constant plant population of 180 000 sorghum plants per ha, Singh (1978) noted no significant difference in its yield by paired row planting — i.e., two rows planted 30 cm apart and two such pairs placed 60 or 90 cm apart compared to normal sorahum rows of 45 cm (Table 2). The modified system affords a better solar energy harvest in the space between any two pairs of rows. By spacing sorghum rows 90 cm apart instead of the normal 45 cm, Mohta and De (1980) did not notice any effect on the sorghum yield. Growing soybean in between the 90-cm rows increased the land equivalent ratio (LER) by 35% (Table 3).

Mohta and De(1980) studied a maize/soybean intercropping system for different planting geometries for the years 1970-1974. It was noted that by maintaining a plant population of 65 000 plants per ha, no significant difference in maize yield occurred whether the rows were placed 60 or 120 cm apart. In the intervening

Table 2. Effect of planting geometry at constant plant population on the grain yield of sorghum (average of 20 experiments, 1974-1977).

Planting pattern	Grain yield (kg/ha)
Uniform rows 45 cm	4410
Uniform rows 60 cm (1-row intercrop)	4220
Paired rows 30-30-60-30-30 cm (1-row intercrop)	4370
Paired rows 30-30-60-30-30 cm (2-row intercrop)	4280
Paired rows 30-30-90-30-30 cm (2-row intercrop)	4340

Table 3. Seed yield and land equivalent ratio (LER) of sorghum/soybean intercropping system.

Cropping system[a]	Seed yield (kg/ha)		
	Sorghum	Soybean	LER
Sole-crop sorghum (45 cm rows)	2380		1.00
Sole-crop sorghum (60-cm rows)	2180		1.00
Sorghum + soybean 1:1 (alternate rows 30 cm)	2060	950	1.26
Sorghum (90-cm rows) + 1 row of soybean	1830	1500	1.35
Sole-crop soybean (45-cm rows)		2960	1.00

a. Sorghum plant population 180 000 per ha.

space, soybean was planted, which increased the LER by 54% (Table 4). Plant population rather than planting geometry thus had a determinant role on the yielding ability of the crops. In the case of pearl millet, also, the experiments conducted under the All-India Coordinated Millet Improvement Project have shown that at an optimum plant density of 220 000 plants/ha of pearl millet in paired rows (30-30/70 cm) or 3 row blocks (30-30-30/90 cm) did not much differfrom the recommended 45-cm row distances. Shelke and Krishnamoorthy (1978) have reported an increase in the case of trebled row pearl millet compared to the paired-row system.

Table 4. Seed yield and land equivalent ratio (LER) of maize/soybean intercropping system.

Cropping system[a]	Seed yield (kg/ha)		LER
	Maize	Soybean	
Sole-crop maize (60-cm rows)	2370	-	1.00
Sole-crop maize (120-cm rows)	2410	-	1.02
Maize (120-cm rows) + 3 rows of soybean	2320	1310	1.54
Sole-crop soybean (45-cm rows)	-	2340	1.00

a. Maize plant population 65 000 per ha.

Planting Time and Technique

Adjusting planting time is an important criterion for avoiding competition between two crops with the same growth habit — i.e., similar growth rates in time and space. Staggering planting time so that their peak periods of growth would not coincide helps to realize the yield potential of both crops. This could sometimes be achieved by changing the planting time and technique of the two crops. De et al. (1978) observed that the yield of mung in an intercropping system with pearl millet was considerably increased by delaying the planting of pearl millet (Table 5). This was achieved by sowing a seedling nursery of pearl millet at the sametime as the sowing of the mung crop in the field in the second week of July. After 20 days, the pearl millet seedlings were transplanted in mung rows in the space earlier earmarked for this purpose. This modified system of intercropping was much more productive than planting both crops together. In the Dharwar area of Karnataka, it is a common practice to sow guar bean or mung at least 2 to 3 weeks prior to planting of cotton as an intercrop (Kadappa, personal communication).

Table 5. Yield of pearl millet and mung intercrop as affected by planting date and technique.

Cropping system	Grain yield (kg/ha)	
	Pearl millet	Mung[a]
50-cm row planting of pearl millet		
Direct seeded, 9 July	2460	-
Treble-row planting of pearl millet (30/90 cm)[b]		
Direct seeded, 9 July	2680	200
Transplanted, 29 July	2400	490

a. Mung seeded on 9 July.
b. Treble-row planting (30/90 cm) means 3 rows of pearl millet 30 cm apart; 2 such 3-row blocks 90 cm apart.

Fertilizer Management

When two crops of dissimilar nutrient requirements are grown together, it sometimes becomes operationally difficult to meet the nutrient needs of the two crops simultaneously. A cereal/legume intercropping system is a case in point, where heavy N fertilization of the cereal is often not conducive to the growth of the legume component. Very little work, however, has been done to evaluate the fertilizer needs of a mixed crop stand. Hegde (1977) reported that P needs of an intercropping system of pigeonpea with cowpea or mung was 74 kg P202/ha, whereas 54 kg p20s/ha was optimum for the pigeonpea crop.

Water Balance

For crops grown under dryland conditions, if the quantity of water stored in the profile or that received from rainfall remains constant, it would be expected that the water-use efficiency (WUE) of an intercrop system would be better than by a sole crop. In 1974 and 1975, De et al. (1978) grew maize alone and in an intercropping system with soybean and mung. The WUE was 10.3 for maize pure. It increased to 16.8 and 19.4 in intercropping systems with soybean and mung, respectively.

Ganguly and De (unpublished) found that while the consumptive use of irrigated sugarcane was 1090 mm, that of sugarcane plus mung *or* cowpea was 1100 and 1190 mm, respectively. The corresponding water-use efficiency values were 64.5, 67.4, and 60.9 (Table 6). The lowest WUE was noted in a sugarcane/castor intercropping since the castor crop completely shaded the sugarcane and drastically reduced its yield.

Weed Management

It has generally been observed that intensive cropping increases the competitive ability of crops to reduce the growth of weeds. However, certain weeds associated with specific crops or intercropping systems may become dominant if such a cropping system is practiced over the years.

Rao and Shetty (1976) reported that intercropping sorghum and pigeonpea reduced the weed growth considerably. Nearly 50 to 75% reduction in weed infestation was noted by intercropping pigeonpea with sorghum, millet, cowpea, or field peas. Panwar and Rathi (1977) observed scanty weed population in pigeonpea intercropped with green gram or black gram.

Bhan and Singh (1972) recommended the use of alachlor or nitrofen at the rate of 2 kg a.i. per ha for a maize/cowpea mixture. Damodaran and Shankaran (1974) reported alachlor (1.0 kg a.i. per ha) suitable for a sorghum/cowpea intercrop.

Succession and Incidence of Insect Pests

Intercropping leads to a change in the microclimate of the canopy and thus influences the succession and population build-up of insect pests. When two crops of similar plant type and host range for a particular insect pest are cultivated together, the incidence of the pest increases. On the other hand, intercropping of nonhost plants brings about considerable decline in the incidence of most of the insect pests. Singh and Singh (1974) reported high incidence of *Pyrilla* when sorghum was intercropped with pearl millet, while intercropping sorghum with pigeonpea or black gram, or pearl millet with black gram, considerably reduced the population of this pest. Singh and Singh (1977) reported a lower incidence of grey weevil and green jassids when pearl millet was intercropped with mung or black gram.

Table 6. Water, total water use,* and water-use efficiency of different intercropping systems with sugarcane.

Cropping system	Yield of crops (kg/ha)		Total water use	WUE sugarcane	WUE biomass[b]
	Sugarcane (x 10^2)	Intercrop			
Sole-crop sugarcane	704		1090	64.5	21.9
Sugarcane + mung	742	192	1100	67.4	22.7
Sugarcane + cowpea	723	110	1190	60.9	20.5
Sugarcane + dwarf castor	655	484	1240	53.0	18.7

a. The crops were irrigated at 0.65-bar soil-moisture tension measured at 23 cm.
b. Biomass includes dry weight of sugarcane and the intercrops.

Intercropping Studies in Sorghum

S. P. Singh*

Abstract

Experiments are presented in which the planting geometry of sorghum, the compatability of different intercrops, and the possible beneficial effect of a legume intercrop on the nonlegume base crop are described. Three series of experiments are reported:

- *Series* I: *Sorghum was compared in uniform (45-cm) rows and paired (30/60-cm) rows with different intercrops.*
- *Series* II: *Sorghum was compared in uniform rows of 60 cm with two paired row patterns of 30160 cm and 30190 cm, again with different intercrops.*
- *Series* III: *Sorghum was grown at a uniform spacing of 60-cm rows with a range of legumes at a number of locations; at IARI in 1976, a rainfed-vs-irrigated comparison was included.*

Growing sorghum in paired rows of 30160 cm does not reduce yield when compared to uniform rows of 45 cm, and the space created by paired-row patterns enhances legume intercrop yield. A list of compatible intercrops for different locations is given. Some beneficial effects of legume intercrops on sorghum yield are also reported.

In India, sorghum is generally sown mixed in the summer rainy *Sharif*) season. These traditional mixtures were primarily developed as an insurance against total crop failure due to adverse weather conditions. In these mixtures, either the seeds of the crops are mixed and then sown, or some definite proportions of rows are adopted, both of which methods usually result in reduced population of all the crop components and ultimately all the yields. Therefore, these mixtures are equivalent to individual crops in separate areas of the field, except for possible interaction between crops mixed and for cases of reduced incidence of pests.

The concept of intercropping is now changed to maximize production per unit area per unit of time, owing to the availability of crop varieties of different maturity durations and growth rhythms, plant protection measures, and fertilizers. Development of such feasible and economically viable intercropping systems largely depends on adoption of proper planting geometry and selection of compatible crops.

It is a general observation that the growth of the companion crop is depressed substantially if it is interplanted between normal equidistant rows (45 cm) of hybrid sorghum; therefore, the technique of paired-row planting has aroused interest in the recent past. This planting geometry may provide additional space for the intercrop component without having any adverse effect on the productivity of the base crop. It will thus augment the utilization of available space, time, nutritional factors, and light to boost the production per unit of natural and applied inputs.

Crop compatibility per se constitutes an essential ingredient for the success of an intercropping system. A careful selection of crops could reduce mutual competition to a considerable extent. The growth rhythm, duration, and capacity to photosynthesize at low light intensities are some of the important considerations in the selection of a companion crop. The properly selected legumes may also benefit the nonlegume base crop in the system.

With these points in mind, a series of experiments were conducted at the Indian Agricultural Research Institute (IARI), and at different centers in the sorghum tract of the country under the auspices of All-India Coordinated Sorghum Improvement Project. The results of these experiments are presented in this paper.

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Methods and Materials

The following three series of experiments were conducted at different locations in the country during recent years.

Series I

In kharif 1972 the experiments were initiated with two planting patterns (uniform rows 45 cm and paired rows 30/60 cm). In between two rows in the uniform pattern and in the 60-cm space in paired rows, one and two rows of intercrops were planted. The selection of intercrops varied from location to location and numbered between three to five. In both patterns, a solid stand of sorghum was also taken. In these experiments, the optimum amount of N for sorghum was applied in the furrows, whereas 40 to 60 kg P_2O_5/ha was broadcast in the field before the final plowing. The recommended population of 150 000 to 200 000 plants/ha of sorghum was maintained. This series was discontinued after kharif 1974.

Series II

This series was started from kharif 1974. Three sorghum/intercrop patterns were tested: (1) planting of sorghum in paired rows of 30/60 cm with one and two rows of intercrop in the 60-cm space; (2) paired rows of 30/90 cm with two rows of intercrop in the 90-cm space; and (3) uniform row spacing of 60 cm, with one row of intercrop between two rows of sorghum. In addition, solid stand of sorghum and intercrops were planted. Solid stands of both crops were in the normal planting pattern. These geometries were tried with the best two or three intercropping systems determined from the results of experiments of Series I. In all the experiments, the recommended population of sorghum and intercrops was maintained. Nitrogen was applied in sorghum rows only at the optimum level, whereas 40 to 60 kg P_2O_5/ha were uniformly broadcast before the last plowing.

Series III

This series was established to screen various crops for intercropping purposes. These experiments consisted of only one planting geometry — i.e., sorghum in equidistant rows of 60 cm with one row of intercrop between two rows of sorghum. The number of intercrops varied from location to location. Other conditions were similar to the earlier series.

At IARI, New Delhi, the experiments were slightly modified from kharif 1975. In kharif 1975 and 1976, the experiments of Series II were conducted under rainfed conditions, and in kharif 1976 under irrigated conditions. In all these experiments the amount of N applied was only two-third of the optimum — i.e., 60 kg/ha under rainfed and 80 kg/ha under irrigated conditions. However, P was applied at the uniform rate in all the experiments at seeding. Other conditions were the same.

Results

Selection of Planting Geometry

In 10 out of 12 experiments of series I, the two planting patterns did not bring out perceptible differences in sorghum yield. In the remaining two experiments — at IARI in 1973 and at Indore in 1972 — however, the paired-row technique significantly outyielded the uniform row technique in respect of sorghum yield. The mean yields of sorghum due to uniform (45-cm wide) rows and paired (30/60 cm) rows were 3060 and 3100 kg/ha, which clearly convinces us that sorghum can be planted in paired rows (30/60 cm) without reduction in sorghum yield.

In the Series II experiments, the differences in yield of sorghum due to different planting geometries were negligible at most of the locations. It is interesting to note that different planting geometries did not show any effect on plant growth and panicle size. It may be recalled here that to maintain the optimum population of 180 000 plants/ha, the intrarow spacings varied in different geometries, but this increase in intrarow competition could not reduce the sorghum yield, probably due to the pattern of interception of solar energy in wider patterns. This might have provided sufficient light to the lower leaves to continue photosynthesis.

This clearly suggests that the yield of sorghum is independent of planting geometry at optimum population density. Therefore, sorghum may be planted in wider rows to accommodate another crop. From the results of these experiments, it is also evident that wider row planting — i.e., paired rows of sorghum (30/90 cm) with two rows of intercrop in the 90-cm space — resulted in relatively higher yields of intercrops than did other planting geometries. This may be attributed to better plant growth and a higher number of pods per plant of intercrops as a result of penetration of more sunshine.

Selection of Compatible Intercrops

Different crops have been tried at different centers under these three series of experiments in the preceding years. From the results of these studies, it may be concluded that the choice of compatible crop varied from location to location. The most compatible crops for different centers are listed in Table 1.

In all these studies, the yields of intercrops were bonus yields after the sorghum. Gross returns of sorghum intercropping systems were appreciably higher than a solid stand of either crop.

From the results of these experiments, it is evident that all the intercrops listed above did not reduce the yield of sorghum. Therefore, the yields of intercrop components were a bonus. It was noted, however, that pigeonpea had a depressing effect on sorghum, reducing yields up to 30%. But the total productivity and returns increased substantially at all the locations.

These results clearly show that productivity per unit area per unit time may be enhanced by intercropping sorghum with compatible crops, which, at most locations, are pulses. This practice may help provide higher production of pulses without changing the cropping pattern in sorghum-growing areas of the country.

Cereal-Legume Association Effect

As reported earlier, experiments on intercropping in sorghum were conducted at IARI, New Delhi, under rainfed and irrigated conditions. In these studies, the beneficial effects of legumes on sorghum were observed. The grain yield of sorghum increased to the extent of 20, 17, 27, 34, 12, and 8% due to green gram, black gram, cowpea (grain), cowpea (fodder), groundnut, and soybean, respectively, over solid stand of sorghum under rainfed conditions. In irrigated conditions, the increase in sorghum yield due to intercropping with green gram, groundnut, soybean, cowpea (grain) and cowpea (fodder) over a sole crop of sorghum were 6.8, 2.4, 7.3, 9.6, and 17.2%, respectively. Similar results have also been reported by other workers.

Table 1. Compatible crops for intercropping in sorghum.

State	Center	Crop
Delhi	IARI, New Delhi	Rainfed: cowpea (fodder or grain) green gram, soybean (black)
		Irrigated: groundnut, cowpea, soybean
Uttar Pradesh	Kanpur	Soybean, green gram, black gram
	Pantnagar	Red gram, soybean, black gram
Madhya Pradesh	Indore	Red gram, soybean, green gram
Rajastrtan	Udaipur	Red gram, soybean, green gram
Gujarat	Navsari	Soybean, groundnut, green gram
Maharashtra	Akola	Red gram, green gram, groundnut
	Jalgaon	Red gram, green gram, cowpea
	Karad	Red gram, soybean (black), black gram
	Parbhani	Red gram, cowpea, black gram
Andhra Pradesh	Rajendranagar	Soybean, cluster bean, castor (dwarf)
Karnataka	Dharwar	Cowpea, black gram, castor (dwarf)
Tamil Nadu	Coimbatore	*Dolichos lablab,* red gram, black gram (pods)

Adding a Competition-free Period to the Intercrop Component: A New Concept

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Abstract

Several experiments carried out at the Indian Agricultural Research Institute on intercropping with pearl millet are reported. In 1974, a delayed sowing of pearl millet on 11 August gave a lower millet yield than earlier sowings on 12 and 27 July, but the yield of a pigeonpea intercrop was increased. Experiments in the 3 subsequent years established that the decrease in millet yield due to late sowing could be minimized by transplanting instead of direct sowing. This technique still gave an increased yield of a pulse intercrop (in this case green gram). The increased intercrop yield was attributed to the competition-free period created by the delayed establishment of the millet. In the first 2 years of the experiments, the optimum time difference in establishing the two crops was 3-4 weeks, but in the 2 later years it was 2 weeks.

In all 4 years two planting patterns were compared in which two rows of millet 30 cm apart were alternated with (a) a double row of intercrop (70 cm between pairs of millet rows), or (b) a triple row of intercrop (90 cm between pairs of millet rows). The latter arrangement consistently gave higher intercrop yields with little or no loss in millet yield.

Some effects of the different treatments on nodule number in the intercrops are also reported.

Intercropping, an age-old practice, needs to be reappraised as new plant types are evolved in order to uphold its validity . Yield levels of intercrop component are generally low (De et al. 1978); nevertheless, intercropping tends to be an inevitable practice in the near future as greater attention is needed to increase production per unit area per unit time.

New technological modifications in time, technique, and pattern of planting of crops grown in association have made intercropping an economically viable and feasible practice. For maximum yield advantage, there should be some element of complementarity between crops in order to reduce to a minimum the competition between the base and the intercrop components. Planting a short-stature crop in advance and a tall crop a little later is one example of an intercropping pattern that would create a competition-free environment for the short-stature crop. Crookston and Kent (1976) indicated that a combination of tall and short crops seems to work, especially if the tall crop is planted a little later. Usually, a delay in planting a tall crop to create a competition-free environment for the intercrop might impair the production efficiency. Thus, it is imperative that a new technique be developed that may compensate for the loss in production efficiency with delayed sowings.

The optimum time to seed pearl millet (*Pennisetum typhoides* [Burm. f.] Stapf & C. E. Hubb) under Delhi conditions is the first fortnight of July. However, transplanting 3-week-old seedlings generally gives a better start to the crop and checks the ill-effects of delayed sowings (Pal 1973). This increases the possibility of adding a competition-free period to the intercrop component.

Another way to increase the yields of intercrops is to alleviate competition between the associated crops by changing the crop geometry. The studies conducted so far have indicated that planting of pearl millet in paired

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or treble rows is possible. This type of planting geometry may provide additional space for better growth of the intercrop component.

With these views in mind, several studies were conducted by the Division of Agronomy, Indian Agricultural Research Institute (IARI), New Delhi, with pearl millet and pigeonpea. The results of these experiments have formed the subject matter of this paper.

Methodology

Studies described by Anjaneyulu (1975) were used as the experimental design: there were three planting dates (12 July, 27 July and 11 August), two planting techniques (direct sowing and transplanting), and two planting patterns (30/70 cm and 30/90 cm). There was no treatment of transplanting in the first date of sowing. This experiment was conducted on pearl millet (NHB3) as the main crop with pigeonpea (Prabhat) as the intercrop during *kharif* (rainy season) 1974 under rainfed conditions. The design was a randomized block with four replications.

Data reported by De et al. (1978) were obtained from the experiment conducted during kharif 1975. In this experiment, pearl millet was intercropped with green gram (PS-16) under dryland conditions. The treatments comprised three planting dates (9 July, 29 July, and 18 August), two planting patterns (30/70 cm and 30/90 cm — i.e., paired and trebled rows), and two planting techniques (direct sowing and transplanting). The design was a randomized block with four replications.

The above experiment was conducted for two kharif seasons (1976 and 1977). The treatments included three planting times (18 July, 1 August, and 15 August in 1976 and 7 July, 21 July, and 4 August in 1977), two planting patterns (30/70-cm paired rows and 30/90-cm treble rows), and two planting techniques (direct seed-

Table 1. Productivity of pearl millet and pigeonpea under different treatments in 1974.

Treatment		Grain yield (kg/ha) Pearl millet	Grain yield (kg/ha) Pigeonpea	Pearl millet equivalent (kg/ha)[a]	Gross return (Rs/ha)
Planting date:					
12 July		1200	103.8	1407.6	2052
27 July		1200	224.4	1648.8	2364
11 August		390	247.5	885.0	1205
	CD. (0.05)	190	59.4		249
Planting technique:					
Direct seeded		780	240.6	1261.2	1776
Transplanted		810	231.3	1272.6	1792
	CD. (0.05)	N.S.	N.S.		N.S.
Planting pattern:					
Paired rows (30/70 cm)		920	168.0	1256.0	1790
Trebled rows (30/90 cm)		840	251.0	1342.0	1885
	CD. (0.05)	N.S	43.5		N.S.
Sole cropping vs intercropping:					
HB3 pure (50 cm)		1150	400.0	1950.0	1725
HB3 paired-row+ Arhar		1350	88.0	1526.0	2236
HB3 treble rows + Arhar		1050	120.0	1290.0	1867

a. For computing total productivity in terms of pearl millet equivalent, 2 kg pearl millet was considered to be equal to 1 kg pigeonpea.

ing and transplanting). Green gram (PS-16) as an intercrop was sown on only one date in all the intercropped plots upon the first monsoon shower. In all, there were 16 treatment combinations, which were compared in a randomized block design with three replications.

In all the seasons, pearl millet was fertilized with 60 kg N/ha, half at sowing and the remaining half side-dressed 4 weeks later. No fertilizer was applied to the intercrop.

Findings

In the 1974 season, sowing time of pearl millet influenced the grain yield of pigeonpea (intercrop) as well as pearl millet itself. There was no difference in the yield of pearl millet due to sowing on 12 July and 27 July, but sowing done on 11 August gave 810 kg/ha less than the earlier dates (Table 1). On the contrary, the maximum yield of the intercrop (247.5 kg/ha) was attained when pearl millet was sown on 11 August, and it gradually decreased in earlier dates of pearl millet sowing.

Data of the 1975 season revealed no difference in yield when pearl millet was seeded on 9 July or transplanted on 29 July (Table 2). The yield of the intercropped green gram, however, was significantly affected in any system of planting by the date of seeding or transplanting of pearl millet. Delay in pearl millet seeding/planting consistently increased the grain yield of green gram, but reduced the yield of pearl millet. When seeded on 18 August, the yield of pearl millet was so much reduced that the yield from intercropped green gram failed to offset the decline in total productivity of the system (pearl millet equivalent). However, transplanting pearl millet on 18 August in the trebled-row system produced as much pearl millet equivalent yield as was obtained when both the crops were sown on 9 July. In the last two seasons (1976 and 1977), transplanting also proved its superiority over seeding under delayed conditions (Table 3). Data further revealed that intercropped pearl millet with green gram gave as much grain yield as that of sole-cropped pearl millet (Table 4), but the productivity of the intercropping system was far superiorthan sole

Table 2. Productivity of pearl millet and green gram as affected by different treatments in 1975.

Treatment	Grain yield (kg/ha): Pearl millet	Grain yield (kg/ha): Green gram	Pearl millet equivalent (kg/ha)[a]
Paired-row planting (30/70 cm):			
Direct seeded - 9 July	2464	103	2670
Direct seeded- 29 July	2077	253	2883
Transplanted - 29 July	2584	260	3104
Direct seeded - 18 August	845	316	1477
Treble-row planting (30/90 cm):			
Direct seeded - 9 July	2677	196	3069
Direct seeded - 29 July	2211	419	3049
Transplanted - 29 July	2397	493	3383
Direct seeded - 18 August	788	419	1626
Transplanted - 18 August	1545	652	2849
Sole-crop pearl millet (50 cm):			
Direct seeded - 9 July	2457	—	2457
Sole-crop green gram (30 cm):			
Direct seeded - 9 July	—	699	1398
CD. (0.05)	211	65	-

a. For computing total productivity in terms of pearl millet equivalent, 2 kg pearl millet was considered to be equal to 1 kg green gram.

Table 3. Grain yield of pearl millet as influenced by sole cropping and intercropping in 1976 and 1977.

Treatment	Grain yield (kg/ha) 1976	1977
Sole cropping	2360	2250
Intercropping	2450	2230
C.D. (0.05)	N.S.	N.S.
As influenced by planting date (D), pattern (P), and technique (T)		
$D_1P_1T_1$[a]	3060	2440
$D_1P_2T_1$	2950	2360
$D_2P_1T_1$	2300	1950
$D_2P_2T_1$	2120	1820
$D_2P_1T_2$	3280	2540
$D_2P_2T_2$	3120	2540
$D_3P_1T_2$	1210	2120
$D_3P_2T_2$	1200	1990
C.D. (0.05)	590	390

a. D_1 - Planting on 18 July (1976) and 7 July (1977).
D_2-Planting on 1 August (1976) and 21 July (1977).
D_3 -Planting on 15 August (1976) and 4 August (1977).
P_1 - 30/70-cm paired rows.
P_2 - 30/90-cm treble rows.
T_1 -Direct seeding.
T_2-Transplanting.

Table 4. Grain yield of green gram as affected by planting dates, pattern, and technique of pearl millet.

Treatment	Grain yield (kg/ha) 1976	Grain yield (kg/ha) 1977	Pearl millet equivalent 1976	Pearl millet equivalent 1977
$D_1P_1T_1$[a]	106.8	57.3	3.0	1.6
$D^1P_2T_1$	117.2	84.0	3.3	2.4
$D_2P_1T_1$	195.0	106.0	5.5	3.0
$D_2P_2T_1$	211.3	121.6	6.0	3.5
$D_2P_1T_2$	125.7	78.3	3.6	2.2
$D_2P_2T_2$	151.3	98.3	4.3	2.8
$D_3P_1T_2$	263.3	192.5	7.5	5.5
$D_3P_2T_2$	328.3	191.4	9.3	5.4

a. See footnote, Table 3, for explanation of treatments.

cropping of pearl millet (Table 5).

In the first two seasons (1974 and 1975), grain yield of intercropped green gram was higher in three-row blocks (30/90 cm) than in the paired-row system (30/70 cm). This variation in yielding ability of the companion crop may be attributed to the larger space available for the growth of the intercrop in the trebled-row system, which reduced the intensity and extent of competition. Therefore, the modifications in the planting system helped in accommodating compatible

Table 5. Total productivity (kg/ha) and economics of intercropping.

Treatment	Intercropping 1976	Intercropping 1977	Sole cropping 1976	Sole cropping 1977	Gross return (Rs/ha) 1976 Inter-cropping	1976 Sole cropping	1977 Inter-cropping	1977 Sole cropping
$D_1P_1T_1$ [a]	3420	2630	3000	2400	2530.80	2220.20	1998.80	1824.00
$D_1P_2T_1$	3360	2680	2860	2270	2486.40	2116.40	2036.80	1725.20
$D_2P_1T_1$	2930	2200	2220	1990	2168.20	1642.80	1672.00	1512.40
$D_2P_2T_1$	2820	2090	2010	1910	2086.80	1482.40	1588.40	1451.60
$D_2P_1T_2$	3800	2930	3130	2750	2812.00	2316.20	2226.80	2090.00
$D_2P_2T_2$	3490	2840	3180	2520	2582.60	2353.20	2158.40	1915.20
$D_3P_1T_2$	2000	2600	1170	2180	1480.00	865.80	1976.00	1656.80
$D_3P_2T_2$	2040	2510	1290	2020	1509.60	954.60	1907.60	1535.20

a. See footnote, Table 3, for explanation of treatment.

companion crops, thus increasing the land equivalent ratio.

The findings on the possibilities of intercropping in pearl millet clearly revealed that provision of a competition-free period appreciably influenced the grain productivity of the intercrop. This was because of the absence of overlap in the grand period of growth of the two crops owing to differences in the time of their planting. In 1974 and 1975, the competition between the crop components was reduced when intercrops were seeded on 7 July and 12 July and pearl millet was transplanted on 29 July and 11 August, respectively. Both crops expressed their yield potential fully in this system. In 1976 and 1977, grain yield in green gram due to expansion of the competition-free period could not offset the loss in yield of pearl millet. Hence, maximum yield advantage from the intercropping system was obtained at 14 days free period only.

Nodulation Effect

Data presented in Table 6 show that at 0 competition-free period to green gram, nodulation was very active and more nodules were observed on the main roots than on the lateral roots. At 14days competition-free period, nodulation in green gram in transplanted pearl millet was active in comparison to seeded pearl millet. The transplanted crop could have started encroaching upon N from the beginning, and the competition for N was serious by both crops. At 28 days competition-free period,the nodulation process was decelerated. Abundant N (due to lack of competition for 28 days) could have kept the green gram plant idle without fixing N.

Table 6. Nodulation of green gram as affected by planting date, pattern, and technique of pearl millet.

	Main root		Lateral root	
Treatment	1976	1977	1976	1977
At the 4-week stage:				
$D_1P_1T_1$	26.3	14.8	15.6	9.1
$D_1P_2T_1$	19.7	15.1	7.4	5.7
$D_2P_1T_1$	11.0	11.6	9.6	7.2
D2P2T1	9.0	14.3	9.9	5.8
D2P1T2	15.6	10.1	12.6	4.9
$D_2P_2T_2$	12.6	10.6	11.6	5.4
$D_3P_1T_1$	5.9	5.4	12.2	7.9
D3P2T2	5.7	5.5	13.8	7.2
At the 6-week state:				
D1P1T1	8.0	-	1.7	-
D1P2T1	7.1	-	3.5	-
D2P1T,	11.7	-	5.9	-
D2P2T1	9.9	-	10.2	-
D2P1T2	9.0	-	6.0	-
D2P2T2	8.7	-	5.3	-
D3P1T2	10.3	-	15.1	-
D3P2T2	7.6	-	13.9	-

a. See footnote, Table 3, for explanation of treatments.

However, at the 6-week stage, the nodulation process at this competition for N started only after pearl millet was transplanted. It is also interesting to note that at the third date of planting, the number of nodules increased at the 6-week stage when there was no competition-free period. Nodules were degenerated in 1977 at the 6-week stage. Heavy rainfall followed by a prolonged dry spell in 1977 could be held responsible for premature nodule degeneration.

Maximizing Production in a Sorghum/Pigeonpea Intercropping System in the Semi-Arid Tropics

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Abstract

The semi-arid tropical regions of Hyderabad, with their poor soil-moisture storage and a growing season of 150 days, can support only an intercropping system for increasing cropping intensity. The ideal intercrops for the region are sorghum and pigeonpea.

The traditional system of this intercropping is inefficient. Experiments and verification trials on farmers' fields proved that a full yield of sorghum and 60% of the pigeonpea yield could be achieved by (1) switching over to high-yielding hybrids of sorghum (CSH-5ICSH-6) and J 50-day varieties of pigeonpea (HY-2), (2) using 40-30-0 kg N, P_2O^5, and K_2Olha, (3) adopting suitable plant-protection measures, and (4) resorting to a 2: J system of planting with 120 000 plantslha population of sorghum and 40 000 plantslha population of pigeonpea at 45 cm.

Attempts are now in progress for achieving fuller yields of pigeonpea as well.

Basic Resources

The soils of the Hyderabad region are light textured (loamy sand to sandy loam) and shallow. They exhibit mechanical translocation of clay resulting in textural profiles. The subsoils consist of a mixture of nonexpanding illitic clay and small-sized gravel, and they are compact. They are near neutral (pH 6.5-7.5), low in N (0.02-0.04%), poor in available P (0.2 ppm Olsen's P), and adequate in K (500-700 ppm extractable in boiling HNO_3). The moisture-storage capacity in these soils is less than 100 mm. The annual rainfall is 760 mm. The onset of the monsoon is around 10 June; it recedes by 15 October. Thus, the growing season in this region is about 150 days. In such a situation, the cropping intensity can be increased only by intercropping. The main crops of the region are sorghum and castor. In some areas, sorghum is intercropped with pigeonpea.

Traditional System of Intercropping

The traditional system of intercropping in the region is sorghum/pigeonpea in a replacement series, varying from 4:1 to 8:1. About 3-5 metric tons of poorly prepared farmyard manure are applied to previous castor crops, and the residual effects are relied on for the following crops of sorghum and pigeonpea. The plant stands are low for sorghum (up to 120 000 plants/ha) and very low for pigeonpea (up to 14 000 plants/ha). The local sorghum cultivar of PJ8K is tall (300 cm) and thus shades pigeonpea up to 115 days. The local cultivar of pigeonpea matures by about 180 days. The yields obtained are low — about 300-400 kg/ha of sorghum and 50 kg/ha of pigeonpea.

Steps in Maximizing Production in a Sorghum/Pigeonpea Intercropping System

The improvements to obtain higher yields in the traditional intercropping of sorghum/

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pigeonpea could be broadly grouped into the following categories:

1. Use of high-yielding cultivars
2. Improved soil fertility
3. Proper plant protection measures
4. Increased plant population of both crops by adopting suitable crop geometry

The details are discussed in the following sections.

Use of High-yielding Cultivars

Sorghum

The short duration (100 ± 5 days) hybrids of sorghum are found to be top yielders in this region (Table 1). These hybrids are generally of shorter stature as well, with the height varying from 150 cm (CSH-6) to 200 cm (CSH-5).

These hybrids could be harvested at physiological maturity without any loss in yield (Table 2). In fact, in very humid weather, such a harvest helps in avoiding grain deterioration. Further, by harvesting at physiological maturity, the land occupied by sorghum would be vacated, at least by about a week in advance.

Pigeonpea

There is no significantly improved variety found for the region. Among the various cultivars tested, 150-day duration varieties were found to be ideal for the region (Table 3). HY-2, HY-4, and S-8 are relatively synchronous flowering types, while T-21 is an indeterminate type.

Freyman and Venkateswarlu (1977) conducted a series of experiments on the best alternatives with sorghum as the base crop. The results are given in Table 4. Even though the sorghum yield was affected, it was amply compensated by the good yield of pigeonpea, and this system alone was found to be most economical and stable for the region.

Improved Soil Fertility

Traditional fertility was not adequate for fuller expression of the yields of sorghum hybrids in the region. The response to fertilizer N was up to 80 kg/ha for CSH-5 (Table 5); however, the response to fertilizer N was little for the pigeonpea (Table 6).

Table 1. High-yielding cultivars of sorghum.

Hybrid/ Variety	Days to maturity	Grain yield (kg/ha) 1973	1974	1975	Average
CSH-6	95	4520	3210	5370	4370
CSH-5	105	3060	2080	5160	3430
370	95	3800	1660	4290	3250
CS-3541	115	2210		3620	2910
Local	115	2340	1570	2270	2060

Table 2. Yield of sorghum (CSH-6) and age at physiological maturity.

Harvest stage	1974		1975	
	Yield (kg/ha)	Days	Yield (kg/ha)	Days
Full maturity	5070	97	4200	94
Physiological maturity	4380	92	3920	90

Table 3. Yield of pigeonpea cultivars.

Variety	Duration (days)	Yield (kg/ha) 1972	1974	1975
HY-2	154	890	1060	2390
HY-4	145	-	1060	2260
S-8	140	880	1200	-
T-21	151	880	1090	-
HY-3a	180	380	850	-
HY-12	265	-	134	-

Table 4. Performance of different intercrops with sorghum, 1974.

System	Yield (kg/ha) Sorghum (CSH-6)	Intercrop (HY-2)
Sole-crop sorghum	2650	
Sorghum/pigeonpea	1440	1270
Sorghum/soybean	2470	70
Sorghum/cowpea	2120	140
Sorghum/black gram	3100	70

Table 5. Fertiliser N response on CSH-5-sorghum, 1973.

N level (kg/ha)[a]	Yield (kg/ha)
0	1784
40	2910
80	3364
160	3049
CD. (0.05)	704

a. Over a basal dose of 40 kg P_2O_5/ha.

Table 6. Fertilizer N response on pigeonpea, 1973 and 1974.

	Yield (kg/ha)	
N level (kg/ha)	T-21	S-8
0	1428	1002
20	1422	960
CD. (0.05)	N.S.	N.S.

Attempts were then made to maximize fertilizer-use efficiency for the intercropping system (Table 7). The data clearly show that N need be applied only to the cereal component.

Need for Plant Protection

Even though no systematic experiments were conducted for evaluating the contribution of plant protection in the total system, enough indicative observations were made on both crops.

In sorghum, shoot fly could be avoided by early planting within a fortnight of the first seeding (with the onset of the monsoon). Earhead bug incidence, however, was greater with late planting. Peak infestation was found to be by mid-September (Table 8). Unless timely measures were taken to control the bug, yield decline could be dramatic (Table 9). CSH-6 sorghum escaped earhead damage to a considerable extent due to early flowering.

In pigeonpea, the major pest is the pod borer, and its incidence is greater with increased humidity at pod development. Without timely control, the yield losses could be 30-50% as was seen in observational trials.

Thus, timely and proper pest control would be important for enhancing the total production in the sorghum/pigeonpea intercropping system.

Crop Geometry and Plant Population

Crop Geometry

Shelke and Krishnamoorthy (1978) studied the effect of proportional planting of sorghum and pigeonpea (Table 10). The data show that the land equivalent ratio (LER) increases as the ratio between sorghum and pigeonpea decreases. Keeping in mind the native seed drills, a 2:1 sorghum to pigeonpea would be ideal crop

Table 7. Fertilizer use in intercropping of sorghum and pigeonpea, 1977.

	Yield (kg/ha)	
Treatment (40 kg/ha N)[a]	Sorghum (CSH-6)	Pigeonpea (HY-2)
N for both crops	1251	594
N for sorghum only	1966	660

a. P_2O_5 at the rate of 30 kg/ha was broadcast.

Table 8. Peak period of earhead bug infestation In sorghum, 1977.

Period of observation	Bugs/head (Mean of 20 observations)
20-31 August	1.3
1-10 September	2.4
11-20 September	25.0
21-30 September	30.0
1-10 October	25.0

Table 9. Damage due to earhead bug in sorghum hybrids, 1977.

	Grain yield (kg/ha)	
Treatment	CSH-5	CSH-6
No control	Failed (0%)	1610(75%)
Control measure taken	1310(100%)	2160 (100%)

geometry for proportional planting. Such a system enhances the yield of both crops, as both of them would be benefitted by border effects.

Plant Population

With proportional planting, an LER of 1.3 was achieved. Subsequent experiments showed that by enhancing the population of the sorghum crop to sole crop level (180 000 plants/ha), fuller yields of sorghum could be achieved and the LER enhanced to 1.6. The average of several experiments by Shelke and Krishnamoorthy (1978) are given in Table 11.

Large Plot Field Testing

The *2:1* planting of sorghum and pigeonpea with 180 000 and 40 OOO'plants/ha, respectively, was tested on farmers' fields (Table 12). There is an enormous increase in the total yield of the improved system over the traditional proportional planting.

Ongoing Research

Having obtained full yield of sorghum and about 60% of pigeonpea, efforts are now being made to maximize the yield of pigeonpea as well. They include:

1. Change in crop geometry
2. Increase in pigeonpea population
3. Early harvest of sorghum
4. Selection of suitable cultivars.

Limited data suggest that sorghum can be planted in paired rows up to 14 cm without significant reduction in yield (Table 13).

Pigeonpea was planted at 120 cm. The data suggest a potential for fuller expression of pigeonpea yield. In normal intercropping systems, lower branches of pigeonpea were seriously reduced, which might be one of the factors for reduction in the yield of pigeonpea (Table 14). This might be compensated by adopting the planting system suggested above

Table 10. Yield of sorghum (CSH-5) and pigeonpea (HY-2) in proportional planting (1975).

Ratio of sorghum to pigeonpea	Yield (kg/ha)		Land equivalent ratio
	Sorghum	Pigeonpea	
5:0	3950	-	1.0
4:1	3630	650	1.2
3:2	2750	1190	1.3
2:3	1880	1580	1.3
1:4	1020	2190	1.3
0:5	-	2030	1.0
CD. (0.05)	350	280	-

Table 11. Average yield of eight experiments on intercropping of sorghum and pigeonpea.

System	Yield (kg/ha)		Land equivalent ratio
	Sorghum	Pigeonpea	
Sole-crop sorghum	3440		
Sole-crop pigeonpea			
Sorghum/pigeonpea intercrop (2:1)	-	-	1.60
		880	
	3330	550	

Table 12. Field testing of the improved sorghum/pigeonpea intercropping, Rajendranagar Block, Hyderabad, 1976.

System[a]	Yield (kg/ha)		Population
	Sorghum (CSH-6)	Pigeonpea (HY-2)	
Proportional 4:1	2140	80	144 000 plants/ha sorghum + *20 000 plants/ha pigeonpea*
Improved	3270	230	180 000 plants/ha sorghum + 40 000 plants/ha pigeonpea

a. Fertilizer used was 30-30-0.

or by increasing the population of pigeonpea (Table 15).

It is already established that sorghum can be vacated from the land at physiological maturity—i.e., about a week in advance of normal harvesting. This leads to a saving both in time and space for the benefit of the associate pigeonpea.

The sorghum plant type and duration as well as the type of branching in pigeonpea would affect the yield of pigeonpea in an intercropping system. Types with erect growth and branching on top (HY-4) outyield bushy types (HY-2). Similarly, shading by sorghum on pigeonpea could be minimized by choosing dwarf plant types with short duration in addition to changing the crop geometry.

Detailed investigations are now in progress on these aspects.

Table 13. Yield of sorghum planted in pairs of different distances between pigeonpea planted at 120 cm, 1977.

	Yield (kg/ha)	
Pairing distance of sorghum rows (cm)	Sorghum (CSH-6)	Pigeonpea (HY-2)
38	4760	1080
30	3740	1160
22	4120	1120
14	3980	1320
6	3060	1300

Table 14. Effect of intercropping on the primary branches, spread, and pods of pigeonpea at harvest of sorghum.

System	Primary branches (no.)	Spread (cm)	Pods (no.)
Sole-crop pigeonpea (27 600 plants/ha)	8.0	57.0	148.9
Intercropping (27 000 plants/ha)	5.1	32.0	86.8

Table 15. Yield of sorghum (CSH-S) and pigeonpea (HY-2) with full population of sorghum and varied population of pigeonpea.

	Yield (kg/ha)			
	1975		1976	
System	Sorghum	Pigeonpea	Sorghum	Pigeonpea[a]
Sole-crop sorghum	2660		2330	
Sole-crop pigeonpea		1110		330
Sorghum + 25 250 pigeonpea	2390	570	2080	120
Sorghum + 50 500 pigeonpea	2300	700	2220	160
Sorghum + 75 000 pigeonpea	2390	800	1820	190
Sorghum + 101 000 pigeonpea	2260	830	1730	220
CD. (0.05)	N.S.	150	N.S.	30

a. Low yields due to early recession of monsoon.

Genotype-Plant Density Considerations in the Development of an Efficient Intercropping System for Sorghum

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Abstract

Investigations on the various crop combinations with sorghum as a base crop were carried out from 1971 to 1974 to identify an efficient sorghum intercrop system and to assess its productivity and monetary advantages. Studies were undertaken in 19751 1976 on the development of an optimum sorghumlpigeonpea intercropping system by growing suitable crop genotypes under different planting patterns of sorghum inter-cropped with pigeonpea at two plant densities to assess total productivity and economic profitability.

Sorghum yields at various planting patterns were on a par with a recovery of 97% yield of its sole crop. When intercropped with pigeonpea, reduction in sorghum yield was more (12%) from the HY-2 cultivar than from the erect, long-duration cultivar HY-3a (8%). Higher total yield and net returns were obtained in paired-row patterns of sorghum intercropped with a lower density of pigeonpea (27 000 plants I ha). In the wide-row patterns, however, there was better expression of pigeonpea yield even at its full density.

The optimum sorghumlpigeonpea intercropping systems, therefore, were paired rows (60-30 cm) of sorghum intercropped with 27 000 plantsIha of pigeonpea, or the wide-row (60-cm) pattern of sorghum intercropped with full (55 000 plantslha) pigeonpea density. Sorghum population in both systems would remain at 148 000 plantslha. Wide rows of sorghum are preferred from the crop management point of view.

Sorghum and pigeonpea are established components of a cereal-legume mixed cropping system in rainfed agriculture. Traditional low-yielding, long-duration varieties of both crops are generally grown in alternating strips with plant density kept at less-than-optimum, and the system as a whole probably provides some insurance against crop failure due to uncertain weather and pest hazards in traditional subsistence agriculture.

Genotypic manipulations in cereals and pulses in the recent past furnished a choice of varieties differing in plant habit, growth rhythm, maturity periods, and response to high plant density.

In the present investigation with sorghum as a base crop, different crop combinations of varying duration, height, canopy display, etc., were initially studied. Such studies have proved the efficiency of the sorghum/soybean and sorghum/pigeonpea systems. The sorghum/pigeonpea system was chosen for detailed studies, and the results are presented in this paper.

Experimental Methods

The experiments were conducted during the *kharif* (rainy) seasons from 1971 to 1976 at the IARI Regional Station, Hyderabad, on light clay loam soil (N = 0.048%; P_2O_5 = 11.4 kg/ha; K_2O= 185 kg/ha; pH = 8.0). Total rainfall during the crop season was as follows: 1971, 521 mm; 1973, 732 mm; 1974, 586 mm; and 1975, 691 mm. Although 1975 was a wet year, 1971 was a year of low rainfall with dry spells (of 15 days) in every month. Such dry spells also occurred in

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July-September 1973 and August-September 1974; in 1976, rains totally ceased from the second week of September.

Studies on Sorghum Intercropping System: 1971-74

1971

Sorghum var. 148 was planted in five planting patterns:

1. Uniform rows 45 cm apart;
2. Paired rows 30, 20, and 10 cm apart with interpairs space of 60, 70, and 80, cm respectively;
3. Paired rows 30 cm apart with interpairs space of 90 and 120 cm with hill spacing adjusted for constant plant density.

The six intercrops with diverse canopy structure and maturity ranges were: (1) soybean, Bragg (low canopy, 60 days); (2) groundnut, TMV-2 (low canopy, 120 days); (3) green gram, HB-45 (low canopy, 60 days); (4) castor, Aruna (bushy, 130 days); (5) sunflower, Sunrise selection (erect, leafy, 100 days), and (6) pigeonpea T-21 (bushy, 150 days). There were 42 treatment combinations.

1973

Sorghum var. 302 was planted only in the paired-row 60-30 pattern. Only the following four intercrops were tried and green gram and sunflower were eliminated from further testing: (1) soybean, Soy-1; (2) groundnut, TMV-2; (3) castor, 413-A; and (4) pigeonpea HY-3a. For castor and pigeonpea, new genotypes with a less spreading, more erect habit were introduced. There were 6 treatment combinations.

1974

Sorghum var. 370 was planted in three planting patterns: (1) paired-rows 60-30 cm; (2) wide (alternate) rows 60 cm; and (3) a 3:1 land area ratio of sorghum to intercrops. The intercrops and the genotypes planted were the same as in 1973, except for castor (157-B). There were 21 treatment combinations.

Studies on Sorghum/Pigeonpea Intercropping System: 1975—76

Sorghum (CSH-6) was grown in five planting patterns:

1. Paired-row 30 cm apart with interpair space of 60 and 90 cm;
2. Wide rows 60 and 90 cm apart;
3. Sorghum and pigeonpea grown in a 3:1 land area ratio. Pigeonpea was planted at two plant densities: sole crop optimum (55 000plants/ha) and 50% of the optimum (27 000 plants/ha). During 1975, only the HY-2 cultivar (bushy, 130 days) was planted, while during 1976, HY-3a (erect with no basal branches, 170 days) was also compared with it. There were 17 treatment combinations in 1975 and 28 in 1976.

Plant density of sorghum was constant at 150 000 plants/ha in all the planting patterns throughout the seasons tried. Sorghum and intercrops were grown in uniform rows, and each had optimum density as a check throughout the five seasons.

Results and Discussion

Sorghum Intercropping Systems

To assess the yield advantage of the sorghum intercropping system in the present investigation, the criterion adopted was to obtain possibly a near maximum yield equal to that of a sole crop of sorghum along with the additional yield of the intercrop. Improved genotypes of sorghum from a dwarf, compact-headed, medium-duration var. 148 in 1971 to an early-maturing, less-shading, thin-leaved var. 370 were tried in different planting patterns. To begin with, in 1971, intercrops of diverse canopy structures and maturity periods were tried to select the crop and the combination with the best yield advantage.

Among the planting patterns tried, sorghum yield was either on a par with or slightly superior to that of a sole crop in the 60-30 paired-row pattern (Table 1). Yield was depressed as the two sorghum rows were progressively compressed beyond 30 cm in the paired-row pattern. Yield of sorghum planted in the wide-row 60-cm pattern was on a par with that of the paired-row 60-30 pattern. Among the

Table 1. Grain yield (q/ha) of sorghum in various planting patterns, rainy season 1971-74. (1q = 100 kg)

Cropping system	Planting pattern							
	Uniform row 45 cm	Paired rows					Wide row 60 cm	Area ratio (3:1)
		60-30	70-20	80-10	90-30	120-30		
1971								
Sole crop	41.2	41.9	36.4	30.3	26.2	34.7	-	-
Intercropped	29.6	36.4	30.2	28.7	25.0	28.1		
1973								
Sole crop	67.7	75.7	-	-	-	-	-	-
Intercropped		69.2						
1974								
Sole crop	42.5	50.8		-			46.7	43.8
Intercropped		38.7	–			–	37.8	37.7

Table 2. Grain yield (q/ha) of sorghum and intercrops and total returns (Rs/ha), rainy season 1971 (mean overall patterns).

Cropping system	Yield			LER	Total returns
	Sorghum	Intercrop	Total		
Sole-crop sorghum	41.25	—	41.25	1.00	3217
Sorghum + soybean	40.78	8.13	48.91	1.61	4151
Sorghum + groundnut	36.10	5.07	41.17	1.57	3221
Sorghum + green gram	37.31	1.14	38.45	1.06	3104
Sorghum + pigeonpea	26.74	4.43	31.17	1.04	2618
Sorghum + castor	26.48	11.23	37.71	1.08	3530
Sorghum + sunflower	10.49	16.39	26.38	0.88	3046
S.E. ±	2.96				451
CD. (0.01)	8.11				1237

intercrops, low-canopy, early-duration crops (soybean, groundnut, and green gram) could give from 90 to 98% yield recovery of sorghum (Table 2). Sorghum yield was reduced by 35 to 75% with the bushy, long-duration castor, pigeonpea, and highly competitive sunflower crops, respectively. Sunflower and green gram were observed to be aggressive and suppressed crops with sorghum, respectively, with corresponding land equivalent ratios (LER) of 0.88 and 1.06, as against an average of 1.60 for soybean and groundnut; these crops, therefore, were deleted from further studies.

These findings were confirmed in 1973 and 1974. With the introduction of the erect pigeonpea HY-3a which has no basal branches, and the dwarf castor variety 413-A which has convergent spikes, both of which have growth patterns that differ in time from sorghum, the yield recovery of sorghum, as compared to its sole crop yield, was improved considerably: i.e., 90 and 80% for pigeonpea and castor, respectively. The role of improved genotypes in the intercropping systems has been stressed by Krantz et al. (1976) and Tarhalkar and Rao (1975) (Table 3). For sorghum/soybean and sorghum/pigeonpea systems, the mean LER value of 1.50, as well as the mean total returns of Rs 8700 and

Rs 8100, respectively, were highest for the 1973 and 1974 seasons (Table 4). For the sorghum/soybean system, the base crop of sorghum is longer in duration, while the reverse is true for the sorghum/pigeonpea system, resulting in a reduction of intercrop competition by utilizing the growth resources at different periods of crop growth (Willey and Osiru 1972) and thus showing a complementary effect (Donald 1963).

Sorghum and pigeonpea crops are the principal components of the traditional cropping systems in rainfed agriculture in India (Aiyer 1949). Limited information, however, was available on the plant density-genotype interaction in the sorghum/pigeonpea system. High-yielding genotypes are plastic by nature and can perform remarkably well under high plant density conditions. Therefore, studies were undertaken to further reduce the intercrop competition and to increase the productivity of the system by growing sorghum in various planting patterns intercropped with improved pigeonpea genotypes at different plant densities.

Table 3. Grain yield of sorghum and Intarcropa and total returns in various systems, rainy season 1973.

Cropping system	Yield (q/ha)			LER	Total returns (Rs/ha)
	Sorghum	Intercrop	Total		
Sole-crop sorghum	67.7		67.7	1.00	6772
Sorghum paired row (60-30)	75.7		75.7	1.12	7571
Sorghum + soybean	73.2	4.1	77.3	1.43	7806
Sorghum + groundnut	69.8	1.8	71.6	1.26	7521
Sorghum + castor	65.2	4.4	69.6	1.29	7614
Sorghum + pigeonpea	68.5	8.7	77.2	1.54	8422
S.E. ±	212.7				198.7
CD. (0.05)	771				720

Table 4. Grain yield (q/ha) of sorghum and intercrops and total returns (Rs/ha) in various systems, rainy season 1974.

Planting pattern	Intercrop[a]			
	Soybean	Groundnut	Castor	Pigeonpea
Paired row (60-30)	44.1 (4.0)	41.1 (2.3)	31.2 (6.9)	38.3 (11.4)
LER	1.42	1.28	1.11	1.43
Net return	6495	5768	4791	6949
Wide row (90)	41.7(6.5)	39.5 (3.2)	32.6 (7.2)	36.7 (12.8)
LER	1.58	1.35	1.19	1.45
Net return	6451	5652	5265	6901
Area ratio (3:1)	39.2 (7.0)	38.3 (4.2)	34.4 (8.6)	38.9 (12.2)
LER	1.58	1.46	1.28	1.48
Net return	6066	5639	5651	7193

CO. (0.01) for sorghum yield = 10.96
CD. (0.01) for returns (Rs) = 418

a. Numbers in parentheses denote Intercrop yield.

Sorghum/Pigeonpea Intercropping System

Grain yield of sole crop sorghum (CSH-6) in the two paired rows and in the wide rows (60 cm) planting patterns was similar (Table 5). The yield recovery was up to 97% when planted in rows 90 cm apart. This remarkable plasticity exhibited by CSH-6 sorghum for stable yield performance under alternative planting patterns makes it highly suitable for intercropping purposes.

As compared to the sole crop, the sorghum yield was reduced more (12%) when it was intercropped with bushy, early-branching, medium-duration cultivar HY-2 than with the erect, late-maturing cultivar HY-3a having no basal branches (7%). High recovery of sorghum yield (92% of its sole crop yield) was possible when intercropped with pigeonpea at a density of 27 000 plants/ha than at its optimum sole crop density of 55 000 plants/ha (85%) (Table 6).

The intercrop competition by pigeonpea was different in various planting patterns, as observed by the sorghum yields obtained in

Table 5. Grain yield (q/ha) of sorghum (CSH-6) in various planting patterns, rainy season 1975-76.

Season	Planting pattern					
		Paired rows		Wide rows		
	Sole crop	60-30	90-30	60	90	(3:1)
1975	41.1	46.7	44.0	43.4	39.7	42.7
1976	59.3	67.2	63.8	66.9	58.2	58.8

Table 6. Grain yield (q/ha) of sorghum (CSH-6) and pigeonpea (HY-2 and HY-3a) and net returns (Rs/ha) in the sorghum/pigeonpea system, rainy season 1975—76.

Planting pattern	1975[a]		1976[a]			
	HY-2		Hy-3a		Hy-2	
	LD[b]	FD[c]	LD	FD	LD	FD
Paired row (60-30)	44.0(14.0)	34.7 (9.8)	59.8 (11.4)	54.8 (10.9)	56.1 (8.8)	52.0 (8.0)
LER	1.71	1.29	1.46	1.35	1.33	1.23
Net returns	5963	4069	9378	8494	8222	7376
Paired row (90-30)	36.2 (13.6)	30.9(13.0)	57.3 (11.7)	54.1 (12.5)	55.0 (9.8)	52.8(11.0)
LER	1.51	1.35	1.48	1.40	1.34	1.37
Net returns	4822	4066	9106	8786	8180	8245
Wide row-60	36.6(10.6)	39.8(13.1)	57.7(12.5)	53.6 (13.8)	55.3 (9.7)	51.1 (12.0)
LER	1.38	1.32	1.46	1.44	1.35	1.38
Net returns	4491	3940	9849	9060	8315	8255
Wide row-90	36.3 (13.8)	31.6(17.9)	53.5(12.8)	50.7(15.6)	51.0(15.3)	49.2 (14.9)
LER	1.51	1.59	1.40	1.47	1.44	1.48
Net returns	4936	4898	8899	9087	8608	8715
Area ratio	38.1 (12.0)	34.4(14.3)	52.6(10.6)	51.3(11.3)	49.4 (9.7)	47.4(10.8)
LER	1.48	1.50	1.30	1.21	1.26	1.27
Net returns	4911	4715	8024	8097	7490	7423
Sorghum yield: C.D.(0.05)		462				37

a. Numbers in parentheses denote pigeonpea yield.
b. LD = pigeonpea at 27 thousand plants/ha.
c. FD = pigeonpea at 55 thousand plants/ha.

these patterns. The reduction in sorghum yield was less (8%) In the paired-row pattern, while it was 12% in the wide-row pattern. Sorghum seems to utilize growth resources better in paired rows, as is evident from high sorghum yields in this pattern. Pigeonpea competition to sorghum was thus lower in the paired-row pattern. However, in turn, pigeonpea receives higher competition from sorghum in the paired-row pattern since it yielded 8% lower than in the wide-row pattern. In wide rows, pigeonpea yield was higher and sorghum yield was lower than in paired rows, since the flourishing pigeonpea offered a higher competition to the sorghum.

As compared to its pure crop yield, the recovery of pigeonpea yield when intercropped with a high-yielding, early-maturing sorghum was on an average only about 50%. This might be due to the initial competition by sorghum at the developmental stage of the medium-duration, bushy HY-2 cultivar. The potential of the erect, long-duration HY-3a cultivar could not be properly assessed due to the seasonal effect (early cessation of rains in 1976 season), and its behavior was similar to the HY-2 cultivar. A higher LER as well as higher monetary returns were obtained when sorghum was intercropped with HY-3a. High monetary returns were obtained when sorghum was grown in the paired-row 60-30 pattern and intercropped with 50% of the optimum plant density of pigeonpea. However, in the wide-row patterns, there was better expression of the pigeonpea yield, and the LER values and the net monetary returns were also the same at both high and low pigeonpea densities. Sowing of crops, weed management by intercultivation, and other management practices, however, are easier in the wide-row pattern.

Plant Population and Spatial Arrangement Study on the Intercropping of Maize and Beans (*Phaseolus vulgaris* L.) in Northeast Brazil

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Abstract

In Northeast Brazil, the peasant farmers usually raise their crops in mixture, and the intercropping of maize and beans (Phaseolus vulgaris *L.*) *is very frequent.*

In order to examine plant populations and spatial arrangements of maize and beans intercropped, an experiment was carried out at Filadelfia, Brazil, located at 10°45' S and 40°07' W at 550 m altitude. The average annual rainfall of the area is 811 mm.

The statistical design was a randomized complete block with a split-plot arrangement, with four replications. Four population levels of maize (25 000, 50 000, 75 000, and 100 000 plantsiha) and beans (150 000, 200 000,250 000, and 300 000 plantslha) formed the main plots. The subplots were composed of five spatial arrangements (sole maize; 1M:2B; 1M.3B; 1M:4B; and sole beans).

It was concluded that the best spatial arrangement was 1:3, comprising 12 500 p/antslha of maize and 150 000 plantslha of beans.

Northeast Brazil occupies an area of 13% of the Brazilian territory and according to Hargreaves (1974), half of this land is classified as semi-arid tropics. The Brazilian semi-arid tropics are located between 3 and 18° south and 35 and 46° West, comprising an area of around 1 million km^2 including parts of the following states: Maranhao, Piaui, Ceara, Rio do Norte, Paraiba, Pernambuco, Alagoas, Sergipe, Bahia, and Minas Gerais.

According to Brasil. Sudene (1975), 73% of the holdings in Northeast Brazil are less than 50 ha and occupy 12% of the total area of the region. As shown in a survey carried out in the first 20 nuclei of the "Sertanejo" Project[1] by Brasil. Sudene (1977), the farmers *can* be classified as follows:

40% —farmers without land
56% —farmers having small properties
4% — farmers having medium and large properties

At the present time, the cultivated land accounts for only one-sixth of the total area of the agricultural holdings (Franco 1977).

In Northeast Brazil, the small farmers normally manage afarming system involving small areas planted in food crops such as maize, beans, cassava, squash, and fruits (banana or mango) and cash crops such as cotton and castor beans. Crop combinations vary with the region. Moreover, to complement their food or cash needs, they raise chickens, pigs, and goats. Until recently, the research programs devoted to semi-arid tropics had not sufficiently considered the farming systems, and most research objectives had been to improve production techniques only for single crops or animal species, independently of each other (Dillon et al. 1978). So it is urgentto spread the use of new technology emphasizing farming systems as a whole, and there is nobody better than farmers themselves to provide the basis for this goal.

Krantz (1974) reported that two important factors, namely climate and soils, have

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1. Government project to promote the development of typical holdings in the semi-arid tropics of Northeast Brazil, leading to the minimization of drought effects.

influenced farmers in developing their cropping patterns in the semi-arid tropics. The rainfall is erratic and undependable, so in a single cropping season, it is possible to have excessive rainfall and droughts of short duration. The soils have a very low content of organic matter and native fertility. Adding these factors to the erratic and undependable rainfall pattern makes crop production in the semi-arid tropics a hazardous enterprise.

Limited capital resources and risk aversion of small farmers associated with other characteristics caused the early farmers in the semi-arid tropics to develop special cropping patterns based on multiple cropping, where more than one crop is grown on the same land in one year. In Northeast Brazil the most common situation is intercropping, where two or more crops are grown simultaneously on the same land in rows in definite patterns.

In terms of cropping combinations, there are two clear situations in the semi-arid tropics of Northeast Brazil related to the rainfall regime. In regions with too erratic rainfall and limited suitability for rainfed agriculture, the most common combination is maize x beans [i.e., cowpea, (*Vigna unguiculata* L Walp)] x perennial cotton (*Gossypium hirsutum* L. var. 'Maria Galante' Hutch.), with some variation for cassava, castor bean, or palma cactus (*Opuntia cochinellifera* Mill.) for forage. The second situation, occurring in those regions with less erratic rainfall and a higher moisture availability index (MAI) (Hargreaves 1974), is predominantly maize x beans (*Phaseolus vulgaris* L), with variation for cotton (*Gossypium hirsutum* L), cassava, or palma.

In Northeast Brazil, some studies have been carried out on intercropping involving cereals and legumes (Faris et al. 1976; Araujo et al. 1976; and Lopes et al. 1976), where the advantage of intercropping in relation to sole crops can be seen. However, in these studies, the different aspects of plant population, proportional population, and spatial arrangement have not been clearly distinguished.

This experiment was planned with the objective of studying these aspects in detail.

Materials and Methods

The experiment was carried out at Filadelfia county (State of Bahia), located at 10°45' South and 40°07' West, at 550 m altitude.

The soils of the area are deep eutrofic red yellow laterite with the following characteristics:

PH	6.5
P_2O_5	5.5 ppm
K_2O	0.2 meq/100 g
O.M.	0.8%
Al	0.05 meq/100 g

The average annual rainfall is 811 mm, concentrated from November to July. A rainfall gauge, set up at the experimental site, recorded 212.1 mm during the growing season.

The region has an average slope of 8% at the site of the experimental area. A system of ridges and furrows of 150 cm was prepared with three rows on the bed.

The statistical design was a randomized complete block with a split-plot arrangement, with four replications. Four population levels of maize and beans formed the main plots. Each main plot was divided into five subplots composed of three different spatial arrangements of maize and beans, sole maize, and sole beans.

The populations were distributed as follows:

Population	Maize	Beans
1	25 000	150 000
2	50 000	200 000
3	75 000	250 000
4	100 000	300 000

The populations were combined with the following spatial arrangements:

- Sole maize (100%)
- 1:2 — 1 row of maize (33%): 2 rows of beans (67%)
- 1:3 — 1 row of maize (25%): 3 rows of beans (75%)
- 1:4 — 1 row of maize (20%): 4 rows of beans (80%)
- Sole beans (100%)

The distance between rows was 50 cm, except for sole maize, where it was 1 m. The different plant populations were obtained by using the row spacings of 80, 40, 26, and 20 cm for maize and 13, 10, 8, and 6.5 cm for beans, respectively. For sole maize, the spacings were 40, 20, 13, and 10 cm.

At planting time, 20 kg/ha of N, 60 kg/ha of P_2O_5, and 30 kg/ha of K_2O were banded near the seeds. Forty-five days after planting, 40 kg/ha of N was added as a top dressing to maize.

The experiment was sown on 19 May. Three seeds were placed in each planting hole, and plants were thinned to one plant per hill, 18 days after planting.

The variety of maize utilized was Centralmex, and the variety of beans was IPA 74-19, with growth cycles of 150 days and 90 days, respectively.

During the growing period, the crops were kept weed free, and regular chemical sprayings were applied to control *Spodoptera frugiperda* and *Heliothis zea* on maize and *Empoasca kraemeri* (1957) on beans.

Each subplot of sole maize was planted with five rows, and the subplots of sole beans or maize x beans were planted with nine rows, giving thefollowing number of harvest rows for each crop:

Sole maize — Three central rows
1M : 2B — 1 row of maize and 2 rows of beans
1M: 3B — 1 row of maize and 3 rows of beans
1M: 4B — 1 row of maize and 4 rows of beans
Sole beans — Three central rows.

The moisture content of the seeds was determined at harvest time, and correction was made to 13% on beans and 15.5% on maize on a wet basis. The number of plants of each crop was counted within the harvest area.

The bean crop was harvested on 22 August and the maize crop on 23 October.

Results and Discussion

Grain Yields

Table 1 shows the grain yields for mixtures and sole crops at different population levels. The statistical analysis indicates significant differences for spatial arrangement.

Table 1 also shows significant differences for plant population in sole maize and mixture 1:3. There was no significant difference for population in the other mixtures.

The best yield advantages occurred at higher plant population levels (Table 1), which is in agreement with Willey and Osiru (1972). According to De Wit (1960), this situation takes place when the individual species utilize slightly different parts of the environment. For population 3, the best grain yields occurred in mixture 1:2, without significant difference for the mixture 1:3. In regard to population 4, the best grain yields occurred in mixture 1:2, differing statistically from the other combinations.

It can be observed in Table 1 that the yield of sole maize decreased with the increase of plant population. The difference between population 1 and population 4 reached 46.2%. This fact is explained by high competition within the same

Table 1. Yield (kg/ha) on the intercropping of maize and beans, Filadelfia (Brazil), 1978.

	Crop	Sole maize	1:2	1:3	1:4	Sole beans
Population 1	Maize	3753	1940	1361	996	—
	Beans	-	1344	1449	1576	1890
	Total	3753 Aa	3284 Aab	2810 Bbc	2572 Acd	1890 Ad
Population 2	Maize	3494	2250	2184	1698	-
	Beans	-	1083	1421	1536	2019
	Total	3494 ABa	3333 Aa	3605 Aa	3234 Aa	2019 Ab
Population 3	Maize	2904	2768	2473	1527	-
	Beans	-	1060	1233	1294	1862
	Total	2904 Bb	3828 Aa	3706 Aa	2821 Ab	1862 Ac
Population 4	Maize	2021	2852	1852	1384	-
	Beans	-	1051	1220	1286	1881
	Total	2021 Bcd	3903 Aa	3073 Ab	2670 Abc	1881 Ad

a. Within each column, means not followed by the same capital letter, and within each row, means not followed by the same small letter, are significantly different at the 5% level of probability, as determined by TUKEY test.

species, causing a reduction of the cob index with an increase of the maize plant population, varying from 1.1 in a population of 25 000 plants/ha to 0.4 in a population of 100 000 plants/ha, as shown in Table 2. Table 2 also shows that the higher cob index occurred at lower population levels and in spatial arrangements with a lower proportion of maize.

Sole beans showed a stable yield with maximum variation of 7.8% (Table 1). It is supposed that this situation could be due to the use of high plant population levels maintaining all grain yield at a population plateau. This result can be explained by the significant compensation effect of the number of pods per plant. That is, on an average, the lower population treatments produced 62.5% more pods per plant than the higher plant population (Table 3). Also, it can be seen in the same table that there was no significant difference for number of pods per plant among spatial arrangements.

Table 4 shows the land equivalent ratio (LER)

Table 2. Cob index in maize intercropped with *Phaseolus vulgaris* L., Filadelfia (Brazil), 1978.[a]

Population	Sole Maize	1:2	1:3	1:4	Mean
1	1.1	1.5	1.6	1.6	1.4 a
2	0.8	1.2	1.4	1.5	1.2 b
3	0.7	1.0	1.1	1.2	1.0 b
4	0.4	0.8	1.0	1.1	0.8 c
Mean	0.7 c	1.1 b	1.3 a	1.3 a	

a. The figures followed by the same letters are not significantly different from one another at the 5% probability level, as determined by TUKEY test.

Table 3. Number of pods per plant of *Phaseolus vulgaris* L intercropped with maize, Filadelfia (Brazil), 1978.[a]

Population	Sole Beans	1:2	1:3	1:4	Mean
1	16	17	15	15	16a
2	14	11	13	12	12 b
3	12	12	11	11	11 c
4	11	10	10	10	10 d
Mean	13a	12a	12a	12 a	

a. The figures followed by the same letters are not significantly different from one another at the 5% probability level, as determined by TUKEY test.

Table 4. Land equivalent ratio (LER) and percentage of lodging of maize plants on maize/beans intercropping, Filadelfia (Brazil), 1978.

	Sole maize	1:2			1:3			1:4		
Population	Lodging		LERs	Lodging		LERs	Lodging		LERs	Lodging
		Maize	0.52		Maize	0.36		Maize	0.26	
		Bean	0.67		Bean	0.72		Bean	0.78	
1	12	Total	1.19	3	Total	1.06	2	Total	1.04	17
		Maize	0.60		Maize	0.58		Maize	0.45	
		Bean	0.54		Bean	0.70		Bean	0.76	
2	56	Total	1.14	10	Total	1.28	12	Total	1.21	4
		Maize	0.74		Maize	0.66		Maize	0.41	
		Bean	0.52		Bean	0.61		Bean	0.64	
3	65	Total	1.26	23	Total	1.27	16	Total	1.05	15
		Maize	0.76		Maize	0.49		Maize	0.37	
		Bean	0.52		Bean	0.60		Bean	0.64	
4	97	Total	1.28	45	Total	1.09	25	Total	1.01	21

and percentage of lodging in maize. In comparing yield data of Table 1 with LER and lodging of maize contained in Table 4, it can be seen that the LER of mixture 1:2 in population 4 presents a yield advantage of 28%, with a lodging in maize of 45%. In population 2, of special note is the combination 1:3 where the LER indicates a yield advantage of 28% with a lodging in maize of 12%. In general, it can be seen that the percentage of lodging rose with the increase of plant population of maize, especially in sole maize treatments, that reached 97% at higher population level. This result is in accordance with Francis etal. (1976), in several experiments carried out at CIAT.

Competition between the Species

As shown in Table 1, in all population levels the bean yield increased as its proportion in the spatial arrangement increased. In the maize crop, the situation was the opposite. In regard to the different population levels within each spatial arrangement, the results show that the maize became increasingly competitive as population increased. These results are in agreement with those found by Willey and Osiru (1972) and Aidar (1978).

Conclusions

Considering the conditions in which the experiment was carried out, it can be concluded that:

1. Grain yield of sole maize decreased with an increase in plant population. However, bean yield remained unchanged with an increase in plant population.
2. Total grain yields in mixtures gave better advantage at higher plant population levels, especially in the spatial arrangement of 1:2 and 1:3.
3. Considering the LER and percentage of lodging in maize, it can be concluded for the conditions in which this experiment was carried out that the best spatial arrangement was 1:3, corresponding to 1 row of maize to 3 rows of beans, comprising 12 500 plants/ha of maize and 150 000 plants/ha of beans.

A further trial is suggested to confirm the results reported.

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Studies on the Intercropping of Sorghum and Corn with Phaseolus Beans (Phaseolus vulgaris) and Cowpea (*Vigna unguiculata*)

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(*Translated by T. A. Machado*)

Abstract

A study about the intercropping of corn and sorghum with cowpea (Vigna unguiculata) and beans (Phaseolus vulgaris) was carried out in the "Agreste" and "Sertao," two ecological zones of the state of Pernambuco, Brazil. The number of plant-units was the same in both the intercropping and the sole-crop systems, since one row of corn or sorghum was replaced by one row of cowpea or two rows of beans. The results clearly indicate that corn can be replaced by sorghum in intercropping cornllegume systems without damage to the legume yield. This replacement should promote a yield stability because sorghum is less affected by the weather than corn.

Intercropping is a system that aims to utilize all the environmental resources. In the intercropping of two or more crops, the following can be expected: better interception of the sunlight energy; more effective utilization of nutrients and water; risk reduction; and a higher exploration of the growing factors related to the environment (Faris et al. 1976, 1978; Osiru and Willey 1972; Willey and Osiru 1972).

Among the traditional agricultural systems utilized in the tropical semi-arid regions of the Brazilian northeast, intercropping represents a general pattern which is followed by most farmers. Frequently, the intercropping of beans and corn is used in the "Agreste" region, while in the "Sertao" region, the more usual intercropping is Moco cotton (Gossypium hirsutum L.) + corn + cowpea. At the beginning, a general idea was developed about intercropping since this system was considered an indication of underdevelopment that had to be modified as development takes place. Lately, the northeast researchers have given greater attention to this matter. Thus, Faris et al. (1976, 1978), in a preliminary study on the intercropping of corn and sorghum with cowpea and beans, where the planting density of the cereals was practically the same in both systems, report that the cereals severely reduced the legume yields and that the intercropping system was more productive than the sole crops. Lira (1978) verified that the intercropping of sorghum + corn + cotton was an advantageous one during the years with a favorable rainfall, though some kinds of intercropping were inferior in performance during the dry years.

The current study was developed with the purpose of continuing the intercropping studies and it is based on the investigations of Faris et al. (1977). Here some other objectives, as described below, are examined:

a. To study two of the intercropping systems commonly used in the tropical regions: corn + cowpea and corn + beans,
b. To study the possibility of replacing corn by sorghum in these systems,
c. To evaluate the performance of the two legumes in these systems, and
d. To determine the possible advantages between the intercropping and the sole-crop systems.

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Materials and Methods

The trials were carried out at Serra Talhada in 1976 and 1977 and in Caruaru, Aguas Belas, and Santana do Ipanema in 1977. The geographic coordinates of these locations are as follows: 8-9° S, 38° N, and 500-600-m altitude. Table 1 shows rainfall distribution during crop development in the different localities and years.

With the exception of the "coluvio" trial area, in Serra Talhada, the trials were carried out on the rocky soils which predominate in the crop production areas. In general, this kind of soil, common to the physiographic zones of the "Agreste," offers few restrictions as far as the chemical constitution (Table 2) is concerned.

In some localities — Serra Talhada and Caruaru — two trials were carried out; one was fertilized with NPK and the other was not fertilized. The applications were equivalent to 40-80-30 and 60-60-30 kg of N, P_2O_5 and K_2O per ha, in 1976 and 1977, respectively. Urea, simple superphosphate, and potassium chloride were the nutrient sources. In the fertilized trial, in Serra Talhada (1976), the P and the K were broadcast, and the N was distributed into two portions, one-third at planting time and the remainder 41 days after planting. In 1977, in both Serra Talhada and Caruaru, the fertilizer was drilled at the row sides. The N was divided into two portions in only the trial of Serra Talhada.

The cultivars utilized in the different trials were Centralmex corn; Serena sorghum in 1976, and Icapal sorghum in 1977; IPA-74-19 beans and Serido cowpea.

Table 1. Rainfall distribution (in mm) by year and locale during crop development.[a]

Month	Approximate Ten day period	1976	1977		
		Serra Talhada	Serra Talhada	Caruaru	Santana do Ipanema
1	I	82.3	–	83.9	–
	II	0.0	-	42.9	90.8
	III	18.5	18.8	46.0	74.4
	Sub total	100.8	18.8	172.8	165.6
2	I	43.3	20.5	179.0	57.8
	II	137.5	11.0	48.5	52.6
	III	5.5	4.0	25.0	49.2
	Sub total	186.3	35.5	252.5	159.6
3	I	0.0	0.8	97.0	62.4
	II	0.0	33.0	33.5	19.6
	III	4.2	39.7	64.0	53.2
	Sub total	4.2	73.5	193.5	135.2
4	I	0.0	49.5	69.0	8.0
	II	0.5	32.5	21.5	19.6
	III	0.8	69.0	42.5	16.2
	Sub total	1.3	151.0	133.0	43.8
5	I	–	97.0	8.5	8.0
	II	-	172.4	4.5	19.2
	III	-	113.5	6.0	19.8
	Sub total	-	382.9	19.0	47.0
	Total	292.6	661.7	770.8	551.2

a. Data from Agues Betas are not available.

Table 2. Analysis of the chemical characteristics of the soil types found in the trial fields.

Locality	Year	Fertilization	Characteristics P (ppm)	K (ppm)	Ca+Mg (meg%)	Al (meg%)	pH (H_2O)
Serra Talhada	1976	without			not analyzed		
Serra Talhada	1977	without	30	100	8.1	0.0	7.0
Serra Talhada	1976	with[a]			not analyzed		
Serra Talhada	1977	with[b]	30	100	9.0	0.0	6.9
Caruaru	1977	without	30	100	8.3	0.0	6.9
Caruaru	1977	with[b]	20	100	5.1	0.0	6.3
Aguas Belas	1977	without	16	66	3.3	0.0	6.4
Santana do Ipanema	1977	without	3	50	2.0	0.3	5.6

a. NPK at 40-80-30 kg N, P_2O_5, and K_2O per ha.
b. NPK at 60-60-30 kg N, P_2O_5, and K_2O per ha.

The experimental design was randomized blocks, with four replications. The eight treatments studied were:

1. Sole sorghum. Spaced rows of 0.80 m with 20 plants per linear meter (250 000 plants/ha).
2. Sorghum + beans. Sorghum planted in spaced rows of 1.60 m, with 20 plants per linear meter. Two bean rows between those of sorghum; each bean row 0.60 m from sorghum, and 0.40 m between the two bean rows. In the bean row, two hills were made with two plants in an equal distance of 0.2 m (sorghum at 125 000 plants/ha and beans at 125 000 plants/ha).
3. Sorghum + cowpea. Sorghum planted in spaced rows of 1.60 m, with 20 plants per linear meter. One bean row between those of sorghum; two plants per bean hill and 0.4 m between hills, (sorghum 125 000 plants/ha and cowpea 31 250 plants/ha).
4. Sole corn. Spacing of 0.80 m x 0.50 m; two plants per hill (50 000 plants/ha).
5. Corn + beans. Distribution of cereal and legume identical to that in treatment no. 2 (corn at 25 000 plants/ha and beans at 125 000 plants/ha).
6. Corn + cowpea. Distribution of cereal and legume the same as in treatment no. 3 (corn at 25 000 plants/ha and cowpea at 31 250 plants/ha).
7. Sole beans. 0.40 m x 0.20; two plants per hill (250 000 plants/ha).
8. Sole cowpea. 0.80 m x 0.40 m; two plants per hill (62 500 plants/ha).

In these trials, the following data were observed: stands of germination and harvesting, plant height, number of panicles and cobs, production and mean weight of the grains, number of pods per plant, and number of seeds per pod, as well as the production of sorghum and corn stover. The data were submitted to a statistical analysis in accordance with the experimental design utilized. Land productivity was also calculated by means of the land equivalent ratio.

Results and Discussion

The trials were carried out in different selected localities, but due to the influence of conditions such as time of planting and soil and fertilizing scheme, it was not possible to identify the exact effects of different environments. Thus, the trials classification "without fertilizing" and "with fertilizing" for the different localities and years will be utilized as a superficial dissimilarity of several environments.

In the trials of Serra Talhada, the beans were not considered in the evaluation since the plants died after germination in both 1976 and 1977. It seems that the decrease of the cereal productivity *in* the intercropping systems with beans, especially with sorghum, was not only caused by the population reduction (Table 3). The short time of coexistence between the legume and the cereals may have affected this latter, implying that the decrease of activity risk is not constant (Faris et al 1977; IRRI 1974). Sorghum yield was always higher than that of corn, though it gave a similar reduction in the yield of cowpea (Table 3). This legume was competitive in different ways, being more aggressive in relation to sorghum during the drier year. The stronger action on the corn may have been the consequence of the longer period of effective coexistence between the two species. This did not happen in the last year due to the drastic rainfall reduction in the phase of most active crop growth and, especially, in the reproductive phase, so that in practice corn development was restrained.

The yield analysis of the grains obtained from the trials which were carried out in the counties ("municipios") of Caruaru, Aguas Belas, and Santana do Ipanema demonstrated that, in most of the situations and almost independent of the systems, sorghum yield was higher than that of the corn (Table 4). This verifies the greater capacity of this species as related to its adaptability to the conditions of the Northeast semi-arid tropics. Beans were more competitive. It decreased the sorghum yield by 56% and that of corn by 32%. Cowpea demonstrated more ability than beans to intercrop with cereals, maybe because of its greater capacity for symbiotic N fixation. This may have decreased the competition among the species for this nutrient that is common in situations where water is not a limiting factor (Kurta et al. 1952; Agboola and Fayemi 1971).

Based on the data obtained from the trials at Caruaru, a study was made on the correlation between the legume productivity, population, and the biological components of the crop. The regression analysis demonstrated that the legume production was more dependent on the plant population than on the number of pods per plant (Table 5). On the other hand, the greater productivity of legumes from the trial which received fertilization was revealed through a higher number of pods per plant, irrespective of the cultivation system. Other biological components, such as the number of seeds per pod and the mean weight per grain, were not affected by the soil fertility level or by the cultivation system (Table 5).

In general, sorghum produced a greater quantity of stover than the corn, especially in the areas where the fertilizers were used (Table 6). In the sole-crop system, an extensive cereal stover availability was verified. This contribution of cereals is fundamentally important with regard to cattle raising in the semi-arid zones

Table 3. Grain yield (kg/ha) under different cropping systems in Serra Talhada.

		1976		1977	
Cropping system	Component	Not fertilized	Fertilized	Not fertilized	Fertilized
Sole-crop sorghum	Sorghum	1008	1331	1474	1604
Sorghum + beans	Sorghum	612	994	1498	1315
	Beans[a]	-	-	-	-
Sorghum + cowpea	Sorghum	543	856	1035	1107
	Cowpea	219	67	252	295
Sole-crop corn	Corn	284	116	1026	1117
Corn + beans	Corn	309	113	969	634
	Beans[a]	-	-	-	-
Corn + cowpea	Corn	268	92	492	634
	Cowpea	205	101	251	298
Sole-crop beans	Beans[a]	-	-	-	-
Sole-crop cowpea	Cowpea	604	332	665	747

a. Plants died after germination.

Table 4. Grain yield (kg/ha) under different cropping systems in various localities, 1977.

Cropping system	Component	Caruaru		Aguas Belas	Santana do Ipanema
		Not fertilized	Fertilized	Fertilized	Not fertilized
Sole-crop sorghum	Sorghum	3535	4969	1075	1016
Sorghum + beans	Sorghum	1484	2416	550	344
	Beans	1002	1354	258	190
Sorghum + cowpea	Sorghum	2154	2981	593	560
	Cowpea	195	416	164	130
Sole-crop com	Corn	1683	2369	396	699
Corn + beans	Corn	1255	1581	274	433
	Beans	918	1172	193	172
Com + cowpea	Corn	1432	1883	324	690
	Cowpea	258	397	69	112
Sole-crop beans	Beans	1059	2062	363	204
Sole-crop cowpea	Cowpea	441	651	300	91

Table S. Population and biological components of legume yield in different cropping systems, Caruaru, 1977.

Component	Fertilized			Not fertilized		
	Legume + sorghum	Legume + corn	Sole-crop legume	Legume + sorghum	Legume + corn	Sole-crop legume
Beans						
Stand, 1000 plants/ha	123.00	123.00	247.00	123.80	123.00	246.80
No. of pods/plant	12.69	10.76	9.82	7.99	8.81	6.01
No. of seeds/pods	4.68	4.67	4.64	4.63	4.57	4.65
Weight of a grain (g)	0.21	0.20	0.21	0.20	0.21	0.20
Grain yield (kg/ha)	1354	1172	2062	1002	918	1059
Cowpea						
Stand, 1000 plants/ha	3125	30.99	60.08	30.45	30.82	60.72
No. of pods/plants	6.74	6.04	6.39	3.96	4.39	4.19
No. of seeds/pods	11.34	11.12	11.22	10.92	11.02	9.52
Weight of a grain (g)	0.22	0.20	0.21	0.18	0.19	0.22
Grain yield (kg/ha)	416	397	651	195	258	441

where forage is usually scarce during the dry season of the year. Therefore, in an activity characterized by cattle raising, it seems that the intercropping system does not offer the same conditions which are present in a sole crop especially utilizing the sorghum. It is important to note that the bean stover, largely utilized as forage, was not computed. Maybe this fact would reduce the intercropping disadvantage.

The evaluation of the total land productivity in the different systems was partially affected by the fact that the beans failed during 2 years in Serra Talhada. In general, the results demonstrated that intercropping revealed greater advantage under conditions without water restriction. This was also verified by Fisher (19756). With the exception of Serra Talhada in 1977, the total land productivity of the inter-

Table 6. Yield (t/ha) of sorghum and corn stover in several production systems.

			Sorghum			Corn		
Locality	Year	Fertilization	Sole	With beans	With cowpea	Sole	With beans	With cowpea
Serra Talhada	1976	Without	1.64	1.02	0.99	1.88	1.00	0.98
Serra Talhada	1976	With[a]	7.50	4.10	4.23	2.31	1.85	1.36
Serra Talhada	1977	Without	13.66	9.31	7.08	2.09	1.54	1.21
Serra Talhada	1977	With[b]	20.30	12.91	11.90	2.44	1.70	1.42
Aguas Belas	1977	Without	2.65	1.12	1.05	1.18	0.64	0.66
Sertania	1977	Without	2.30	1.10	1.56	2.18	1.10	1.36
Caruaru	1977	Without	2.58	1.15	1.64	1.58	0.72	1.24
Caruaru	1977	With[b]	3.85	2.23	2.69	2.30	1.04	1.70

a. NPK at 40-80-30 kg N, P_2O_5, and K_2O per ha.
b. NPK at 60-60-30 kg N, P_2O_5, and K_2O per ha.

cropping system is higherthan that of any of the sole-crop systems, particularly the intercropping of cereal + cowpea (Table 7). Though the system corn + cowpea showed the highest land equivalent ratios, previous studies carried out in Northeast Brazil indicated that intercropping sorghum + cowpea was superior (Faris et al. 1976, 1978). The failure of beans during the 2 years and the poor performance of the intercropping sorghum + cowpea in 1976 and of corn + cowpea in 1977 did not give conditions for a satisfactory evaluation of the different systems in Serra Talhada.

The results obtained differ from those reported by Faris et al. (1976, 1978) who found a smaller reduction of the cereal productivity capacity and a greater total land productivity in the intercropping systems. The number and the disposition of the components were different in these two studies. Faris et al. (1976,1978) added legumes to a cereal population, while in these trials, one row of corn or sorghum was replaced by one row of legume, keeping the same number of plant-units in the intercropping and sole-crop systems, according to Willey and Osiru (1972). In this way, the competition effect of the species was reduced, but it decreased the beneficial effect ofthe intercropping.

Table 7. Land equivalent ratio.

	Serra Talhada		Mean figures of the other locations, in
Cropping system	1976	1977	1977
Sole-crop sorghum	1	1	1
Sorghum + beans			1.25
Sorghum + cowpea	0.87	1.07	1.34
Sole-crop corn	1	1	1
Corn + beans			1.38
Corn + cowpea	1.18	0.87	1.58

The results obtained suggest the following conclusions:

1. Corn can be replaced by sorghum in the intercropping of corn + legume, without damaging the productive capacity of the legume.
2. This replacement will permit a greater stability of the production, since sorghum is less influenced by the climatic conditions.
3. When the contribution of cereal stover is important, a sole-crop, using fertilized sorghum, offers a higher stover production.
4. Beans (*Phaseolus vulgaris*) are not adapted to the conditions of Serra Talhada. However, they were superior to cowpea in the other localities.

Population, Time, and Crop Mixtures

E. F. I. Baker*

Abstract

The effects of plant-population change within crop mixtures are briefly reviewed, particularly with reference to mixtures of cereals. Yield gain in such mixtures was because yield per plant increased; harvest index did not change.

ft is suggested that replacement mixtures consist generally of crops from the same phenological group and that yield gain in such mixtures is from a simple response to "reduced" plant population because of complementarity in space, time, or both. It is shown that yield may be further increased when plant population is increased by an amount proportional to the difference in plant size and length of season.

This contrasts with superimposed mixtures which generally consist of crops from different phenological groups. In these mixtures, yield of the determinate component (almost always a cereal) does not differ from that of the sole crop, whereas the yield of the indeterminate component is dependent upon the rate of recovery during the reproductive phase once the cereal has been removed. Harvest index of the indeterminate component is much increased and the plant is reduced in size because of competition during the vegetative phase.

In superimposed mixtures, population of the determinate component should remain the same as the sole crop, whereas that of the indeterminate crop may need to be raised above that of the sole crop by an amount dependent upon the canopy cover remaining after the cereal has been removed.

Thus, genotypes for replacement mixtures should show a very plastic response to population change whereas indeterminate components of superimposed mixtures should show a rapid recovery from competition in the vegetative phase by compensation during the reproductive phase of growth.

The practice of mixing crops together in the same space and at the same time has been with the agricultural world for a very long time, whatever may have been, or may be, the reasons for the system. That there are sound practical reasons for mixed cropping is no longer disputable. Norman (1972) showed that in Nigeria variability of annual returns from crop mixtures was less than that from sole crops; Norman also collected data which demonstrated that labor was more uniformly used through the season under mixed cropping, as did Aiyer (1949). Other reasons included the speculative use of atmospheric N by cereals when mixed with legumes. Experiments on this were begun many years ago. This aspect is again receiving much attention. There was, in fact a large amount of work done with crop mixtures in the earlier part of this century; for example, there were some 300 experiments at the Institute of Agricultural Research, Nigeria, between 1924 and 1960. However, interest has been spasmodic until recently, possibly because of the difficulties of experimentation, or, possibly because subsistence agriculture (and mixed cropping is the mainstay of subsistence agriculture) has often been regarded only as a nuisance that must be tolerated to feed the farmer and of no interest to "real" agriculture. In any event, there is now widespread recognition that the ability to expand world food supplies will depend largely upon increasing food production by subsistence farmers of the tropics. Consequently, the number of investiga-

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tions on mixed cropping has increased greatly during the past decade (Kass 1978), not only because of the need to increase food production but also because serious questions are being asked as to whether the practice gives better returns than sole cropping and whether, in fact, it is a more efficient way of utilizing environmental resources than sole cropping.

One of the great difficulties confronting those who work with crop mixtures is the almost infinite variety of crops, proportions of each crop, and arrangements of crop within mixtures. The search for patterns, and thence for principles, has been beset by the vast array of mixtures and such statements as "crops are usually planted in a random fashion" (Kass 1978). Nevertheless, if an understanding is to come, there must be a pattern, and a precursor is some form of classification.

Kass listed a range of terms used by various authors to describe the practice of growing two or more crops together simultaneously, and concluded that the term "polyculture" suitably contrasts with "monoculture," the growing of crops in pure stands. The difference between concepts of poly- and monoculture is but one of degree, since the yield of a *plant,* given nonlimiting resources and freedom from pests and diseases, is a function of the genetic makeup of that plant, while the yield of a *crop* is a function of the ability of individual plants to maintain that yield when receiving interference from neighboring plants. Thus, under monoculture, neighboring plants are of the same genotype throughout the entire growing period, whereas under polyculture at least one neighboring plant is of a different genotype, although not necessarily for the entire growing period.

Within polyculture there are two broad classifications of mixtures. One is the *replacement mixture,* wherein one genotype replaces a proportion of another genotype. It is this group that has been most thoroughly dealt with in the literature (de Wit 1960; Donald 1963; Trenbath 1974a). In this mixture it is assumed that competing genotypes would divide a constant environment, and it is implicit in the models developed for replacement mixtures that requirements from the environment by genotypes are similar. Such mixtures are generally of "like" genotypes. The second is the *superimposed or additive* mixture. In these mixtures, one genotype is added to the other (or others) so that the final plant population is considerably more than had either genotype been sown sole. These mixtures generally consist of "unlike" types.

Three broad phenological classes of crops can be distinguished:

1. Those in which yield is produced throughout the season because it is accumulated in vegetative parts (roots, tea, etc.).
2. Indeterminate types, especially those nonphotoperiodic (pulses, oilseeds, possibly groundnuts, and prolific maize).
3. Determinate types where yield is produced in terminal or late-formed inflorescences (dominated by cereals). No more leaves can be formed once the apical bud of the shoot becomes reproductive, and sources for grain filling are the latest formed leaves.

It is suggested that replacement mixtures generally consist of mixtures from within one of these groups of phenologic types, whereas genotypes in superimposed mixtures are usually drawn from different phenological groups.

Replacement Mixtures

In mixtures of this type, overyielding (a total yield higher than that of the highest yielding component) is likely to be the exception rather than the rule. Trenbath (1974b), for example, found only four cases of significant overyielding from published data on 572 mixtures; none of these mixtures consisted *of* mixtures of genotypes from different phenological groups. Where beneficial results from replacement mixtures have been obtained (that is, where LERs exceed unity), it has been because the environment for the genotypes has not been constant. For example, where disease may reduce one component, and the other compensates from having a greater share of the environment (de Wit 1960; Fisher 1978), or where similar requirements are needed at different times. Such is the case where cereals have different growth rates, and it is this mixture which is exploited by subsistence farmers of northern Nigeria. These farmers sow millet and sorghum as a replacement mixture, millet being sown very early with the first rains and the sorghum intersown later when the rains become more reliable. Thus, they adopt a strategy of a low population of a short-season millet grown on early, unreliable rainfall, followed by a full stand when long-season sorghum is intersown, and leaving a low population (after the millet has been harvested) to mature on stored moisture at the end of the season. Because this mixture is dominant in this part of Nigeria (Norman 1972) it has received more attention than others at IAR (Institute for Agricultural Research). Andrews (1972) showed that the mixture gave better returns than either sole-cropped sorghum or relay cropping of millet and cowpea. He concluded that the main source of gain came from sowing early- and late-maturing crops together, since no one crop could efficiently utilize the entire wet season. This work was extended to consider the importance of crop stature and different growth cycles on the gain from mixing. A selection of cereal genotypes, with growing periods ranging from 75 to 160 days, were mixed in all combinations of pairs in a 1:1 ratio (15 mixtures and 6 sole crops). As a measure of yield gain, the "reciprocity" of McGilchrist and Trenbath (1971) was used. This can be written:

$$\text{Reciprocity} = \left[\left(\frac{Y_{ij}}{Y_{ii}} + \frac{Y_{ji}}{Y_{jj}}\right)/2\right] - 1$$

where Y_{ij} = yield of crop i grown with crop j
Y_{ii} = yield of crop i grown sole
Y_{ji} = yield of crop j grown with crop i
Y_{jj} = yield of crop j grown sole

It is comparable with the land equivalent ratio (LER).

It was found that 83% of the variation in reciprocity was accounted for by the difference in days to harvest, showing that there was a gain from mixing when cereal genotypes differed by at least 43 days between harvests and that the gain increased as the difference became larger. Further, it was shown that the gain was due to larger ears (maize) or more grain from an increase in the number of tillers (millet), both normal responses to a decrease in plant population. There was no evidence of any change in harvest index. Table 1 gives harvest indices for the cereals grown mixed and sole.

In a second series of experiments, using seven varieties of sorghum chosen so that they either matured at the same time but were of different heights at maturity, or matured at the same time but were of the same height, it was demonstrated that 68% of the variation between varietal gains was associated with the linear components for height and age differences at harvest. Yield of a variety was higher in mixtures if height at harvest differed by more than 0.59 m, and age by more than 51 days. Thus, provided the upper part of the canopy, particularly the flag and upper leaves known to contribute most to grain production, experienced reduced interference from neighbors during the 40-50-day period from ear-head initiation to grain maturity, either because of difference in height or because one crop had been removed, then yield gain was obtained over the sole-crop yield. This is more clearly shown by Figure 1, which shows height curves with time for five cereals (Ex-Borno millet, Bomo local maize, S 123 maize, 096 maize, and

Table 1. Harvest indices for six cereal genotypes grown in mixtures with one another and grown sole.

	Grown with					
Cereal	Ex-Ghana millet	Ex-Borno millet	Bomo local maize	S 123 maize	0 96 maize	Short Kaura sorghum
Ex-Ghana millet	.34	.36	.33	.42	.43	.36
Ex-Borno millet	.37	.33	.37	.36	.35	.35
Borno local maize	.39	.33	.39	.38	.39	.36
S 123 maize	.48	.49	.49	.44	.49	.41
0 96 maize	.32	.29	.35	.32	.34	.32
Short *Kaura* sorghum	.25	.26	.24	.27	*.22*	.23

Differences between harvest indices for each genotype were not significant.

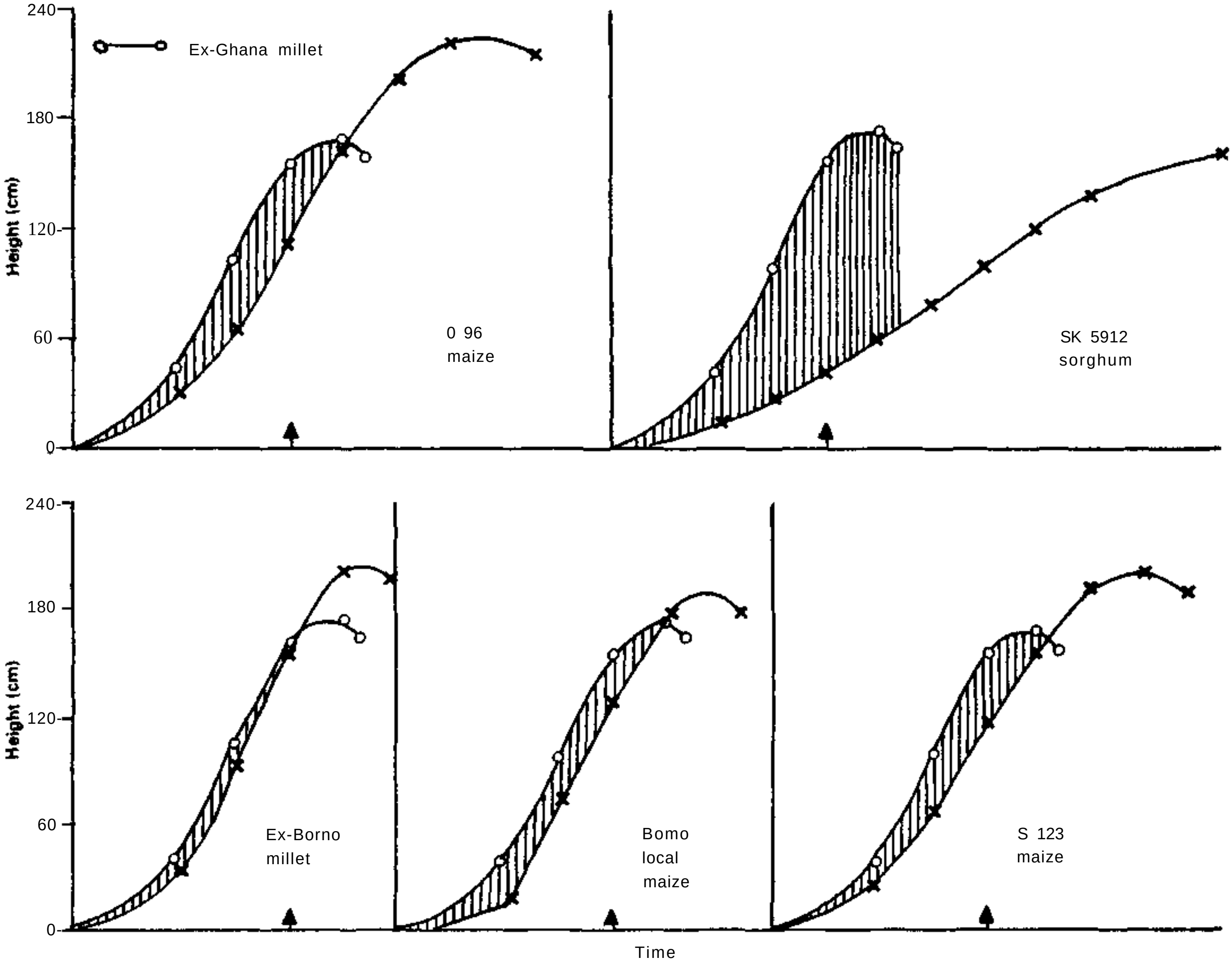

Figure 1. Height curves with time for five cereals compared with Ex-Ghana millet.

Short Kaura sorghum) compared with height curves for Ex-Ghana millet with which each was mixed. The correlation between accumulated excess in height of Ex-Ghana millet over the other cereal in the mixture was highly significant (r=0.9456, P<0.015). In such mixtures, yield gain by the components relates to difference in height for the early cereal and the period for which plant population is reduced for the latter.

In all the experiments described above, each cereal was sown at a spacing the same as that normally used for that cereal when sown sole. Thus yield gain from mixing was because individual plants yielded more. Yield per unit area *(Y)* is a function of yield per plant (y) and the number of plants *(P).* Simply, $Y = yP$. An optimum population is one which maximizes Y, and where cereals are concerned, this falls on a second-degree curve (Duncan 1958; Holliday 1960). Any shift from optimal population will result in a decrease in *Y,* although *y* will increase or decrease depending upon which direction population is moved. In cereals, grain per plant will increase if population is lowered, and it is argued, therefore, that in the experiments described, plant population in the mixture was suboptimal compared with the sole crop for one or both of the components because of decreased interplant competition resulting from complementary plant habits. That is, the part of the early cereal which is above the canopy of its neighbor is at half the sole-crop population, and all of the later cereal is at half the sole-crop population after the earlier cereal has been harvested.

To test this further, two series of experiments were carried out at IAR. The first attempted to relate population for a mixture with different lengths of season of the components by considering population over the whole season (the length of season of the longest component). Thus:

$$\bar{P} = \frac{\frac{1}{2}M_1(P_1 + P_2) + \frac{1}{2}P_2(M_2 - M_1)}{M_2}$$

$$= \frac{M_1P_1 + M_2P_2}{2M_2} \quad (1)$$

where M_1 and M_2 are the number of days to harvest of each component, and P_1 and P_2 are the proportions of sole crop "optimum" populations, respectively. For example, a 1:1 mixture of 096 maize and Short Kaura sorghum, with each sown at sole crop optimum spacing would have:

$$\bar{P} = \frac{120(1) + 160(1)}{320} = 0.875$$

Five spacings for both 096 maize and Short Kaura sorghum were chosen to give a range of P from 0.5 to 1.3. In addition, each crop was sown sole at the same spacings. The trials were done over a 3-year period. Table 2 gives LERs for the 25 mixtures, with LER based upon the maximum sole crop for each crop as determined from sole-crop population curves.

The shape of the population response curve was the same whether the cereals were sown mixed or sole, but that for maize showed a maximum at a spacing equivalent to 60 000 plants/ha compared with 48 000 plants/ha for sole maize. Sorghum optimum population in the mixture differed only slightly from that for the sole crop. In thetable above, maximum LER was obtained when maize was sown at a spacing to give 56 000 plants/ha, and sorghum 51 000 plants/ha. These spacings would give P = 0.99. Thus, as a crude guideline for recommendations to farmers (and all our work at IAR leads to this), one should simply raise the population of the early cereal so that population "through the season" becomes unity. In these trials, sorghum, which initiated flowering well before maize was harvested, could not compensate for the subsequently reduced population, possibly because this variety uses only that N taken up before flowering for growth of the head (Kassam 1973).

Earlier experiments having shown that yield gain was related to difference in height between components, a second series of experiments was designed to investigate this by growing six varieties of maize, of different ear heights, with Short Kaura sorghum. To keep the experiment within manageable proportions, use was made of the linear relationship between maize yield per plant and population (Duncan 1958), thus allowing a population response to be derived from two points. For added precision, a third population was included. Sorghum was sown at a constant population, and all mixtures were sown at a 1:1 ratio on an area basis. Spacings for maize along the row were chosen to give populations of approximately 12 000, 24 000, and 48 000 plants/ha. Results are given in Tables 3 and 4.

The first point of interest is that the population at which yield would have been a maximum (*Pmax*) is negatively correlated with ear height ($r = -0.7659$, $P<0.06$). This is to be expected since large plants would reach a maximum yield at a lower population than small plants; maize plant height is approxi-

Table 2. LER for maize/sorghum mixtures based upon maximum sole-crop yield.

Proportion of maize sole-crop population	Proportion of sorghum sole-crop population				
	0.65	0.85	1.05	1.25	1.45
0.53	0.90	1.00	1.27	1.07	1.16
0.80	0.97	1.16	1.26	1.24	1.11
1.06	1.07	1.33	1.29	1.26	1.21
1.33	1.31	1.34	1.08	1.12	1.23
1.60	1.13	1.12	1.09	1.12	1.13

Table 3. Maize grain yield, mean of 2 yaars, for three populations, and calculated population at which yield would have been a maximum (P_{max}).

Variety[a]	Cropping system[b]	Ear height (m)	Population (plants/ha) 12 000	24 000	48 000	P_{max}
UVE	S	0.71	1391	2546	4048	71 120
	M		1687	2814	4740	67 742
BL	S	1.03	1357	2303	3430	54 622
	M		1324	2244	3736	68 833
NCB	S	1.11	2258	3306	4734	44 127
	M		2177	3386	5249	51 712
BY	S	1.00	1243	2332	3344	60 552
	M		1269	2220	3374	59 102
NCA	S	1.08	1601	2707	4437	65 157
	M		1647	2291	4575	68 500
0 96	S	1.43	2276	3804	5140	47 250
	M		2074	3463	5953	71 167

a. UVE - Upper Volta early; BL = Bomo local; NCB = Nigeria Composite B; BY - Biu Yellow; NCA = Nigerian Composite A; 0 96 - Orin 96.
b. S = sole, M = mixed.

Table 4. Length of season, ear height, ratio of calculated maximum maize population to calculated maximum sole population, and calculated maximum *P*.

Variety*	Season (days)	Ear height (m)	*Pmax (M)IPmax(S)*	Pmax
UVE	80	0.71	0.95	0.74
BL	90	1.03	1.26	0.85
NCB	100	1.11	1.17	0.87
BY	105	1.00	0.98	0.82
NCA	115	1.08	1.05	0.88
0 96	120	1.43	1.51	1.07

a. See footnote *a,* Table 3.

mately double ear height, which was measured from 10 random plants of each plot of sole-crop maize at 48 000 plants/ha. Secondly, the ratio *P*max(M)/*P*max(s) was positively correlated (r = 0.8613, P < 0.03) with ear height (H). That is, the extentto which plant population for maize in the mixture required raising to maximize yield was proportional to ear height. However, it was the relationship between *Pmax* (the value obtained by substituting Pmax(m)/Pmax(s) for P1 in equation (1) and ear height which may be of most interest. This was:

$$Pmax = 0.38 + 046H \quad (r = 0.9755, \; P = 0.001).$$

Thus, by substituting this relationship in equation (1), and rearranging terms, an equation is derived which may be used to determine plant population at which maize of known length of season and ear height should be grown with Short Kaura sorghum. This was:

$$P\ \text{maize} = \frac{2M_2\ (0.38 + 0.46H) - M_2P_2}{M_1} \qquad (2)$$

This is, of course, an empirical relationship. Also, ear height is a plastic character which may vary from season to season. However, relative ear height of genotypes may be more constant (correlation between ear heights for the 2 years = 0.8993, $P < 0.04$), and the equation may be a useful guide. A further criticism, and seen in Table 3, is that many of the calculated optimal populations were outside the range of experimental treatments, always a dangerous situation from which to infer results. For this reason, the second year included an additional, high, population of approximately 90 000 plants/ha. An analysis of that year's data, including the high population, gave results similar to those from the three populations of both years ($P_{max} = 0.55 + 0.30H$, $r = 0.6814$, $P < 0.1$), although clearly there is much variability.

Superimposed Mixtures

There is considerably less information in the literature concerningthese mixtures, particularly where plant population is concerned. Where they have been described, they consist predominantly of mixtures of unlike phenological types, e.g., cereallegume.

While the same principles apply to these mixtures, that yield gain is associated with freedom from competition during the reproductive phases, the manner in which that gain is achieved is different. Table 1 has indicated that gain in yield of cereals in a mixture is not due to a change in harvest index. The same may well be true of cereals when grown in superimposed mixtures with noncereals. Table 5 gives yields and total dry matter for cowpea and sorghum.

Sole sorghum was not grown in this experiment, and, although harvest indices were high, they were not affected by treatments.

Harvest index of cowpea showed a considerable increase from being grown in the mixture. Similar results were obtained at ICRISAT (unpublished) with a mixture of maize and pigeonpea. Harvest index of pigeonpea increased from 0.17 to 0.30 when grown in mixture. There was no evidence of any change in the harvest index of maize. In these experiments, competition during the vegetative phase reduced total dry matter of the legume, reduced the number of branches, and changed the "shape" of the plant. Yield from the legume was obtained by very considerable compensation in the reproductive phase, resulting in an increased harvest index, the amount of compensation being dependent upon the amount of freedom from competition during the reproductive period.

Tables 6 and 7 show yields of cowpea and cotton when grown with cereal genotypes of different seasons to maturity. All cowpeas were sown under maize 6 weeks after sowing maize. In the experiment shown, branching was reduced and flowering delayed by up to 10 days, and may be up to 14 days.

In the cotton experiment, sympodia production was reduced and delayed by an amount depending upon harvest date of the cereal and date of sowing of the cotton. Table 8 shows sympodia produced by cotton at 27 September 1976 as a percentage of the total number finally produced.

Delay in the production of sympodia, and consequently bolls, resulted in a reduction in yield but a narrowing of the picking period.

Table 5. Grain yield, total dry matter, and harvest index for cowpea and sorghum.

	Grain yield (kg/ha)		Total dry matter (kg/ha)		Harvest index	
Treatment[a]	Cowpea	Sorghum	Cowpea	Sorghum	Cowpea	Sorghum
A	242	4006	720	6840	0.34	0.59
B	793	3841	1420	6420	0.56	0.59
C	572	3532	1140	5860	0.50	0.60
Sole	723		2585		0.28	

a. A, B, and C refer to alternating cowpea and sorghum singly, or as clumped pairs or threes along the ridge.

Table 6. Yield (kg/ha) of eight cowpea varieties grown underthree varieties of maize.

Cowpea variety	Maize variety UVE	S 123	0 96
7	915	134	141
588/2	442	468	391
3	374	111	143
2479	1381	538	400
593	515	551	302
556/2	937	305	255
1696	1859	752	430
TVU 4557	514	267	148
Mean	867	391	141
Maturity (days)	75	110	120

Cotton was picked over a 68-day period for the first sowing date; no cotton was available for picking during the first 34 days of this period for the last sowing date, and all cotton was picked during the last 34 days.

In none of the experiments described in Tables 6, 7, and 8 was the cereal yield affected by mixing with a nonlegume. Thus, in these mixtures "overyielding" can be expected and LERs are generally much higher than those obtained from replacement mixtures. Subsistence farmers, in fact, insist that in these mixtures the cereal yield must *not* be affected.

Summary

Although I have not been able to describe much of the effects of population change within mixtures, nor of the effects of date, I have tried to

Table 7. Yields (kg/ha) of cotton sown at four dates within four cereal genotypes.

Sowing date	Cereal Ex-Ghana millet	Ex-Borno millet	Bomo local maize	R 960 Sorghum	No cereal
With cereal	1534	1035	760	658	2490
21 days later	746	633	529	323	1257
42 days later	610	353	106	20	1281
63 days later	284	178	69	3	722
Mean	794	550	481	251	
Maturity (days)	75	85	90	106	

Table 8. Sympodia produced by cotton on 27 September 1976 as a percentage of the number finally produced.

Date sown	Cereal Ex-Ghana millet	Ex-Borno millet	Bomo local maize	R 960 sorghum
7 June	88.7	68.8	52.4	60.7
28 June	53.4	25.2	21.7	16.4
19 July	26.3	16.2	0	0
9 August	39.5	0.8	0	0

generalize two classes of mixture and to differentiate between two types of response to mixing. In the first class of mixture, almost always mixtures of cereals, gain is associated with reduced competition during the reproductive phase as a consequence of a "reduced" plant population. Gain in yield is obtained from a larger plant but the same harvest index, a typical response to a lowered population, and a formula can be evolved to determine the extent to which population needs to be raised to maximize LER. In the second class of mixture, superimposed mixtures of cereals and noncereals, yield gain is also associated with freedom from competition during the reproductive phase; but, whereas the cereal yield remains constant with a constant harvest index, yield from the noncereal comes from a very much increased harvest index and a very much smaller plant. In the examples described, branching of the noncereal is reduced and may be completely suppressed, resulting in a different "shape" of plant. In these cases, there is considerable scope for increasing plant population of the noncereal. In the ICRISAT maize/pigeonpea mixture the pigeonpea canopy never closed and the population should be raised accordingly. In the cotton experiment, light interception at ground level was almost complete at harvest for sole cotton, but less than 60% under mixed cotton after maize had been harvested. Similarly, population of cotton should be raised above that of the sole crop.

It is to be inferred that in replacement mixtures the best genotypes for mixing would be those with a very plastic response to population change; in the superimposed mixtures the best genotypes of noncereals would be those which can make a very rapid recovery in the reproductivephaseoncecompetition has been removed.

Cereal-based Intercropping Systems for the West African Semi-Arid Tropics, Particularly Upper Volta

W. A. Stoop*

Abstract

The West African semi-arid tropics are characterized by a rainy season of 3 to 6 months with often erratic, high-intensity rainfall showers. This, in combination with fragile, low-fertility, sandy soils, which are sensitive to acidification by acid fertilizers and to erosion by wind and water, provides a delicate environment for agricultural improvement.

The traditional cereal/legume cropping systems based on photosensitive tall, tillering sorghum and millet varieties in combination with photosensitive spreading cowpea, are well adapted to early planting and thus provide an effective soil coverage early in the season. Moreover, with the aid of various crop combinations—e.g., millet cowpea or sorghum cowpea—the full length of the season both for poor, shallow and for good, deep soils is utilized.

With the introduction of improved sorghum, millet, and cowpea varieties, often with very different plant types and maturity cycles than the local materials, it is possible to develop more productive cereal cowpea cropping systems. However, it is importantthat such improved cropping systems also have the stability typical for the traditional system. This involves, among other things, adaptation to different major soil types (shallow and deep soils), effective soil coverage, and yield stability even at fairly low "plant populations.

In the West African semi-arid tropics, intercropping has been for centuries the traditional practice followed by the great majority of farmers.

However, with the arrival of commercial crops (such as groundnut and cotton) and the accompanying "modern" crop-management techniques (planting in lines; chemical fertilizer and insecticide applications; animal traction), a trend away from intercropping was established. In certain cases, this trend was further reinforced by land development and land resettling programs, which have made farmer credits conditional on following the prescribed practices.

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But within the framework of weak national economies, subsistence types of agriculture and the frequent absence of reliable road systems, it is questionable whether the modernization of agriculture should be achieved through greater reliance on imported inputs and away from such traditional techniques as intercropping.

Moreover, the majority of soils in the area are rather fragile; they are vulnerable to considerable erosion by wind and water and also to rapid acidification when regularly using chemical fertilizers such as urea, ammonium sulfate, concentrated superphosphates, etc. (Jones 1976). With the change from shifting cultivation to semipermanent and permanent cropping, which presently occurs, these problems will likely become even more serious (Ruthenberg 1974; Marchal 1977).

In these respects, intercropping offers important advantages because it exploits effectively the various elements of the environments (e.g., soil, moisture, light, and nutrients), the temporal factors, and the limited labor resources (Norman 1975). Most attractively, these advantages are achieved without extra costs or risks to the farmer.

With the introduction of new sorghum, millet, and cowpea varieties, often with shorter maturity cycles and different plant types than the traditional varieties, a whole new array of intercropping possibilities is opening up. It is importantthat these new intercropping combinations are not only superior in yield but have at least the same yield stability as traditional systems.

In this paper, certain aspects of thetraditional systems and reasons for their stability will be discussed and contrasted with some improved systems within the context of West African agriculture.

For this purpose, frequent references will be made to the environmental conditions in the central and northern zones of Upper Volta, where most of the ongoing intercropping research by the ICRISAT West African Program is taking place. Therefore I will start with a short introduction about the prevailing climate and soils in that area.

Physical Environment for Upper Volta

Climate

Upper Volta, which falls in the Sudanian climatic zone, can be subdivided into three major climatic zones based on the length of the rainy season (Table 1). For all zones the rainfall follows basically a unimodal distribution, starting in April and gradually building up to reach a maximum in August, then often abruptly ending by the end of September.

The onset of the rains is quite variable from year to year. For instance, for the central zone (including the Ouagadougou area) it has been shown that once every 4 years the rains will be established by the first week of June or earlier; also once out of 4 years this happens only at the last week of June or later.

The months of April and May just prior *to* the onset of the rains, as well as the month of October, are characterized by high temperatures (mean maximum >38°C) and peaks in evapotranspiration. During the dry winter months, differences between day and night temperatures become very large with maximum temperatures around 33 to 35°C and minimum temperatures between 10 and 15°C.

Soils

Apart from some relatively small areas with black soils (Vertisols) the majority of soils are sandy to various degrees mainly belonging to the Alfisol order.

In the Sahelian zone, dune formations occur with deep sandy soils of wind-blown origin. Depending on their relative position on the slopes, the soil-moisture characteristics will be more or less favorable, with a risk of inundation for the lowlying areas.

In the gently undulating central zone, three major soil types, which closely follow the topography, can be recognized:

1. Shallow (< 50 cm deep), gravelly sandy loam soils over laterite on the plateau and upper slopes.
2. Fairly deep (50-100 cm) sandy loam to

Table 1. Characterization of the rainfall pattern in three major ecological zones in Upper Volta.

Ecological zone	Mean annual rainfall (mm)	Approx. start of rainy season	Duration of rainy season (months)	Approx. no. of rainy days	Peak rainfall months
South Sudanian zone	>1000	May	5 to 6	80 to 95	July, Aug, Sept
North Sudanian zone	650-1000	June	4 to 5	60 to 70	July, Aug
Sahelian zone	< 650	July	2.5 to 4	40 to 50	Aug

loamy sand often gravelly soils on the slopes.

3. Deep (> 100 cm), sandy loam soils of the lower slopes which extend into the swamps *(bas fonds)* and then show hydromorphic characteristics.

The moisture-storage capacity is of course very limited in the shallow soils, but reaches values between 100 and 150 mm for the deep soils. Though the moisture-storage capacity is reasonable, many soils have weak structures in the topsoil due to low organic-matter content, thus causing serious crusting of the soil surface, which greatly reduces water infiltration rates and increases runoff rates.

From a chemical point of view, all these soils *are* very poor: P and N deficiencies are widespread, followed by K deficiencies and probably lack of a range of microelements. The decrease in soil fertility is further aggravated by the increasing demands for land because of population pressure. As a result, the length of the fallow periods has been reduced, but also unsuitable areas with shallow soils have been cleared for agricultural purposes, as described by Marchal (1977) for the Yatengo area, in Upper Volta.

Traditional Cropping Patterns: Local Varieties

Prevailing cropping patterns are closely linked to the climatic zones. Thus, going from the extreme south to the north, one passes through, respectively, the maize/sorghum, then the sorghum/millet, and finally the millet zones.

In addition to this broad division, which corresponds to the rainfall pattern (Table 1), there is also a more intricate cropping pattern within each zone which is closely linked to soil types.

Interactions between Soil Types and Cropping Patterns

The relationship between soil type and cropping pattern forthe central part of Upper Volta is schematically represented in Table 2. The same pattern with certain minor modifications will also occur in the other zones as well as in the neighboring countries.

In this setup, planting of the best and deepest soils (near the *bas fonds* or the well-manured plots near the houses) is started with the first rains after the end of April. The crops involved will be mainly photosensitive varieties of sorghum, millet, cowpea, and early maize.

Gradually, the planting operation moves to the poorer and shallower soils, while replanting earlier seedings when necessary. Finally, after the cereal plantings are completed, early groundnuts are planted at the beginning of July, and the planting operation is concluded with the transplanting of millet and rice, the latter when sufficient water has accumulated in the *bas fonds.* In this way, the peak labor requirements for planting and weeding are spread out as effectively as possible, while the full length of the cropping season is utilized to a maximum for each specific soil condition. Obviously, the better the soil in terms of fertility and water-holding capacity, the less will be the risks involved in planting early when the rains are still very irregular. Moreover, residual moisture will be available at the end of the season (during the dry October and November months) to support the crop, particularly sorghum, when it is in the grain-filling stage.

Adaptation of Local Varieties to Different Cropping Patterns

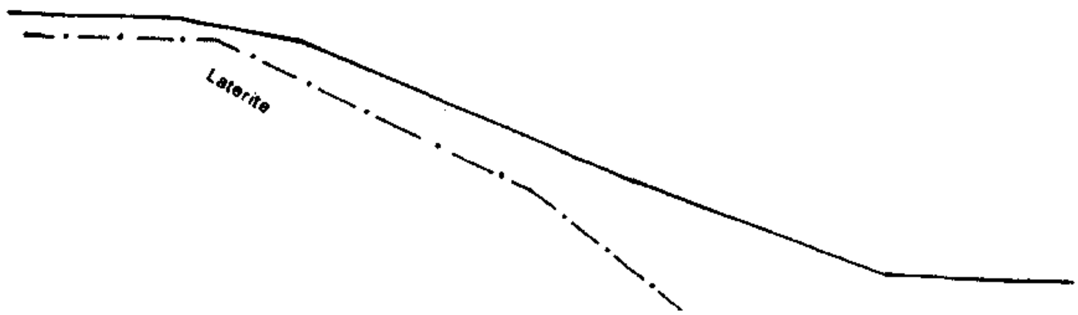
The local sorghum, millet, and cowpea varieties are photosensitive and, thrus, well adapted to early planting and repeated planting in the same field up to a certain date. Beyond that date (for central Upper Volta around the third week of June) serious yield losses will occur, irrespective of higher plant populations (Table 3).

Moreover, the local sorghum and millet varieties, when planted early, tiller profusely and produce large panicles, thus effectively compensating for missing plants. This effect is demonstrated in Table 3, forthe early planting date in which 80% of the sorghum plants were lost due to a 3-week drought in June. Very similar results have been obtained for millet and cowpea (Stoop 1978, 1979).

In addition to millet and sorghum, virtually all local fields have a small population of spreading, photosensitive cowpeas, which will provide a soil coverage in those open spots, where the cereals did not succeed. Summarizing, the combination of tillering cereals with spreading cowpeas is well adapted to early planting because of its ability to fill the available space

Table 2. Schematic relationships between soils and traditional patterns with local crop varieties for central zone of Upper Volta.

	Plateau and upper slopes	Slopes	Lower slopes and *bas fonds*
Physiography			



	Plateau and upper slopes	Slopes	Lower slopes and *bas fonds*
Soil type	Shallow gravelly sandy loam over laterite	Intermediate to deep, sometimes gravelly sandy loam	Deep sandy loam
Drainage	Well drained	Well drained	Temporarily waterlogged
Drought risk	Sensitive to drought	Moderately sensitive to drought	Little drought risk
Soil depth	<50 cm	50 to 100 cm	100 cm
Major crops and relative planting dates	Millet (II, III, IV)	Millet (I, II) early sorghum	Late sorghum (I)
	Early cowpea (II) groundnut (III)	Early cowpea (II)	Late cowpea (X) Early maize (X) Rice (XV)
Approx. harvesting time	October	October/November Maize in August	

a. Planting times: I = With first rains starting from end April (also planting of well-manured plots near dwelling on the plateau).
II = May/early June.
III = End June/early July.
IV = End July (mainly transplanting rice and millet).

effectively even at relatively low plant populations and to provide an early soil coverage. Both these factors also *favorably* reduce the *labor* needs for planting and weeding.

With respect to varieties, both short- and long-cycle photosensitive local varieties of sorghum and cowpea are available; the short-cycle ones are generally for use on shallow upland soils, and the full-cycle ones for the deep soils.

An interesting situation occurs at the lower end of the slopes near the *bas fonds* where sorghum, cowpea, maize, and rice meet (Table 2). With the first heavy shower toward the end of April, an early maize variety is planted. At the upper part, the maize will occur in association with the *full-cycle* sorghum/cowpea crop and *at* the lower end, sequential cropping with rice will be practiced. In years with abundant early rains, as in the 1978 season, the rice may even be put in as a relay crop by mid-July.

Some Other Aspects of Cereal/ Cowpea Intercropping

It has been estimated that in order to meet his daily calorie requirements a person would need

Table 3. Aspects of yield stability in the improved local sorghum variety 'Ouedezoure', grown during the 1977 season at Kaibo.

Component	Date of planting		
	3 June	28 June	17 July
Intended plant population (plants/ha)	90 000	90 000	90 000
Plant population at harvest (plants/ha)	16 800	91 000	87 000
Flowering date	14 Oct	14 Oct	17 Oct
No. of panicles/plant	3.42	2.07	1.42
Panicle weight (g)	140	33	54
Total grain yield (kg/ha)	1940	1600	1590

Source: AW 1978

245 kg cereal plus 30 kg grain legumes per year (AW 1978). This includes an assumed 10% grain loss during storage.

These estimates correspond rather nicely with the field observation that farmers are primarily interested in the cereal crop and that the cowpea in the mixture is more or less viewed as a bonus.

Nevertheless, this bonus, provided by local spreading cowpea, probably has important secondary effects under the low-input, traditional farming system. The following aspects may not contribute all that much to annual yield gains (therefore their effects are difficult to quantify), but they will contribute almost certainly in the long run:

1. Soil fertility maintenance resulting from N fixation by the legume.
2. Soil protection by providing additional soil coverage, thus reducing erosion, runoff, soil compaction due to raindrop impact, and crusting.

In addition, the spreading cowpea will effectively compete with weeds.

On the other hand, cowpea's susceptibility to insect pests in the absence of chemical control measures is well known. Observations in Upper Volta indicate that the attack of thrips *(Taenio thrips sjostedti)* and maruca *(Maruca testulalis)* is particularly severe during August and September and has catastrophic effects in both sole and intercropped cowpea when following the high plant populations recommended for chemically treated sole stands aimed at producing maximum yield.

To reduce insect damage in the absence of chemical control measures (the cereal intercropping situation), one has a choice from the following options:

a. Early planting of early, nonphotosensitive varieties which escape the major insect attack, even when using fairly high plant populations.

b. Early planting of local photosensitive varieties (indeterminate flowering) at low plant populations (the present traditional system).

c. Delayed planting of early nonphotosensitive varieties (indeterminate types) at low plant population.

Besides reducing insect damage, low cowpea populations are also in agreement with the farmer's aim to maintain his cereal yields near 100%.

The ICRISAT Intercropping Program in Upper Volta

Based on the prevailing cropping patterns in combination with the different soil types as outlined earlier, the ICRISAT intercropping work is aiming at two major systems:

System 1. For conditions which allow cropping for > 120 days—i.e., generally the central zone of 700-mm rainfall or more; or further north with lesser rain on deep soils near the *bas fonds.*

System II. For conditions which allow cropping for < 120 days—i.e., generally the northern zone of 450 to 650-mm rainfall or on the shallow soils in the adjacent higher rainfall zone further south.

The first system allows the combination of full-season crops (photosensitive sorghums) with early maturing intercrops (millet; maize; nonphotosensitive cowpea), which is known to give large yield advantages (Baker and Yusuf 1976; Willey, in press).

For the second system, the season is too short to effectively combine two crops with different maturity cycles. Therefore, intercropping advantages should be realized by crop combinations which are able to exploit the environment (soil, nutrients, light, moisture) more effectively in each other's presence than if in sole stands. Because there are no temporal factors to be exploited, yield gains from intercropping are expected to be somewhat less than in the first system.

Some Results Obtained in System I

The aim of crop combinations in System I is basically to exploit the rainy season as fully as possible, by planting as early as the beginning of May and harvesting by mid-November, using deep soils with good moisture-storage capacities.

The base crop is a full-season photosensitive sorghum (S29 local or VS 703 improved variety, Table 4) the intercrops are either early-maturing varieties of maize (80 days), millet (87 days), or an erect cowpea (60 days) as contrasted with the local photosensitive spreading cowpea(135 days).

After two cropping seasons, the results are still tentative; however, the following promising combinations were identified: sorghum/maize and sorghum/erect cowpea. The latter yielded 90 and 250 kg cowpea/ha with, respectively, local and improved sorghum in the absence of insecticide treatments. The local spreading cowpea appeared to compete seriously with the improved sorghum (VS 703), but not with the local sorghum. Nevertheless, its yield was 70 kg/ha with the latter and 0 with VS 703.

The sorghum/millet combinations were unsuccessful, sorghum yields being reduced, whereas the millet (ICH 118) proved unadapted to early planting, leading to a poor seedset (75% barren heads with local sorghum and 55% with VS 703). Though this was not clearly reflected in this year's data, it is felt that tillering sorghum varieties offer more flexibility in utilizing the space vacated by early companion crops. Moreover, sorghum varieties, which respond greatly to increased plant densities (Table 4) will likely miss theflexibility to utilize effectively any extra space provided in this cropping system. This lack in flexibility applies also to the erect cowpea varieties in comparison with the local spreading types.

From a theoretical point of view, the combination of sorghum (both full-season varieties for deep soils and early varieties for shallow soils) with early cowpea looks promising. In these systems, the cowpea will generally escape the major insect attack, whereas any fixed N might even become available to the sorghum later in the season. An indication of the importance of cowpea in maintaining soil fertility was obtained in the 1978 season when sorghum following cowpea yielded 2 tons grains/ha, whereas the sorghum/sorghum rotation gave only half that yield.

However, the early, erect cowpeas do not offer the type of soil coverage provided by the local spreading varieties (Table 5) for soil protection. These aspects will still require considerably more work to define optimum combinations.

Table 4. Some characteristics of sorghum varieties reflecting differences in their stability and flexibility.

Variety	Planting date	Grain yields (kg/ha) Shallow soil	Grain yields (kg/ha) Deep soil	Days to 50% flowering Shallow soil	Days to 50% flowering Deep soil	Approx. plant height (cm)	Panicles[a] per plant (no.)	Yield[a] from tiller (%)	Yield[b] increase due to increased populations (%)
S29 (local)	4/6	220	1475	112	105	350	3.2	49	-20
VS 703	4/6	280	3265	107	86	160	1.6	20	+ 16
VS 702	15/7	595	1770	72	68	110	1.0	0	+ 45
VS 701	15/7	530	1290	74	73	95	1.0	0	- 8

a. At plant populations of 30 000 plants/ha grown on deep soil.
b. Comparisons between plant populations of 30 000 and 100 000 plants/ha.

Table 5. **Estimated number of cowpea plants/ha to achieve full soli coverage about 6 weeks after planting.**

Cowpea variety	Plant type	No. of Plants/ha for full soil coverage
Local (late)	Spreading; photo-sensitive	8 000
TVx 289-4G	Prostrate; nonphoto-sensitive	25 000
TVx 1193-9F	Erect; nonphoto-sensitive	70 000

Some Results Obtained in System II

Crop combinations in System II are directed toward optimum land use under high risk conditions, due either to a short cropping season with irregular rainfall distributions or to the use of shallow, drought-sensitive soils of somewhat higher rainfall areas. In either case, the base crop for the system is millet, with groundnut or cowpea as the intercrop. Under these conditions, planting arrangements and different genotypes capable of exploiting the environment more effectively are important factors.

During the last season, four millet genotypes were compared, when grown as sole crop (100%) and intercropped (50%) with groundnut either in single, alternate rows (1:1) or in paired, alternate rows (2:2). The millet genotypes included two full-season, photosensitive, tall varieties, one intermediate tall, early hybrid (ICH 162) and one early dwarf variety (3/4 Ex-Borno).

All the millet varieties responded very favorably to intercropping, with 3/4 Ex-Borno the least responsive (LER millet varying from 0.8 for photosensitives to 0.55 for dwarf variety). Meanwhile, the millets performed best when grown in an alternate line rather than in a paired-line system, producing more heads/ plant as well as a lower percentage of barren and diseased heads. However, groundnut responses were opposite, favoring the paired-row system (LER = 0.5) over the alternate-row system (LER = 0.4).

Interestingly enough, these two results complement each other. Summarizing the results indicates that systems using relatively low populations of millet (around 20 000 plants/ha) in a widely spaced arrangement can be very effectively intercropped with groundnut and most likely also cowpea.

In view of the relatively short season under which this system has to operate, as well as the importance of a rather complete soil coverage during the entire season, there would seem more scope for the spreading types of cowpea than for the erect types.

Discussion

Though the results obtained by the ICRISAT intercropping program in West Africa until now are still tentative, some important guidelines for future research have been established.

For the introduction of improved varieties of sorghum, millet, and cowpea, it is essential to consider in advance the needs and limitations of the major ecological zones combining the following factors:

- Rainfall distribution
- Prevailing soil types
- Prevailing traditional cropping systems and patterns

For instance, in these environments it cannot be considered efficient from the point of labor, land utilization, or the spreading of risk to crop deep soils for only part of the season by using early, nonphotosensitive sorghums planted at the end of June or in early July. Rather, these sorghums should be utilized on shallow soils or deep soils further north or in emergency situations caused by a late start of the rains. In all cases, the varieties will be most useful for various cropping systems when their stability is high, as indicated, for instance, by a small difference in flowering date under good and bad soil conditions (Table 4). Moreover, it is desirable that yields remain stable even at relatively low plant populations, indicating the flexibility of the variety to fill extra space effectively (if not by tillering, by larger plant and panicle sizes; see also Table 4). These characteristics form an important defense against the damage from early droughts.

The vast majority of farmers in Upper Volta and in the neighboring countries are still planting by hand for 1 or 2 days following every good shower. Obviously, the time and labor required for planting in a hand-labor system is much less when using tall, tillering cereals and spreading cowpeas adapted to low plant populations than when using short, nontillering cereals and erect cowpeas generally requiring higher populations. With the introduction of animal traction and mechanization, the scope for the latter systems will no doubt gradually increase.

For the time being, however, there seems considerable scope for improved varieties to be utilized in such intermediate cropping systems as early nontillering sorghum with spreading cowpeas (shallow soils), late-tillering sorghum with early erect cowpeas (on deep soils), and early millets with spreading cowpea (on shallow soils).

If a very early, adapted millet could be identified, it might be useful as an intercrop with full-season sorghum for soils with intermediate soil depths (Table 2), changing to an early maize intercrop further down the slope.

In developing new cropping systems one should be aware, also, that for the prevailing hand-labor systems, factors such as minimization of risk and labor are likely to be more important than the aspect of yield maximization.

Crops and Cropping Patterns of the Savanna Region of Nigeria: the Kaduna Situation

J. Y. Yayock*

Abstract

The state of agriculture in Kaduna state is briefly described, because it is believed to typify the situation in the Sudan zone of Nigeria. Certain important problems related to the production of field crops are identified, and suggestions for improvements are discussed.

No clearly defined or rigid cropping patterns exist in any of the three ecological zones of the state. However, although intercropping, the growing of more than one crop on the same field at the same time, is practiced throughout the state, its predominance decreases from north to south. The "gicci, "a system of intercropping characteristic of the relatively dry Sudan zone, is presently the only identifiable rational approach to this type of cropping that may be described as a pattern. In most cases the choice and number of crops in a mixture is an arbitrary decision, and, as such, the practice does not easily lend itself to rotations.

Sole cropping, the other system of cropping, is very much less widely practiced and invariably diminishes in importance from south to north. In a few instances, definite patterns of cropping are recognizable, but, in most cases, the rotation of crops is neither rational nor widely practiced.

Among numerous agronomic factors responsible for low crop yields in all parts of the state are the use of unimproved varieties, untimely planting, failure to maintain a full and lor high plant population, inadequate soil amendment, and poor control of weeds, pests, and diseases.

Until the late 1960s and early 1970s when the rapid exploitation of mineral oil began to have a great impact on Nigeria's foreign exchange earnings, the economy of the country had hitherto been mostly dependent on agriculture. Even with an abundance of oil, however, the agricultural sector has continued to remain the most vital and stable sustainer of the nation's economy and well-being and directly involves 75-80% of an estimated 80 million Nigerians. Modern thoughts on conservation of energy, the recognition that mineral oils are not inexhaustible, and the appreciation of the fluctuating and unstable nature of oil prices are some of the reasons that various governments, as well as other concerned agencies and bodies, have continued to strive to maintain and increase agricultural production in order to make the nation self-reliant. Like most of the 19 states in the Federation, Kaduna State (Fig. 1) is not behind in this noble effort.

In an effort to contribute to the overall objectives of the present workshop, the agriculture of the Savanna region of Nigeria, as typified by Kaduna State, is broadly described. Specifically, the paper surveys the major crops of the area, describes the existing cropping patterns, and highlights some of the more important problems of production inherent in the cropping systems.

Ecological Division

Occupying a total of over 70 000 km^2, Kaduna State lies approximately between latitudes 9°05' and 13°05' N and longitudes 7° and 8°50'E

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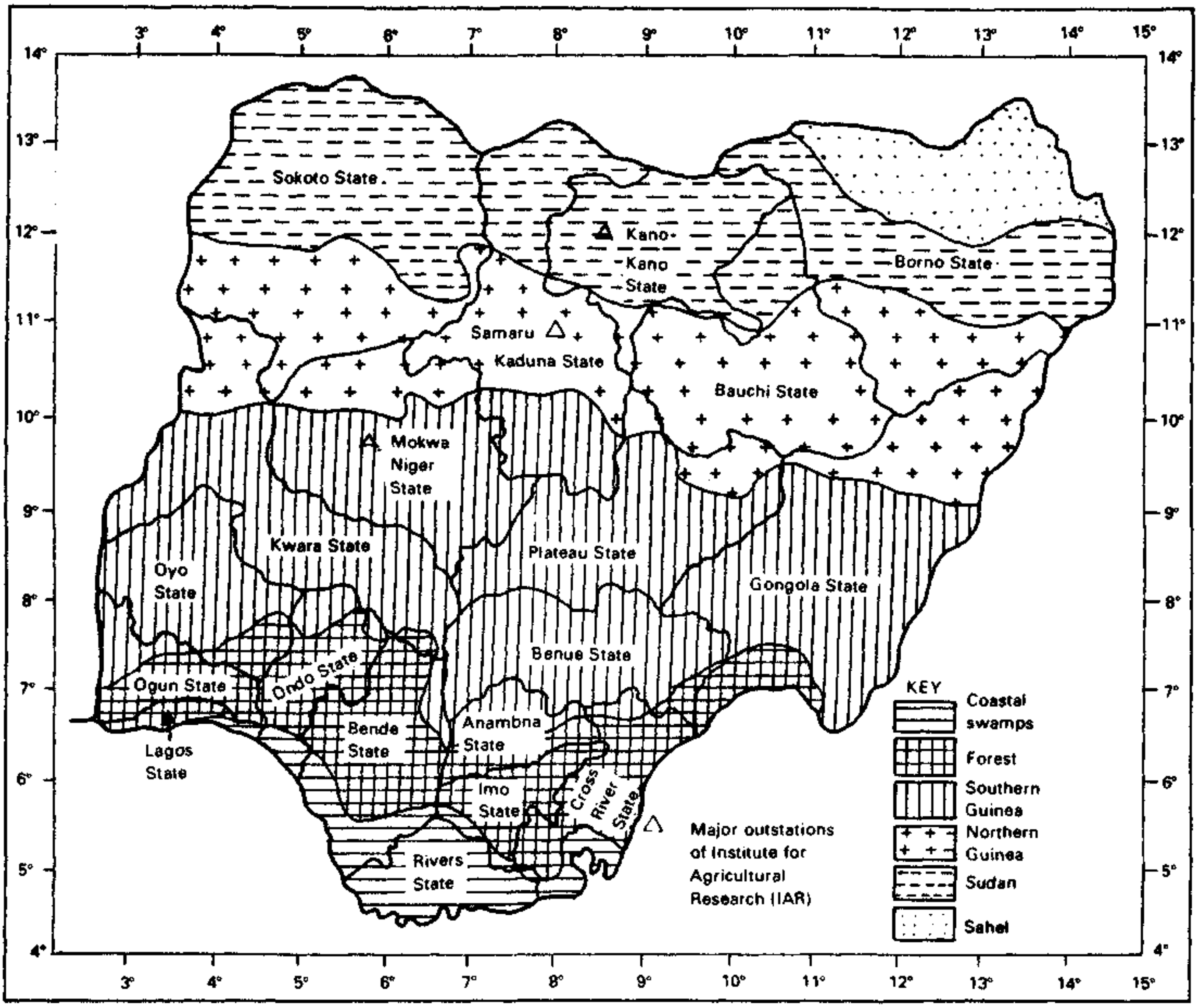


Figure 1. Main ecological zones, states, and major out-stations of Institute for Agricultural Research (IAR) in Nigeria.

(Fig. 2). The State is bordered by the Republic of Niger in the north, Niger and Plateau States in the south, Kano in the east, and Sokoto in the West. A little over a third of the State, approximately between latitudes 10°15'N and 11°40'N, falls within the Northern Guinea savanna ecological zone, with half the remaining area to the north lying in the Sudan savanna while the rest of the State to the south is within the Southern Guinea.

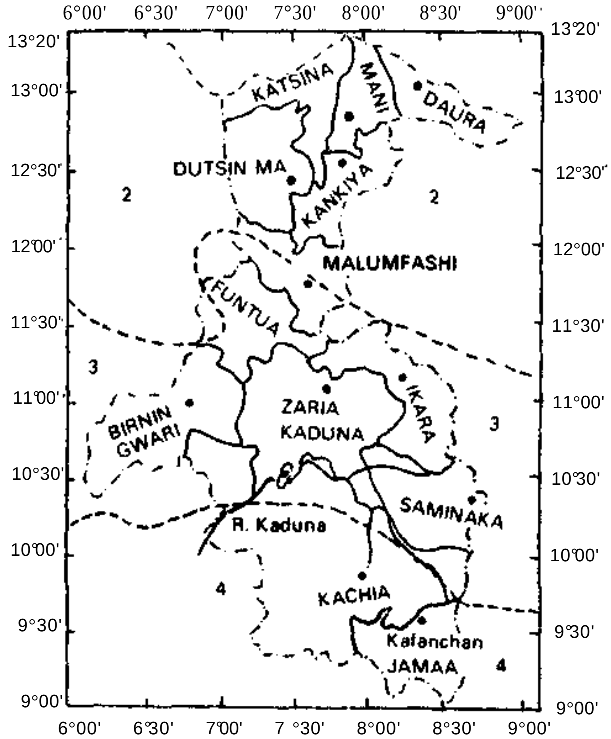
Relief

The rivers Kaduna and Rime (Goda), both tributaries of the Niger river, are among the main rivers in the State, and these show significant flow even during the dry season. Other important and relatively large rivers include Gurara, Galma, and Mada. Numerous smaller rivers exist, but most carry little water during the dry season. Fadamas and swamp plains occur, although rarely in the Sudan zone.

The land is relatively flat, except for limited highlands extending from the Jos Plateau to areas in Jema'a. Compared with an altitude of 426 m above sea level at Daura (13°02' N), for example, Zonkwa (09°44' N) is located at over 830 m above sea level, with Kaduna (10°36' N) being intermediate at 644 m (Table 1).

Soils

There is much variation in the soils, ranging from sands in the north to sandy loams and clay



10 0 10 20 30 mis

SCALE: 1:2,000,000

2 Sudan 3 Northern Guinea 4 Southern Guinea

— — — Slate boundary ——— Administrative area boundary

State capital ——— Vegetation boundary

• Administrative capitals

Figure 2. Ecological divisions, local government areas, and administrative capitals of Kaduna State, Nigeria.

loams in the extreme southern portions of the State. All the soils fall into the ferruginous tropical group developed over basement complex as described by d'Hoore (1964). The soils are weakly buffered and have a very small exchange capacity; organic-matter content of the soils is generally very low in the Sudan zone in the north and increases, even if only slightly, going south. Because of the high proportion of free metal oxides present in the soils, there is a pronounced tendency for phosphate to be immobilized, and most crops respond well to the application of phosphatic fertilizers. But the total content of available plant nutrients in these soils is very small either because of leaching, runoff, or soil erosion, or a combination of the three. Under conditions of continuous or intensive arable farming, deficiency of micronutrients (or macronutrients such as K, which was previously considered adequate) might occur.

Rainfall

The pattern of agriculture and the length of the growing season is dependent on the distribution of annual rainfall. Seedbed preparation, seed germination, and early stages of crop growth are entirely dependent on an adequate amount and frequency of precipitation, since the soil profile and particularly the soil surface carries a large soil-water deficit at the beginning of the growing season. Consequently, in their early stages of growth, crops cannot rely on water stored in the soil and are dependent on rainfall alone.

There is a pronounced south-north movement in the spread of rainfall and a corresponding north-south pattern in its termination. Usually there is a gradual increase in the amount of precipitation with the advance of the rainy season, eventually culminating in a peak in August. For the purpose of this report, when accumulated rainfall for the year reaches 75 mm in the Northern Guinea and Sudan zones and 100 mm in the Southern Guinea, rains may safely be said to be established (Table 1). Thus, the start of rains varies from April in the south to July in the extreme north of the State. The retreat of rainfall signals the approaching end of the rainy season. The end of the rains begins earlier in the northern parts of the State, about mid-September, than in the southern parts, about end of October.

Temperature

Regardless of how favorable moisture and other conditions may be, plant growth ceases when temperature drops below a certain minimum value or exceeds a certain maximum value. Between these limits there is an optimum temperature at which growth proceeds most rapidly. Most of our crops have an optimum temperature range of 22-30℃.

During the first part of the year, there is a gradual increase in mean temperature, interrupted by the onset of rains (Table 2). This occurs later in the year at higher latitudes. The cooling effect of the rains reduces the mean monthly temperatures. This is usually most pronounced in August when mean monthly temperatures are reduced to between 20 and 27℃.

Evapotranspiration, the combined evaporation from all surfaces and the transpiration of

Table 1. Differences in rainfall establishment and mean annual precipitation at certain locations in Kaduna State.[a]

Location	Lat. N °	Lat. N ′	Long. E °	Long. E ′	Altitude (m)	Mean annual rainfall (mm)	Progression in rainfall establishment[b] monthly total (mm) Jan	Feb	Mar	Apr	May	June	Aug
Kafanchan	09	36	08	18	762	1651	6.6	7.4	36.6	88.9	155.9	211.1	299.7
Zonkwa	09	44	08	23	838	1493	1.5	2.54	29.9	60.9	181.6	233.4	274.5
Nimbia	09	30	08	33	603	1826	0.0	0.2	19.0	128.0	210.5	203.4	382.7
Kaduna	10	36	07	27	644	1285	0.5	2.5	10.6	71.9	146.0	178.0	217.1
Birnin Yero	10	48	07	31	670	1145	3.0	1.5	10.9	63.7	103.3	158.2	233.1
Kudaru	10	35	08	27	762	1305	0.0	0.2	11.1	57.9	145.8	201.4	251.2
Faskari	11	44	07	01	640	1132	0.5	1.1	5.8	52.8	108.4	151.8	230.3
Daudawa	11	38	07	09	701	1082	0.0	1.7	4.0	41.1	104.1	167.6	225.0
Bakori	11	34	07	26	640	955	0.0	0.0	5.3	23.6	90.4	154.6	191.2
Kankara	11	56	07	26	579	1008	0.0	1.7	3.8	19.0	68.8	130.3	224.0
Danja	11	23	07	33	670	1018	0.0	0.7	2.0	33.0	98.3	160.7	232.4
Samaru	11	11	07	38	685	1107	0.2	1.5	0.7	36.8	125.2	165.6	221.4
Malumfashi	11	47	07	38	655	982	0.0	0.5	1.2	12.7	88.1	143.5	222.7
Danmusa	12	15	07	12	609	901	0.0	0.0	3.5	23.6	56.1	136.4	197.1
Musawa	12	09	07	41	624	886	0.0	0.1	0.0	3.8	53.0	119.3	201.4
Kafinsoli	12	32	07	45	548	805	0.0	0.0	1.0	5.8	42.4	103.6	201.6
Mani	12	52	07	52	457	746	0.0	0.0	0.2	2.0	30.4	80.5	208.2
Baure	12	50	08	45	411	645	0.0	0.0	0.0	3.0	15.7	45.4	201.4
Katsina	13	01	07	41	517	751	0.0	0.0	0.2	5.0	54.8	96.7	190.7
Daura	13	02	08	13	426	675	0.0	0.0	0.0	1.7	34.2	76.7	175.5

a. Compiled from Kowal and Knabe, 1972.

b. As a rough guide, rains can be considered to be established when accumulated precipitation for the year reaches 75 mm in the Sudan and Northern Guinea savanna and 100 mm in the Southern Guinea.

Table 2. Monthly mean daylength in hours and tenths at latitudes 9-13°N and long-term monthly mean air temperatures at three locations in Kaduna State.[a]

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Latitude (°N)												
9	11.6	11.84	12.08	12.33	12.53	12.64	12.59	12.41	12.17	11.93	11.72	11.62
10	11.61	11.80	12.08	12.35	12.58	12.70	12.60	12.45	12.18	11.91	11.68	11.56
11	11.55	11.77	12.07	12.38	12.63	12.76	12.70	12.48	12.18	11.88	11.63	11.49
12	11.51	11.74	12.07	12.40	12.68	12.82	12.75	12.51	12.19	11.86	11.58	11.44
13	11.45	11.71	12.06	12.43	12.73	12.88	12.81	12.55	12.20	11.84	11.54	11.38
Temperature (°C)[b]												
Kaduna	23	26	28	28	27	25	24	23.	24	25	23	23
Samaru	22	24	27	28	27	25	24	23	24	24	23	22
Katsina	21	24	28	31	31	29	26	25	26	27	23	21

a. Compiled from Kowal and Knabe, 1972.
b. Averaged over 30-42 years of record.

plants, is a continuous process, and it is estimated that between 66 and 85% of the annual precipitation at Samaru (11°11' N) is returned to the atmosphere by direct evapotranspiration.

Daylength

The importance of daylength is recognized by the fact that certain plants such as cowpea, will not flower unless at the correct daylength (12 hours or less), even when differences are as seemingly small as 15 minutes. Table 2 summarizes the daylengths for the various months at each latitudes.

Agricultural Diversification

Agriculture and agriculture-related preoccupation of the peoples of Kaduna State are varied and range from forestry (including game reserves) mainly in the south to stock raising (including dairying and hides and skins) largely in the north. But by far the most important agricultural trade, involving perhaps 80-90% of the land area, and not less than 80% of the population, is the cultivation of crops.

Numerous types of plants are grown in the State, and it is not possible to document all of these in any great details. The typical farmer normally uses local crop varieties, the seed of which is saved from the previous year's crop. The seed is rarely dressed before sowing, and this invariably results in poor germination, which, combined with incorrect spacing, leads to suboptimal plant populations. Unimproved varieties of crops are characterized by their adaptation to local conditions; they generally possess some resistance to local pests and diseases and have the ability toproduce at least some yield, even if variable, over a wide range of climatic conditions. Their yielding potential however, is low. In contrast, the primary characteristic of improved crop varieties generated by the various breeding programs is that their potential yield is significantly greater. Some of these improved varieties have a restricted tolerance to variation in environmental conditions and, therefore, carry a greater risk of crop failure under unfavorable conditions.

All improved technology presently available is based on the sole-crop system. The adoption of recommended practices not only implies the use of improved varieties, the correct seeding and fertilizer rates, but also presupposes the use of seed dressing, timely sowing, and good weed, pest, and disease control.

Cropping Patterns

The important field crops includemainly guinea corn, millet, maize, groundnut cowpea, cotton, yams, cassava, tobacco, sugarcane, and rice.

No clearly defined cropping pattern can be said to exist within any one ecological zone. The dry season lasts anywhere from 4 months in the southernmost parts of the State to 7 months in the northernmost parts; because of the relatively short rainy season, farmers normally aim at growing as much crop as possible, in terms of both land area and crop numbers. This results in the wide practice of mixed (or inter-) cropping, particularly in areas with low rainfall, wheretwo or more crops aresimultaneouslygrown on the same piece of land. Indeed, in the drier parts of the State (approximately north of latitude 11° N), where intercropping is most widely practiced, less than 17% of the farms grow sole crops. In general terms, therefore, two broad systems of cropping are practiced in the State: intercropping and sole cropping.

Intercropping Patterns

There are no defined or rigid patterns of intercropping, and different farmers appear to grow crops in a great number of different combinations. In a study at three villages around Zaria, for instance, 24 different crops were observed in 174 different combinations. The most frequently occurring mixtures involving two crops usually consist of millet and sorghum or cotton and cowpea. For a three-crop mixture, the most widely practiced combination involves cotton, sweet potato, and cowpea. Millet, sorghum, cowpea, and groundnut constitute the most often occurring four-crop mixture. A typical five-crop mixture is composed of millet, sorghum, cotton, groundnut, and cowpea. Mixtures involving morethan five crops also occur.

Even with the flexibility of the intercropping system, however, a certain generalized rationalization of the practice is possible. This is the so-called "gicci" system used mainly north of 11°N and particularly in the Sudan zone. Typically, a cereal, particularly short-season 'Gero' millet (although it could be sorghum or both), is sown very early with the first rain virtually without any real land preparation. The seed is sown at wide spacing along old furrow bottoms approximately 1 m apart. At 3 to 4 weeks after sowing the cereal(s), the field is weeded at the same time as old ridges are split and reformed around the cereal(s), after which groundnut or long-season sorghum (if the first cereal is millet) is sown between the stands. The strategy here is that cultivation of the land is delayed until the ground is soft, and weeding and ridging form a single operation. In addition, a low population of a short-season cereal (in the case of 'Gero' millet) is sown early in the season when the rainfall is unreliable followed by a near-full stand of a longer season crop intersown when rains have established. When the millet is harvested, beginning late July to early August, total plant population is reduced, and the long-season crop then matures mainly on stored moisture at the end of the season.

With early-planted millet (Gero) harvested early in August, cowpea, late millet (the Maiwa type), or even late cotton are sown at about this time. Even though, for the best yield, cotton should be planted in mid-June, the farmer invariably gives priority to his food crop before paying attention to such a cash crop as cotton.

No studies have been done about the intercropping situation in the southern third of the State, particularly the Southern Guinea zone where growing conditions, particularly rainfall, are more favorable. A keen observer would, however,come away with the impression that intercropping as a system is not as prevalent in the wetter south as in the drier north. Most sorghum crops are grown sole, although often stands of maize, benniseed, roselle hemp, and niger seed are interspersed as minor crops. When other crops are sown in yam fields, they invariably include maize, okra, pumpkin, melon, or peppers. The only millet grown in the Southern Guinea is the 'Dauro' type, and the common practice is to grow the millet on a field recently put to groundnuts; if this is done within the same rainy season, the two crops may occupy the same field for 2 to 3 weeks, after which the groundnut is harvested. Beans, mainly the lima types, are often interplanted with maize, although they are mostly grown sole.

Intercropping appears less widely practiced in the Northern Guinea than in the Sudan zones but is more prevalent than in the Southern Guinea. As in the other ecological zones, there are no defined cropping patterns.

Compared with sole cropping, intercropping diversifies production while serving as a security practice against possible total cropfailure as a result of adverse conditions. In addition to achieving higher yields than sole cropping in a given season, the practice stabilizes variability of annual returns while at the same time results in a more uniform use of labor throughout the season. There is also evidence to the effect that intercropping gives better control over weeds, pests, and diseases.

Patterns in Sole Cropping

Most of the cassava crop in the Sudan savanna is grown sole, and this is probably because it is the crop planted last in the season. Except the few (perhaps 10% or less) sole crops of groundnut, millet, cowpea, sorghum, or cotton, the bulk of crops in this ecological zone are intercropped.

In contrast, more crops are grown sole in the Southern Guinea, although it is difficultto make estimates. Whether crops are grown sole or as intercrops, invariably ridges are made before sowing, and this operation serves in preparing a good seedbed while at the same time controlling the abundant grass and other weed growth that occur by the time rains are established. There are no defined patterns of production, but invariably millet (the 'Dauro' type) is grown on land cropped with groundnut, either in the preceding year or during the same year (in which case both millet and groundnuts are intercropped for 2 to 3 weeks, after which the groundnut is lifted). It is not often the practice for sorghum to be grown after sorghum; most sorghum is grown after millet. Maize is not the serious crop it perhaps ought to be in this ecological zone as most of the maize is produced mainly around homes primarily for consumption as green cobs. Cassava, ginger, and tobacco are invariably grown sole in the Southern Guinea but without any rigid pattern of cropping.

Many hectares of land that had previously been cropped are observed to be uncultivated and have reverted to bush. While this may be a deliberate effort in fallowing in a few cases, it would appear that probably because of labor problems, many farming families are cultivating less and less hectarage, and land to which they are unable to attend invariably reverts to bush.

Although growing cotton followed by guinea corn and groundnut is known to be the best pattern of crop production in the Zaria area (Northern Guinea), it is rare to find this being applied in practice since only about 16% of the crops are grown sole in this area. Within this ecological zone, and particularly south of 11°N, it is almost always necessary to cultivate to have weeds in check (mostly by ridging) before planting.

Some Problems of Production

The first recognizable common factor in the production of crops in Kaduna — as in the other States—is the fact that no clearly defined pattern of cropping exists. Intercropping, the predominant practice in the State, is too variable and complex and crop combinations seemingly too arbitrary for efficient rationalization into a definite pattern within any one ecological zone.

In sole cropping, agronomic practices usually havean enormous influence on the final yield; while the same is true of intercropping, the effects are more complex. In addition to agronomic practices having major effects on the general level of yield, they also influence what proportion of yield is obtained from each crop and the extent to which intercropping may or may not be advantageous over sole cropping. The more important factors limiting production, particularly in the context of the cropping practices in Kaduna State, include the following.

Low Plant Population

Although plant population and spacing effects are pretty well understood in sole crops, they have often been the cause of some confusion in intercropping. Invariably, both the component and total populations are always much too low. For many intercropping situations, it is believed that better use of resources are made and yield advantages maximized when total populations are greater than the optimum for their component sole crops.

Also of concern is the common failure to maintain a full stand of plants at whatever level of population density the farmer is operating; this often comes about as a result of poor establishment.

Insufficient Fertilizers

Although the technology of fertilizer use is available in terms of types, amounts, and methods of application, only a small proportion of farmers use inorganic fertilizers. No doubt the consumption of fertilizers has been on the increase, but a lot of farmers use animal refuse, cattle dung, or house refuse while a large proportion of them, possibly the majority, rarely return even crop residues to the field.

In general, N and P fertilizers are recommended for use in nonleguminous crops while only P is used on legumes. Recent research results have shown a necessity to apply P fertilizer to crops, notably groundnuts, grown in soils that have previously been intensively cropped. The levels of fertilizers recommended for use are the barest minimum and take cognizance of the farmers' usually poor crop management — use of low-yielding varieties, inadequate seedbed preparation, noncompliance with recommended planting depth and sowing date, nonmaintenance of a full plant stand, inadequate soil amendments, lack of adequate weed and disease control, as well as untimely harvest. Under high-management practices and/or in the presence of adequate irrigation water or high rainfall (as is the case approximately south of latitude 11°N), fertilizer rates higher than those recommended can be beneficially used.

It would appear that the most important factor responsible for the limited use of fertilizers by only a small proportion of farmers is not so much the "ignorance" of the farmer (as to their values, methods of use, or even the costs involved) but simply that fertilizers are not readily available, particularly at the time they are most needed. In addition to the lack of adequate quantities of fertilizers in the State at any one time, there is also inadequate distribution, so that these fertilizers do not reach the farmer at the planning stages of production.

There is yet another type of problem regarding fertilizer use. All existing information on fertilizer use emanates from sole cropping and yet its application is mostly on intercrops. Although some yield increases are achieved this way, production is not at its best when results obtained from sole cropping are directly applied to the intercropping situation.

Poor Control of Weeds

Weeds constitute one of the major constraints to increased agricultural production. Probably because of the scarcity of family labor and the general high cost of paid hand labor, many fields are either inadequately weeded or they are weeded too late. No herbicides are presently recommended, and none are used. Although intercropping provides a more competitive effect against weeds, obligate parasites like striga (*Striga* spp.) may in fact be perpetuated since the system does not allow for effective rotation.

Unsuitable Varieties

The identification of suitable varieties is just as necessary for intercropping as for sole cropping. Even within a given crop, different genotypes may be needed for different intercrop combinations. However, through no fault of his own, the more industrious farmer practices intercropping using improved, high-yielding varieties selected under sole cropping; no deliberate research efforts have yet been made to select genotypes under intercropping systems.

The extent of improved crop varieties being used leaves much room for improvement. In the case of groundnut, for example, not more than 6% of total land carrying this crop in any one year is cropped to recommended varieties; the rest of the groundnuts are unimproved low-yielding varieties. This is mainly as a result of inadequate arrangement to multiply improved seed for distribution to farmers. The timely provision of new stocks of such improved seed in adequate amounts each cropping season will not only lead to improvement in yield levels, but will also result in increased and wider use as well as maintenance of the purity of genotypes.

Other Observations

In the light of the agricultural practices and problems as described for Kaduna State, a few suggestions may now be advanced aimed at those of us charged with devising appropriate plans, programs, and policies for the development and improvement of this level of agriculture.

Provision of Improved Seed

It is to be emphasized that unless recommended (and invariably high-yielding) crop varieties are used, imposing agronomic practices, even in the most efficient manner, cannot result in the best of production. Although improved varieties have been recommended for most field crops grown in various parts of Kaduna State, relatively few farmers have easy access to them. Even with the recent establishment of the National Seed Service, which assists states, including Kaduna, in the provision of improved seed, this is far from being adequate.

Meanwhile, research efforts should be intensified toward looking into varieties specifically improved under intercropping conditions. When grown in combination with one another, such varieties should, in general terms, decrease intercrop competition as they increase complementary effects. But until such varieties become available, the use of high-yielding material selected under sole-crop conditions is imperative and is better than having to continuously grow varieties with low-yielding potential. For the present, however, crops and varieties to be intercropped should be chosen and combined to obtain the greatest yield advantage.

Access to Fertilizers

Most crop varieties currently recommended and all promising material yet to be released to the farmer are invariably bred, screened, and selected under moderately high soil fertility. Unlike improved local varieties that have mostly become adapted to poor fertility conditions, the use of inorganic fertilizers almost always increases the yield potential of crop varieties recommended. Thus, to grow improved varieties of crops without providing the necessary types and quantities of nutrient amounts to an underexploration of the full yield potential of the variety. There is a definite need for the procurement of a lot more fertilizers than the quantities currently being made available.

Cultivation and Weeding

Of all the various phases of crop production, weeding constitutes the most serious problem under all systems. Most often the early-planted crops become ready for weeding at a time when late-planted crops are still being sown. This invariably results in inadequate attention being given to all crops whether they are sown late or early. Because of the complex nature of intercropping, and in view of its widespread use in the State, it is unlikely that the use of herbicides will become of serious consideration in the very near future. Of course, where sole cropping is practiced, it is relatively easier to obtain advice as to what herbicides to use and how. But no matter which system of cropping is used, chemical weedkillers are likely to be the final answer to the problem of weed control in crops. Meanwhile, about the only workable approach is to devise cultural control supplemented by hand weeding.

Crop Rotation

Growing crops as intercrops makes the agronomically desirable practice of rotating crops somewhat complex if not impossible. About the best that can be suggested is for one of the component crops in a mixture to be a legume, although this in itself may not be an advantage of intercropping. An advantage only occurs if the process of N fixation, or the use of fixed N by an associated crop, is more efficient than when the crops are grown separately but in some suitable sequence.

Sorghum/Pigeonpea and Finger Millet/ Groundnut Mixtures with Special Reference to Plant Population and Crop Arrangement

D. S. O. Osiru and G. R. Kibira*

Abstract

SorghumIpigeonpea and finger milletlgroundnut mixtures were examined in alternate-row and within-the-row arrangements. A "replacement-series" technique was used; all treatments were examined at four levels of population. Yields of mixtures were large in comparison to respective sole-crop stands. In the sorghum Ipigeonpea mixture, yield advantages up to 29% were achieved; in the finger milletlgroundnut mixture, yield increased up to 44%. As with the earlier experiments, it is suggested that the higher yield from mixtures occurred because the component crops were able to utilize the environment better than their sole-crop stands.

The practice of growing two or more crop species on the same piece of land as mixed cropping is an old system of farming. For many centuries the peasant farmer has practiced this system despite the emphasis placed on sole-crop stands. The exact reason for this is not clearly understood; however, more recently there has been a wide international interest in trying to understand the biological validity of the system. In the earlier experiments at Makerere, it was shown that higher total yield could be achieved from mixtures than from sole-crop stands. Mixtues of maize/beans and sorghum/beans produced yield advantages of up to 38% and 55%, respectively (Willey and Osiru 1972; Osiru and Willey 1972). Evidence for higher yields from mixtures have been reported from experiments carried out elsewhere (Andrews 1972; Willey and Lakhani 1976; Fisher 1977a, 19776).

These results show considerable yield advantages from mixtures and they must have been achieved because, to a larger extent, resource use by the component crops was complementary rather than purely competitive. In the Makerere experiments, for instance, the bean variety used was of a shorter maturity period than the cereals (85 days and 120 days). Thus the suggested complementarity could have occurred because:

a. The peak growth demands of the component crops occurred at different times — in other words the component crops were using resource factors at different times.
b. Differences in plant heights and combinations of leaf canopy could have allowed better utilization of light.
c. Differences in the rooting depths and rooting patterns could have allowed an improved utilization of the soil resources.

Crop species and varieties grown by traditonal farmers vary tremendously in maturity period, height, size, shape, rate of establishment and growth, and rooting pattern. An important implication of this is that for any cropping situation there should be a combination of plant types which will often give maximum utilization of environmental resource factors. From some of the earlier Makerere experiments, it was concluded that the greatest potential yield benefits of mixtures were likely where there was greatest scope for exploiting the environmental factors —that is, where there was greatest scope for combining crops of very different growth patterns (Osiru 1974). Further experiments were therefore undertaken

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at Makerere to study a range of mixtures which would give different combinations of maturity periods, heights, and rooting patterns. The present paper reports some of the results of the sorghum/pigeonpea and finger millet/ groundnut mixtures.

Materials and Methods

The experiments were carried out on the Makerere University farm, at Kabanyolo, which lies just north of Kampala (0°28' N, 32°37' E) at an altitude of 1200 m. The farm receives an average annual precipitation of 1300 mm fairly equally divided into two distinct rainy seasons with peaks in April and November. The experiments were carried out during the first and second rains of 1976 and the first rains of 1977. The actual rainfall totals for these seasons were 376, 314, and 394 mm, and the mean solar radiation values were 371, 404, and 368 k cal/cm^2, respectively. The soils are the deep ferralitic type, naturally high in K but low in N and P.

Mixtures of Sorghum and Pigeonpea

Two identical experiments were carried out during the first and second rains of 1976. The sorghum was 'Dobbs,' an improved local variety recommended for areas around the shores of Lake Victoria (Dunbar 1969; Acland 1971). It is a medium tall variety (130-140 cm), and, at Kabanyolo, it matures in about 120 days. The pigeonpea was a determinate short variety which was found to be reasonably resistant to *Mycovellosiela* leaf spot, a very serious fungal disease of pigeonpea in Uganda. The variety is fairly high-yielding and matures in about 130 days at the farm.

The experiments examined the treatments in a replacement series as in the earlier experiments. The actual mixtures were three-quarters sorghum/one-quarter pigeonpea, one-half sorghum/one-half pigeonpea, and one-quarter sorghum/three-quarters pigeonpea. Previous experiments at the farm had shown that the optimum population of the variety of sorghum and pigeonpea was about the same — i.e., 20 plants/m^2. Thus, in forming mixtures, one plant of sorghum was regarded as being equivalent to one plant of pigeonpea. All treatments were studied at four levels of plant population, and both the alternate-row and the within-the-row arrangements of the component crops were examined.

The sole-crop treatments were sown on 30-cm rows, and, at any given plant population, the within-the-row spacing was the same for both crops. These were 60, 30, 15, and 7.5 cm for populations 1, 2, 3, and 4, respectively. In the alternate-row arrangement, mixtures were achieved by sowing complete rows of either sorghum or pigeonpea in the required proportions. For instance, the three-quarters sorghum/one-quarter pigeonpea (Sp) mixture was achieved by replacing every fourth row of sorghum with one row of pigeonpea. One-half sorghum/one-half pigeonpea (SP) was achieved by sowing alternate rows of the two crops, and one-quarter sorghum/three-quarter pigeonpea (sP) was obtained by replacing every three rows of sorghum with pigeonpeas. The within-the-row arrangements were similarly obtained by planting the individual plants of the two species in the required proportions within the row. For instance, three-quarter sorghum/ one-quarter pigeonpea was achieved by replacing every fourth plant of sorghum with a pigeonpea plant.

Both experiments received preplanting application of 70 kg/ha of P_2O_5 as single superphosphate and 50 kg/ha of K_2O as muriate of potash. Nitrogen was applied in two split applications; the first application was given when the sorghum plants were about 15 cm and the second application was given just before heading. For each experiment the total amount of N was 130 kg/ha as calcium ammonium nitrate. The experiments were laid out in a split-plot design with mixtures and sole-crop stand treatments randomized in main plots 6.6x30 m. The main plots were then subdivided into four subplots for plant population treatments.

Mixtures of Finger Millet (*Eleusine coracana*) and Groundnut

A similar experiment was carried out during the first rains of 1977, but the sorghum was replaced by finger millet and the pigeonpea by groundnut. The finger millet used was Serere I, a high-yielding variety which shows some resistance to lodging and "neck blast" The variety normally grows to about 70-80 cm, and, at the

University farm, it matures in about 110 days. The groundnut used was 'Bl.', a variety with an erect type of growth. It is high-yielding and matures in about 95 days at the University farm. All treatments and designs were similar to those described for the sorghum/pigeonpea mixtures.

Results and Discussion

The two sorghum/pigeonpea experiments were identical in treatments and design, and they also produced a similar pattern of results. The results, therefore, are presented as means of the two seasons. The plant populations recorded at harvest time are presented in Table 1. In both cases (alternate-row and within-the-row arrangements), the plant populations achieved were less than those planned. For sorghum, this was mainly due to the problems encountered with sorghum shoot fly *(Atherigona* spp.). Despite intensive spraying schedules with endosulphan, some plants were damaged, although the damage was found to be fairly evenly distributed throughout all treatments. In the pigeonpea, the low plant population achieved was mainly due to rather poor germination and establishment. There was no particular difference observed between the alternate and within-the-row arrangements of the species.

The plant densities for finger millet/groundnut mixtures were similarly lower than those expected (Table 2), although the general appearance of both crops during the growing period was quite good. The low plant populations achieved were mainly due to plant losses

Table 1. Plant populations of two planting arrangements of sorghum and pigeonpea at harvest ($plants/m^2$) (mean of first and second rains, 1976).

Population	Sole sorghum[a]	3/4 Sorghum/ 1/4 pigeonpea	1/2 Sorghum/ 1/2 pigeonpea	1/4 Sorghum/ 3/4 pigeonpea	Sole pigeonpea[a]
Alternate-row arrangement					
1. Sorghum	4.91	3.64	2.30	1.15	-
Pigeonpea	-	1.21	2.28	3.24	4.28
Total	4.91	4.85	4.58	4.43	4.28
2. Sorghum	8.01	5.93	4.07	1.98	-
Pigeonpea	-	1.92	4.06	6.00	7.86
Total	8.01	7.85	8.13	7.98	7.86
3. Sorghum	16.34	12.18	8.33	4.01	-
Pigeonpea	-	4.00	8.28	12.06	14.59
Total	16.34	16.18	16.61	16.07	14.59
4. Sorghum	25.31	19.25	12.83	6.62	-
Pigeonpea	-	6.46	13.12	19.16	26.48
Total	25.31	25.71	25.95	25.84	26.48
Within-the-row arrangement					
1. Sorghum	4.91	3.57	2.15	1.14	-
Pigeonpea	-	1.20	2.07	3.33	4.28
Total	4.91	4.77	4.22	4.47	4.28
2. Sorghum	8.01	5.97	4.01	2.05	-
Pigeonpea	-	2.03	4.07	6.03	7.86
Total	8.02	8.00	8.08	8.08	7.86
3. Sorghum	16.34	12.26	7.96	3.96	-
Pigeonpea	-	3.80	8.04	10.76	14.59
Total	16.34	16.06	16.00	14.72	14.59
4. Sorghum	25.31	19.11	13.50	6.19	-
Pigeonpea	-	6.38	13.56	19.80	26.48
Total	25.31	25.49	27.06	25.99	26.48

a. Sole-crop figures are the same in both arrangements.

Table 2. Plant populations of two planting arrangements of millet and groundnut at harvest (plants/m^2) (first rains, 1977).

Population	Sole Millet[a]	3/4 Millet/ 1/4 groundnut	1/2 Millet/ 1/2 groundnut	1/4 Millet/ 3/4 groundnut	Sole groundnut[a]
Alternate-row arrangement					
1. Millet	6.32	5.03	3.01	1.62	-
Groundnut	-	1.67	3.01	4.06	5.98
Total	6.32	6.70	6.02	5.68	5.98
2. Millet	9.60	7.51	5.72	2.46	-
Groundnut	-	2.50	5.74	7.36	9.40
Total	9.60	10.01	11.46	9.84	9.40
3. Millet	24.28	18.21	12.75	6.71	-
Groundnut	-	6.07	12.04	18.13	23.98
Total	24.28	24.28	24.79	24.84	23.98
4. Millet	28.92	21.21	14.46	7.60	-
Groundnut	-	7.07	14.50	21.04	28.06
Total	28.92	28.28	28.96	28.64	28.06
Within-the-row arrangement					
1. Millet	6.32	4.27	3.18	1.58	-
Groundnut	-	1.42	3.18	4.74	5.98
Total	6.32	5.69	6.36	6.32	5.98
2. Millet	9.60	6.81	5.38	2.40	-
Groundnut	-	2.44	5.37	7.20	9.40
Total	9.60	9.25	10.75	9.60	9.40
3. Millet	24.28	16.86	12.10	6.07	-
Groundnut	-	5.62	12.64	18.20	23.98
Total	24.28	22.48	24.74	24.27	23.98
4. Millet	28.92	20.70	13.95	7.73	-
Groundnut	-	6.90	14.13	21.29	28.06
Total	28.92	27.60	28.08	28.92	28.06

a. Sole-crop figures are the same in both arrangements.

during germination and establishment. During the last 3 weeks of growth, groundnut was infected by *Cercospora* leaf spot which led to rather early leaf defoliation. However, this effect was considered unimportant because the infection occurred when pod filling was more or less complete.

The seed yields have been presented as "replacement series" graphs in Figure 1 for sorghum/pigeonpea mixtures and in Figure 2 for finger millet/groundnut mixtures. As can be seen, the general yield levels were extremely good. The sole-sorghum yield increased steadily with an increase in plant population, giving maximum yield of 4251 kg/ha at population 3. At population 4 there was a marked decline in grain yield. The sole pigeonpea showed a similar trend of yield. The mean maximum yield for the two seasons was 1037 kg/ha at population 3. Thus both species gave their maximum grain yield at population 3, which supports the assumption made earlier that, when forming mixtures in a "replacement series," one plant of sorghum is approximately equivalent to one plant of pigeonpea.

In the finger millet/groundnut experiments, the sole-crop treatments showed similar yield trends except that the maximum yield of both species occurred at population 4 (Fig. 2s). This suggests that the plant population used was less than the optimum. As with the sorghum and pigeonpea experiments, the fact that finger millet and groundnut achieved their maximum yield at the same population confirms the assumption made earlier when forming mixtures in "replacement series."

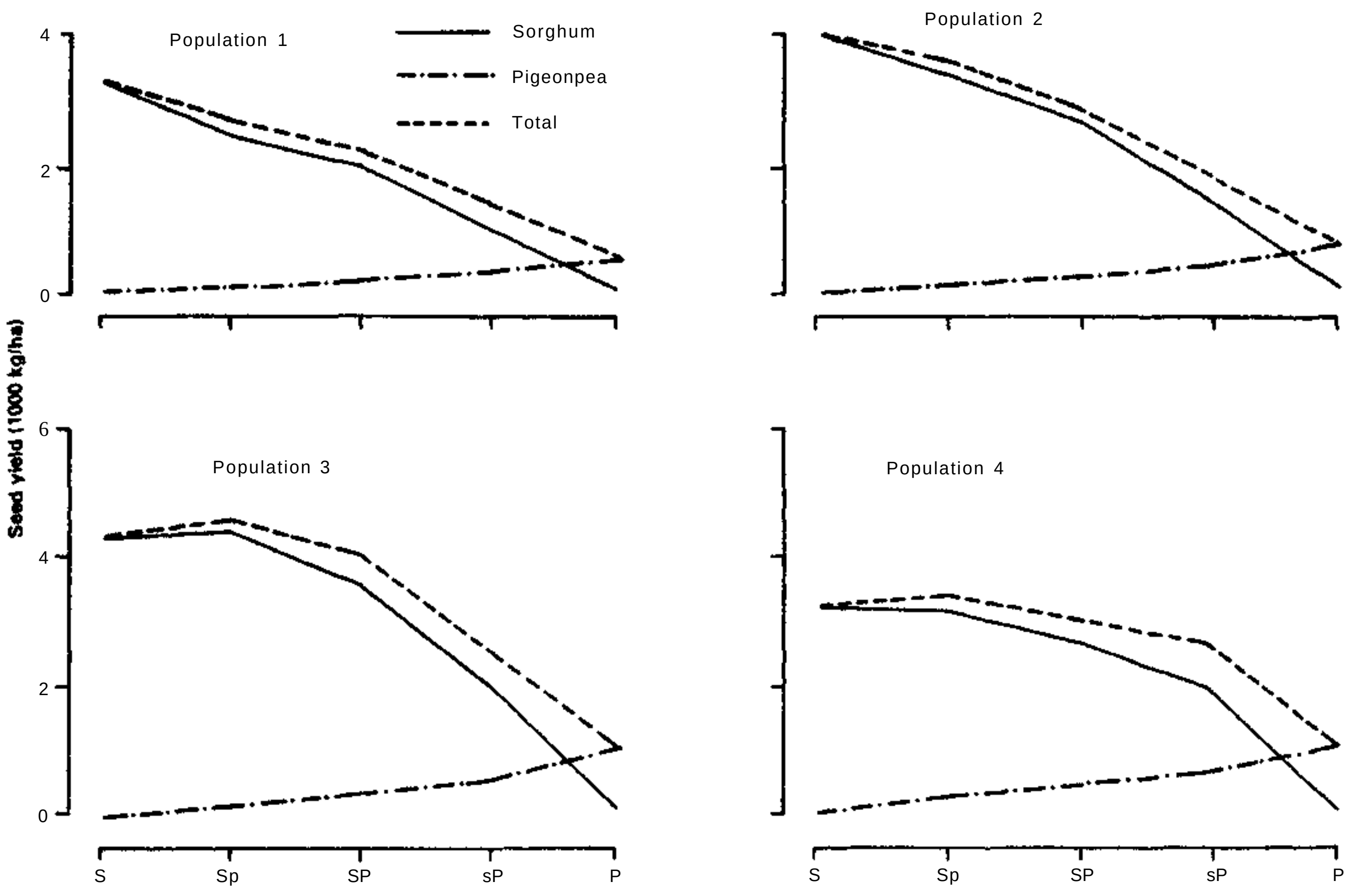

Figure 1a. Mean seed yields for the replacement-series treatments at each level of population for the alternate-row arrangement (LSD [0.05] within a given population: sorghum = 374; pigeonpea =68; total = 709 kglha). (S= sole sorghum, Sp = three-quarter sorghum and one-quarter pigeonpea, SP = half sorghum and half pigeonpea, sP=one-quarter sorghum and three-quarter pigeonpea, P=sole pigeonpea.)

As in the earlier experiments (Willey and Osiru 1972; Osiru and Willey 1972), the effects of mixtures are best examined by taking a sole-crop of one species and then considering the effect of replacing increasing proportions of this by another species. Considering the sorghum/pigeonpea mixtures in the alternate-row arrangement first it can be seen that replacing one-quarter of sorghum with pigeonpea at low population gave a significant decrease in sorghum yield. This decrease could not be compensated by the pigeonpea yield, so that total yield remained lower than that of the sole-crop at the same population level (Fig. 1a). Replacing larger proportions of sorghum with pigeonpea gave marked reductions of sorghum yield, which could not be compensated by the pigeonpea yield. A similar yield pattern was recorded for population 2 except that the yield levels were higher.

At higher populations (P3 and P4), replacing one-quarter of sorghum with pigeonpea in fact gave a slight though nonsignificant increase in sorghum yield. The pigeonpea yield was therefore a surplus. Thus, the predominantly sorghum mixture outyielded the sole-crop stands at the high densities. The total grain yield achieved from mixtures at population 3 was also the highest yield achieved in the whole experiment. This yield advantage is also supported by the land equivalent ratio (Andrews and Kassam 1976; Fisher 1977a) of 1.17 achieved at population 3. When one-half and three-quarters of sorghum were replaced with pigeonpea, there were large reductions in the sorghum yield, which could not be compensated by the pigeonpea yield. The total yields of the mixtures were therefore lower than the yields of pure stands at comparable population pressure.

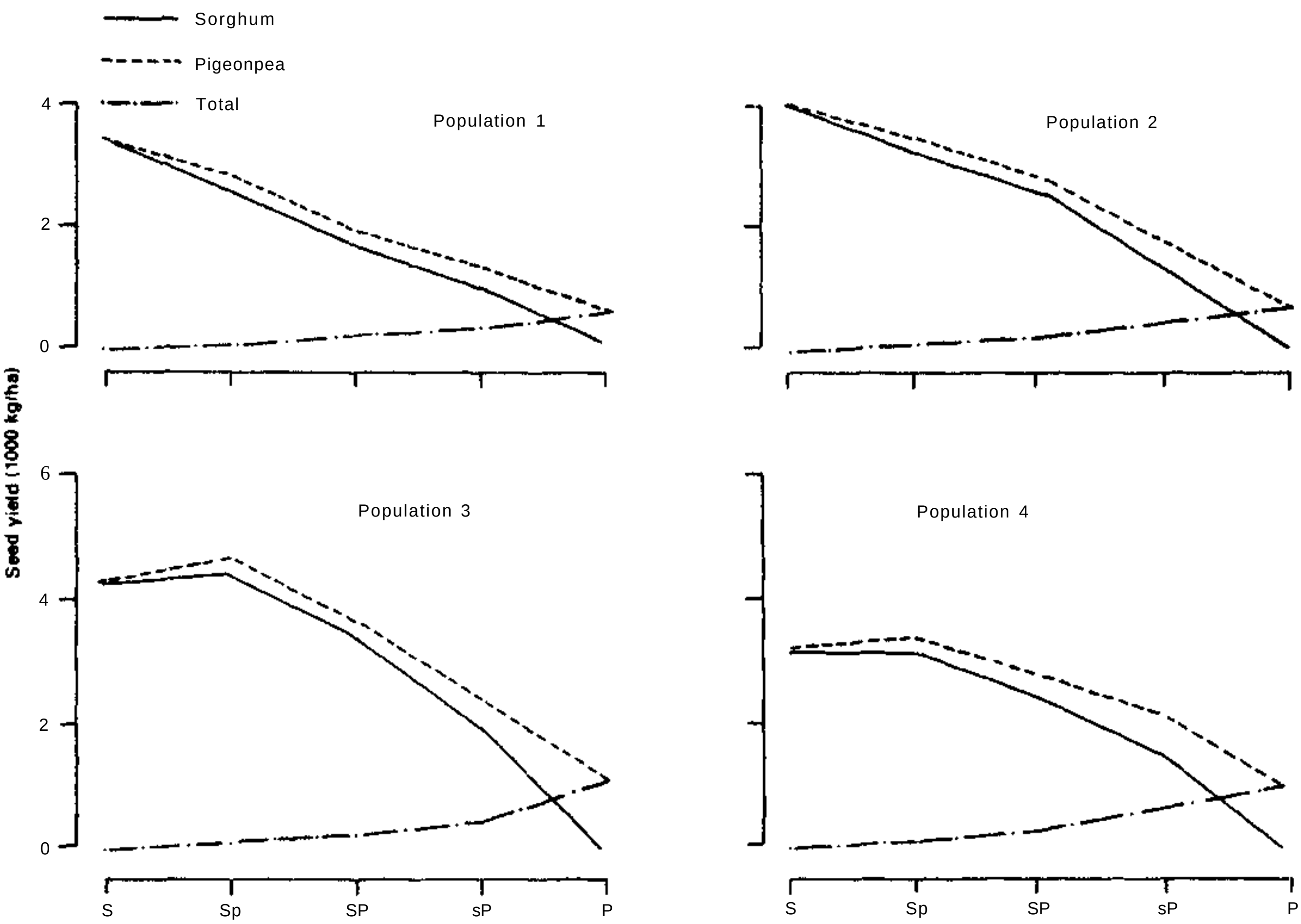

Figure 1b. Mean seed yields for the replacement-series treatments at each level of population for the within-the-row arrangement (LSD [0.05] within a given population: sorghum = 374; pigeonpea = 68; total = 709 kglha).

In the finger millet/groundnut mixtures a similar pattern of yields was obtained, except that the highest yield of mixtures occurred at population 4 (Fig. 2). At this population, replacing one-quarter of finger millet with groundnut gave an increase in finger millet yield. The total yield of the mixtures was therefore higher than that achieved from any sole-crop treatment in the whole experiment, giving an LER of 1.19. In contrast to the sorghum/pigeonpea mixture, when one-half of finger millet was replaced with groundnut there was only a slight and nonsignificant decrease in finger millet yield. This decrease was well compensated by the groundnut yield giving a slightly higher total yield of mixtures than the sole crops.

In both experiments, there was no striking difference in seed yield between the two methods of crop management. It is clear from Figures 1 and 2 that the total seed yield achieved from the mixtures in the within-the-row arrangement followed an identical pattern to those of the alternate-row arrangement. In the sorghum/pigeonpea mixture, the highest yield was also achieved at population 3, giving an LER of 1.18. In the millet/groundnut mixture, the highest yield was again achieved at population 4 as with the alternate-row arrangement. It is therefore evident that in these experiments crop arrangement did not have a significant effect on grain yield. This is of interest because a number of conflicting results have been reported on this aspect. Bodade (1964), for instance, suggested that there was more benefit in mixing crop species in the same row than in planting them in the same ratio in adjacent rows. In fact, he claimed more yield advantage when he mixed groundnut with sorghum in the same row than when he planted the same crops in adjacent rows. Harper (1961) showed that in

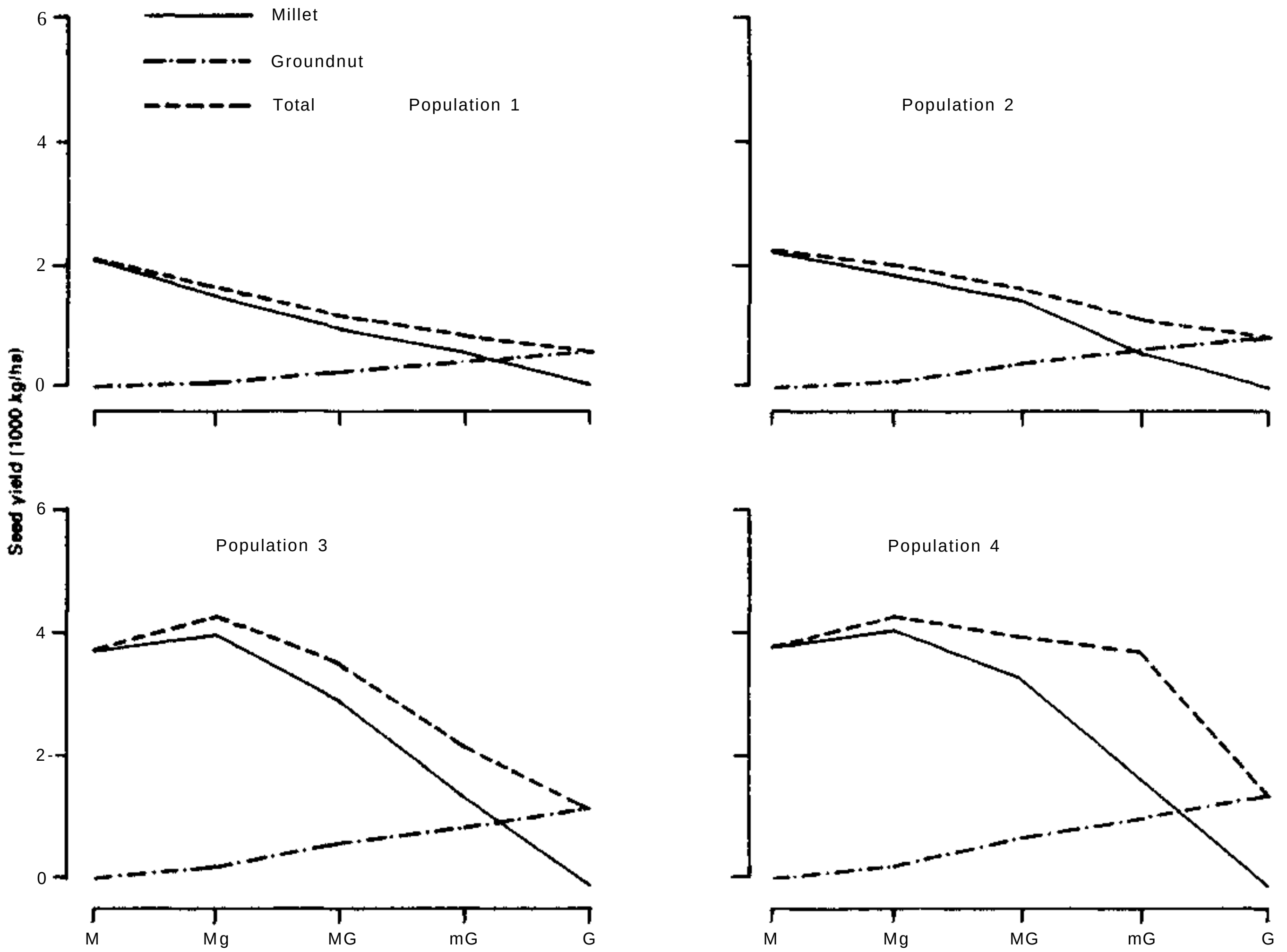

Figure 2a. Mean seed yields for the replacement-series treatments at each level of population for the alternate-row arrangement (LSD [0.05] within a given population: finger millet =203; groundnut = 156; total = 933 kg/ha).

pot experiments the effects of mixing two species could certainly change as planting pattern changed. Evans (1960), on the other hand, found no significant difference between yields of maize or sorghum with groundnut whether grown in alternate-row or within-the-row arrangements.

Conclusion

The results of these experiments have shown higher yields from mixtures than from sole-crops. In the sorghum/pigeonpea mixtures, the predominantly sorghum mixture achieved an LER of 1.17 at both populations 3 and 4. When comparisons were madeat comparable population pressure, as in the earlier experiments (Willey and Osiru 1972; Osiru and Willey 1972), yield advantage achieved was 28%; similarly, in the millet/groundnut mixtures an advantage of 44% was achieved.

As with the earlier experiments, these yield advantages have been achieved at higher levels of crop management than can be expected in traditional farming situtations. The yield advantages must have occurred, therefore, because the component crops were able to utilize environmental factors much more efficiently. The mixtures were perhaps able to do this because of the greater differences in the growth cycles of the component crops. Thus, in general, these results lend support to the earlier conclusions that crop mixtures are likelytogive yield advantages where the component crops are of very different growth patterns. The results also give further evidence that mixtures are likely to give greater advantages at higher populations.

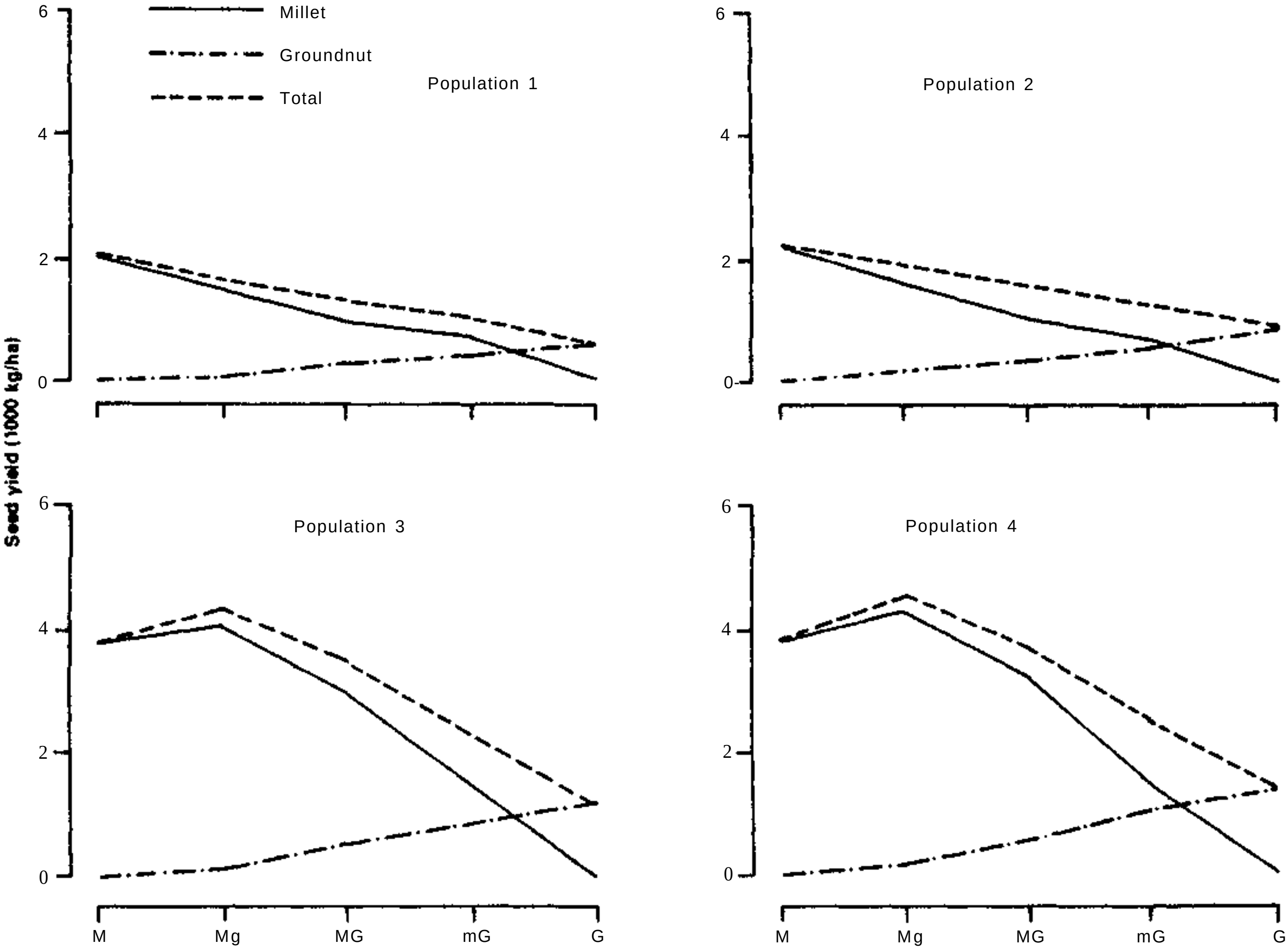

Figure 2b. Mean seed yield for the replacement-series treatments at each level of population fot the within-the-row arrangement (LSD [0.05] within a given population: finger millet =203; groundnut = 156; total = 933 kg/ha).

Relay Cropping and Intercropping: An Approach to Maximize Maize Yield in the Marginal Rainfall Areas of Kenya

H. M. Nadar and G. E. Rodewald*

Abstract

An experiment conducted to study maize yield response to two planting methods, three row spacings and two cropping systems, in a marginal rainfall area of Kenya with bimodal rainfall pattern, is discussed. Results from this experiment and the economic survey of the farming systems employed by the farmers in the study area indicated that the maize yields in the long rains can be greatly improved by minor modification of the technologies presently used by these farmers. One of the most critical factors determining maize yield during the long rains was the planting date. Delay in planting beyond the first week of March resulted in substantial yield losses. Relay cropping is found to be a means of planting maize early in the long rains.

In intercropping with beans, bean yield was found to be almost the same under maize row spacings of 60, 75, and 90 cm, while maize yield was significantly reduced in the 75-cm row spacing. An effort made to determine the effect of introducing a new technology on net farm income by using three linear programming models developed from the survey data is discussed.

The marginal rainfall areas under study in Kenya are characterized by a bimodal rainfall pattern. An area with 500 to 800 mm rainfall per year is considered of marginal agricultural potential. The main factor influencing such classification is the rainfall frequency and duration during the season rather than the total amount.

Figure 1 is a flow chart summarizing the agronomy research approach to develop economically feasible cropping systems for the marginal rainfall areas of Kenya. This approach emphasizes the importance of rain pattern analysis to indentify the probability of drought periods during the growing season. It also emphasizes the importance of phenology analysis of the crops under production. By determining the duration of each major growth stage and its level of sensitivity to drought stress, we can decide on the best time for planting each crop to let the least drought-sensitive growth stage coincide with the expected drought period.

This will, naturally, depend on how much flexibility we have in the planting date. That is where relay cropping can come into play.

In the area under study, farmers grow mainly maize, beans, pigeonpeas, cowpeas, and, to a lesser extent, sorghum and pearl millet, either as a monocrop or in an intercrop of two or more crops. The main intercropping systems are maize intercropped with beans or pigeonpeas. Maize is considered the major staple food in Kenya. Improvement in maize production, then, especially in the marginal rainfall areas, would be expected to have a direct impact on the economic conditions of the farmers in these areas.

The study reported here is the result of an experiment to study maize yield response to two planting methods, three row spacings, and two cropping systems.

These results were compared with an economical analysis of the farming systems employed by the farmers in the study area.

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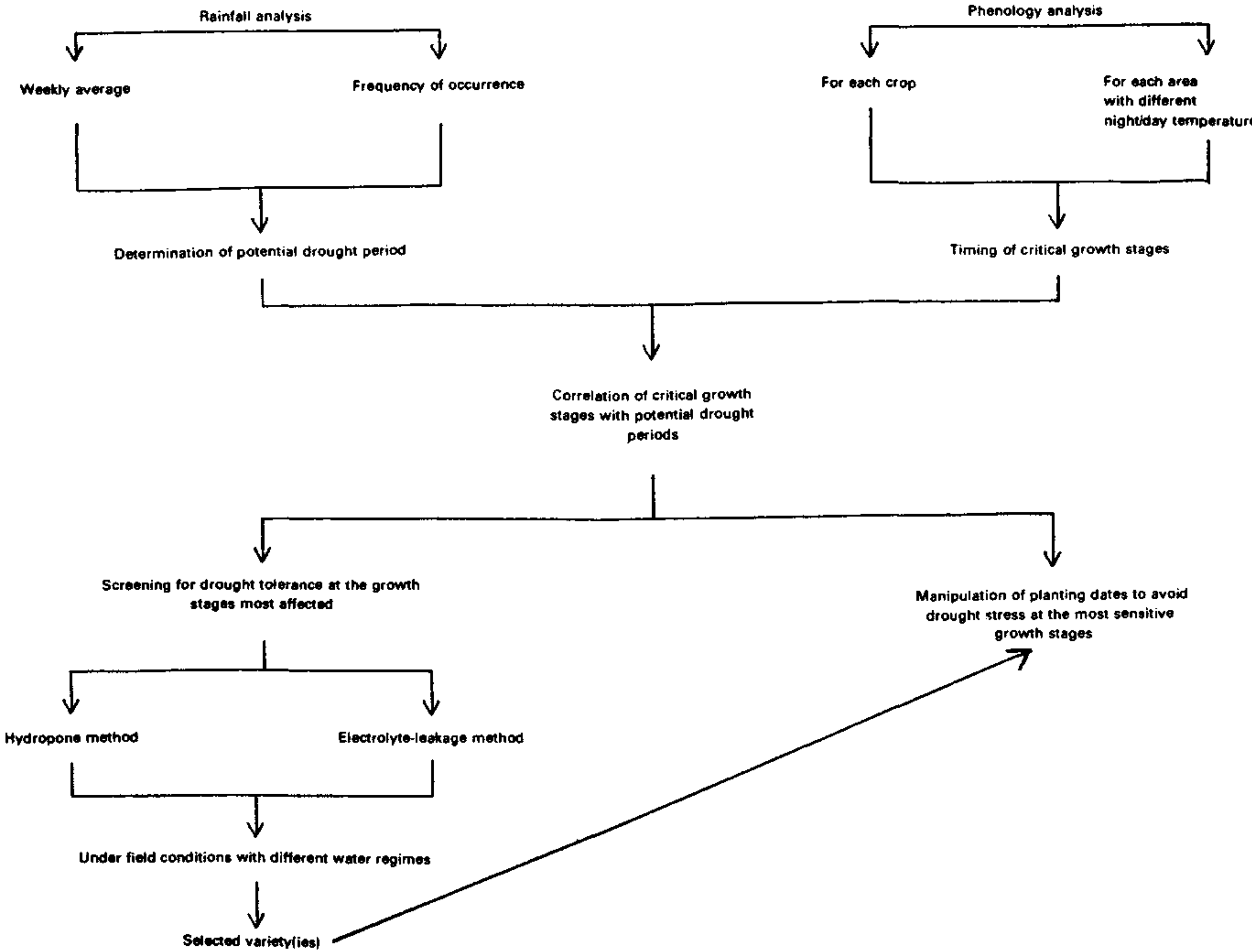

Figure 1. An approach to maximize crop yield under marginal rainfall conditions.

Rainfall Analysis

From the analysis of 20-year rainfall data for the Machakos meteorological station, we can draw the following conclusions:

1. While the weekly rainfall varies greatly from year to year, there are periods with high likelihood of measurable rain and other periods with very low likelihood.
2. The rain trend in the Machakos area is bimodal; there are two rainy seasons which are:
   (a) The long rains which last for approximately 3 months (Mar, Apr, and May).
   (b) The short rains which usually last for 8 to 9 weeks, (from the last week of Oct to the third or fourth week of Dec).

Figure 2 shows the average rainfall frequency and amounts during the year. From this histogram we can see that the two rainy seasons are separated by two dry seasons. One long (4 to 5 months), almost completely dry period follows the long rains. The second period which follows the short rains is 2 months in duration and is not always dry. Usually considerable rains fall during January and February. It is clear the marginality of the rainfall in the Machakos area is not due to the total amount of rain falling during the season, but it is more influenced by the length of the rainy seasons and the predictability of the rainfall.

Focusing on the long rains, we find that the maximum duration is 13 weeks with uncertain rainfall in the first 2 weeks of Marehand the last 3 weeks of May.

A survey of 40 farm operators in the Mbuini area of Machakos district during the long rain season of 1977 revealed low yields for all crops grown. The yields experienced are shown in Table 1 by level of technology used, where technologies 1 and 3 are local and improved seed used without fertilizer and technologies 2 and 4 are local and improved seed used with fertilizer. Note that only maize and beans were grown under all levels of technology.

The area devoted to the various crops grown are shown in Table 2 by technology as well as by total. As shown, 14.46% of the total acreage for the crops was in maize. Of the 10.68 ha in maize, 43.56% was improved and fertilized. Fewer ha were devoted to beans alone, only 3.7; however, 42.86% of those ha were improved and fertilized. In addition, 1.8 acres were devoted to maize interplanted with beans. The total land

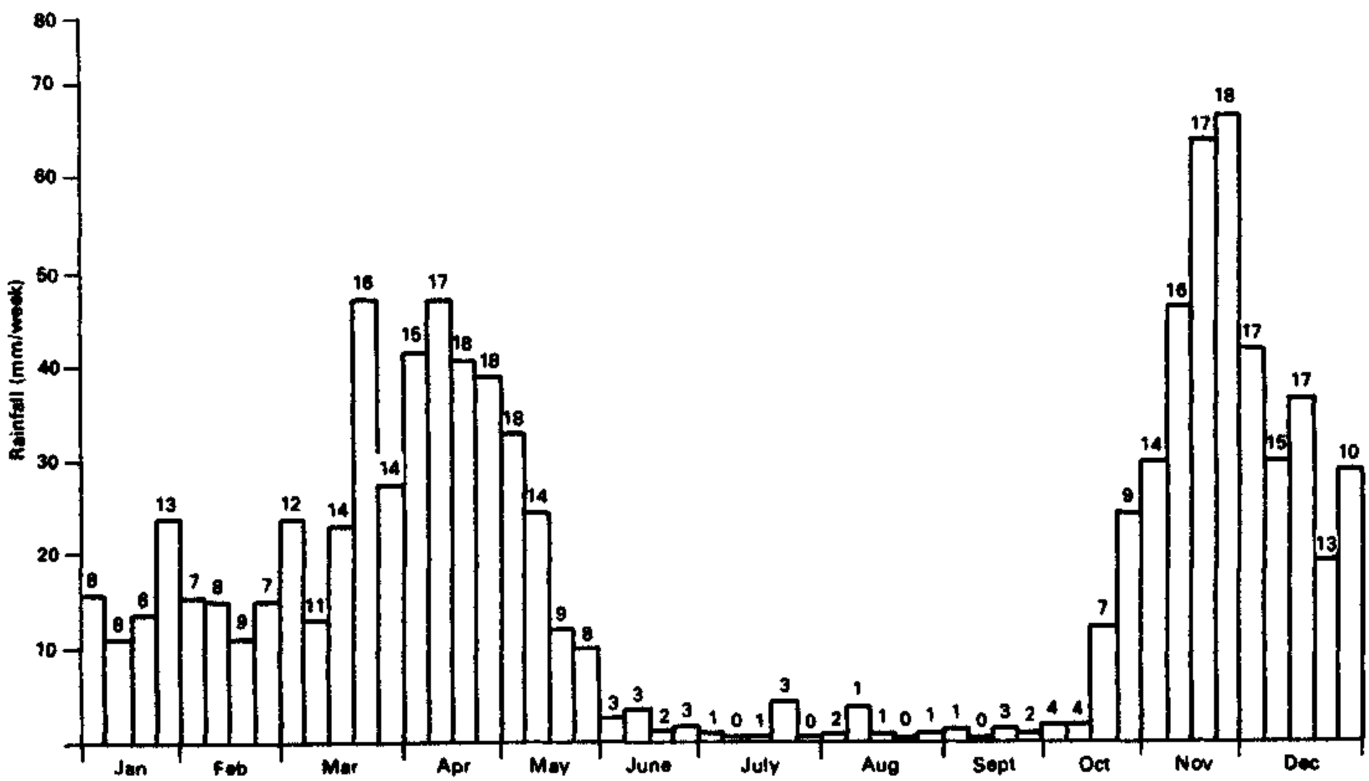

Figure 2. Twenty-year average of weekly rainfall at Machakos weather station (number over bar = number of years with more than 5 mm of rain during that week).

Table 1. Average yields (kg/ha) by crop by technology level, Machakos survey data.

Crop or crop combination		Technology level[a] 1	2	3	4
Maize		240	324	261	739
Beans		338	525	283	551
Pigeonpea		250.01	-	-	-
Cotton		611.82	-	-	-
Tobacco		397.94	-	-	-
Sunflower		312.70	-	-	-
Millet		247.00	617.50	-	-
Sorghum		889.20	370.50	-	-
Maize/pigeonpea:	Maize	441.51	-	232.97	323.15
	Pigeonpea	194.34	-	204.96	127.28
Maize/beans:	Maize	-	-	-	769.63
	Beans	-	-	-	237.12
Maize/cowpea:	Maize	227.24	487.50	316.16	-
	Cowpea	88.92	129.95	37.05	-
Cowpea/pigeonpea:	Cowpea	102.92	-	-	-
	Pigeonpea	139.50	-	-	-

a. Technology 1 = Local seed, no fertilizer used.
2 = Local seed, fertilizer used.
3 = Improved seed, no fertilizer used.
4 = Improved seed, fertilizer used.

Table 2. Total acreage of annual crops grown in Machakos sample area and acreage of crops at each technology level with percentage of acreage in each crop at each technology level.

Crop or crop combination	Total annual crop (acres)	Annual crop cropland in crop (%)	Acreage of crop grown under technology level[a]				Percentage of crops grown at each level of technology			
			1	2	3	4	1	2	3	4
Maize	26.4	14.46	6.1	5.3	3.5	11.5	23.11	20.08	13.26	43.56
Beans	9.1	4.99	1.0	0.9	3.3	3.9	10.99	1.00	36.26	42.86
Pigeonpea	9.5	5.20	9.5	-	-	-	100.00	-	-	-
Cotton	72.9	39.94	72.9	-		-	100.00	-	-	-
Tobacco	1.8	0.99	1.8	-	-		100.00	-	-	-
Sunflower	5.0	2.74	5.0	-	-	-	100.00	-	-	-
Millet	0.8	0.44	0.4	0.4	-	-	50.00	50.00	-	-
Sorghum	1.5	0.82	1.0	0.5	-	-	66.67	33.33	-	-
Maize/pigeonpea	33.6	18.41	14.9	1.0	10.1	7.6	44.34	2.98	30.06	22.62
Maize/beans	4.5	2.46	-	-	4.5		-	-	100.00	-
Maize/cowpea	6.9	3.78	3.5	0.9	2.5		50.72	13.04	36.23	-
Cowpea/pigeonpea	10.5	5.75	10.5	-	-	-	100.00	-	-	-
Total	182.5	-	126.6	9.0	23.9	23.0	69.37	4.93	13.10	12.60

a. See footnote in Table 1.

area in the sample devoted to maize and beans was grown only under maize technology 3. In all plots the maize variety was Katumani and the bean variety was Mwezi Moja.

As shown in Table 1, when used, fertilizer increased yields. However, it is evident that the yield remained below what would be expected if rainfall were adequate and the timing of the rain was proper for maximum plant growth.

Planting Dates

Katumani maize is an early-maturing composite. Its growing season, from planting to physiological maturity, is about 120 days or 17 weeks. This shows that, under average rainfall conditions, Katumani maize needs to utilize 4 weeks more than the whole duration of the long-rain season. Figure 3 illustrates the different developmental stages of 115- and 138-day growing season maize relative to the rain frequency of the long rains. If maize is planted on 1 March, drought will be expected to affect the 115-day plants in the late-dent stage while the 138-day plants will suffer drought at the late milk stage. Any delay in planting date will add to the severity of the drought effect on the maize yield. It is our opinion that if Katumani maize is to be grown during the long rains, it must be planted no later than the first week of March.

The survey conducted in the Machakos area (Table 3) revealed that during the long rains of 1977, only 6.5% of the maize and 10.4% of the bean areas were planted by the first week of March. The total amount of rainfall during March, April, and May 1977 was 500 mm, *or* about 120 mm abovethe average rainfall during the same period (381 mm). On the other hand, the maize yield realized from our 1978 long-rain experiment at Machakos averaged 5110 kg/ha (Table 4). Total rainfall during March, April, and May 1978 was 371 mm, or 10 mm below average. In our opinion, late planting was the main reason for the low maize yields realized by the local farmers as shown in Table 5.

We planted our experiment on 2 March 1978 to test row spacing and population which experienced drought by the end of the third week of May, at the late milk stage. This drought caused an average yield reduction of 10 to 15%. If maize had been planted 2 weeks later, the

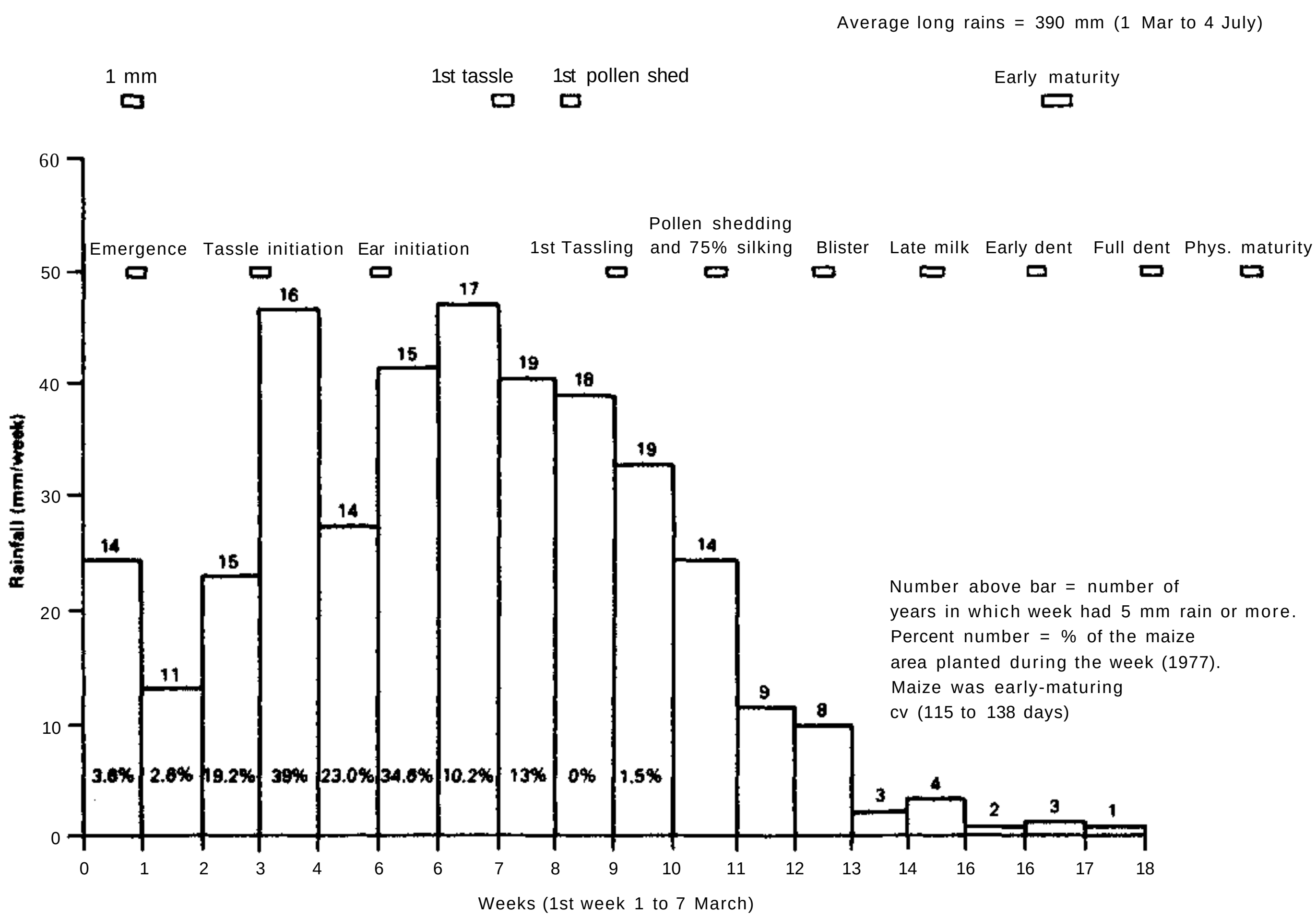

Figure 3. Average weekly rainfall of the years 1953 to 1972 (20 years) at Machakos.

Table 3. Weekly planting of maize, beans, cowpeas, and pigeonpea expressed as percent off the total area planted during the long rain season, 1977.

Month	Week	Total area planted during the week (%)			
		Maize	Bean	Cowpea	Pigeonpea
Last week of					
Feb	8	3.9	3.4	0.0	0.0
Mar	9	2.6	7.0	0.0	0.0
	10	19.2	24.1	4.8	2.1
	11	3.9	0.0	4.8	0.0
	12	23.0	24.1	23.8	2.1
	13	34.6	20.7	33.3	0.0
Apr	14	10.2	13.8	19.0	4.2
	15	1.3	3.4	0.0	4.2
	16	0.0	3.4	0.0	0.0
	17	1.3	0.0	0.0	0.0

Table 4. Yield results expressed as kg of maize per ha (corrected to 15.5% moisture).

Row spacing	Tillage practice	Method of planting			Total	Mean
		1 plant/hole	1 plant/hole	2 plants/hole		
60 cm	Till	4 748	5 403	5 727	15 878	5 293
	No till	4 663	5 772	5 658	16 093	5 364
Total		9 411	11 175	11385	31 971	-
Mean		4 705	5 587	5 693	-	5 328
75 cm	Till	5 243	5 240	6 657	17 140	5713
	No till	4 347	5 033	5 983	15 363	5 121
Total		9 590	10 273	12 640	32 503	-
Mean		4 795	5 136	6 320	-	5 417
90 cm	Till	3 946	4 753	5 199	13 898	4 633
	No till	3 423	5 281	4905	13 609	4 536
Total		7 369	10 034	10 104	27 507	-
Mean		3 684	5017	5 052	-	4 584
Total	Till	13 937	15 396	17 583	46916	-
Mean	Till	4 646	5 132	5 861	-	5 213
Total	No till	12 433	16 086	16 546	45 065	-
Mean	No till	4 144	5 362	5515	-	5 007
Grand total		26 370	31 482	34 129	91 981	-
Overall mean		4 395	5 247	5 688	-	5110

drought effect would have been experienced by the plants at the pollen shedding stage, and the yield loss would have been considerable. Marimi (personal communication) found that during long rains in 1974, delay of planting for 8 days after the onset of rains, at Kampi ya Mawe, reduced yield from 2530 kg/ha to 410 kg/ha, or about 84%. He concluded that late planting was the singlefactor accounting forthe most severe reduction in yield. Jurgens et al. (1978) found that when drought was imposed 10 days after pollination, yield was reduced by 42% of the control. From Figure 4 we can see the period between pollen shedding and the blister stage is 1 week. This 1 week can make the difference between yield and no yield.

Table 5. Average maize and baan yield (kg/ha) producad by tast-araa farmars from tha long rain season, 1977.

Type of Technology	Yield	
	Maize	Bean
Local seed + no fertilization	240	338
Local seed + fertilizer	324	525
Improved seed + no fertilizer	261	283
Improved seed + fertilizer	739	551

Dagg (1965) suggested the approach of matching water availability to crop demand for determining the probable success of growing maize at Muguga. He found that rain that falls during June, July, and August was critical for survival and yield of maize grown in that area during the long rains. Virtually no measurable rain falls in the Machakos area during June, July, and August. This offers a limited growing season duration with which we have to deal. Soil temperature during the long rain period decreases with the advance of the season. Table 6 shows the maximum, minimum, and average daily temperatures from 6 April to 16 July 1978. The soil temperature trend shows that beyond the third week of June, soil temperature is not adequate for maize growth. Soil temperature dropping below 20℃ affects root activities and the overall biological function of the plant. Soil temperature drop, therefore, is an added limitation for the long-rain growing season. From the analysis of class A pan evaporation records, Stewart and Wang'ati (1978) showed that Katumani maize potential yield reached 6.7 tonnes/ha if planted around 1 March and decreases 10-15% for each week delay in planting beyond that date.

All these factors, added together, emphasize the importance of early maize planting for the long-rain season. The first week of March is considered the date beyond which definite yield reduction would be expected.

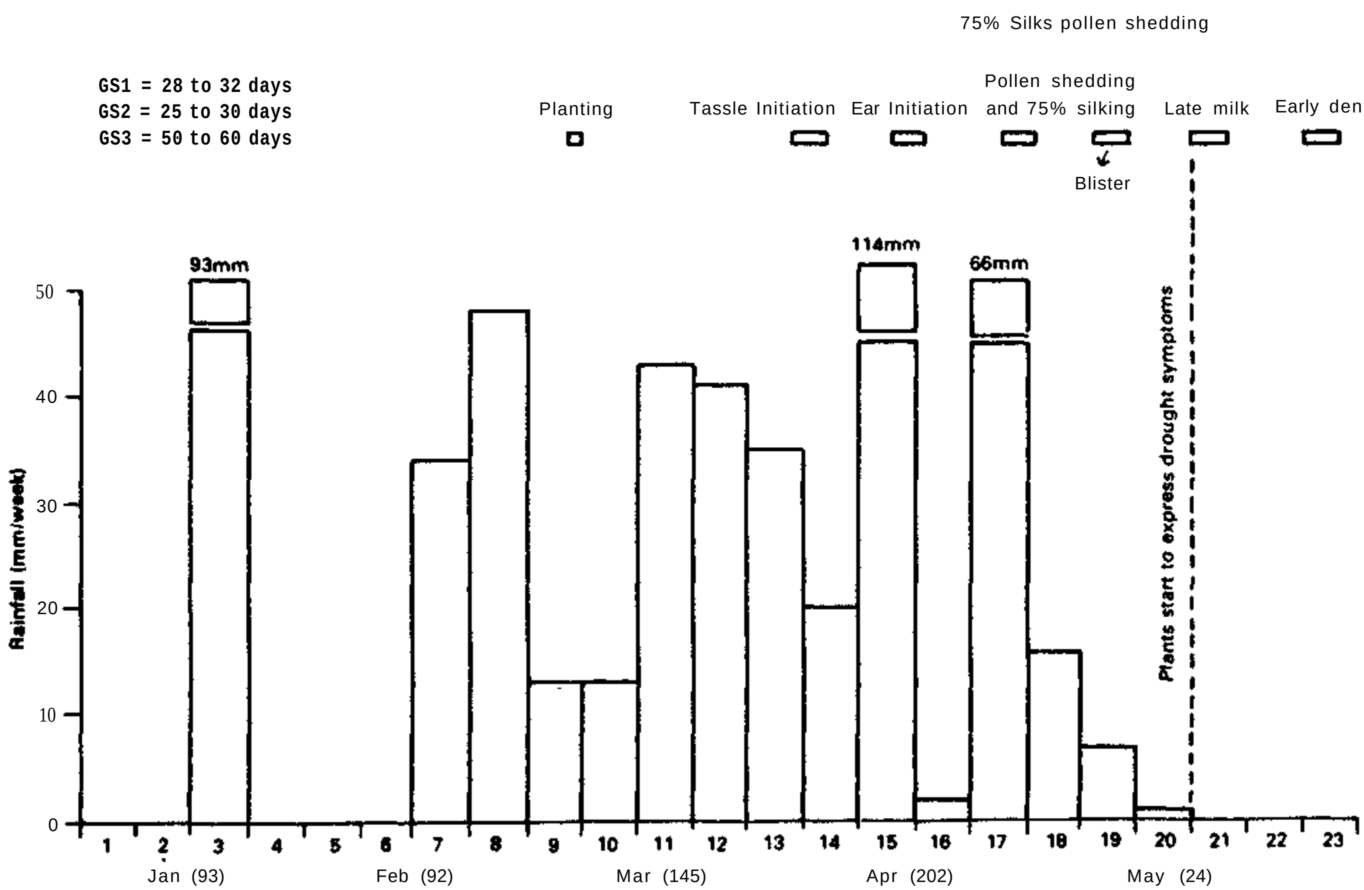

Figure 4. Weekly rainfall at Katumani Station from January to May 1978, with Katumani maize phenology analysis superimposed.

Table 6. Soil temperature in Katumani from 6 April to 16 July 1978.

Day	Max (℃)				Min (℃)				Average(°C)			
	April	May	June	July	April	May	June	July	April	May	June	July
1		23.6	24.5	21.1		21.1	19.7	19.1		22.4	22.1	20.1
2		23.8	23.9	21.1		20.3	20.6	18.8		22.1	22.3	20.0
3		24.0	24.5	22.1		20.4	20.9	18.6		22.2	22.7	20.3
4		22.7	25.6	20.5		20.8	21.1	17.9		21.8	23.4	19.2
5		21.3	25.0	19.8		19.3	20.7	18.8		20.3	22.3	19.6
6	27.9	23.0	25.1	19.6	21.11	19.4	20.4	18.0	24.5	21.2	22.8	19.7
7	25.3	23.1	25.4	21.5	21.4	20.7	20.7	17.6	23.4	21.9	21.1	19.6
8	27.6	22.3	23.8	22.4	20.9	20.0	20.8	17.7	24.3	21.2	21.6	20.0
9	27.8	22.3	22.7	20.0	21.8	19.2	20.5	18.2	24.8	20.7	21.6	20.0
10	26.0	22.9	23.4	20.9	19.1	19.8	19.4	17.8	22.6	21.4	21.7	19.3
11	26.1	21.1	24.9	21.9	20.5	19.9	19.3	18.1	23.3	20.5	22.0	20.0
12	25.1	21.8	23.9	21.9	20.5	18.8	21.0	18.1	22.8	20.3	22.4	20.0
13	25.8	22.0	22.8	20.8	20.3	18.6	20.3	19.1	23.0	20.3	21.6	20.0
14	24.9	22.2	23.2	21.3	19.6	19.5	19.1	18.4	22.2	20.8	21.1	19.8
15	24.9	22.5	23.8	19.9	19.8	19.2	19.0	18.9	22.3	20.8	214	19.4
16	24.8	22.9	22.6	20.3	20.2	19.6	20.1	17.3	22.5	21.2	21.4	18.8
17	23.2	24.4	23.3		20.3	19.5	19.6		21.7	22.0	21.4	
18	23.8	24.8	23.1		21.0	20.2	19.6		22.4	22.5	21.4	
19	24.4	23.3	22.3		21.2	20.4	20.3		22.8	21.8	21.3	
20	24.6	22.5	22.0		22.0	19.3	19.9		23.3	20.9	21.0	
21	25.2	23.0	21.4		22.3	20.3	19.6		23.8	21.7	20.5	
22	24.8	23.1	21.4		22.5	19.1	18.9		23.7	21.1	20.2	
23	25.0	24.2	22.9		22.3	20.4	18.6		23.7	22.3	20.8	
24	24.7	23.1	21.3		22.4	19.9	19.4		23.5	21.5	20.4	
25	23.8	23.7	22.6		21.1	19.9	17.6		22.5	21.8	20.1	
26	23.4	23.2	-		20.9	19.9	-		22.1	21.5	-	
27	23.1	22.9	21.4		21.1	20.3	-		22.1	21.6	-	
28	22.9	23.6	20.9		20.1	20.0	19.3		21.5	21.8	20.1	
29	23.6	24.3	21.4		20.0	19.8	19.3		21.8	22.1	20.3	
30	24.2	23.9	20.9		20.4	20.1	19.5		22.3	22.0	20.2	
31		24.3				19.7				22.0		

Relay Cropping

To deal with the suggested planting dates for the long-rain season, the farmer faces difficulties in plowing the land and preparing the seedbed before that suggested planting date. The major difficulty is that the previous crop (usually maize) is not ready for harvest by the first week of March.

An experiment was designed to test the significance of plowing for seedbed preparation vs planting under the existing crop (maize) without any seedbed preparation other than weeding. Within this experiment, row-spacing, population, and intercropping with beans were tested. The complete experiment was planted on 2 March 1978 and fertilized with 30 kg/acre of N as ammonium sulfate and 15.5 kg/acre of P_2O_5 as single superphosphate. The previous crop was harvested 2 weeks after planting.

The results in Table 4 show that the average yield/ha was 5213 kg for the tilled area and 5007 kg for the nonfilled area. Statistical analysis showed no significant difference between the two seedbed preparation practices. This result suggested that the time of planting is much more critical, with respect to yield, than the seedbed preparation practices. This result shows that there is no benefit to gain from plowing the land before planting, especially if that practice will cause a delay in the recommended time of planting.

Row Spacing, Population, and Intercropping

Within the seedbed-preparation practice study, 60-, 75-, 90- cm row spacings were studied with 30 cm within-row spacing and one plant and two plants/hole. The one plant maize/hole was either planted as a monocrop or intercropped with beans (variety Mwezi Moja) planted between the maize plants on the same row. Yield was determined and adjusted to 15.5% of moisture content. Bean yield was converted *to maize* yield by multiplying by a bean price to maize price ratio:

Beans 1.45 KSH/KG

Maize 0.71 KSH/KG

The nonsignificance of the seedbed-preparation treatment increased the efficiency of the factorial experiment, testing row spacing, population, and intercropping. Row spacing and population effects were both significant. Yield increased significantly with the decrease in row spacing when we have 1 plant/hole while with two plants/hole, the 75-cm row spacing yield was superior to both 60- and 90-cm row spacing. Figure 5 presents the regression of yield over population at the different row spacings. While the R^2 value for the overall regression is 0.53, it is 0.74 for the 75-cm row spacing and 0.22 and 0.14 for the 90-cm and the 60-cm row spacings, respectively. Thus, the 75-cm row spacing provides the best population geometry for Katumani maize under Katumani conditions.

Intercropping with beans increased yield significantly over one plant/hole in all row spacings, but two plants/hole yielded higher especially at the 75-cm row spacing (Fig. 6).

In an effort to determine the effect on net farm

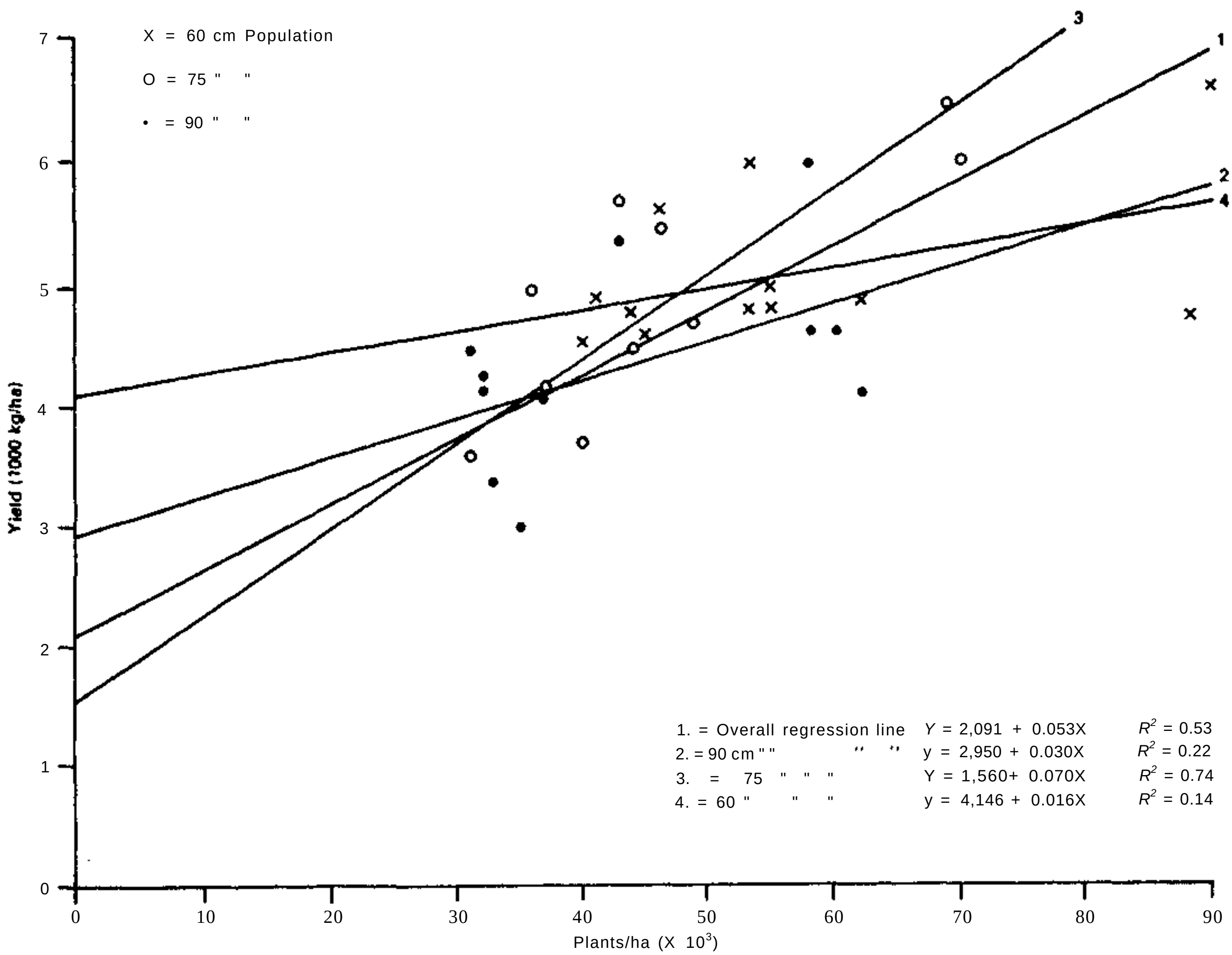

Figure 5. Linear regression of maize yield on plant population per ha, as influenced by row spacing.

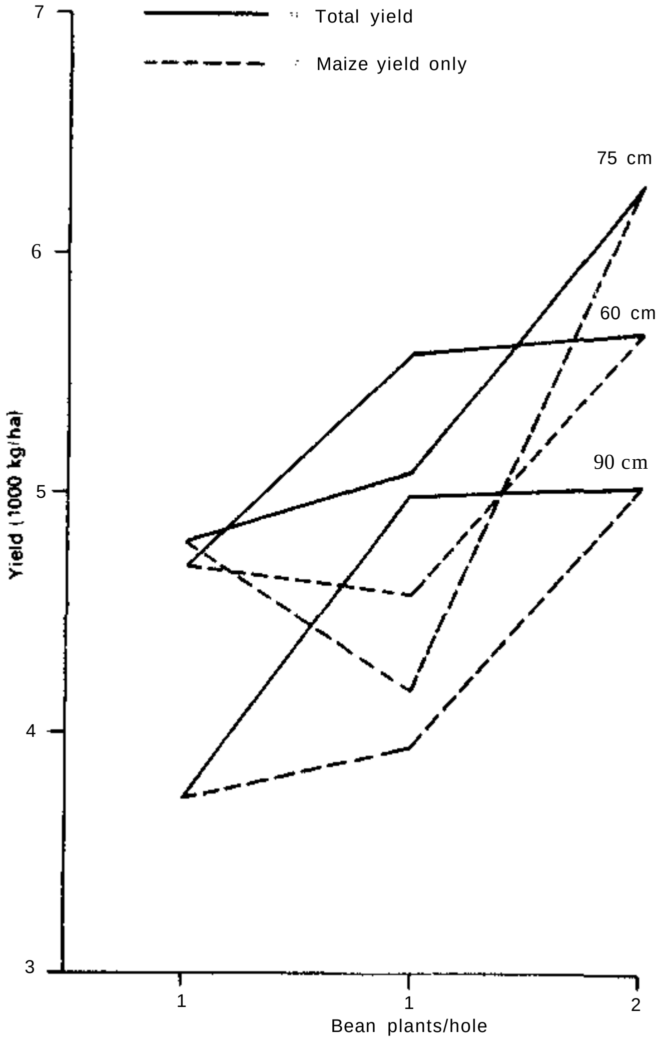

Figure 6. Yield response to population and intercropping with beans, as affected by row spacing.

income by introducing a new technology, three linear programming models developed from the survey data were used. The objective in this analysis was to determine how the types of crops grown change and what effect this change has on net income as the yield of crops change. The linear programming models are farm management models. As such, they include all the possible crop alternatives by technology that are shown in Table 1. In addition, they include as constraints the amount of land available, the amount of family labor available, the amount of money available for growing crops, and the amount of money that can be borrowed during a growing season.

The assumptions under which all three models were run are:

1. That food needs would be satisfied before a food crop was sold. After satisfying food need, the model maximizes profit.
2. That the farmer has to borrow short-term capital and his use of borrowed funds is restricted to the expected net return from the cash crops of cotton or sunflower.
3. That labor use could be defined for 16 periods throughoutthe year. Each of these periods could then be assigned a total labor availability figure corresponding to available family labor.

As designed, the linear program will choose the crop or crops that will maximize net income. The first two models differ only in the yields assumed for the crops. In model 1, the yields assumed are those shown in Table 1 and are average yields. In model 2, the yields are the highest yields attained by the farmers in the IADP survey. Model 3 differs from model 1 in that 18 new maize and maize/bean technologies were introduced. These technologies are those shown in Table 4. Each of these technologies assumes a different cultural practice and, as shown, has associated with it a different yield. The results of these three linear programming models are shown in Table 7. The results show the ha of crops chosen by the program. These crops are those which would maximize profits afterfood needs are satisfied. In models 1 and 2, the technologies listed as maize 5-16 and maize/beans 5-10 were not included. These were available only in model 3.

With the yields assumed for model 1, the farmer would maximize returns to annual crops by growing 1.45 ha of Katumani maize interplanted with beans and by growing 0.88 ha of cotton. The cotton crop furnishes credit for the other crops. Note that with average yields the farm could lose Shs. 396.

With the yields assumed for model 2, the farmer could maximize returns to annual crops by growing local maize interplanted in pigeonpeas, 0.4 ha not fertilized and 0.02 ha fertilized; 0.93 ha of 'Mwezi Moja' beans not fertilized; and 0.93 ha of cotton. The cotton again furnishes the credit for growing the other crops. Net returns to annual crops increases to Shs. 968, or almost Shs. 1200 over model 1 results.

With the yields and technologies assumed for model 3, the farmer would maximize returns to annual crops by growing 1.48 ha of Katumani maize interplanted with beans in 60-cm rows under a no-till cultural practice or 0.44 ha of Katumani maize alone in 75-cm rows without tillage with two plants per hole, and 0.4 ha of cotton.

Table 7. Results of linear programming at Machakos representative farm under different yield assumptions and cultural practices.

Crop technology		Crops grown (ha)		
		Model 1	Model 2	Model 3
MAIZ5	Maize 1 plant per hole 75-cm row Tilled			
MAIZ6	" " " " No till			
MAIZ7	" " " 90-cm " Tilled			
MAIZ8	" " " " No till			
MAIZ9	" " " 60-cm " Tilled			
MAIZ10	" " " " No till			
MAIZ11	" 2 " " 90-cm " Tilled			
MAIZ12	" 2 " " " No till			
MAIZ13	" 2 " " 75-cm " Tilled			
MAIZ14	" 2 " No till			0.44
MAIZ15	" 2 " " 60-cm " Tilled			
MAIZ16	" 2 '* " " No till			
MABE5	Maize/Beans 75-cm " Tilled			
MABE6	No till			
MABE7	" *' 90-cm " Tilled			
MABE8	No till			
MABE9	" " 60-cm " Tilled			
MABE10	No till			1.48
BEAN1	Beans No Fertilizer		0.93	
BEAN2"	Fertilizer			
BEAN3	" Rosecoco No Fertilizer			
BEAN4	Fertilizer			
MAIZ1	Maize local seed No Fertilizer			
MAIZ2""""	Fertilizer			
MAIZ3	" " Katumani No Fertilizer			
MAPP1	Maize/Pigeonpea, local seed No Fertilizer		0.40	
MAPP3	Katumani Maize/Pigeonpea "		0.02	
MAPP4	Katumani Maize/Pigeonpea Fertilizer			
SUNFI	Sunflower			
TOBAI	Tobacco			
COTTI	Cotton	0.88	0.93	0.40
PIPEI	Pigeonpea			
MILL1	Millet No Fertilizer			
MILL2	Fertilizer			
SORG1	Sorghum planted in short rains			
SORG2	" " " long rains			
MACP1	Maize/Cowpeas No Fertilizer			
MACP2	Maize/Cowpeas Fertilizer			
MACP3	Katumani maize/cowpeas No Fertilizer			
CPPP1	Cowpeas/Pigeonpeas			
MABE4	Katumani maize/beans Fertilizer		1.45	0.05
Net Income		Shs.-369/44	Shs. 968/48	Shs. 3275/86

Again cotton furnishes credit for the two other crops. Returns increased over model 1 by Shs. 3644 and over model 2 by Shs. 2444.

The yields for maize used in models 1 and 2 were compared to actual maize yields obtained from a sample of 100 farmers in the same area in which the yield estimates were measured from a 5 x 5 m area for three replications per farm. In that sample, the average yield was 512 kg/ha, the lowest 128 kg/ha, and the highest

3136 kg/ha.[1] The high and low yields for the IADP survey was 74 kg/ha and 1556 kg/ha, respectively. The average yields appear by technology in Table 2.

Summary and Conclusion

The experimental results and economical survey indicated that yields obtained by local farmers, during a season with well above average rainfall, was very low and can be greatly improved by minor modification in the technologies presently used by these farmers.

One of the most critical factors in determining maize yield during the long rains was found to be planting date. Any delay beyond the first week of March would result in substantial yield losses. Relay cropping is one means of early planting. No significant yield loss was found to be caused by relay cropping.

Row spacing has a significant influence on yield: 75-cm row spacing most probably provides the best population geometry, especially at higher populations (two plants/hole). On the other hand, in the 60-cm and 90-cm row spacings, yield does not increase significantly with the increase in population. In intercropping with beans, bean yield was almost the same under the different row spacing conditions, while maize yield was significantly reduced in the 75-cm row spacing.

The effect of one crop on the yield potential of the other is the subject of an ongoing experiment. Our short-term objective in the agronomy research program is to optimize yields of the already cultivated crops in the study area, in years with average to good rainfall. This approach would realize surpluses during these years which can offset the effect of occasional crop failures in years with very low rainfall. The long-range objective would be to stabilize farm output by selection for drought tolerance and introduction of more hardy crops.

1. "Objective maize yield survey in joint project Machakos study area" by Simeon R. Onchere.

Intercropping Studies in Swaziland: Present Status and Future Projections

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Abstract

This paper discusses the present status of intercropping in Swaziland agriculture and projections for the development of this system in the future.

Swaziland has two types of land aquisition and ownership, namely modern and traditional land tenure systems. The area in which the traditional land tenure system operates is called the Swazi Nation Land and it covers 56% of the rural land. Agricultural practices of this area are pervasively subsistent in character. It has been estimated that 42.8% of the fields in the Swazi Nation Land are intercropped. Maize is normally the dominant crop here and it is grown intercropped with other cereals, legumes, cucurbits, and other crops. An intercropping research and extension project has been proposed with a general objective of increasing the productivity of principal intercropping systems practiced by the small-scale subsistence farmers in Swaziland. The composition of the research team and activities of the proposed project are discussed in detail.

Swaziland is a landlocked country of 17 368 km^2 and is located between the. 25th and 28th parallels of latitude in the southeastern part of Africa. It has a maximum length from north to south of about 190 km and a maximum breadth of about 145 km and is bordered to the east by the People's Republic of Mozambique and elsewhere by the Republic of South Africa.

The economic system of Swaziland reflects a high degree of dualism, with a modern sector (controlled mainly by expatriates) accounting for over 80% of Gross Domestic Product and wage employment. About 30% of the labor force is absorbed into the modern sector, and the rest is in subsistence agriculture based predominantly on maize production and cattle holding. Per-capita GNP was estimated in 1975 at US $470, although this figure does not reveal the extent of maldistribution of income between the relatively few participants in the modern economy and the vast majority of Swazis who are supported by the traditional farming sector. It is estimated that per-capita income in the traditional sector is less than US $100 per annum.

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Agroecological Zones

Swaziland consists roughly of four well-defined agroecological regions running from north to south of approximately equal width. These zones are as follows.

The Highveld

The highveld (5 200 km^2) lies along the western border of the country. Its average elevation is 1000-1800 m. It is characterized by a humid climate with rainfall ranging from 1000 to 1750 mm per year. The highveld is predominantly rocky with a series of broken escarpments. Its granite mountains are frequently too steep for cultivation, but, where the gradient is gentler, there are good, deep, red, orange, and yellow soils of medium texture. All soils in this area are acidic, associated with a high rate of leaching, soil acidity, depletion of bases, and possible toxicity of Al. Major constraints to intensive crop and pasture production are lack of N, P, and K. Low availability of Mo is often an obstacle to effective nodulation in legume crops (Murdoch 1970).

The Middleveld

The middleveld (4700 km^2) lies directly east of the highveld and has an average elevation of 350-1000 m. The climate is subtropical with a rainfall of 750-1 200 mm per annum. The geology of the area is chiefly granite with gneiss, dolerite, and other rock types. Soils are deep, friable, red, clay loams with grey-brown sands and sandy loams in areas of restricted drainage. They overlie mottled sandy clays or hard pans with iron concretions. The soils in this area are also in the acid range. Mineral stress features in these soils are N, P, K and Mo deficiencies and soil acidity (Murdoch 1970). Most of the major commercial crops, such as cotton, tobacco, pineapples, citrus, and other tropical fruits, are grown in this area.

The Lowveld

The lowveld (6200 km^2) lies east of the middleveld and is gently undulating with altitude ranging from 60 to 375 m. It has a subarid climate with rainfall of 500-800 mm per annum. Most of the hills in this area are formed from north-south dolerite dykes. In general, the western lowveld has acid rocks, and basic rocks are found in the eastern parts of the lowveld. Soils in the west have features resembling middleveld, and those in the east are shallower red and black clays (Vertisols). Base saturation in the Vertisols is high, and Pand Zn availability are generally low. Saline soils, showing high concentrations of soluble salts, high osmotic pressure of the soil solution, moisture stress, and a hindrance to normal ion uptake by plants, are also present in the lowveld. Sodic soils with high sodium saturation *are* also common in the lowveld. The stress phenomena in sodic soils are excess of Na and reduced availability of N, P, K, Zn, Cu, Mn, and Fe. The decisive limiting factors to plant growth in sodic soils are the poor physical condition of Na-saturated clays, unfavorable internal drainage, and the limited amount of available moisture (Murdoch 1970).

The Lubombo Plateau

The Lubombo Plateau (6200 km^2), located in the extreme east, has an altitude range of 450-850 m. It is a broken plateau with subhumid climate and a rainfall of 750-900 mm per annum. The plateau is built of acid to intermediate lavas, including rhyolite. The soils are deep reddish and are of medium to heavy texture.

Existing Agriculture and Land Tenure Systems

Agriculture plays a key role in the economic development of Swaziland. As stated earlier, it contributes about 35% of the Gross Domestic Product and over 40% of domestic exports, and it provides income and livelihood to about 90% of the country's population. Of the total land area of Swaziland, 65% is employed for grazing, 10% is used for cultivation, and 10% is considered ideal for intensive cultivation. The principal commercial agricultural products are citrus and sugar. Maize is the staple product in the subsistence sector. The raising of livestock (as reflected by the land area used for grazing) is an important occupation and a source of cash income, especially among the traditional population of Swaziland.

Several significant factors bear upon the process of growth and economic change in the agricultural sector of Swaziland. The agricultural sector is characterized by a series of marked dual systems which tend to stifle the continued rapid expansion of the country's rural economy. For instance, Swaziland has a dual system of land acquisition and ownership, namely, the modern and traditional land tenure systems. The latter system accords individuals the right of land use but not that of ownership. It holds that land is a communal factor which is held by the King in trust for the nation. Consequently, all grazing pastures falling underthis system are communally utilized, and only parcels of arable land and homestead sites (allocated to individuals by area chiefs) are used by individual households. The area in which the traditional land tenure system operates is called the Swazi Nation Land (SNL) and is the area in which most of the Swazis reside and farm. The SNL covers about 56% (931 494 ha) of the rural land area of Swaziland. The agricultural practices of the SNL are pervasively subsistent in character, and, as a result, only a very small proportion of this area's produce is marketed.

Operating side by side with the traditional land tenure system is the so-called modern land tenure system which allows for freehold or concessionary title deed by individuals and corporations. The area in which this system operates, called the Individual Tenure Farms (ITFs), covers 40% (800 000 ha) of the rural land area of Swaziland and includes most of the country's commercial farms and timber plantations. The ITFs thus constitute a predominant percentage of the country's agricultural commercial sector and produce most of the country's commercial agricultural output. Most of the freehold land is owned by expatriate farmers and companies and can conceivably be considered a foreign sector in the country's economy.

Arising from the above duality in land ownership and from the fact that farming practices differ according to the land tenure system, yields in the traditional sector are rather low, and only incidental surpluses reach the marketplace. Consequently, there is a gross imbalance in economic productivity and incomes between the two agricultural sectors, with a predominant share of the farming income accruing to the modern rural sector. The major task now facing the Swaziland government is to promote balanced growth between the two sectors and to evolve an equitable distribution of the benefits of development by identifying and implementing rural development projects that are designed to transform the traditional sector into a modern and commercial sector. The Government is attempting to achieve this by creating a series of programs, called Rural Development Area Programs (RDAP), for the promotion of dryland mixed farming and irrigated agriculture schemes and to upgrade social services within the SNL. Currently, the RDAP is active in four areas, covering 7% of the Swazi Nation Land, and plans are well under way to expand the RDAPto 14 project areas with funding from the World Bank and USAID. This expanded program will cover approximately 60% of the SNL.

Present Status of Intercropping in Swaziland

Intercropping is a ubiquitous cultural practice in the traditionally farmed Swazi Nation Land. It has been estimated that approximately 42.8% of the fields in the SNL are under mixed cropping. Table 1 reflects the extent of the mixed cropping practice in the SNL and the various crops that are intercropped. Maize is usually the dominant crop and is intercropped with cereals, legumes, cucurbits, and other crops.

For the traditional Swazi, planting mixed crops helps insure against natural hazards and provides an individual household a wide spectrum of crop produce. As shown in Table 1, the extent of intercropping in the SNL seems to be a function of crop varieties and combinations and various environmental factors obtaining in each agroclimatic region.

Table 1. Percentage of fields under mixed cropping by crop mixtures and location In Swazi Nation Land.

Region	Maize + pumpkin	Maize + groundnut	Maize + beans	Maize + cowpea	Maize + jugo bean	Maize + sweet potato	Maize + sorghum	Maize + cotton	Maize + other crops	All other crop mixtures	Total for mixed crops
Highveld	28.1	1.0	2.6	7.3	0.3	0.3	1.0	–	3.4	2.3	46.3
Middleveld	26.5	2.8	0.7	2.4	1.0	1.5	0.4	0.4	3.8	1.0	40.5
Lowveld	14.1	5.0	1.1	6.1	4.7	0.3	1.7	5.5	5.8	1.4	45.7
Lubombo	15.1	4.8	—	0.6	0.6	5.4	0.6	—	7.8	4.2	39.1
Country	23.0	3.1	1.1	' 4.1	1.6	1.4	0.9	1.4	4.5	1.7	42.8

Source: Annual Survey, 1977/78.

The Proposed Intercropping Research and Extension Project

Although the usefulness of the mixed cropping practice has often been condemned as inherently primitive and without any scientific basis, the impression is currently being gained that this system of farming has scientific merit and is one of the best suited to the African environment because of the agronomic and economic benefits accruing to both the soil system and the nutritional requirements of the farm family.

Since in the past intercropping was considered unworthy of development, there is a paucity of knowledge regarding the status of intercropping in Swaziland and on how the practice can be optimized for maximum economic benefits for each farmer. Considerations such as efficient use of land involving optimum combination of mixed crops, management of such crops for optimum and economic yield, and the impact on the socioeconomic structure of the farming unit have hardly been considered by the agricultural and scientific community of Swaziland.

It is for the above reasons that a group of agricultural scientists at the University of Botswana and Swaziland (Faculty of Agriculture) has constituted itself as a team to study the agronomic, economic, and social ramifications of the mixed cropping practices in Swaziland with a view to elaborating intercropping systems that are ideal for Swaziland and to contribute to the advancement of intercropping research in southern Africa and elsewhere.

Objectives

The objectives of the research project are to study and improve the productivity of the principal intercropping patterns practiced by small-scale subsistence farmers in Swaziland. The specific objectives are as follows:

1. To evolve improved cropping patterns in the various ecological zones through the selection of high-yielding and adapted crop/crop mixtures of cereals (maize and sorghum), legumes (cowpeas, jugo beans, dry beans, and groundnuts), and cucurbits (pumpkins and melons);
2. To develop integrated agronomic practices for growing suitable intercrops by examining both (a) time of planting and optimum plant populations and (b) fertilization trials and screening crop varieties with respect to soil problems;
3. To improve the long-term productivity of the soil through multiple/relay crop rotations and crop residue management;
4. To determine the relationship between farm inputs and outputs by assessing the costs and returns of existing and improved cropping patterns; to assess the economic importance of crops in the farm enterprise; and to monitor the marketing patterns and relative prices of the crops under study;
5. To describe and monitor the influence of existing and improved cropping patterns on the social attitudes, beliefs, customs, traditions, and institutions of the small farmer;
6. To provide further training for graduate students through formal course work and field research and to make research results available to the Extension Service of the Ministry of Agriculture for the ultimate benefit of the small farmer in Swaziland.

Research Team

The staff undertaking this research consists of an interdisciplinary research team of the University's Faculty of Agriculture. The principal researchers are in the disciplines of agronomy, soil science, entomology, economics, and extension. The research project is coordinated by the Head of the Department of Crop Production.

The research team will be assisted by two research assistants whose major responsibility will be to implement the field trials and three field technicians who will supervise the casual labor and collect the requisite data.

In addition to the above, an Advisory Committee consisting of the research team, the research assistants, the field technicians, and members of the Ministry of Agriculture and the RDAs and chaired by the Project Coordinator, will be formed to monitor and coordinate the research project.

The Survey

The initial stage of the project will consist of an extensive farm survey. A composite questionnaire has been designed by the research team and will be administered by the field technicians. A random sample of at least 40 farmers in each of the selected zones will be interviewed using the prepared questionnaire. The purpose of the survey will be to collect pertinent information on the farming practices conducted by the small subsistence farmers, including existing cropping patterns, types of crop mixtures and combinations, and frequency and time of weeding and other agronomic practices. After the survey, the following research will be initiated.

Agronomy

When two crops are planted together, they tend to compete for light, nutrients, and water. As the density of each crop increases, the intensity of competition also increases. Therefore, optimum plant populations in intercropping are inherently different from those in monoculture. It is for this reason that experiments will be conducted on the crop mixtures enumerated in Table 1 to investigate the optimum plant populations in both intercropping and monoculture. Studies will also be conducted to determine the degree and nature of mixing.

Another important criterion for determining the success of intercropping will be the relative planting dates for the mixed crops so that neither crop suffers from excessive competition. Thus, relative planting dates for various crops will be an integral part of the agroeconomic study. In addition, an effort will be made to investigate the feasibility of mixing crops that are slow to establish, such as cassava and pigeonpeas, with crops that have a short growing and maturation season, such as cereals and grain legumes.

Other agronomic studies will include evaluation and screening of varieties of grain legumes which have different morphology and duration and which favor rapid ground cover to reduce weed competition, raindrop impact, and subsequent soil erosion and to promote mutual production benefits.

Observations on leaf area index, light interception, yield and economic aspects will also be made.

Weed Management

Crops and weeds have similar requirements for growth and development. The chief factors for which crops and weeds compete are light, water, and nutrients. Crops and weeds may also influence each other by secreting metabolic products which remain in the soil as residues of decaying material.

Herbicides are extensively used for controlling weeds in temperate regions, buttheir use is not so widespread in the tropics. The possible reasons for this phenomenon may include availability of cheap labor for hand weeding, high cost of herbicides, lack of suitable spraying equipment, and unavailability of herbicides suitable for treating crop mixtures consisting of dicotyledons and monocotyledons.

Herrera and Harwood (1973) demonstrated that weed problems were abated by intercropping due to the rapid growth of the intercrop canopy and higher interception of light.

In the cropping systems and soil fertility experiments, weed species, weed weight, and nutrient uptake will be studied with a view to elaborating more efficient methods of managing weed problems under intercropping.

Pests and Disease Management

It has been suggested that species grown in polyculture tend to be less subject to attack by pests and diseases. According to Aiyer (1949), polyculture reduces the incidence of diseases by (1) preventing the spread of diseases because of greater separation between the susceptible plants, (2) one species serving as a trap crop for a disease or pest to which another is susceptible, and (3) the associated species serving as a repellant for a disease or pest of another species. However, Aiyer also cited three ways by which polyculture may increase the incidence of pests or diseases: (1) reduced cultivation and greater shading due to the presence of associated species; (2) associated species serving as alternate hosts; and (3) crop residues of the species first harvested remaining in the field and serving as a source of inoculum. The cases of both increased or decreased pest and disease incidence are reviewed by Kass (1978).

In cooperation with entomologists and pathologists, the research team will make efforts to study and monitor pest and disease incidence in various cropping systems and soil fertility experiments with the aim of selecting cropping systems in which pests and diseases can be kept at a tolerable level.

Screening Crop Varieties with Respect to Soil Problems

Recently, plant breeders and soil scientists have recognized the existence of varietal and species differences in tolerating adverse soil conditions. A better understanding of species differences may provide significant insights in the adaptation of such species to areas which could require lower investment in fertilizers.

Aluminum toxicity and P deficiency frequently occur together in acid soils and are considered as serious limiting factors of crop production in the high- and middlevelds of Swaziland. In previous years, liming and P fertilization to optimum levels, along with their residual effects, have been considered the main strategies to solving these problems. Tolerance studies on Al toxicity and Tow available P provide an additional dimension. This new strategy does not mean the elimination of liming and P fertilization. However, it can reduce liming and P fertilizer requirements needed to obtain adequate yields. Salinity, alkalinity, and micronutrient deficiencies are considered other limiting soil factors for crop production in the lowveld of Swaziland.

Extensive work on varietal screening with respect to adverse soil condition is going on at CIAT, IRRI, IITA, CSIRO (Australia), India, Beltsville (Maryland), Riverside (California), Brazil, and other places.

The purpose of a series of greenhouse and field experiments will be to screen and select cultivars of cereals, grain legumes, root crops, and cash crops more tolerant to the abovementioned soil factors. Selected varieties of various crops will be used in the intercropping research program.

Fertilizer Needs of Intercropping Systems

It has been reviewed by Oelsligle et al. (1975) and Kass (1978) that polyculture removes more N, P, K, Ca, and Mg from the soil than does monoculture. Lesser amounts of these elements are available for subsequent crops when polyculture is used. No efforts have been made to study the fertilizer needs of intercropping systems in the country. The following experiments have been planned and will be subject to modifications in the light of the initial agroeconomic survey.

1. Nitrogen fertilization of maize/bean mixtures:
   Main plots = N rates of 0, 30,60,90,120, and 150 kg N/ha
   Subplots = (1) maize, (2) beans, (3) maize/beans (75:25), (4) maize/beans (50:50), (5) maize/beans (25:75).
2. a. Effect of phosphate rates on maize/bean mixtures:
   Main plots = P rates of 0, 10, 20, 30, 40, 50, and 60 kg P/ha
   Subplots = Crop combinations as in 1 above,
   b. The residual effect of P will be evaluated by growing maize/groundnut mixtures.
3. a. Effect of liming rates on maize/bean mixtures:
   Main plots = 0, 0.5, 1, 2, 4, 6, 8 tonnes/ha
   Subplots = Crop combinations as in 1 above,
   b. The residual effect of liming will be evaluated by growing maize/groundnut mixtures.
4. a. Effect of K rates on maize/bean mixtures:
   Main plots = 0, 10, 20, 30, 40, and 50 kg K/ha
   Subplots = Crop combinations as in 1 above,
   b The residual effect of K will be evaluated by growing maize/groundnut mixtures.

The experiments will also encompass investigations on S and micronutrient requirements of the abovementioned crop mixtures.

Observations will be made on dry matter, nutrient uptake, yield, protein, change in soil nutrients, and land equivalent ratio. The economics of these experiments will also be calculated.

The fertilizer requirements of other crop mixtures, i.e., maize/cowpeas, maize/jugo beans, maize/pumpkins, maize/sweet potatoes, and cotton/grain legumes will also be established.

Crop Residue Management and Fertilization with Beef and Dairy Cattle Manure

Since fertilizers are expensive and frequently beyond the purchasing power of small-scale farmers, it is necessary that organic residues be used not only as a source of N but also for purposes of increasing the efficiency of applied N for crop production. Over two-thirds of the K and Zn and one-third of the N, P, and S taken up by crop plants are contained in the leaves and stems of the plants. If these residues are returned to the field, either directly or indirectly, the need for applied chemical fertilizers and the toxic effect of certain elements can be reduced.

Highveld and middleveld areas with acid infertile soils and lowveld areas with saline and sodic soils (presently used for beef and dairy production) are also areas of food crop production. The use of locally available beef and dairy cattle manure to fertilize food crops is an obvious alternative to the use of chemical fertilizers.

The details of experiments will be worked out in the light of the initial agroeconomic survey.

Economic and Social Factors

Although much has been written about traditional agriculture, there is a paucity of studies that have investigated the socioeconomic validity of intercropping systems in less developed countries. It is anticipated that the transition from active promotion and recommendations, based on monoculture studies, to recommendations designed to foster intercropping practice in Swaziland is likely to have socioeconomic impacts and disruptions. Consequently, a detailed understanding of present production processes and decision behavior in the small-scale farming sector of Swaziland can be of paramount socioeconomic importance in reducing confusion. Therefore, studies will be mounted to determine the relevance, practicality, and potential success of improved intercropping systems and management designed to optimize yields.

Information will be collected on the utilization of available resources to effect an optimum combination of crop varieties, the costs of inputs and returns from output, as well as information on the marketing structure required for the various crops.

In addition, an investigation of the farmers' allocation of production resources and reasons for the allocation (e.g., home use, poll tax, ceremonial purposes, etc.) will be undertaken. Information on the consumption preferences and product acceptability within the household would also be essential in the evaluation of intercropping systems that would suit local conditions.

Finally, information on the existing customs, beliefs, and potential for shifts in such customs and beliefs will be an important consideration in determining the relationship of existing farm practices with the proposed intercropping systems and their management.

The Evaluation of Genotypes for Intercropping

H. C. Wien and J. B. Smithson*

Abstract

Although the selection of genotypes for intercrop conditions has been practiced by farmers in the tropics for centuries, until recently little attempt has been made to use more scientific means to evaluate the suitability of crop plants for mixed cultures. We propose that a successful selection strategy for intercropping requires a sequence of steps to establish the methods and criteria of selection, namely:

1. *Definition of the intercrop systems for which genotypes are to be selected, determined by surveys of the prevalent practices in the area where the intercrop system is to be used, climatic factors, economic considerations, and the results of agronomic experiments.*
2. *Manipulation of time of planting, spacing, and soil-nutrient levels to produce a median level of stress, so that lines truly adapted to the intercrop defined are selected.*
3. *Screening under defined intercrop conditions of a large number of pure lines to identify characters of importance in adaptation to intercropping.*
4. *Determination of the extent to which the same characteristics are also expressed under monocrop conditions so as to allow monocrop selection for intercropping.*
5. *Preliminary negative screening for intercrop adaptation using monocrop conditions—i.e., rejection of disease- and insect-susceptible plants or those with inappropriate growth habits.*
6. *Positive screening of genotypes from no. 5 above for adaptation to the selected intercrop system.*

This progression is illustrated for cow pea by examples from intercropping experiments with cereals and cowpea carried out at three locations in West Africa.

In much of the tropics of Africa and Latin America, the simultaneous culture of two or more crops is the predominant agricultural practice (Francis, Flor, and Temple 1976). The prevalence of intercropping, and its persistence in spite of attempts by extension workers to bring about adoption of sole cropping, has been attributed to a number of factors. These include greater stability of production and therefore minimum risk, a more equal distribution of labor through the growing season, and greater diversity of food and income sources. In recent years, evidence for higher productivity from mixed versus sole culture, through more efficient use of resources by the crops, has also been demonstrated (Andrews 1972; Willey and Osiru 1972; Willey and Lakhani 1976). Slowly, the notion that the practices of subsistence farmers are not worthy of serious study, which has discouraged work in intercropping (Norman 1973a), is giving way to the realization that intercropping systems are stable and productive, and can be made more so by the application of improved technology (Baker 1974).

Research on intercropping has to date focused primarily on the effect of agronomic manipulations such as spacing and date of planting and on the effect of combinations of

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different species on productivity (Ramos 1976). The evaluation of varieties for their suitability to intercropping has been much less studied. Breeding programs to develop varieties of food crops with specific adaptation to intercropping have to our knowledge only recently been established, with the work on beans at CIAT (Francis, Flor, and Temple 1976), and on cowpea at IITA (IITA 1976, 1977). The present paper attempts to relate these and other studies to the development of an effective strategy for selection of cowpea lines for mixed cultures.

Before varieties can be evaluated, it is necessary to define the intercrop system for which they are intended. The definition of a system must be based on a knowledge of the climate of the area in which the crops are to be grown, surveys of prevalent intercropping practices, and the results of agronomic trials that determine the cultural practices necessary to raise the productivity of the intercrop system. This process will be illustrated using the cowpea/cereal intercrop prevalent in the savanna zone of West Africa.

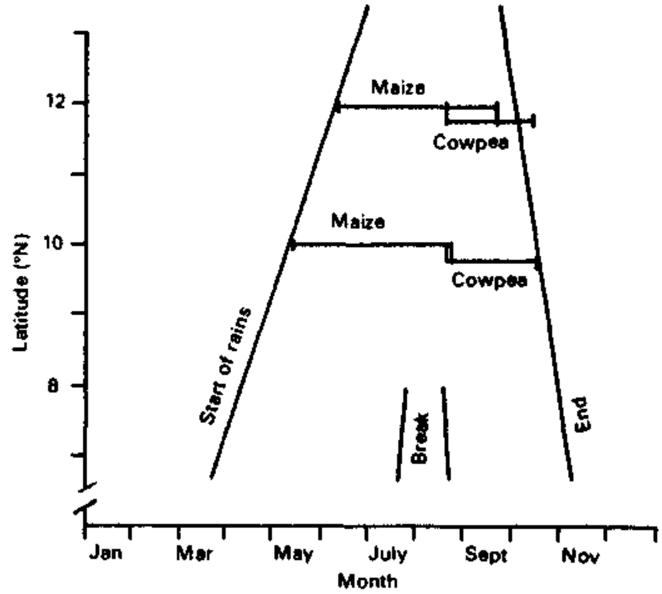

Figure 1. Start and end of rains with latitude in West Africa, as determinants for planting dates of maizelcowpea relay crops of 100- and 55-day duration, respectively. After Kowal and Knabe (1972).

Rainfall and Cropping Systems of West Africa

In West Africa, rainfall characteristics are related closely to latitude, the length of the rainfall period being described by the equation, $y = 364.8 - 21.03x$, where y = time in days and x = degrees latitude (Fig. 1) (Kowal and Knabe 1972). Thus around latitude 12°N, the growing period is around 120 days beginning from May to July and ending in September, and the rainfall is distinctly unimodal. Southward, the rainfall period increases in length and becomes bimodal in character with a period of reduced rainfall in July and August. At latitude 7°N, the growing period is more than 200 days, extending from March or April to October or November.

Traditionally in West Africa, cowpea is almost exclusively grown in association with other crops (Steele 1972; Slade 1977) and usually with cereals. The nature of the associated crop and the cropping system are determined primarily by the length and pattern of rainfall and its association with latitude (Steele and Mehra 1978).

In the drier northern areas (13°N), millet/cowpea combinations predominate, but they are replaced in the south by millet/sorghum/cowpea and then sorghum/cowpea. Generally millet is sown at the start of the rains, followed by sorghum, and cowpea is sown into the standing cereal in July or August, shortly before or at about the time of the millet harvest. Cowpea and sorghum thus occupy the field during the latter part of the season and, because they are locally adapted to photoperiod (Steele 1972; Wien and Summerfield 1978), flower at the end of the rains. Both crops produce grain under the relatively favorable conditions of the early dry season, with cowpea maturing pods at a time when sorghum leaf area is senescing, thereby reducing competition for light.

In areas of bimodal rainfall, millet and sorghum are replaced by maize and root crops. Here photoperiod-insensitive cowpea is sown in April *or* May for harvest in July or August or, less commonly, in August or September for November or December harvest. However, the millet/sorghum/cowpea combinations account for by far the major proportion of cowpea production in West Africa.

In recent years, the production of maize has increased rapidly in northern Nigeria. Because of its higher yield potential (Kassam et al. 1975) and tolerance to wet conditions at harvest, it offers an alternative to sorghum and millet, on which new, more productive cropping systems could be based. Baker (1975) has demonstrated that maize can yield well when intercropped with other cereals, and experiments at IITA have demonstrated the productivity of maize/cowpea mixtures. For this reason, and because the photosensitive local sorghum varieties are restricted in the latitude at which they can be grown, we decided to use the maize/cowpea intercrop system for our studies on genotype selection for intercropping.

Agronomic Considerations

Planting Time

Agronomic experiments at IITA have shown that yield of intercrop cowpea approaches that of monocrop cowpea when it is planted before the cereal (maize), but yield declines to very low levels if planted 30-40 days after the maize and increases again as planting date is delayed still further (Fig. 2).

When cowpea is planted as a relay crop with maize in a manner similar to the traditional cereal/cowpea cropping system, two main factors determine the cowpea yield: the duration of the overlap between the two crops, and the time that remains after the cereal is removed for the cowpea to continue growth before the rains end. The greater the duration of overlap of the two crops, the smaller the yield of the intercropped cowpeas. Similar results were obtained for maize/rice intercrops at IRRI (1977) and for maize/sorghum/millet intercrops in northern Nigeria by Baker (1975). The less the amount of light reaching the cowpeas during this period, the greater the reduction in yield, so that maize plant population has an important effect on cowpea yield (Fig. 3). Date of planting

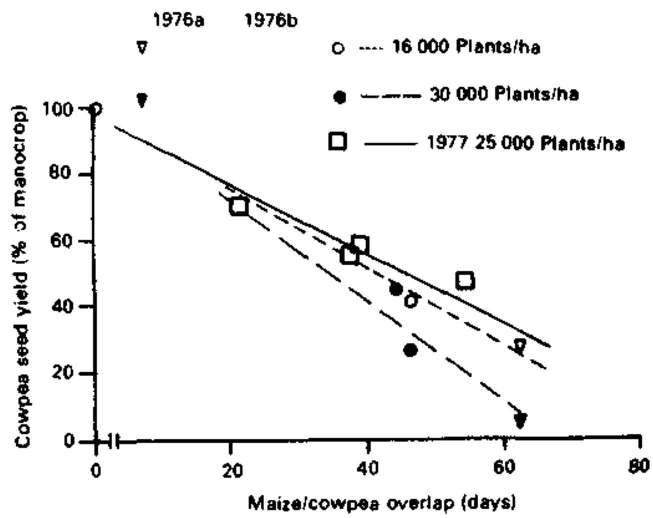

Figure 3. Cowpea seed yield (% of monocrop), as affected by length of the period of maize and cowpea and maize plant population in a series of relay crop experiments conducted at IITA, Ibadan.

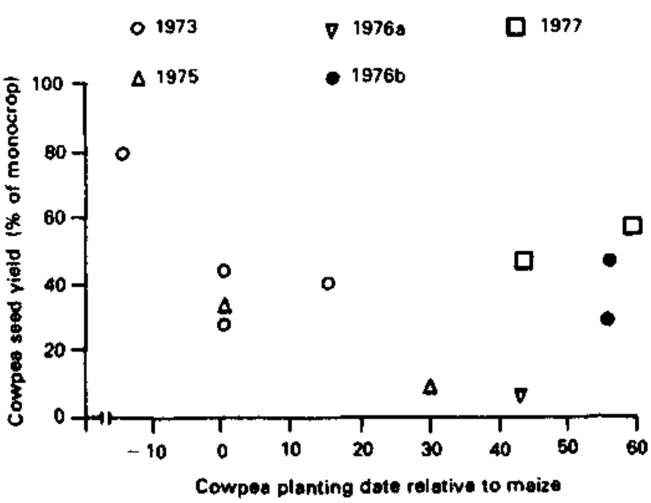

Figure 2. Influence of cowpea planting date relative to maize on cowpea seed yield, expressed as a proportion of monocrop yield, for a series of experiments conducted at IITA, Ibadan.

experiments with cowpea monocrops in the second rains demonstrated that a rainfall period of 50 to 60 days is required for maximum yield, and any reduction below this results in a steep yield decline (Fig. 4). Varietal differences in response to length of the rains are related primarily to flowering dates, as determined by their photoperiod sensitivity. Local Shaki is a photosensitive cultivar, late in flowering, and therefore more severely affected by the end of the rainy period.

To define a maize/cowpea intercrop system

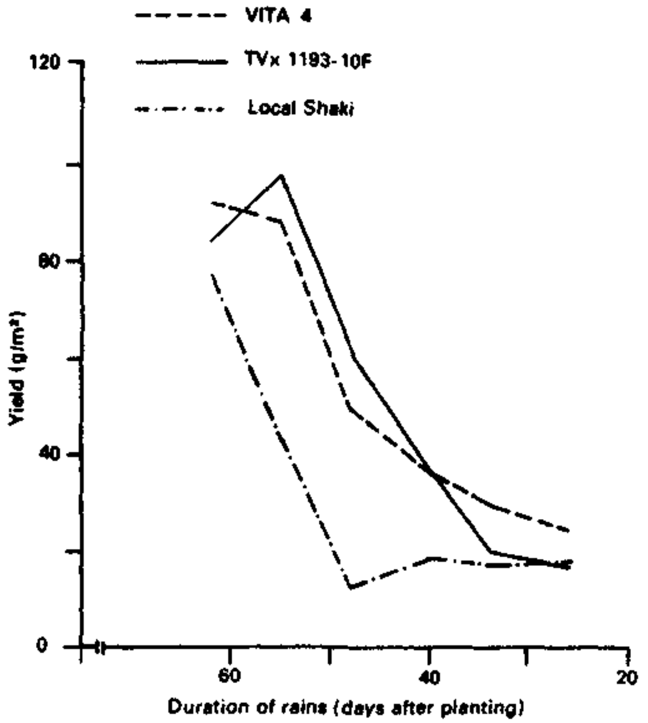

Figure 4. Yield response ofthree cowpea cultivate to duration of the rainy season, as established in a monocrop experiment at Odo-Ogun, Oyo State, 1977.

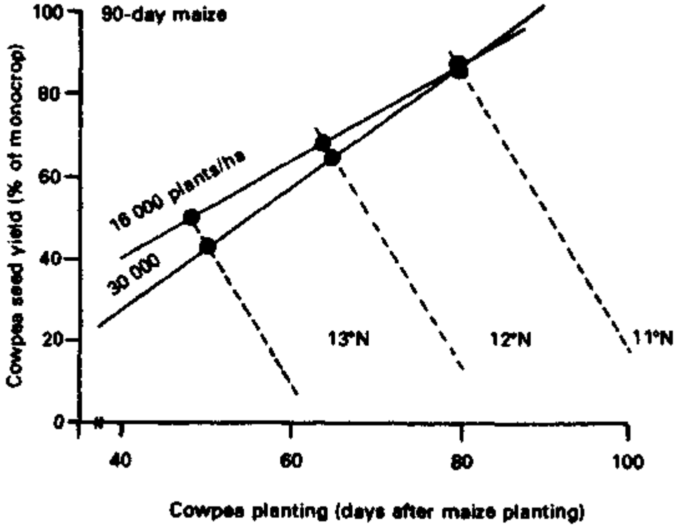

Figure 5. Theoretical cowpea yield response (% of monocrop) when relay intercropped after maize, as influenced by cowpea planting delay in relation to the maize. Solid lines denote maximum yield possible due to influence of the competition between the two crops. The dotted lines represent yield maxima proscribed by length of the rainy season at 11, 12, and 13°N latitude.

suitable for a particular latitude in West Africa, we need to know the duration of the rainy season at that latitude and the duration of growth of the maize. We can assume the season duration-latitude relation described by Kowal and Knabe (1972) (Fig. 1), and that maize will require 90 and 100 days for early and full-season varieties, respectively, in lowland tropical Africa. If maize is sown at the start of the rains, then from the relation between duration of overlap of the two crops (Fig. 3), duration of rains after planting, and yield of cowpea (Fig. 4), we can construct a model which describes expected yield of cowpea for different times of planting after maize (Fig. 5) at a given latitude.

When cowpea is planted into a young maize crop, cowpea yield is limited by the yield-depressing effect of the overlapping of the two crops. If planted into a more mature maize crop, the cowpea yield may be curtailed by the end of the rains, especially at the northernmost latitudes. For each latitude, an optimum yield can be achieved by adjusting the cowpea planting date relative to the maize to minimize these two influences. This adjustment is shown for 100-day maize relay cropped with cowpea at 10 and 12° latitude in Figure 1. For the 90-day maize crop with a population of 30 000 plants/ha, as shown in Figure 5, the optimum cowpea planting date would be 50 days after the maize at 13° and 65 days at 12°. When the optimum planting date is plotted against latitude, a linear relationship emerges, with successively earlier cowpea planting and larger overlap times required at the more northern latitudes to obtain high cowpea yields (Fig 6a). At latitudes below about 10°N, the rainy season is long enough to allow planting of monocrops of maize and cowpea in sequence.

Maize/cowpea intercrops are thus possible in a belt from 10°N to 13 or 14°N, but cowpea yields in such relay crops would be lower at more northerly latitudes (Fig. 66). Such intercrops could of course also be planted at more southerly locations, but in mostyears, they would not completely fill the rainy season (Fig. 1). At latitudes 6 to 8°N, the break in the rains in late

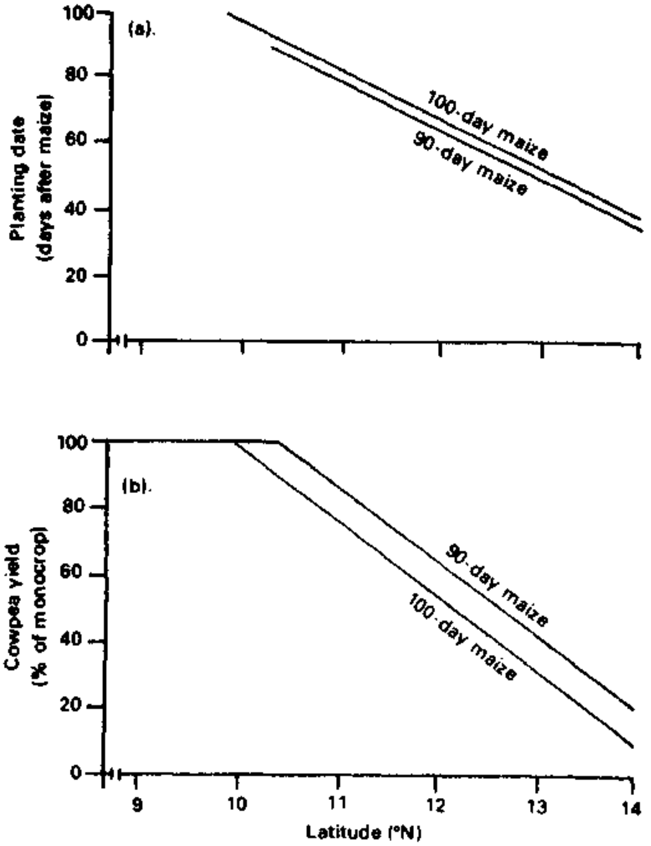

Figure 6. (a) Cowpea planting date for optimum cowpea yield when relay intercropped with maize at various latitudes; (b) Theoretical cowpea yield response (% of monocrop) when relay intercropped after maize, as influenced by location of production (latitude).

July and August cuts the rainy season into two periods of shorter duration, which make the use of relay crops more difficult (Lawson 1975). Therefore, it appears that a maize/cowpea relay cropping system would be feasible over a wide area in West Africa, and work to improve the productivity of such a system would be justified.

Stress Level

In deciding on a suitable system under which varieties might be screened for adaptability to intercropping, consideration must be given not only to the prevalence or potential of the system in the area where it is to be used, but also to the degree of stress to which the varieties will be subjected in the screening system. Experiments at IITA (1976, 1977) and the results of Finlay (1976a) show that as yields of legumes intercropped with cereals decline relative to the monocrop, the magnitude of the yield difference between varieties also decreases (Fig. 7). Stress level can be decreased by lessening the length of the overlap period or by using a wider maize spacing.

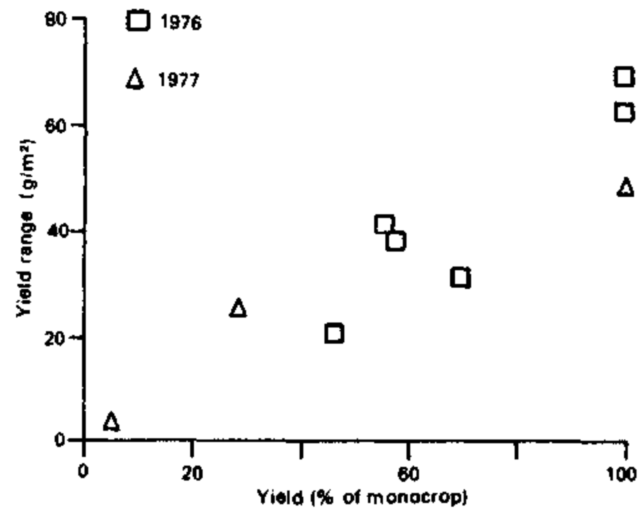

Figure 7. Range in seed yields (max.-min.) as related to yield level (% of monocrop) for grain legumes intercropped with maize, in several experiments at IITA and in Tanzania (Finlay 1976a).

The level of stress to which the cowpea crop is subjected also determines how closely intercropped yields will be correlated with yields of the same varieties under monocrop conditions (Fig. 8). Data from Francis et al. (19786), Finlay (1976a), and IITA (1976, 1977) show that as yield level declines, correlations between monocrop and intercrop yields also decrease. This will be of relevance if one decides to practice selection for intercropping under monocrop conditions. This approach is advocated for early generations of bush and climbing beans selected for intercropping with maize by Francis et al. (1978a, *b).* The authors emphasize, however, that *later generation* testing must be done in the system for which the

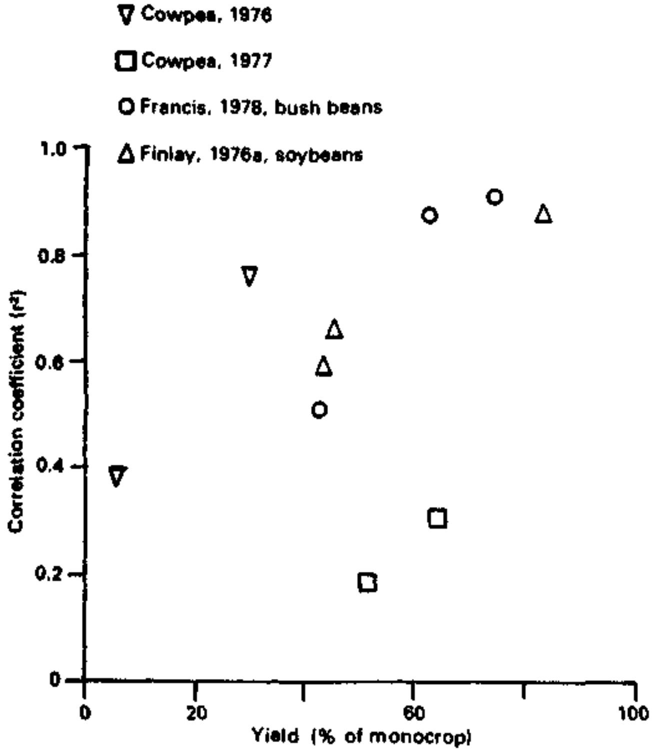

Figure 8. Correlation coefficient of varietal yields under monocrop vs intercropped conditions as influenced by yield level for intercropped soybeans (Finlay 1976a), bush beans (Francis, Prager, et al. 1978b), and cowpea.

lines are ultimately intended. The inherent variability of intercrop conditions, where, for example, a gap in the maize plant stand will result in better growth of the cowpea underneath, would also argue against early generation testing under intercrop conditions. Francis et al. *(1978b)* also mention the advantage of the greater seed production by monocropped plants, allowing more seed to be carried forward to the next generation.

Once the cultural practices required to produce a uniform, medium level of stress on the intercrops have been established, a range of pure lines from existing germplasm should be tested under the system to determine the existence of varietal differences. From the results of such trials, the question of whether a breeding program would be necessary to improve yield performance under intercropping can be answered.

Varietal Responses

Preliminary Data

Frequently the preceding agronomic trials can already provide some information on varietal differences. In one trial, in which the cowpea/maize overlap period was varied by different maize harvest and cowpea planting dates, distinct varietal differences were obtained in yield relative to the monocrop, as length of the overlap period increased (Fig. 9). The local photosensitive cultivar Samaru 2479 was significantly less affected than VITA-4 by long overlap periods with maize. Since this cultivar is

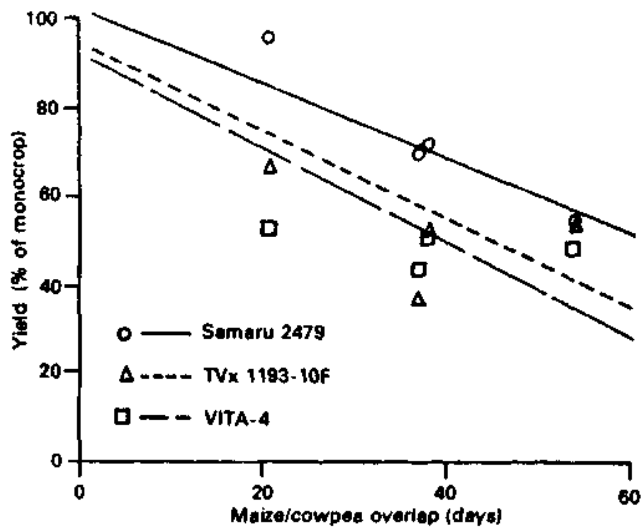

Figure 9. Yield of three cowpea cultivars (% of monocrop) as influenced by length of the maizeicowpea overlap period in an intercrop experiment, IITA, 1977.

lower-yielding in monocrops than the other lines, however, this feature of yield stability under intercropping produces no actual yield advantage (Fig. 10). Further work is needed to determine if such yield stability can be found in lines of higher monocrop yield.

When viewed on a regional scale, differences in response between varieties to length of the cowpea/maize overlap period and the durations of rains lead to interesting predicted yield dif-

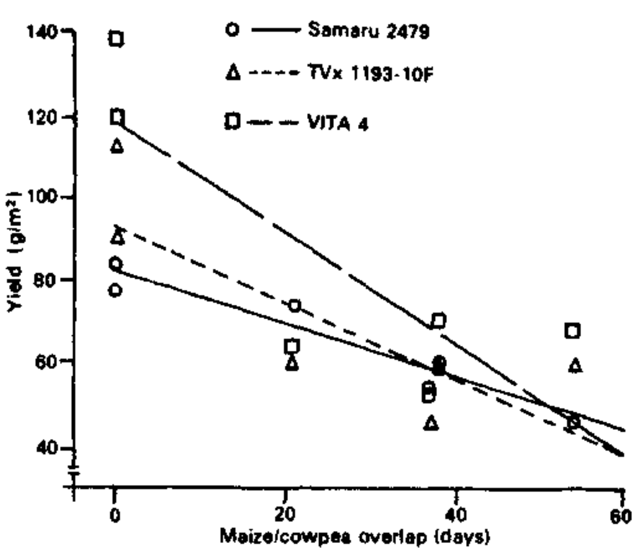

Figure 10. Actual yield of three cowpea cultivars as influenced by length of maizelcowpea overlap period in an intercrop experiment IITA, 1977.

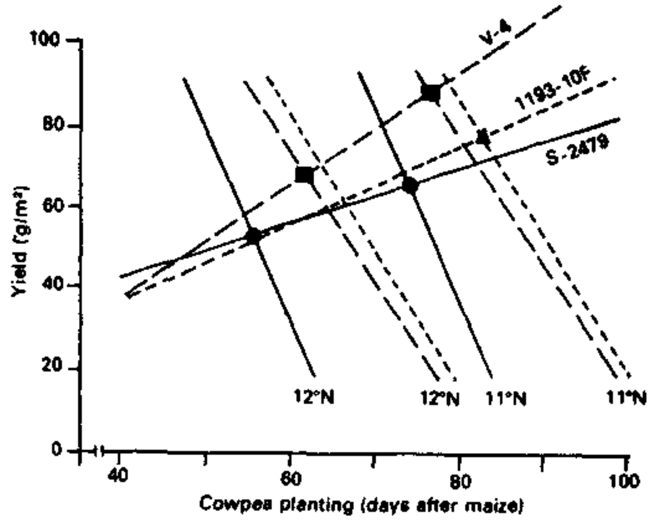

Figure 11. Theoretical cowpea yield maxima in maizelcowpea intercropping, proscribed by competition between the crops (solid lines) and length of the rainy season (dashed lines), for three cowpea cultivars of contrasting plant type.

ferences at different latitudes (Figs. 11, 12). Samaru 2479, because of lower yield potential and later flowering, should produce lower yield than the other lines at all latitudes. VITA -4 has a yield advantage at lower latitudes, where a long rainy season allows a long interval between maize and cowpea planting and, consequently, produces conditions close to monocropping. The erect cultivar TVx 1193-10F is intermediate in response.

Germplasm Evaluation

The foregoing analysis has focused on two key features for good cowpea yield under a relay intercrop situation: the capacity to withstand the adverse effects of the associated crop, and the ability to recover from these adverse effects, determined partly by date of flowering and length of the rainy season. Since none of the three cultivars examined in the preceding paragraphs have all the necessary properties for high yield under intercropping, a larger sample of diverse cowpea lines was examined in a number of trials to identify lines adapted to intercropping. Details of the designs and locations of the trials are given in Table 1.

The associated cereal was maize except at Ouagadougou where sorghum was used. Intercropped cowpea comprised single 4- or 5-m-

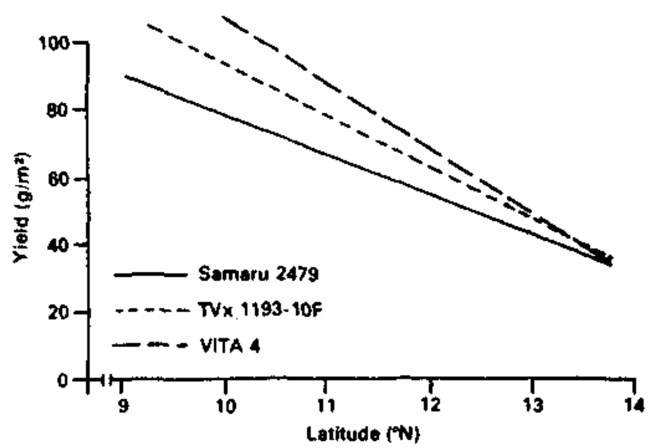

Figure 12. Theoretical yield response of three varieties of cowpea relay intercropped with maize, as influenced by latitude of production.

long rows alternating with single rows of cereal (except in the first season 1978 at Ibadan where two rows of cowpea alternated with single rows of cereal) with 75-cm spacing between and 20-cm (cowpea) and 25-cm (cereal) spacings within rows to give cereal populations of about 24 000 plants/ha. Cowpea was sown either

Table 1. Details of experiments comparing the performance of germplasm and breeding lines under different cropping systems.

Year	Season	Location	Design	No. of reps.	Total entries
1976	1st	Ibadan	Pseudorep	1/49 [a]	222/1 [a]
	2nd	Ibadan	Pseudorep	1/44	209/1
1977	1st	Ibadan	Split plot	2	30
	2nd	Ibadan	Split plot	3	30
	Main	Ouagadougou	Split plot	3	30
1978	1st	Ibadan	Augmented	1/4	80/20
	Main	Daudawa	Augmented	1/4	80/20
	Main	Ouagadougou	Augmented	1/4	80/20

a. Nonreplicated and replicated entries, respectively.

simultaneously with cereal or at anthesis of the maize (about 60 days). These particular conditions were chosen on the basis of the earlier agronomic trials to impose moderate levels of stress on the intercropped cowpea. Monocropped cowpea comprised three rows 4 or 5 m in length with 75-cm spacing between and 20-cm spacing within rows, and all data was collected from the middle row.

In 1976, the entries were lines selected from the germplasm collection and breeding materials on the basis of low disease and insect ratings but with a range of other plant characteristics. These were examined in association with maize at Ibadan; they were sown simultaneously with maize in the first season and at anthesis in the second season. Due to shortage of seed and other restrictions, there was no monocrop comparison and the screening was not replicated, although VITA-5 was included as every sixth row to give an estimate of the variation.

Twenty-four lines exhibiting the best yield performance in either or both seasons were included in replicated trials together with six standard lines in the following year. These included inter- and monocrop comparisons, and the second season trial at Ibadan also included cowpea sown at the same time as and an anthesis of maize.

In 1978, the emphasis was changed to the examination of advanced breeding material developed for monocrop conditions with a view to identifying those lines which were poor under intercrop conditions. One-hundred entries were compared in an augmented design with 20 international trial lines replicated four times and 80 nonreplicated lines which included other international and advanced breeding trial entries together with 11 lines progressing from the previous intercropping trials. Cowpea was sown at anthesis of the maize except at Ouagadougou where the crops were sown simultaneously and there were no monocrop comparisons.

Records were taken of a range of agronomic and disease and insect damage characteristics; seed yield was determined in all trials and yield components were estimated from pod samples at Ibadan. Insecticide was applied and disease and insect damage was found to be usually low and unimportant in determining relative yields.

Seed Yield

Significant interactions between cowpea cultivars and cropping systems for seed yield were demonstrated in one of the three trials in which there were sole: mixed crop comparisons. In the 1977 second-season trial at Ibadan (Table 2), the effects of cropping systems and varieties and the first-order interactions between varieties and cropping systems and varieties and sowing dates were all highly significant. Cowpea intercrop yields expressed as a percentage of the monocrop ranged from 72.9 to 21.2% and tended to be greater among the lines which had been selected for intercrop condi-

Table 2. Seed yields (g/m²) of entries in the 1977 second-season trial at Ibadan (sole and intercropped with maize).

Entry	Cropping system: Mixed	Cropping system: Sole	Mean	Mixed as (%)
TVu 1460	95.7	131.2	113.5	72.9
TVu 420-1B	72.9	122.3	97.6	59.6
TVu 4619	69.9	120.6	95.3	58.0
TVu 2896	58.2	101.7	80.0	57.2
TVu 1593	74.8	131.3	103.1	57.0
TVu 942	53.4	94.3	73.9	56.6
TVu 1552	64.5	120.5	92.5	53.5
TVu 1258	66.4	125.7	96.1	52.8
TVu 2512	60.4	114.8	87.6	52.6
TVu 2320	54.7	112.8	83.8	48.5
TVu 242	62.8	139.8	101.3	44.9
TVx 1836-227E	46.6	107.7	77.2	43.3
VITA-3	49.4	119.3	84.4	41.4
TVu 4576	56.4	140.8	98.6	40.1
TVx 337-3F	59.6	150.1	104.9	39.7
TVx 1193-7D	44.7	115.8	80.3	38.6
TVu 1047-5D	42.1	110.2	76.2	38.2
TVu 3417	59.7	157.7	108.7	37.9
TVu 301	36.9	97.7	67.3	37.8
VITA-1	53.8	144.6	99.2	37.2
ER-7	30.1	87.0	58.6	34.6
TVx 1843-1C	53.2	157.2	105.2	33.8
TVu 645-1B	52.8	157.4	105.1	33.5
TVu 6433	37.3	114.1	75.7	32.7
VITA-5	28.8	94.9	61.9	30.3
Ife Brown	33.7	117.5	75.6	28.7
TVu 1630	39.6	155.4	97.5	25.5
TVu 3518	45.3	178.8	112.1	25.3
VITA-4	30.6	126.7	78.7	24.2
ER-1	13.2	62.2	37.7	21.2
S.E. ±	11.34		8.02	
Mean	51.6	123.7	87.7	
S.E. ±	6.92			

tions in the previous year. In contrast, the ER and VITA lines, which had been included as checks, gave poor yields under intercrop conditions, the best of them being VITA-3, which had formerly been shown to give moderately good performance in mixed-crop situations. Furthermore, in contrast with the results of Francis et al. (19786), the correlations among variety yields in inter- and monocrop conditions was not significant (r = 0.406).

These results indicate that the lines under test in this experiment differ in response to cropping system and that selection in the previous year had been effective in identifying lines better suited to intercrop conditions.

Similar indications were obtained when the data for those varieties which occur across a range of trials were combined (Table 3). For example, TVu 1593 and TVu 1460 were among the highest yielders in all cropping systems

Table 3. Seed yields (g/m²) of common cowpea entries In intercropping trials, 1976 to 1978, Ibadan, Daudawa, and Ouagadougou.

Line	Intercrop A[a]	Intercrop *B*[b]	Mono crop	Mean	Regression coefficient	*r*
TVx 1843-1C	48.9	81.0	132.2	92.0	0.997	0.875
TVu 1460	48.0	105.0	116.0	89.3	0.969	0.935
TVx 337-3F	46.8	70.2	132.5	89.2	1.242	0.934
TVu 1593	41.8	110.9	117.7	89.2	1.075	0.895
TVu 4576	45.0	80.7	122.3	86.2	1.140	0.923
TVu 242	51.5	84.7	112.0	84.8	1.041	0.896
TVx 4619	46.0	99.5	101.6	81.2	0.930	0.829
VITA-1	46.2	57.1	118.4	80.7	0.967	0.903
TVu 3417	34.8	83.2	107.5	76.7	1.179	0.876
TVu 420-1B	34.5	85.9	105.8	76.2	1.012	0.916
VITA-3	43.2	69.5	100.4	73.6	0.945	0.913
TVx 1193-7D	28.1	60.8	111.0	71.1	1.159	0.915
TVu 942	32.3	84.5	85.0	65.9	0.811	0.908
VITA-5	35.5	46.0	95.5	64.0	0.906	0.850
VITA-4	32.2	54.9	85.3	60.1	0.779	0.713
ER-7	33.0	28.3	88.0	56.3	0.773	0.836
S.E.	5.15	9.19	12.55			

a. A = Cowpea sown simultaneously with maize.
b. *B* = Cowpea sown at anthesis of maize.

while TVx 337-3F, the highest yielder in monocrop, is significantly lower in intercrop when sown at anthesis of the cereal. Similarly, TVx 1193-7D performs well in monocrop but is significantly lower yielding than other entries in both intercrop situations. The differences in responses are reflected in differences among the slopes of the regressions on trial mean yields (Fig. 13), resulting in higher coefficients for those lines, such as TVx 337-3F and TVx 1193-7D, which are relatively better under monocrop conditions.

Correlations

To identify characteristics contributing to varietal differences in performance under intercrop and monocrop conditions and to establish selection criteria, correlation coefficients were computed between cowpea seed yields and other plant characteristics (Table 4). The yield components—pods m^{-2} and seeds $pods^{-1}$—were consistently positively correlated with seed yield in ail cropping systems. The only other consistent correlation with seed yield, for both intercrop situations, was plant size in late pod fill, measured as the product of canopy height and width. This will be partially confounded with plant type, which also showed positive correlations with seed yield in some instances but is evidence for the need, in stress situations, for sufficient vegetative growth to support pod development. Further support for this concept was provided by a positive correlation between date of flowering and seed yield, but this only occurred in one experiment and thus may not be generally operative. The smaller yield depression due to intercropping of variety Samaru 2479 than the other cultivars in the agronomic experiment (Fig. 9) supports the need for adequate vegetative growth by the cowpea after the cereal has been removed, before flowering and pod-filling begin. This is achieved by traditional farmers by the use of photosensitive types that flower late.

It appears, therefore, that an initial negative

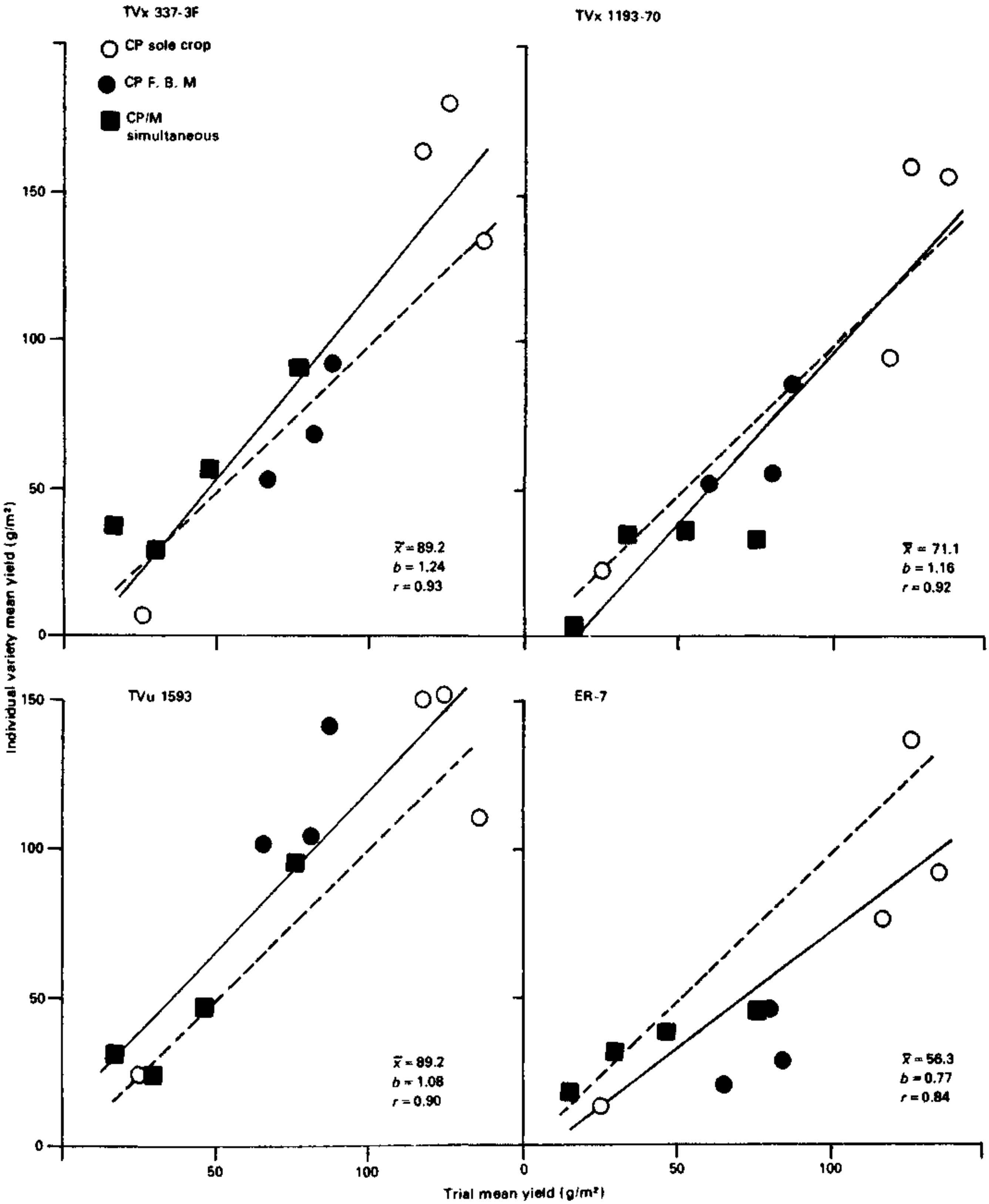

Figure 13. Regressions of individual variety mean yields against trial mean yields for four cowpea cultivars grown in six intercrop trials. Cowpeas were planted as monocrops, or intercropped at the same time as the maize or at maize anthesis.

Table 4. Correlation coefficients of cowpea seed yield (in intercrop) with other plant characteristics.

Year	Season	Location	Days to flowering	Plant size	Plant type
1976	1st	Ibadan	NS	0.35**	NS
	2nd	Ibadan	NS	0.47**	NS
1977	1st	Ibadan	NS	-	NS
	2nd	Ibadan	NS	-	NS
	2nd	Ibadan	0.66**	0.80**	0.64**
	Main	Ouagadougou	NS	-	NS
1978	1st	Ibadan	NS	NS	NS
	Main	Daudawa	NS	0.21**	0.27**
	Main	Ouagadougou	NS	0.27**	0.22**

** Significant at the 0.01 level.

screening can be made under monocrop conditions in early generations for characteristics such as disease and insect resistance, accompanied by the rejection of plants with low vigor and erect plant type. Strict selection for plant vigor would not be possible at this stage because of the large influence of environment.

In later generations, however, our results indicate the importance of testing the material in the system in which it will ultimately be grown. At the medium level of stress used in these experiments, there were significant genotype-by-cropping system interactions that can be exploited to produce higher yields of intercropped cowpea. A selection program with this end is now in progress.

Acknowledgments

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Genotype Studies at ICRISAT

R. W. Willey and M. R. Rao*

Abstract

Genotype experiments carried out at ICRISAT Center during 1976-78 are described. A sorghum Ipigeohpea experiment in 1977 examined 17 genotypes of pigeonpea with a standard sorghum genotype. Sorghum produced yields ranging from 82 to 99% of the sole-crop yield, but no differences were significant. The pigeonpea genotypes achieved yields ranging from 36 to 73% of their sole-crop yields, giving total land equivalent ratios (LERs) up to 1.66. Although absolute pigeonpea yields in intercropping were obviously dependent to some extent on sole-crop yields, this dependency only accounted for 40% of the variability in intercrop yields. There were indications that the most suitable pigeonpea plant type had a reasonably compact growth in the early stages to avoid competition from the sorghum but a spreading habit later to utilize resources after sorghum harvest.

In two experiments, three millet genotypes were examined in all combinations with four groundnut genotypes. The first experiment was a split-plot design with millet genotypes in the main plots; the second was a strip-plot design. Yield advantages up to 25-30% were achieved. It was concluded that the magnitude of the yield advantage was mainly determined by the groundnut genotype, whereas the proportion of groundnut yield to millet yield was mainly determined by the millet genotype.

Three sorghumImillet genotype experiments are described. The first was an unreplicated experiment in which 48 genotypes of pearl millet were grown with a standard sorghum genotype. Correlations between yield advantage and a range of millet plant characters did little to help identify which characters were most desirable in intercropping. Two later experiments examined four sorghum genotypes in combination with four millet genotypes. Yield advantages ranged up to just over 30%. These were considered to be very large advantages for two such similar crops; this combination is particularly worthy of further study.

Genotype Identification

It has frequently been stressed that identification of suitable genotypes is likely to be one of the major ways in which intercropping performance can be improved. There have been attempts to identify suitable genotypes simply on the basis of their known sole-crop performance (Baker 1974; Finlay 1974; Francis et al. 1976; IRRI 1974; Wein and Nagju 1976), but these seem to have met with little success. In fact, some time ago, Harper (1961), as a result of his competition studies, pointed out that "the behavior of mixed stands is not predictable from the behavior of pure stands." Recent knowledge has improved this situation a good deal, and many research workers have begun to formulate fairly specific ideas of genotype requirements for given *situations.* But the extent to which this can be done varies enormously with the crop being considered and the role it plays in a given intercropping situation. For example, it may be relatively easy to define genotype requirements for a crop which is very dominant and which represents the major component in an intercropping system. But it may be much more difficult to define requirements, or predict performance, for a crop which is the dominated one and which is essentially

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growing in an environment which has been modified by the dominated crop. Furthermore, the situation is complicated by the fact that the intercropping performance of a given genotype must be judged not just by its own yield but also by the competitive effect it has on the other crop, and even very dominated crops can show genotype differences in terms of the competitive effects on the other crop. Thus, there seems little doubt that genotypes which are intended to be grown in a given intercropping situation should be at some stage selected actually in that situation.

The objectives of selection can be very simply stated as the selection of genotypes which minimize intercrop competition and maximize complementary effects. Ideally this should involve the identification of suitable plant characters which can best achieve these effects and which can serve as the basis for more meaningful future selection. But in many situations, knowledge of these competitive and complementary effects is still much too limited and selection is still largely empirical.

At ICRISAT, genotype identification for intercropping is a field that has received a good deal of emphasis. This paper briefly describes the experimental approaches being used and some of the results obtained. Although many experiments have contained some aspect of genotype comparisons, the main emphasis has been with three combinations — sorghum/pigeonpea, millet/groundnut, and sorghum/millet—so the work is discussed under these headings.

Sorghum/Pigeonpea

In India the sorghum/pigeonpea situation is one from which the farmer's requirement is to produce a "full" sorghum yield (i.e., as much as a sole crop) and as much "additional" pigeonpea yield as possible. Current evidence (ICRISAT 1978; Shetke 1977) suggests this is best achieved by having the intercrop population of each crop the same as its sole-crop optimum. In this situation, the sorghum is very much the dominant crop and the growth of pigeonpea is very much suppressed. In effect, this means that although there is still some scope for identifying a suitable sorghum genotype (e.g., an early, short type to minimize competition on the pigeonpea), the main scope must lie in identifying pigeonpea genotypes which will withstand the early sorghum competition and then be able to utilize resources reasonably efficiently after sorghum harvest.

In 1977, in conjunction with the pigeonpea breeding work, genotypes which had undergone early selection in a cereal intercropping situation were grown with and without a standard CSH-6 sorghum in a yield trial. The pigeonpea genotype ICP-1, which was used as standard in most other ICRISAT trials, was also included as a check. The genotypes were in main plots on 135-cm rows at 25 000 plants/ha. The sorghum was sown in two rows at 45 cm between the pigeonpea, giving the standard 2 sorghum: 1 pigeonpea row arrangement used in other experiments. One main plot of sole sorghum was included, and the subplots were used for a comparison of "uniform rows" on 45 cm with the "paired-rows" arrangement that sorghum occupied in the intercrop. The experiment was grown on a medium deep Vertisol. A basal dressing of 52 kg P_2O_5/ha was applied throughout, and a topdressing of 80 kg N/ha was given to the sorghum.

The paired-row arrangement of sole sorghum yielded slightly lower (3693 kg/ha) than uniform rows (3952 kg/ha), but the difference was not significant, so the uniform row yield was used to calculate the LER values. Intercrop sorghum yields varied between 82 and 99% of this sole-crop yield, but, again, differences were not significant; thus, no assumption is made that these different values indicate real effects of pigeonpea competition, though they do influence total LER values. For pigeonpea yields, the interaction between genotype and the intercropping comparison was not significant, so individual genotype effects have to be interpreted with care. Sole-crop yields were quite good, four genotypes recording higher yields than the 1389 kg/ha of ICP-1 (Table 1). Intercrop yields ranged from 36 to 73% of sole-crop yields, the decrease being largely due to decreased pods per plant.

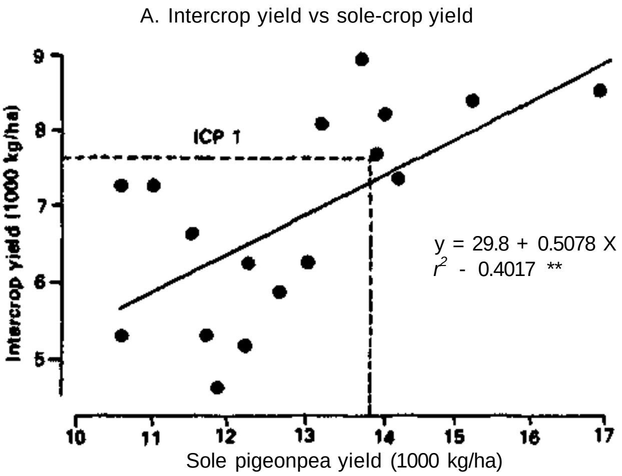
To some extent, absolute intercrop yields were simply a reflection of sole-crop yields, and the top seven genotypes were common to both situations, though not in exactly the same order. However, Figure 1 illustrates that, although this relationship held true in a general way (Fig. la), only 40% of the variation in intercrop yield could be attributed to variation in sole-crop yield (i.e., r^2 = 0.4). This is sup-

Table 1. **Pigeonpea genotypes in sorghum/pigeonpea intercropping.**

Genotype	Pigeonpea yield (kg/ha)		Sorghum yield (kg/ha)	LER			Pigeonpea harvest index	
	Sole	Intercrop		Pigeonpea	Sorghum	Total	Sole	Intercrop
185-9	1699	850	3804	0.51	0.96	1.47	0.25	0.33
6982-6	1525	842	3931	0.57	0.99	1.56	0.23	0.33
1-6	1428	740	3640	0.52	0.92	1.44	0.26	0.34
2223-3	1407	815	3630	0.58	0.91	1.50	0.22	0.31
ICRISAT-1	1389	757	3386	0.57	0.85	1.43	0.22	0.30
2223-1	1376	885	3344	0.63	0.84	1.48	0.26	0.33
830-2	1323	799	3899	0.63	0.98	1.62	0.23	0.31
3156-2	1296	619	3381	0.60	0.85	1.45	0.27	0.36
1951-1	1264	585	3973	0.46	1.00	1.46	0.28	0.37
3048-10	1226	619	3757	0.50	0.95	1.45	0.27	0.35
3193-12	1222	512	3232	0.42	0.82	1.24	0.26	0.39
HY3C-E-20	1185	463	3500	0.36	0.88	1.25	0.23	0.29
HY3C-E-12	1169	503	3323	0.43	0.84	1.27	0.26	0.31
2023-7	1148	661	3930	0.59	0.99	1.58	0.23	0.29
185-8	1106	718	3198	0.66	0.81	1.47	0.23	0.31
1196-2	1063	530	3645	0.49	0.92	1.42	0.26	0.30
1900-11	1058	720	3677	0.73	0.93	1.66	0.22	0.31
Sorghum (sole)			3952			1.0	1.0	
Mean	1287	683		0.54	0.91	1.46	0.25	0.33
SE(M)±			NS	0.1	NS	0.12		
CV(%)			16.3	34.9	16.5	16.4		

ported by the fact that the considerable variation in pigeonpea LER which occurred was not related to sole-crop yield {Fig. \b). Thus, intercrop performance, as indicated by the LER, was dependent on crop characters, which were not directly related to sole-crop performance. This is particularly borne out by the result for the genotype 1900-11, which gave the lowest yield but the highest LER. This was thought to be because it had compact growth in the early stages (thus to some extent avoiding competition with the sorghum) combined with a more spreading habit later; compactness per se did not seem desirable because the two most compact genotypes (the two HY-3Cs) gave low sole-crop yields and low LERs.

Harvest indices of the pigeonpea are also given in Table 1. Unfortunately, estimates of this character were not very accurate; only a small part of the plot (5.4 m^2) could be sampled for final dry-matter yield because the major part of the plot was left to assess ratooning ability of the genotypes. However, the data show that, for all genotypes, there was a constant increase in harvest index due to intercropping; the mean increase was from a mean value of 0.25 for sole crops to a mean value of 0.33 for intercropping. (Much bigger effects have been recorded in other experiments; in one particular experiment, which will be referred to later, harvest index was almost doubled by intercropping.) This effect obviously occurs because sorghum competition takes place during the period of early vegetative growth of the pigeonpea. But it is an extremely important effect, and it allows a greater compensation of seed yield after sorghum harvest than would otherwise be possible. For example, in this experiment, the total dry matter for intercropped pigeonpea at final harvest only averaged 40% of the sole crop, but seed yield averaged 54% of the sole crop. (In the experiment referred to above where effects were greater, an intercrop dry-matter yield equivalent to 40% of the sole-crop yield produced a seed yield equivalent to 70% of sole crop.)



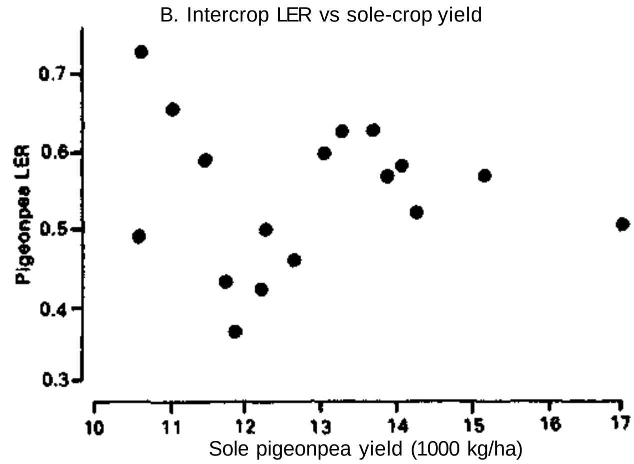


Figure 1. Relationship of intercrop yield and LER with sole-crop yield for 17 genotypes of pigeonpea.

This experiment is being repeated this season with some changes to include a few different genotypes; one notable inclusion is a promising hybrid C-11 which appears to be performing very well. In general, pigeonpea growth is much better than last season, and it is anticipated that yields in intercropping will be equivalent to a larger proportion of their sole crop. It is of interest, however, that this greater pigeonpea growth does not seem to have had any effect on sorghum yield. Sole sorghum yielded 4588 kg/ha: the average sorghum yield in intercropping was 95% of this, and the lowest was still equivalent to 88%.

Pearl Millet/Groundnut

Little information is available on the suitability of genotypes of either groundnut or millet when grown together as intercropping combinations. Two experiments described here were designed to have a preliminary look at some plant characters which were considered likely to be important. In the first experiment, three millet genotypes differing mainly in height and four groundnut genotypes differing in growth habit and maturity period were examined in all combinations: exact details are shown in Table 2.

Intercrops were grown in a row arrangement of 1 millet : 3 groundnut. Sole crops of all genotypes were included, and all treatments were grown in 30-cm rows. The millet genotypes were arranged in main plots and the groundnut genotypes as subplots; the millet sole plots were achieved by having an extra plot on the end of each main plot, and the groundnut sole plots were arranged as a separate main plot. The experiment was sited on an Alfisol which received a basal 52 kg/ha of P_2O_5, and the millet was topdressed with 80 kg/ha of N.

Sole-crop yields and LER values are given in Figure 2. Performance of the various combinations in terms of yield advantages showed quite large differences. Two combinations gave LER values less than 1, namely TMV 2 and MK 374 groundnut with PHB 14 millet. The other ten combinations gave LERs ranging from 1.06 to 1.30, and seven of these had values of 1.10 or more. But few consistent genotype effects emerged. One exception was M-13 groundnut, which gave high LERs with all three millet genotypes. This was probably attributable to the fact that its maturity period was over a month longer than the millets. However, MK 374 groundnut, which had a similar maturity to M-13, gave little evidence of any worthwhile yield advantage.

Millet was the more competitive crop, achieving a mean LER value of 0.46, which was almost twice its "expected" LER of 0.25. Groundnut achieved a mean LER of 0.68, which was only slightly less than its "expected" LER of 0.75. Thus, on an average, yield advantages were mainly due to "extra" millet yield. Rather surprisingly, ail three millet genotypes showed considerable differences in yield across the groundnut genotypes, and overall intercropping performance appeared to be more closely related to millet yields than to groundnut yields. This would seem to suggest that although

Table 2. Genotype characteristics in pearl millet/groundnut experiment.

Millet	Height (cm)	Days to 50% flowering	Groundnut	Growth habit	Maturity in experiment
GAM 73	120	62	TMV 2	Bunch	98
PHB 14	150	57	R33-1	Semispreading	113
IVS-AS75	170	61	M 13	Runner	125
			MK 374	Runner	125

groundnut was the less competitive crop, it still had important competitive effects on the millet. But this suggestion is not well supported by the subsequent experiment.

In the second experiment conducted in 1978, the groundnut genotypes were the same; all the millet genotypes were changed, but they still represented three types very similar to the early ones. The experimental design was changed to a strip-plot one. Millet genotypes were run as strips in one direction and groundnut genotypes as strips in the other direction. A "nil-genotype" strip was included for each crop to provide sole-crop plots of the other crop genotypes. Other details were the same as the first experiment.

It is evident from Figure 2 that yield advantages were more consistent and differences between the combinations were much smaller. Considering the groundnut effects, combinations with M-13 groundnut were again the best, and the mean ranking across all millet genotypes was the same as in the previous experiment, i.e. M-13, R33-1, TMV 2, and MK 374; however, yield advantages were much more consistent and even the MK 374 combinations averaged 15% yield advantage.

Yield advantage for the millet genotypes meaned across groundnut genotypes were extremely constant, all averaging around 20%. However, the millet genotypes did show different competitive abilities, which altered the proportions of millet to groundnut; in the order, BK 560, GAM 73C1, and Ex-Bornu, the proportion of millet decreased and the proportion of groundnut increased. No millet genotype showed any real evidence of being differentially affected by different groundnut genotypes as appeared to be the case in the first experiment. The apparent effects in that experiment were probably due to variability because of the rather low millet yields. In this second experiment, millet yields were high and quite consistent. Putting rather more emphasis on this second experiment, therefore, it appears to be the groundnut genotype which mainly determines the level of yield advantage, but it is the millet genotype which mainly determines the proportion of millet yield to groundnut yield.

Sorghum/Pearl Millet

This combination was first included in an early genotype study which was conducted in 1976 in cooperation with the millet breeders. Forty genotypes of pearl millet were intercropped in a simple nonreplicated layout with three crops of very different growth patterns — setaria, sorghum, and pigeonpea. Growth of setaria and pigeonpea was very poor, and harvest data were recorded only for the millet/sorghum combination. Planting arrangement for this was two rows of millet to one of the sorghum in 37.5-cm rows. (This arrangement was largely decided by what was a convenient standard for all combinations and this was a particularly suitable arrangement for millet/pigeonpea.) In addition, the millet genotypes were grown as sole crops both at an optimum population (220 000 plants/ha) and at a much lower population (44 000 plants/ha); this low population was included to try to get a measure of the "plasticity" of the different genotypes to see how this might be related to intercropping performance.

Intercropping performance was assessed both in terms of the individual millet performance and in terms of the combined intercropping performance (total LER). The basic objective of the experiment was to try to pinpoint desirable intercropping characters by calculating regressions of the intercropping performance on a large number of measured plant characters. It was because of this approach that

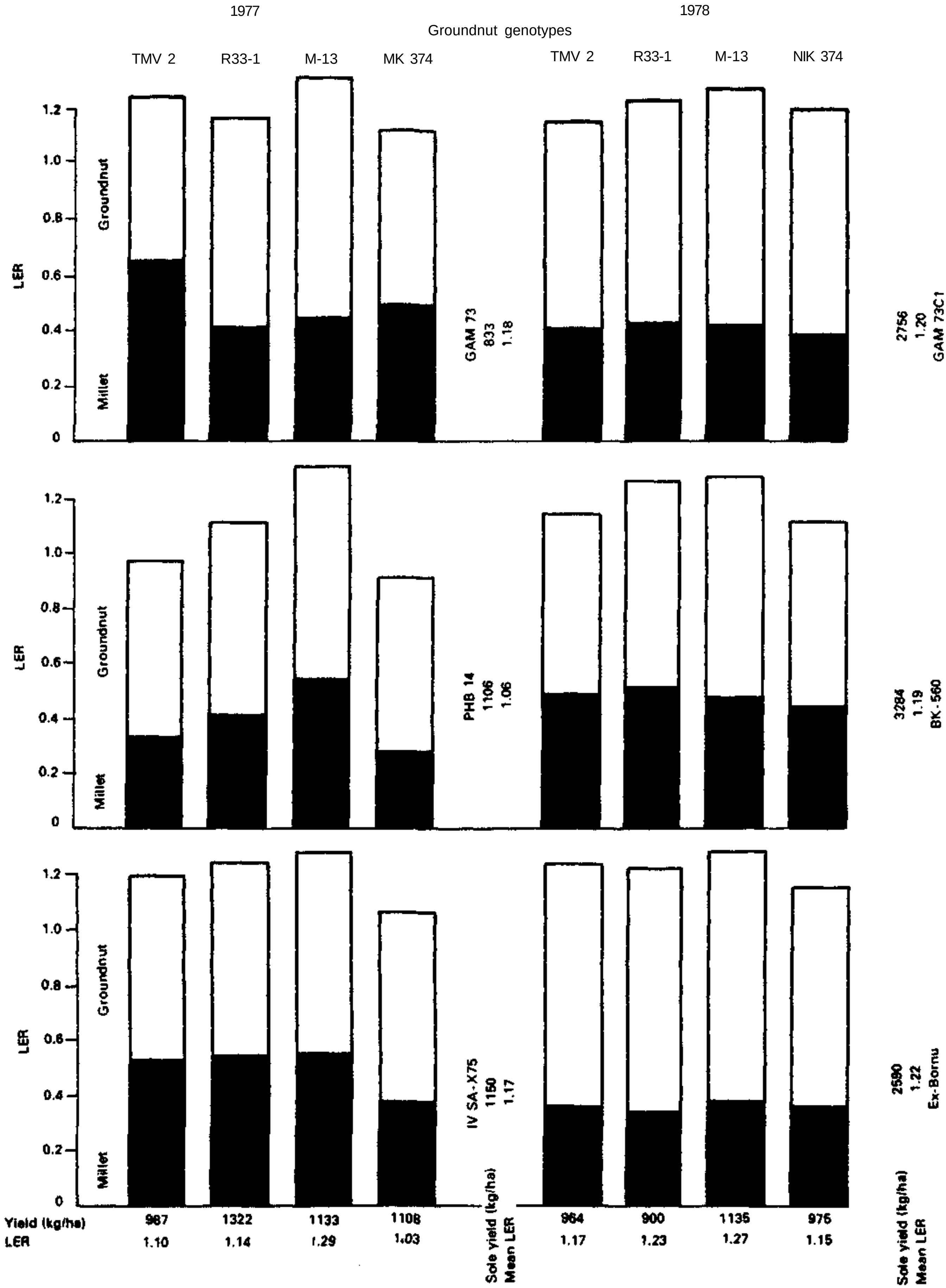


Figure 2. Pearl milletlgroundnut genotypes in intercropping.

replication was sacrificed in favor of a large number of genotypes. However, this technique did not work out very satisfactorily. The best regressions for individual millet performance were on difference in height, difference in maturity, and a simple estimate of the rate of stem elongation (height/time to flowering), but even a combined regression with all three characters only accounted for approximately 30% of the variation in millet performance. The best combined intercropping performance seemed to be where millet LER was particularly high and sorghum LER was still maintained at a reasonable level.

The plasticity of the individual plant was estimated by calculating the intercept value of the linear regression of the reciprocal of yield per plant on population, using the two sole treatments at low and optimum population (after Holliday 1960). A low intercept value describes a "flat-topped" yield per unit area/ plant population response curve which must occur because of highly "plastic" changes in yield per plant. But the data showed little evidence of the intercept being related either to millet performance or to combined intercropping performance. This was at least partly because of the inaccuracy of the data but it may also be partly because "plasticity" is a character which is more important in situations where there are large temporal differences in crop-growth patterns — e.g., a better correlation might have been expected in millet/pigeonpea than in this millet/sorghum situation.

Two further experiments have been carried out with sorghum/millet, but these have examined relatively few combinations (four sorghum x four millet genotypes) sown in alternate rows and replicated four times. In the first experiment, all intercrop combinations and sole plots were arranged in randomized blocks. The genotypes were:

Sorghum

- A GE 196 — Grain grass type, short and early (1.2 m and 48 days to 50% flowering).
- B IS 9237 — Mold resistant line, medium height and maturity (1.9 m and 68 days).
- C CSH-6 — Hybrid, medium height and early (1.7 m and 58 days).
- D Y 75 — Yellow endosperm type, tall and late (2.3 m and 71 days).

Pearl millet

- a GAM 75 — Short and late (1.3 m and 62 days).
- b GAM 73 — Short and early (1.3m and 53 days).
- c PHB 14 — Tall and early (1.7 m and 58 days).
- d Ex-Bornu — Tall and late (2.1 m and 71 davs).

Yields and mean LERs are given in Table 3. Strictly speaking, this combination should perhaps be assessed on the basis of whether intercropping exceeds the sole-crop yield of the higher-yielding component. However, LERs are used here because the initial objective with this crop combination is to determine if these very similar crops are capable of giving any increase in physiological efficiency when intercropped together.

In general, pearl millet was much the more competitive crop giving mean LERs well over 0.5, while the mean sorghum LERs were often less. The millet genotypes GAM 75, GAM 73, and PHB 14 performed similarly when averaged over the sorghum genotypes (average LER 0.64) but the tall, late Ex-Bornu performed better, giving an average LER of 0.79. All millet genotypes performed much better with the short, early, grain grass sorghum (averaging 0.92 LER); with the other sorghums, performance was reasonably constant, giving an average LER of 0.60.

Sorghum performance, averaged over millet genotypes, increased in the order of genotypes listed above and ranged from an LER of 0.20 for GE 196 to 0.66 for Y75. CSH-6 performed relatively well insofar as it yielded better than the taller and later IS 9237 and did not really cause any greater decrease in millet yield. All sorghum genotypes performed poorest with the late, tall Ex-Bornu. With the other millets there was little difference, except for a relatively good performance of CSH-6 with PHB 14.

Figure 3a shows the combined performance of both crops as an LER diagram. There was consistent evidence that this combination can give advantages: 13 of the 16 combinations gave LERs greater than 1, 10 of these showed advantages of 10% or more; and the maximum values showed advantages of over 30%. Some of the advantages could be partly attributed to differences in height or maturity. Thus the two highest advantages occurred with the latest

Table 3. Yields (kg/ha) and mean LERs of pearl millet/sorghum intercropping, Alfisol, 1976-77.

Millet yields

Millet genotype	Sole crop	With sorghum genotype GE 196	IS 9237	CSH-6	Y 75	Mean intercrop yield	Mean intercrop LER
GAM 75	800	830	480	420	440	540	0.68
GAM 73	1370	1120	760	690	740	830	0.61
PHB 14	2020	1720	1190	1100	1060	1270	0.63
Ex-Bornu	2030	2090	1440	1460	1450	1610	0.79
Mean		1440	970	920	920		
Mean LER	-	0.92	0.62	0.59	0.59	-	-

LSD (0.05) to compare mean intercrop yields = 180.
LSD (0.05) to compare mean intercrop yields = 220

Sorghum yields

Sorghum genotype	Sole crop	With millet genotype GAM 75	GAM 73	PHB 14	Ex-Bornu	Mean intercrop yields	Mean intercrop LER
GE 196	1380	350	300	280	190	280	0.20
IS 9237	3150	840	1020	1090	940	970	0.31
CSH-6	3110	1640	1500	1980	1170	1570	0.51
Y 75	1580	1080	1200	1270	660	1050	0.66
Mean	2310	980	1010	1160	740	-	-
Mean LER		0.42	0.44	0.50	0.32		

LSD (0.05) to compare mean intercrop yields = 180.
LSD (0.05) to compare mean intercrop yields = 220.

sorghum + earliest millet (32% with Y 75 + PHB 14) and the earliest sorghum-(-latest millet (31% with GE 196+GAM 75). Also, the third highest advantage was when there was the biggest height difference (Y 75+GAM 75). But other effects could not be explained in these terms — e.g., CSH-6 + PHB 14 gave an 18% advantage with little difference in maturity and nodifference in height. Regressions were computed of intercropping advantage (total LER) on height and maturity differences. Maturity appeared to have more influence than height, but even their combined effect only accounted for 22% of the variation in LER.

The subsequent experiment was carried out in 1978 largely to verify these surprisingly large advantages obtained with two such similar component crops. As the genotypes in the first experiment had not provided as big a range as initially anticipated, some of these were changed; the new range was:

Sorghum	*Pearl millet*
M 35662 — Early dwarf	GAM 73 C1 — Early dwarf
CS 3541 — Late dwarf	GHB 1399 — Late dwarf
CSH-6 — Early tall	BJ 104 — Early medium
KP-Hybrid — Late tall	SYN 7708 — Late medium

In this experiment, a strip-plot design was used as described for the second millet/groundnut experiment. The results of this experiment are not yet fully available, so they are only referred to very briefly. They are presented in Figure *3b* as an LER diagram, and it can be seen that the general pattern of results is reasonably similar to the earlier experiment

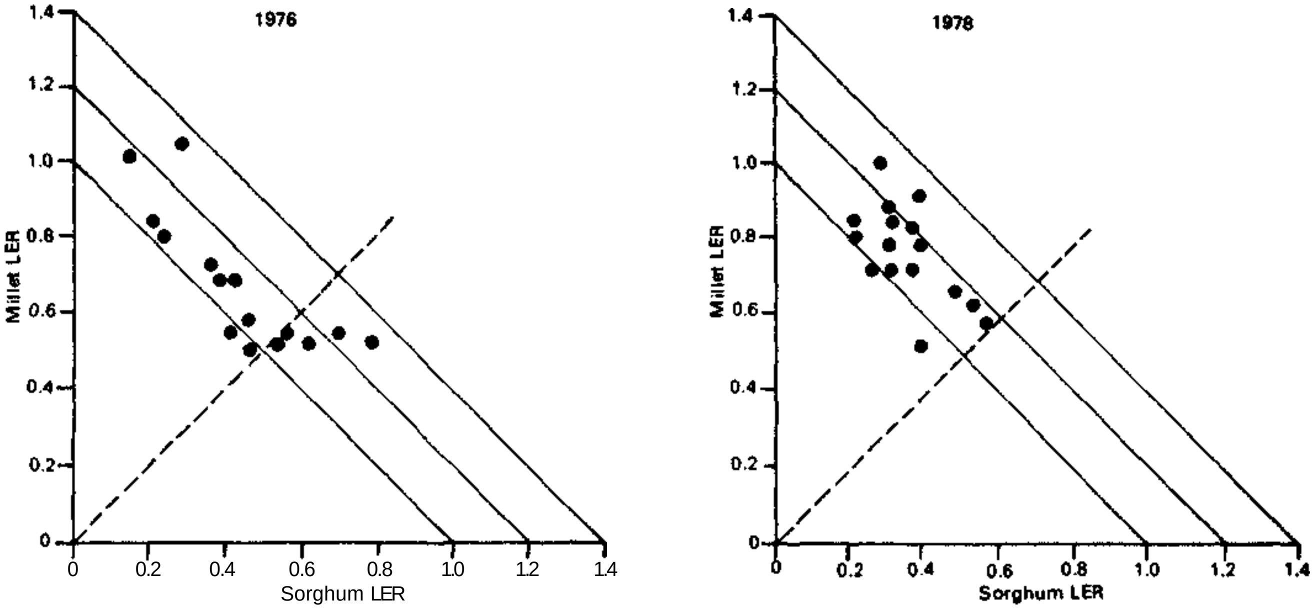


Figure 3. Intercropping experiments with four genotypes of pearl millet x four genotypes of sorghum.

(Fig. 3a). Again, two of the combinations achieved advantages of just over 30%, and 10 of the 16 combinations gave advantages of over 10%. First indications are that advantages were not very closely related to maturity or height differences, so again there seemed to be other characters involved. In view of these relatively large effects, this combination would seem worthy of more attention.

Predicting the Performance of a Given Genotype in Intercropping

Considerable attention has been given to trying to predict the performance of genotypes when grown in different environments as sole crops. A common method has been to examine genotype performance against a range of "environmental index" values which are based on mean yields at different locations (e.g., Finlay and Wilkinson 1963). This same technique has recently been used to predict intercropping performance in different locations (Francis et al. 1975). But a rather different problem is how to predict the performance of a genotype when it is intercropped with different genotypes of another crop. The Finlay and Wilkinson type of analyses suggests a means of doing this by using yields of the genotypes of the other crop as a measure of the 'competitive environment.' This approach is illustrated in Figures 4 and 5for the millet/sorghum genotype data given in Figure 3a. Figure 4 shows the individual yields of the millet genotypes plotted against the *mean* yields of the sorghum genotypes; also, of course, individual sorghum yields can be plotted against mean millet yields. The advantage of using mean yields of the second crop genotypes is that these give a better measure of the average competitive abilities of the genotypes; in terms of the Finlay and Wilkinson analysis, they give a better measure of the "competitive environment" provided by these genotypes. Figure 5 shows fitted regression lines for both crops. It must be emphasized, however, that these regression lines are given here purely for illustrative purposes, since the pearl millet "environments" were rather limited to allow extrapolation of sorghum genotype performance. Also, a background statistical analysis would normally be required to identify whether there were statistical differences between genotype responses and whether these responses could be validly described by linear relationships.

Taking an analogy from other analyses, the slope of a given regression line in Figure 5 can be taken to indicate "general intercropping compatibility" and the deviations from it "specific intercropping compatibility" The ad-

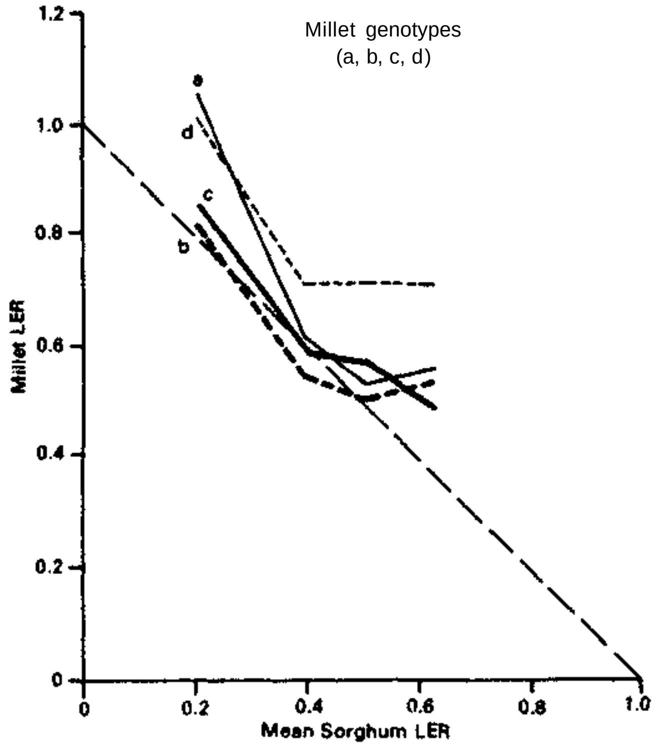
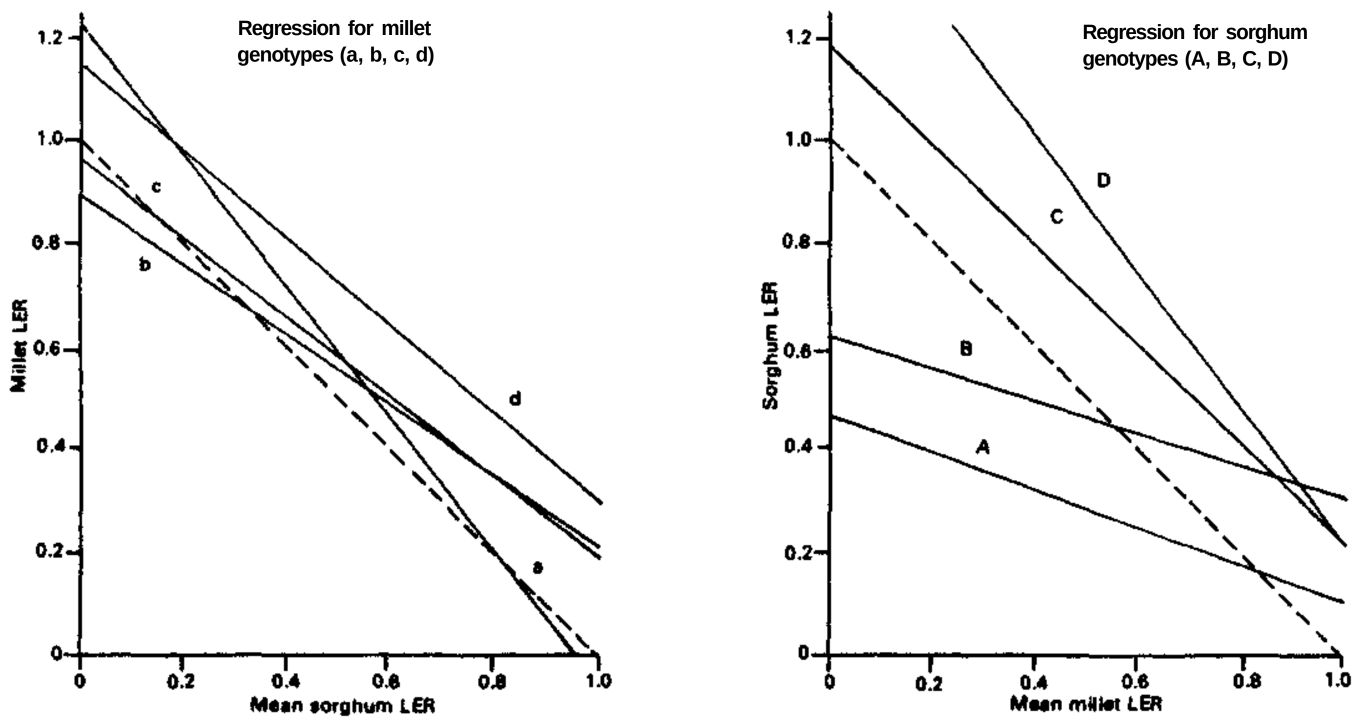


Figure 4. Intercropping compatibility in a pearl milletlsorghum genotype experiment at ICRISA T.

vantage of plotting in LER terms is that the values indicated by the regression lines are particularly meaningful. Ignoring, for convenience, the negative sign of the slope, a slope equal to 1 indicates a genotype which can be expected to give the same relative intercropping advantage (or disadvantage) over a wide range of genotypes of the other crop; a slope less than 1 indicates a genotype more likely to give an advantage in "environments" where the other crop is dominant; and a slope greater than one indicates a genotype more likely to give an advantage when that genotype itself is dominant. The magnitude of any expected advantage from a given genotype also depends on the "height" of the regression line: this could be indicated by the mean yield, but experimentally this depends on the range of "environments" being examined. It would be more useful, therefore, to define an "expected" value for a standard point on the horizontal axis. Thus a "50% compatibility value" could be defined as the "predicted" LER value of a given genotype when an associated crop gives an LER value of



Examples:

		50% compatibility value (y at x - 0.5)	General intercropping compatibility (slope)	r^2
Pearl millet (GAM 73)	b	0.56	-0.7183	0.79
Sorghum (CSH 6)	C	0.68	-0.9829	0.48

Figure 5. Intercropping compatibility in a pearl milletlsorghum genotype experiment at ICRISAT.

0.5. To take two examples, the sorghum genotype C has a 50% compatibility value of 0.68 and a slope virtually equal to 1 (again ignoring sign); thus this genotype can be expected to give an yield advantage of about 18% (i.e., a total LER of about 1.18) in combination with a wide range of pearl millet genotypes. Similarly, pearl millet genotype D, with a 50% compatibility value of 0.74 and a slope of 0.7451, could be expected to give about a 24% yield advantage when an associated sorghum crop gives a 50% yield, and this advantage would be expected to decrease if the millet genotype were more dominant but increase if the associated sorghum were more dominant.

Discussion

India

Yayock
One of the combinations referred to was cotton with cowpea. This was very successful but what was the pest and disease situation?

Rajat De
We observed no shift in either pest or disease situation in intercropping compared with the sole crops.

Andrews
Did you use any sprays in these situations?

Rajat De
Yes, these were protected situations.

Lira
How is weed control practiced in the high density intercropping situation in India?

Rajat De
First of all, weed competition is very much reduced in these high density situations. Secondly, infestation is only in the early stages and this can be quite easily controlled manually. With certain intercropping combinations, herbicides can be used.

M. S. Chowdhury
it was stated that if cowpeas are harvested early for fodder, this gives the best advantage to the sorghum. Is this because of less competition due to removal of the cowpea, or has there been some advantage duetothe transfer of fixed nitrogen?

S. P. Singh
The most important reason probably is that nodules are left behind from the cowpea crop and these release nitrogen for sorghum. From last year we have started more detailed studies and, hopefully, we will have further information very shortly.

S. L Chowdhury
Dr. Singh's data and concepts are more relevant to irrigated agriculture. We must be very careful in trying to transfer this information to dryland situations. He illustrated the importance of a competition-free period. But we are all aware of the dangers involved in delayed sowing of one crop. If sowing of sorghum is delayed by 20 days, you can write it off to shoot fly. Likewise, if pearl millet sowing is delayed, you can write it off to downy mildew or ergot.

Sharma
In his experiment, Dr. Tarhalkar compared two pigeonpea genotypes for the effects of different plant population and canopy configuration. Yet the two pigeonpea genotypes had very different growth durations. How can you conclude that one plant configuration is better than another in this situation?

Tarhalkar
The two genotypes HY 2 and HY 3A only differ in duration by about 20 to 25 days. The main difference in these two genotypes is their branching patterns. HY 2 branches very early and has many basal branches compared with HY 3A which branches later and has few basal branches. Thus, these give a different expression of sorghum yield. Our objective is to have a full sorghum yield compared with the sole crop.

N. G. P. Rao
What is involved here is the effect of two diverse genotypes of pigeonpea on the yield of sorghum. The question is not on the performance of two pigeonpea genotypes which are of different maturity. Dr. Tarhalkar was trying to emphasize that the effect of HY 2 on the sorghum was much greater than HY 3A which has little early basal branching. If we had wanted to compare the yields of the pigeonpeas themselves, then questions of

duration would certainly have to be considered.

Venkateswarlu

Perhaps I could refer to the experiments of Dr. V. B. Shelke who unfortunately is not here. He has compared two pigeonpea genotypes — HY2, the early branching type, and HY 4, the later branching type — with few basal branches. The associated crop was sorghum. The data over six experiments, in which these two genotypes have been compared, clearly indicate that, at a plant population of 40 000/ha, the HY 4 yields better.

M. R. Rao

The difference between HY 2 and HY 3A in Dr. Tarhalkar's data did not appear to be significant. We have had 2 years' experience of examining the effect of pigeonpea genotypes on sorghum. Our findings are that the sorghum is so much the dominant crop that differences in pigeonpea genotype do not affect the sorghum differentially. Whether the pigeonpea genotype is spreading or compact makes little difference to the sorghum. After sorghum harvest it is the spreading genotype which appears to fill in across the rows and produce more yield.

Venkateswarlu

One of my colleagues included cowpea as an intercrop with sorghum in the red soil region of Hayatnagar. He found that when cowpea is harvested as fodder, its beneficial effect is greater than when it is harvested as a grain legume. We initially thought that this was because the cowpea vacated the land early and thus afforded less competition. Thus we collected soil samples, which were then subjected to pot studies to see how much nitrogen was available. There was a substantial difference between the treatments, and there was obviously more nitrogen available when the cowpea was harvested as fodder.

M. S. Chowdhury

Our studies have suggested that when cowpea is removed earlier, there can be a benefit to the associated cereal if the cowpea and cereal are mixed within the same row. However, I think that when the cowpea and cereals are intercropped in alternate rows, the possibility of any nitrogen benefit from cowpea to cereal is questionable because of the greater distance involved.

Shivashankar

I very much doubt the possibility of legumes giving any nitrogen benefit to associated cereal. Possibly there could be other effects such as root exudates. The usual observation is that during the preflowering period of legume growth, say up to 50-60 days, there cannot be any exudation of nitrogen.

Andrews

It certainly seems more sensible that an early legume should be combined with a later-maturing cereal if any benefitfrom the legume is to be achieved. But it does seem striking that there is still very little concrete evidence on this particular aspect.

Snaydon

In my opinion, it is unnecessary to postulate the existence of exudates. It seems to me that when the legume tops have been cut off, the nodules that remain in the soil decompose and the cereal then benefits from the nitrogen released.

Rajat De

We have found that the nitrogen removal by maize was greater when it was grown with a legume intercrop than when it was grown alone. This occurred both at the 0 and 40 kg nitrogen treatments.

Jodha

I get the impression that we are trying to rediscover the wheel. The bulk of things that have been suggested are already being done by the farmer. We have a lotto learn from him. In the context of crop geometry, for example, we only have to look at the farmer's practice. I would particularly refer to Dr. Singh's screening of crop combinations with the legumes. Again, we only have to look at what the farmer is already doing.

N. G. P. Rao

Many of the practices being tried in experimental situations are now very different from those practices being tried out by the farmer. The actual crop combinations may remain the same, but the farmer has tended to intercrop with replacement populations and present research is looking at much higher plant populations and, of course, new genotypes. We are currently trying to produce 100% yield of the base crop, for example, in the case of sorghum, and some additional yield of a second crop.

Andrews

Even if we feel many of the basic systems being examined experimentally are not very different from the existing farmer situation, there is presumably an urgent need to show how new high-yielding genotypes can be fitted into these systems.

Rajat De

Dr. Jodha has brought up a very good point from the social scientists' point of view but one must bear in mind that the traditional farmer has been practicing his intercropping as an insurance against faflure.

Mead

Most of the experiments that we have reported have been carried out at constant density. And yet in Dr. Venkateswarlu's paper we saw a very appreciable response to density. Is it not possible that many of the results being presented are in fact specific to the particular density which was being studied?

Rajat De

Most of the experiments reported have been changing spatial arrangement Thus they are showing effects of spatial arrangement at constant density. I agree they are not taking into account the effect of density itself.

S. L Chowdhury

There are trials indicating that if the population of the main sorghum crop is maintained at the full sole-crop optimum, even the full population of the legume may be inadequate. This happens because the branching of the pigeonpea is much reduced. But this is related to the way the full population of sorghum competes against the pigeonpea.

Brazil

Snaydon

Dr. Lira, I wonder if you could be even better in your intercropping if you raise the population of the legume. The figures in Table 5 suggest that the number of pods per plant is greater when it is growing with a nonlegume than when it is growing with its own species. This suggests to me that your legume population is not high enough.

Lira

Work has been done where the plant population of the legume, and also the total population, has been varied. But in this particular experiment we did not want to introduce another variable. We were following the early experiments of Dr. Willey here and trying to keep "plant units" constant. Thus we were using a replacement series and replacing so many plants of one crop with an equivalent number of plants of the other crop. I think you are probably right that we might have done better to have had more legume plants.

West Africa

Willey

Dr. Baker made some reference to the fact that intercropping was more stable. Were you quoting hard fact? If so, could we have a little bit more information please?

Baker

I can't say too much about this. I was in fact quoting Dr. Norman's work where he collected incomes from different farmers who were practicing intercropping and compared these with incomes of farmers practicing sole cropping. This comparison is a little bit difficult because sole crops only account for 18% of the cropped area, but he clearly showed that systems where a mixture of intercropping and sole cropping was practised gave a lower coefficient of variation of return compared with just sole cropping.

Willey

Was there any change in the crops that were being compared between the sole-crop and intercropping situations? In the Indian situations, a change from intercropping to sole cropping very often means a change of crops.

Baker

Within reason we are talking about the same crops. They were mainly sorghum, cotton, and cowpeas.

M. R. Rao

You mentioned that in replacement series mixtures the LERs tended to be lower than in superimposed mixtures. Is the size of the LER not more closely related with the time difference between crops?

Baker

In the superimposed mixture the farmer insists that his main crop must give a full yield. So you are in effect starting off with an LER of 1. There is much more scope for getting higher LERs, for example, up to 2, in that situation than in the replacement mixtu res whereone is dealing with crops which more or less compete for the same environmental resources, although one can still get gains because of factors like differences in height.

Rajat De

But is Dr. Rao not suggesting that in the replacement series mixtures, LERs are low simply because one is dealing with crops of similar growth rhythms?

Baker

In some of the trials we have had replacement mixtures with crops with different growth rhythms. But the maximum LERs we have had with those have been up to about 1.4.1 would suggestthat in mixtures whereyou havecrops of very similar phonological types, even with quite a big maturity gap between them, you will not get very large LERs. In the sorghum trial, for example, we were getting no gain from the sorghum. We were getting the gain in yield from the earlier crop. However, if we had different crop arrangements we may begin to increase the LERs above those which we have had so far.

Trenbath

I would liketo say that I have information from some wheat replacement mixtures, i.e., a 3 x 3 diallel and also from some wheat variety mixtures. In the literature there is some information on soybean mixtures which show that even in replacement mixtures you can get compensation in harvest indices. So, in fact, harvest indices are not necessarily fixed.

Snaydon

You say that 68% of the variation in varietal gains was attributable to differences in age and duration. How much of the variation was due to each of these and to the interaction between them?

Baker

I can't give you that information for that particular bit of data but I can refer you to the data we were discussing earlier where 83% of the variation was due to the differences in maturity. But there is very often big variation between seasons on how much variability can be accounted for by given factors.

Snaydon

This is an important point and I think we should not attempt to mix together variability due to two very different factors. If from earlier data the suggestion is that maturity differences account for at least 80% of the variability, it would certainly seem that a large part, if not the major part, of that variability indicated by the 68% is in fact due to differences in maturity.

Krantz

I agree with Dr. Stoop's idea that we should see what the existing situations are, but I gather from the last statement in his paperthat he doesn't agree that there would be any form of mechanization for a long time. When you say that do you mean the use of combustion engines or the use of animal equipment with possibly improved implements?

Stoop

In certain parts of the country (Upper Volta) there is of course much better possibility for the introduction of animal power, and there is some work being done in that direction. But for large areas of the country, in the Mossi Plateau, for example, which ranges from Ouagadougou into the north of the country and which is densely populated with small farmers having an average of 4 to 5 ha, there have been some calculations by the French scientists which suggest that simply to keep a pair of oxen alive would require 10 ha. It is from this kind of information that my doubts arise as to the possibilities of introducing animal power.

Krantz

I am very surprised at the figure of 10 ha. This certainly does not equate with any figures that we have from India. One of the points here may be that if you try to introduce animal power with the wooden plow you need a lot of animals. But if we used improved implements we may need only 20 to 25% of that number. We should probably be looking more into the future here because it costs more to bring in more animals to operate a poor implement than it does to bring in fewer animals to operate an improved implement; and of course one gets a reduction in the amount of feed required as well.

Trenbath

I have seen some information in Nigeria for those interested in record LERs. If cowpea is grown as a sole crop I believe it is not uncommon to get 0 yield because of insect attack. If one is then calculating an LER using this, LER values can be infinite.

Stoop

We have had situations where we have also obtained zero yield from intercropping, at least in the absence of spraying. This sorghum/cowpea situation is extremely important in local agriculture, but what we very often see in experimental situations is intercropping on a 50:50 basis with a pure line of cowpea alternated and usually at high densities. In this situation, one may often get the same insect problems in the cowpea as one does in pure stand. So this basically gives no intercropping gain. This certainly needs rethinking for the Upper Volta situation and we really need a more thorough mixing of the two crops in the sorghum/cowpea situation.

Rajat De

You said that the early, erect cowpeas do better in intercropping because they avoid the pest incidence. How well does this type of cowpea fit into the system?

Stoop

They fitted into the system quite profitably this lastyear. Butto avoid the insect incidence they have to be planted early. I have not yet been able to test how well they suit this early planting, for example, how well they might tolerate a drought in June. But even when planted at the end of June they still escaped the insect incidence, though they were at fairly low plant population. Perhaps if we could find a spreading but early maturing cowpea it might be more effective for this particular type of local agriculture.

Laxman Singh

I agree with Dr. Stoop's observation that the foundation for improving intercropping system is a more thorough study of the prevalent cropping systems. I collaborated in some studies on how pigeonpea was grown in one part of our state. There was a tremendous amount of variation in the systems in which pigeonpea and sorghum were grown. The proportions of the crops varied, adapted to the agroclimatic variations and the soil depth. On the plateaus, sorghum became a major component and pigeonpea a less important component. Where soils were deeper, late pigeonpeas formed a major component and sorghum a minor component. Wherever moisture stress was greater, where soil depth was less, and where the September rains were uncertain, sorghum was replaced by a lesser millet. The pigeonpea was still present but it was an earlier-maturing type. So the farmer makes many adjustments to his cropping system. Also, of course, mixing the crops within the row, not just between rows, is common.

Planting density is related to moisture stress. If there is a greater chance of moisture stress, higher densities make the yield less stable. Therefore, the farmer is often reluctant to raise his plant population above a certain limit. For example, where September rains are poor, high populations may give him a drastically low yield. Many farmers do not grow sole pigeonpea and prefer to grow it along with a dominant sorghum, because if sole pigeonpea is grown over several years, wilt becomes a much more serious problem than in an intercropping situation where the pigeonpea is mixed with sorghum. With maize grain, in parts of Madhya Pradesh and Rajasthan, the farmer is still growing these as sole crops even though work has shown that yields of maize can be increased by intercropping with mung. This information has been available for the last 5 to 10 years, but it has not still been adopted. This may well be because of the greater demand on moisture because of a higher planting density. Thus studies of some of these present systems may well help us to explain why many of our current or newer systems are not being adopted by the farmer.

Chairman

We have had some discussion on the individual papers and I wonder if we could now open up the discussion to more general matters. Could we, for example, take up again the point that was being discussed earlier— i.e., the possible contribution from a legume to a nonlegume in an intercropping situation. Would anyone like to comment on this?

Willey

I think in many of the experiments where we have been examining a legume and a nonlegume, there is a particular difficulty. The plant population of the nonlegume is lower in intercropping compared with sole cropping. When this occurs, the nonlegume intercrop yield is usually lower than its sole crop yield, and it is then impossible to separate any possible nitrogen transfer effects from other competitive effects. But in some of the research in India, the nonlegume nas been grown in intercropping at exactly the same plant population and spatial arrangement as in sole cropping. This has been done, of course, because of the need to maintain the full yield of the nonlegume. As a result, what we have got is a situation where we have a normal nonlegume crop to which we have added a legume. As the data have shown, there are several instances where this has increased the nonlegume yield above that of its sole crop. There may be many possible explanations for this, but the simplest is that the nonlegume has benefited from some nitrogen transfer from the legume. In a situation where we can find a simple explanation, why should we pursue a more complicated one?

M. S. Chowdhury

If one does have the situation where there is a legume and nonlegume, the N fixation by the legume is dependent on the amount of photosynthesis of that legume. So if the nonlegume has a full canopy, the possibility of legume fixation is low. My experience in East Africa is that when the legume and nonlegume are grown together, it is the legume that suffers very badly. The farmers in East Africa practice intercropping with legume/nonlegume because if the nonlegume fails, they get some legume crop. Also a further factor is their dietary requirement; they want to produce both carbohydrate and protein from the same area of land. My observation is that there can be transfer of nitrogen when the nonlegume and the legume are planted in the same hole, but the legume suffers drastically due to competition.

We should also remember that when two crops are combined the bacterial flora in the soil changes. We have found that when soybean is planted with maize, the micro-flora of the maize increases tremendously and this increase seems to be related to any yield increase. In quite a few instances, the intercrop yield of maize is similar to the sole crop yield of maize. I think this subterranean population may either be producing some beneficial growth factors or may be affecting the availability of nutrients in the root zone.

Chairman

Dr. Chowdhury's comments are very relevant. His observation that the legume suffers very severely may or may not happen under all situations. Perhaps an important point here is that if breeders can provide us with legumes that can photosynthesize at low light levels, these could be particularly useful in intercropping situations.

Shivashankar

In some of the situations that I have been studying, the legume often benefits from the presence of a nonlegume, e.g., a grass. And we have found that soybean grows well alongside maize. I feel we often need to ask what was the previous crop, what was the initial natural inoculum, was the crop inoculated with rhizobium, and what was the nutrient status of the soil? Perhaps this would help explain the balance of competition between a legume and a nonlegume.

Snaydon

I think we need to separate the additive and replacement situations in these legume/nonlegume experiments. In a replacement situation, we would perhaps expect the nonlegume to grow better simply because it has access to a greater amount of nitrogen. This is because the legume is fixing its own nitrogen. In additive systems, we might expect the yield of the nonlegume to be reduced if there is competition for some other factor such as phosphate, light or water. But it does depend on the extent to which nitrogen is released from the legume. There are so many ways in which this can come about. It may be due to the loss, decomposition and turnover of nodules, or by the cutting of the crop. In a system where an early legume is cut for green fodder, the root system may leave behind large amounts of nitrogen. If the legume is cut near maturity, there may not be much nitrogen left in the soil because a large proportion will have gone into the seeds. A -rough estimate of the amounts in a crop could be up to 500 kg of N in the tops (more likely 200 to 300 kg), about 50 kg in the stems, and possibly 40 to 50 kg in the root system.

Willey

I believe you have carried out some cereal/legume experiments, Mr. Chairman, where legumes ranged from early cowpea cut for fodder, to groundnut of similar maturity to the . cereals. Groundnut gave a smaller increase in the cereal yield than did the cowpea, but it still gave an increase. This must presumably have been more of a current transfer effect than a residual effect.

Trenbath

Therecould of course be organisms other than humans cutting the legumes. There may well be micro-organisms chewing up the root systems and releasing nitrogen. So even if we are not cutting them, there may well be ways whereby nitrogen is being released from the living root systems.

Baker

At Samaru we grew maize in combination with groundnuts in a replacement situation, and applied either phosphate to the groundnuts or nitrogen to the maize, or both. If there was no nitrogen applied to the maize, the maize did not yield at all; certainly there was no nitrogen transfer from the groundnut to the maize, or it came far too late for the maize to benefit from it.

Burford

The only work that I know of in which nitrogen transfer from legume to nonlegume has been examined using isotopes has been at the Cunningham Laboratory in Queensland. The maximum transfer that they could get was of the order of 1% of the total nitrogen in the legume. In this case the legume was not cut so we were looking at the phase where presumably effects were due to nodules being sloughed off, or possibly the decay of roots. But there was very little transfer of nitrogen.

Laxman Singh

In the marginal dryland areas it is almost invariably the nonlegume that is the main component. The legume is then an additional crop. Thus any enhancing effect of the legume, even a small one, can be extremely important. It also makes the legume population very critical. It should be just sufficient presumably to produce an enhancing effect without producing any competitive effect.

Chairman

I think this discussion has shown that there is lot of scope for further study in this field, first of all to determine whether there is any transfer of nitrogen and why this is so.

Lira

All the discussion has been on the nitrogen fixation ability of the legume in intercropping. Should we not also be considering the nitrogen fixation ability of the cereal?

Shivashankar

Because of the rhizosphere activity, there can also be nonsymbiotic fixation whenever there is a carbohydrate supply. This could also enhance the growth of a nonlegume.

Sharma

The results presented by Dr. Osiru indicate that if there is any advantage of mixed cropping, it is at the very high plant population level. We saw a similar situation earlier. This makes me question the stability of such a system, especially where moisture is in shorter supply. Would such a high population system not be more vulnerable to moisture stress, especially if this comes suddenly. All the data presented so far seem to suggest that the most stable system is a low population one.

Laxman Singh

Dr. Sharma has a point but in this particular experiment it should be noted that 20 plants/m^2 were considered optimum either for sole sorghum or sole pigeonpea. The highest yields in intercropping were achieved at only 16 plants/m^2. None of these populations were in fact very high.

Baker

We should not forget that both the sole crop and the mixed crop will suffer at high population in the event of moisture stress. Even though moisture use might be somewhat higher in mixtures, the distribution of water demand may be rather different and we may well get less moisture stress. This point is well understood by farmers in northern Nigeria who in fact do not plant a high population but gradually build up the population. They start at the beginning of the rains with a low population, building up to a high population during the main rains; after harvest of the early crop they have a low population which matures on stored moisture at the end of the season. Thus I think we have to be very careful about recommending high populations in mixtures to farmers, particularly the kind of farmers I am talking about. If they have to sow a high population, they would have to wait until the main rains had established because there simply is not enough moisture to support a high population at the beginning of the season.

Sivakumar

When you were fitting population against yield, you used a linear relationship but at zero population this gave intercept values between 1.4 and 4 tons. Biologically this has no meaning. Should the line not have been forced through the origin, or should you perhaps have used a curvilinear relationship?

Nadar

In this situation there were many factors other than population that were influencing yield; population was only one of several in a complicated array of factors.

Willey

I think Dr. Sivakumar has a valid point here because biologically these yield/population response curves rise from the origin. But I do not think it would make very good sense to fit linear relationships which arise from the origin. After all, there are a number of well-known curvilinear relationships for fitting sole crops to this plant population/yield situation. I make this point because in my earlier paper I stressed that we had not made sufficient use of these curvilinear relationships in the intercropping situation. The relationship I showed was after Holliday; it fits the reciprocal of yield per plant against population, and there is in fact very good reason for doing this. It gives a very good fit for a wide range of crops and over a wide range of situations.

Mead

Dr. Magagula suggests specific experiments on fertilizer needs. I knowthese *are* only general outlines of experiments but it struck me that to do an experiment on each of different fertilizers, using quite a large number of levels of each, is probably very uneconomical. I would suggest that you consider factorial experiments with several levels of different fertilizers in each, but probably not as many as the six or seven levels you suggest. Also, I would not suggest that you use a split plot design because I am not sure that your comparisons are primarily between different mixtures. I suspect they are mainly between different fertilizer levels.

Genotypes

Sharma

With reference to Dr. Wein's paper, our experience is that once we group material for a given maturity period and select within that maturity period we do not then find any genotype system interaction significant. So if we select for a given maturity period, the correlation between sole-crop performance and intercrop performance is then very high. In other words we can then estimate intercropping performance simply by examining sole-crop performance.

Wein

I think in this context one has to talk specifically of a given crop combination. In our relay cropping with cowpea + maize, we find that even after grouping varieties according to plant type, we get varietal differences, i.e., there is a system x variety interaction. So there is still room for selection even after grouping into given plant types, or given maturity periods, and so on.

Sharma

I would accept that grouping on the basis of plant type may give variety x system interaction, but I was stressing that on the basis of grouping into maturity period there may be no interaction. And I believe similar results were obtained at CI AT.

Wein

But the results that I have reported here are for cowpea of very similar durations. And the variety x system interactions were significant but the relationship between sole-crop performance and intercrop performance was not. So our results seem to be at variance with what you are suggesting.

Snaydon

But you are referring to only half the system, i.e., the cowpea. We also need to know what is happening to the other half of the system. For example, if you increase the yield of the cowpea, do you decrease the yield of the maize?

Wein

I should have indicated that in the presentation. In fact when cowpeas are relay planted into maize, i.e., in the later stages of maize growth, maize yields are not affected. To try to select for both crops simultaneously, as some workers have suggested, would enormously complicate the system. In our system it would not make sense because one does not get effects of the cowpea on the maize. Where you do have an interactive system when both crops are affecting each other, it would be very difficult to select genotypes of either of the crops.

Laxman Singh

We have also found in our pigeonpea studies that within a given maturity group sole-crop performance and intercrop performance are highly correlated. Thus if one is selecting a good genotype for sole cropping one is selecting a good genotype for intercropping also. Do I understand that in your system there is also quite a high correlation between sole-crop performance and intercrop performance?

Wein

Not high enough to be significant.

Stoop

You have not yet mentioned the insect problem that is so important to us in Upper Volta. I believe that in all your studies, you have used insecticides. If you use cowpea in an intercrop situation surely one of the goals is to reduce the insect damage. Do you think you would get a different ranking of the genotypes if you were to carry out the trials in an unsprayed situation? We have carried out one observational trial in Upper Volta which suggested that especially the early, rather determinate, type of cowpeas were most susceptible to insect damage. The longer maturing, more indeterminate type was still attacked but it still produced some yield.

Wein

We have relatively little choice in this because we are carrying out our experiments on an experimental station where we are growing cowpeas all the year round. The insect pests are always there. At other locations, this would not be a factor butthen one would have to contend with a tremendous variability. This has been our experience in a number of situations, e.g., northern Nigeria or Upper

Volta, where in one experiment one might get a particular result because a particular insect was present, and in another situation a completely different result because a different insect is present. I would prefer to leave this task to the traditional farmer because this is what he has already been doing. The genotypes which he is using in his traditional system are in fact the long maturing photosensitive types which often do not flower until the end of the rain and can produce pods 1 to 2 months after the rains have ceased. I think if we want to improve that system for traditional farmers we have very little chance of doing so. Our real opportunity is in selecting genotypes for an improved situation, although this could still be an intercrop.

Sharma

Have you looked into the question of heritability and selection efficiency under mixed and sole cropping situation?

Wein

We have not done this as yet.

Sharma

Our experience is that in the mixed crop situation the range of variation becomes very narrow between genotypes and then the heritability is lower. It then becomes very difficult to select for a definite yield advantage.

Andrews

You have been suggesting that when selecting genotypes of the dominated crop it does not seem to matter too much what the genotype of the dominant crop is. You also suggested that as intercropping pressure decreases, the correlation between intercropping performance and sole-cropping performance improves for the dominated crop. Would you care to make any comment about the relationship between sole-crop performance and intercropping performance for the dominant crop? Can we simply use the sole-crop yields to predict intercrop yields?

Wein

Certainly if the dominant crop is not being affected by the dominated crop then it should simply perform as a sole crop.

Trenbath

If you want to estimate 50% compatibility values would it be worth considering the use of a curvilinear rather than the regression that you proposed. I suggest this because some very big extrapolations are involved and the points seem to lie on curves.

Willey

I agree that one would get a better fit with a curvilinear relationship, if it is in fact meaningful. We were striving for some simple relationship to explain the way in which genotypes might behave. I would not claim that we got very much from this particular set of data, but of course we were mainly exploring the method. Perhaps one important conclusion was that we did not have a sufficient range of competitive environments for either of the crops. To use this type of relationship efficiently, I think one would have to ensure that any particular genotype was very suppressed at one end and very dominant at the other.

Mead

I think there is a danger here that you are selecting for pigeonpea genotypes that give low sole crop yields. This is because when you relate intercrop yield to sole-crop yield the smaller the divisor, i.e., sole-crop yield, the bigger the contribution to the LER. I would like to suggest that what you are looking for is some way of combining a sorghum yield and a pigeonpea yield. So first one must define the scales against which you are going to measure the two quantities, and then you can add them up. Thus I think there may be a lot to be said for using one standardized measure of pigeonpea yield, and I don't think it matters a great deal what it is, particularly where the yield range is only between 700 to 1000 kg. I think this would make your LERs a lot more comparable.

Jana

You reported up to 30% yield advantages with sorghum/millet intercropping. Can you explain how this happened?

Willey

This is undoubtedly a situation where there are not so many obvious reasons for yield advantages. But I think there are still some.

Where we were getting 30% yield advantage, this was usually where we had a reasonable maturity difference between the species, e.g., 14 to 20 days. So even small temporal differences between the species we thought might have been quite important. There was also some suggestion that a large height difference might have contributed to the advantage, though possible beneficial canopy effects are not obvious when we are combining two C-4 plants. But it is possible that there is some beneficial effect of spreading the young, active leaves throughout the canopy. I think there have been suggestions that millet tends to take up more of its nitrogen in the early stages compared to sorghum. Thus it may be possible that we have a temporal difference in the demand for soil resources between these two crops even when their maturity periods are similar. But this data does indicate that there are many things that we need to explore further.

Snaydon

I am finding myself very confused about the method adopted to select the dominated crop which supposedly is not affecting the dominant crop. Both speakers have been suggesting that there was no effect of the dominated crop on the dominant crop. If we look at Table 1 of Dr. Willey's paper, there seems little correlation between a high LER and performance in intercropping. Thus, for example, the best LER of 1.66 is given by a genotype which is just average — in fact eighth — in intercropping. The second best LER is given by the variety which comes fifth. The only time when we seem to have a reasonable relationship is when we look at the last three. Thus selecting for yield in intercropping does not really seem to allow us to get to the maximum LER, anymore than selecting for sole crop performance allows us to get to intercropping performance. An additional problem is whether LER is what we are really looking for. We could get a very good LER by having a very low-yielding pigeonpea genotype. So LER itself is presumably not a particularly good criterion. I am feeling very confused and I cannot see any single attribute that can be used sensibly.

Willey

The crux of this question is in your last sentence, namely that you cannot see any single criterion, because I think we may often have to use several criteria to decide exactly what we have achieved from any given intercrop situation. We were using LER in that first situation — i.e., using sole-crop values for individual genotypes — because we were trying to find pigeonpea genotypes with plant characters that will allow them, when grown in intercropping, to express a large proportion of their potential sole-crop yield. If these characters are associated in the early stages with low yield, this is of course undesirable, but I think Dr. Wein pointed out that we have at least defined some characters that we can then try to combine with high yield to get what we eventually want.

Session 2

Physiological Aspects

Chairman: J. S. Kanwar

Rapporteur: C. N. Floyd

Light-use Efficiency of Crops and the Potential for Improvement Through Intercropping

B. R. Trenbath*

Abstract

Light interception by sole crops is affected by the positions of the light sources, the leaf area index, and the inclination and distribution of the leaves. Mathematical models can often successfully take account of these effects.

Species vary greatly in the way their leaf net photosynthesis (Pn) responds to light level. Whereas leaf- Pn *responses to level of intercepted light flux (\\) are hyperbolic, the responses of whole-canopy* Pn *(and also of growth) to* \\ *tend to show strict proportionality. The proportionality constant in the resulting "proportional-response" model is the light conversion efficiency of the canopy (Pnl\\). Simulations of daily* Pn *in a mixed intercrop of similar canopies differing essentially only in height suggest that the proportional-response model may apply also to individual components within intercrops.*

The photosynthetic light-use efficiency (LUE) of the canopy is the product of two components: proportion of the incident light that is intercepted (Ii/I$_o$) and the canopy Pn/Ii. *The possible contributions of relay and intercropping to increasing* Ii/Io *are discussed, with special attention given to shade adaptation in short-statured plants in mixed stands. To increase* Pn/Ii, *analytical and experimental studies on sole crops and calculations of Pn in mixed stands suggest that intercrops should consist of (a) an upper canopy of small, inclined leaves with high maximum rates of leaf photosynthesis, and (b) a lower canopy of more horizontal leaves, arranged possibly in mosaics, with low maximum rates of leaf photosynthesis. A method for choosing intercrop components with the right leaf and canopy characteristics is briefly described. A more refined approach would use a dynamic rather than a static model.*

One of the fundamental processes in the growth of green plants is photosynthesis. In this paper, I will assume that soil conditions are favorable and will describe (a) the factors that determine the efficiency with which crop plants utilize the available light in photosynthesis, and (b) the ways in which improved intercropping methods may be able to increase the rate of biomass accumulation. Since current economic factors favor intercropping in the tropics and subtropics rather than at higher latitudes, examples will be chosen as far as possible to refer to crops and conditions found in the warmer regions of the world.

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The Interception of Light by Leaf Canopies

Details of the light fluxes incident on crop canopies have been fully described by Walsh (1961), Anderson (1966a, *b)* and Monteith (1977), and so this section considers mainly how much of this incoming light is intercepted.

Light penetrating a plant stand is diminished through interception and absorption by the leaves and other parts ofthe shoot systems. The potential shares of the light that will be gained by components of an intercrop are determined by the relative heights of their canopies and by the efficiency with which they intercept and absorb light.

When the distribution of foliage is fairly uniform in the horizontal plane, the penetration of light into the stand can be described approximately by Beer's Law (Monsi and Saeki 1953):

$$I = I_o e^{-KL} \quad (1)$$

Where I is the light flux density to a horizontal surface below L units of LAI (leaf area index), I_o is the light flux density to a similar surface above the canopy, e is the base of natural logarithms, and K is an extinction coefficient. Monsi and Saeki (1953) showed that Beer's Law applies to a range of natural plant stands and the Law has since been used widely to summarize the light-interception characteristics of crop and pasture canopies (e.g., Pearce et al. 1967; Sheehy and Cooper 1973; Alvim 1977).

When most of the light is coming from near the zenith, prostrate-leaved ("planophile") canopies have the greatest K and therefore intercept most light per unit of LAI. Under these conditions, steeply-inclined leaf ("erectophile") canopies have the lowest K and intercept the least light (Monsi and Saeki 1953; Anderson 1966b). Under overcast conditions, planophile stands show K values up to about 1 if the leaves are randomly distributed horizontally; if the leaves are regularly distributed in light-catching mosaics, K values may be between 1 and about 1.5. When most light is coming from an elevation of between 30 and 40°, leaf inclination has little effect on K. When light comes from elevations lowerthan 30°, the effect of leaf inclination is reversed and the prostrate leaves show the *lower* K (Anderson 1966b).

Although the relative values of the Ks of planophile and erectophile canopies depend on the elevation of the light source, there is a general absolute decrease in K values with an increase in the elevation of the source (Anderson 1966/7). Thus, on a cloudless day, as the sun moves toward the zenith, direct sunlight penetrates deeper into all canopies with nonhorizontal leaves; at the same time, the proportion of the incident light that is intercepted becomes less.

Using information on the physical aspects of homogeneous plant stands (solar elevation, strengths of light sources, reflectivity and transmissivity of the leaves, distribution of leaf inclination, soil reflectivity, etc.) and making some simplifying assumptions, the penetration and interception of light can be predicted (e.g., Duncan et al. 1967; Niilisk et al. 1970). The mathematical models required are necessarily complex. The predictions of such models have been exhaustively checked against observations in a range of temperate sole crops and often show excellent agreement (e.g., Torssell and McPherson 1977). Relatively few tests have been made of the adequacy of the light-penetration models in stands of woody species (Miller 1969; Eckardt et al. 1975); however, suitable data may soon become available for cocoa (Alvim 1977). No satisfactory way of calculating interception by large, branching, woody stems yet seems to be available, although the effects of small, vertical stems have been modelled (Trenbath 1972).

When the foliage density in a stand varies greatly in the horizontal plane, as, for example, in a patchy canopy of shade trees (Hadfield 1974a; Eckardt et al. 1975) or in young row crops (Tsunoda 1959), Beer's Law underestimates the penetration of light. Complex mathematical methods have been used to calculate the penetration of light into such stands (Fukai and Loomis 1976; Oikawa 1977a,b; Trenbath et al. 1977), although simpler approaches may sometimes be adequate (Miller 1972). A relatively simple technique for estimating the proportion of direct sunlight that penetrates directly to short-statured intercrops is illustrated in Figure 1. In the present version of the method (Trenbath et al. 1977), individual plants are represented by cylinders, but alternative shapes could easily be used. The penetration of direct sunlight and/or sky light to any point in a canopy can be estimated from photographs taken with an upward-directed "fish-eye" lens (Anderson 1966a; Bonhomme 1973).

Leaf Responses to Light

To understand the photosynthetic responses of canopies to light, it is necessary first to understand how the individual component leaves respond. Typical responses of net photosynthesis rate *(Pn)* to levels of incident light flux are shown in Figure 2a. If the rate of CO_2 efflux observed at zero illuminance ("dark" respiration) is taken to represent the respiration rate at all levels of illuminance, curves of "gross" photosynthesis can be derived by adding this respiration rate to each curve of net photosynthesis. (We thus ignore photorespiration.)

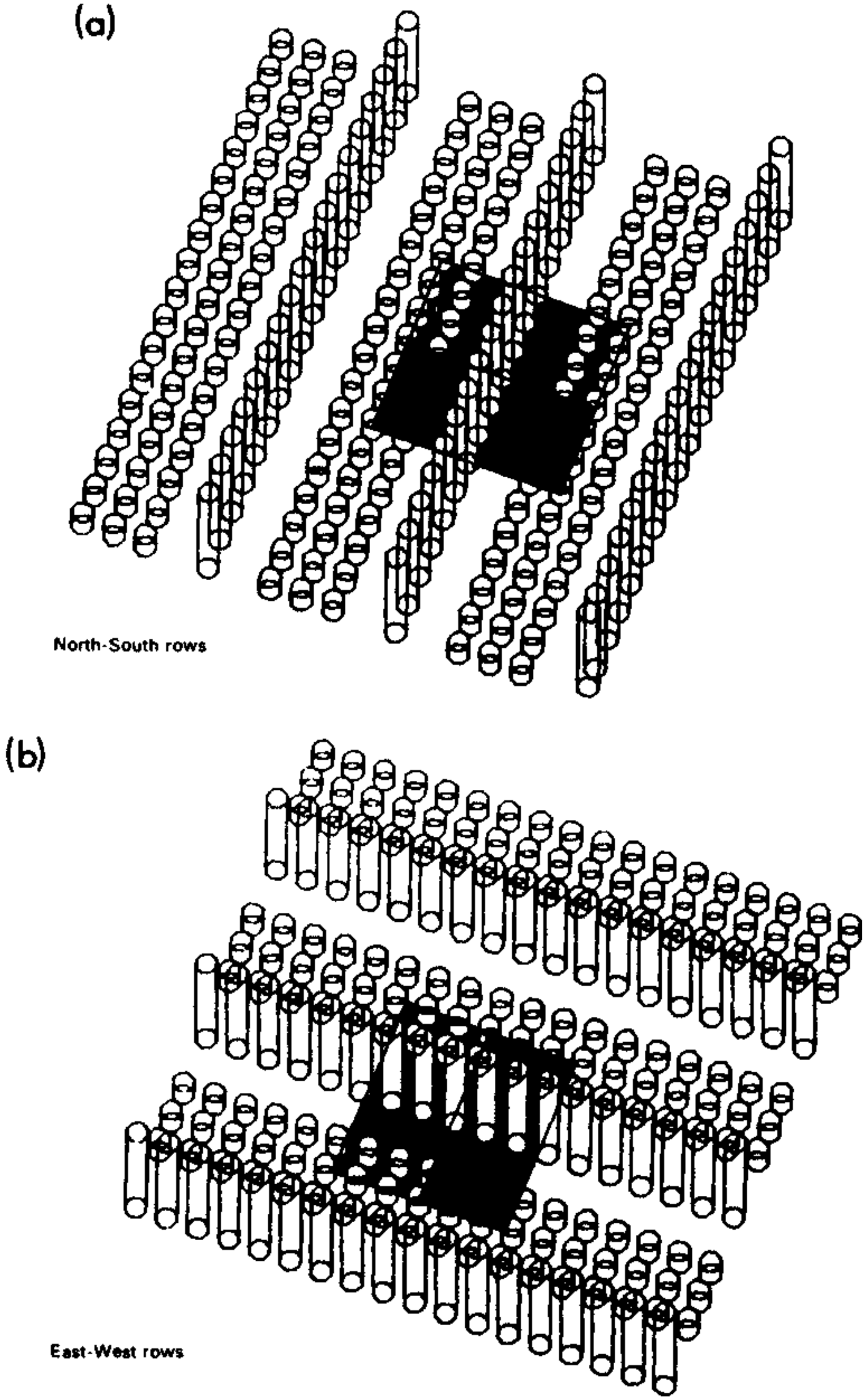

Figure 1. A rough method for estimating the increase of light interception due to intercropped short-statured plants. Sun-eye views, drawn by computer, of two "maize"{"soybean" stands are shown for one-half hour before true solar moon at 3.5° N on 15 June. Within the indicated units of pattern, the blackened areas indicate the proportions of light directly striking the ground either in a sole crop of "maize" or in the mixed stand. Judging by the areas shown blackened, the addition of the "soybean" increased interception at this time of day from 23% in the N-S planting and from 39 to 60% in the E-W planting.

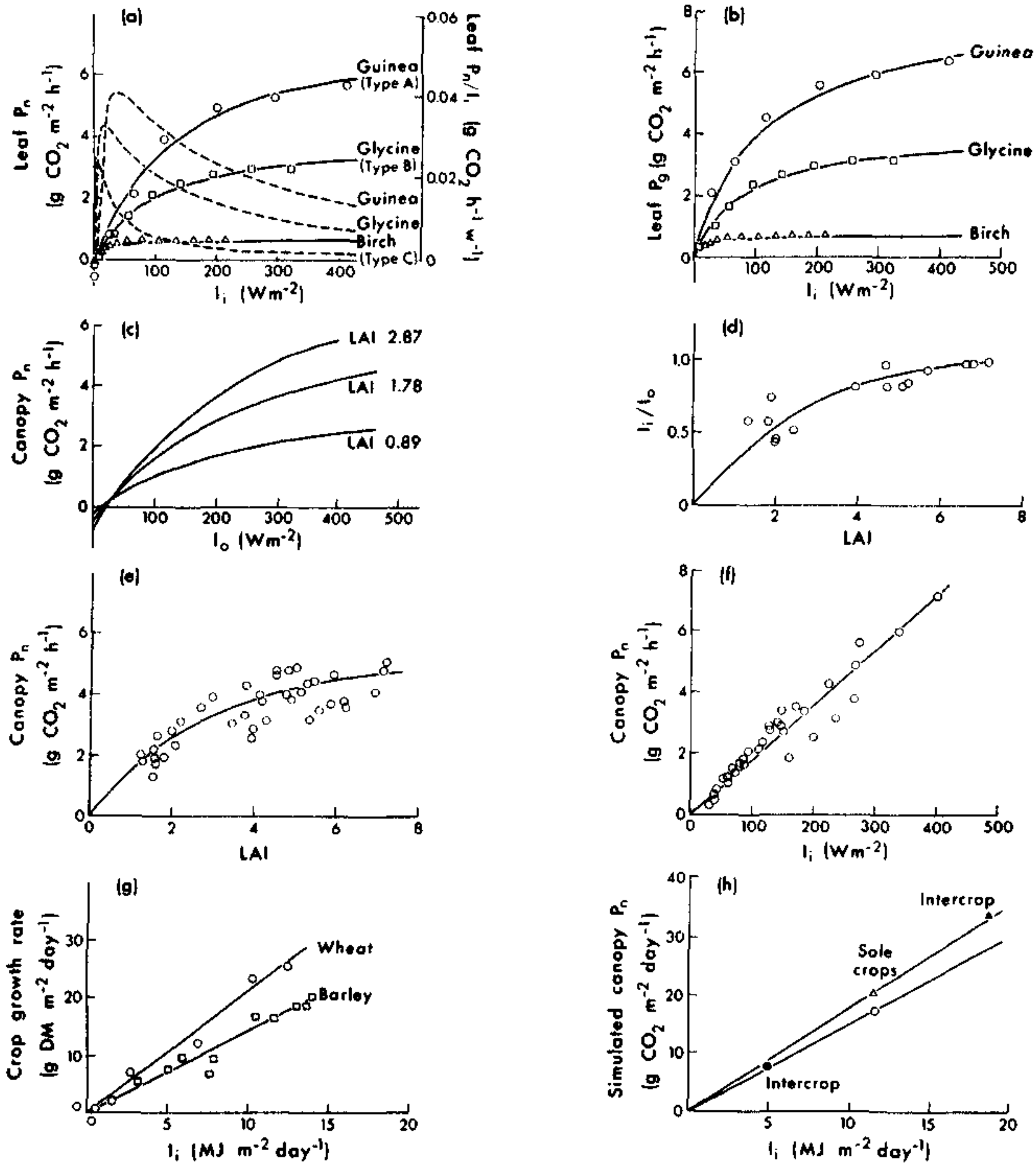

Figure 2. Relationships among incident light Io, intercepted light Ii, leaf and canopy net photosynthesis Pn, and crop growth rate, (a) Responses of leaf Pn {solid lines) and leaf types of species: Guineagrass (C4), glycine (tropical legume, C3) and yellow birch (shade-adapted leaf, temperate tree, C3) [data of Ludlow and Wilson 1971, and of Logan 1970, assuming 100 000 ftc. = 528.6 W m^2]. (b) Responses of leaf Pg to It; dark respiration has been added to the curves of Pnin (a), (c) Responses of canopy Pn to Io at three stages of growth in sunflower [Horie and Udagawa 1971, data points omitted]. (d) Relationship between proportion of incident light intercepted and LAI in rice [data of Tanaka and Kawano 1966; pooled over two cultivars and two N levels\ (•) Relationship between canopy Pn and LAI in rice at 80 Kfux (~.320 Wm2) [Tanaka and Kawano 1966]. (f) Response of canopy Pn to Il in cotton [Baker and Meyer 1966; data points for N-S plantings only], (g) Relationship between crop growth rate and light energy intercepted over a period in wheat [Biscoe and Gallagher 1977]. (h) Test of the application of the proportional response model to simulated results of daily Pn in two sole crops and a 1:1 intercrop.

The resulting responses of gross photosynthesis *(Pg)* to light can be described approximately as rectangular hyperbolas (Fig. 2b):

$$P = \frac{P_{g^\infty} I}{I + K_I} = \frac{bI}{I + bI/P_{g^\infty}} \qquad (2)$$

where P_g^{∞} is the light-saturated value of P_g, I is the illuminance of the leaf (numerically equal to *li*), *Ki* is the value of / giving Pg^{∞}, and $b = P_g^{\infty}/Ki$ (the initial slope of the curve).

The *leaf-Pg : li* curves of Figure 2b show striking differences in the values of Pg^{∞}. Species with the C_4 photosynthetic mechanism *("C_4 species,"* most of the tropical grasses) have the highest values of Pg^{∞}, and the *Pg : li* curves continue to rise up to the highest levels of light flux (Fig. 2b Type A; Bull 1969; Monteith 1977). Herbaceous species with the C_3 mechanism ("C_3 species") have intermediatePg=values and are often near light-saturation at one-half of full sunlight (Type B; Evans and Wardlaw 1976). Woody species, shade-adapted ecotypes of herbaceous species, or long-shaded or senescent leaves of normally light-loving forms have lowest values of *Pg=* and are light-saturated at correspondingly low light levels (Type C; Bjorkman and Holmgren 1963; Kumura 1968b; Logan 1970).

While the wide variation in Pg^{∞} is well established, it is generally believed that all species with the same photosynthetic mechanism (C3or C_4) have relatively similar values of/), the initial slope of the *Pg : li* or *Pn : li curve* (Monteith 1977). This gradient of the line at very low light fluxes indicates the maximum efficiency with which the leaf can convert light energy into chemical energy (the "quantum yield"). However, technical difficulties in the measurements of *b* leave uncertainty about the truth of this, and a least-squares fit of Eq. 2 to a range of published *Pn : li* data suggests at least a six-fold variation among C_3 species (B. R. Trenbath, unpublished). Some of this variation in *b* must be the consequence of unstandardized temperature and light pretreatments (Bjdrkman and Holmgren 1966; Ehleringer and Bjdrkman 1977). Because leaves of C_3 species show photorespiration, their maximum efficiencies at present CO_2 levels are about 60% those of C_4 species (Bull 1969; Ludlow and Wilson 1971). Recent estimates of the maximum possible values of this measure of efficiency (at 300 ppm CO_2) are 17.2 μ gCO_2 J^{-1} for C_4 species and 13.3 μg CO_2 J^{-1} for C_3 species (initial gradients of, respectively, 0.062 and 0.048g CO_2 h^{-1} W^{-1}; Monteith 1977; but see Ehleringer and Bjorkman 1977).

The respiratory loss (/?) from a leaf in the dark is near to being strictly proportional to the rate of light-saturated gross photosynthesis (Tooming 1970; Horie and Udagawa 1971):

$$R = cPg^{\infty} \qquad (3)$$

where *c* has a value of between 0.1 and 0.3 depending on the species (Tooming 1977). A consequence of this relationship is that, at low light fluxes, plants with Type B or C performance may export more carbohydrate from their leaves than will plants with a Type A leaf response.

The ratio leaf *Pnlli* is a measure of the efficiency with which the leaf converts intercepted light to net photosynthate; the broken lines in Figure 2a show that at very low light fluxes, Type C leaves convert the light to *Pn* with the greatest efficiency. The significance of this will be considered in more detail later.

Crop Responses to Light in Pure and Mixed Stands

A crop with a low LAI has a photosynthetic response to increasing incident light flux much like that of a single leaf (Fig. 2c). In a crop with a high LAI, shaded leaves at the bottom of the canopy can continue to respond to an increase in incident light flux even if leaves high in the stand are light-saturated. Thus, as they grow, canopies — and, hence, whole shoot systems — respond to increasing light flux up to progressively higher levels (Fig. 2c).

As a canopy becomes thicker it also intercepts a greater proportion of the incident light: the ratio of quantity of light intercepted by the canopy to incident flux *(lillo)* rises asymptotically to unity. In Figure 2d are plotted approximate values of *lillo* measured in rice canopies of various LAI at noon through the early part of the Philippine dry season (data of Tanaka and Kawano 1966). Since the light measurements can be assumed to have been made under standardized conditions of /o, a similar relationship probably applies also to // itself.

In the same experiment, canopy *Pg* at full sunlight (80 Klux, or about 320 $W\ m^{-2}$ visible range) was shown to be related to LAI by a similar asymptotic curve (Tanaka and Kawano 1966). Using the relationship *R* = 0.4 *Pg* derived from a similar experiment with rice (Cock and Yoshida 1973), canopy *Pn* can be estimated from the reported *Pg* (Fig. 2e). Since, at constant light level, the estimated response of *Pn* to increasing LAI is of similar form to that of *lillo,* and probably also of//, to LAI, it becomes easier to understand the proportionality observed (Fig. 2f; Hesketh and Baker 1967) between canopy *Pn* and *Ii* In such cases, the canopy light conversion efficiency *(Pnlli)* remains apparently constant over a wide range of light interceptions.[1]

The proportionality relationship between instantaneous *Pn* rate and the quantity of light intercepted by a canopy, in turn, helps to provide an explanation for a similar proportionality (Fig. 2g) often observed between growth over a period and the quantity of radiation intercepted by the canopy (Monteith 1972; Biscoe and Gallagher 1977).

Short-term fluctuations seem likely to affect canopy conversion efficiency *Pnlli* in ways that can be predicted from curves like those in Figure 2c. Thus, the proportionality constant relating accumulated canopy *Pn* to /i over a period will be determined mainly by the *Pn-.h* curves of leaves in the canopy and by the time distribution of incident light flux levels. If, however, instead of short-term changes, the effects of long-term changes in light are considered, any constant of proportionality will not be so easily predicted because the leaf *Pn.li* curves themselves change in response to light level. In general, the lower the average illuminance of a leaf during its development, the lower the P_g^{∞} at its maturity (Woledge 1973,1977); shading after leaf maturity similarly leads to a reduction in P_g^{∞} and a correlated reduction in respiration rate (Eq. 3; Kumura 19686; Horie and Udagawa 1971). Limited recovery is possible if illuminance is later increased (Kumura 19686). The size of the responseto light level is apparently determined genetically, for the (low) Pg^{∞} values of shade-adapted species and ecotypes may not be much reduced by culture at extremely low light levels, whereas the P_g^{∞} of sun forms may be almost halved (Bjdrkman and Holmgren 1966). Similarly, culture in deep shade may increase the *b* value of shade forms but decrease it in sun forms.

The consequences of these kinds of adaptation have not yet been worked out for mixed stands, although their importance in determining growth rate in pure stands is now recognized (Leafe 1972). Responses to density in pure stands (Woledge 1977) suggest that leaves of a tall-statured component grown at reduced density in an intercrop will develop higher P_g^{∞} values than similar plants grown at full density in a sole crop. The higher illuminance of this component's leaves in the intercrop will not therefore necessarily lead to the lower leaf *Pnlli* expected from Figure 2a. As a result of this adaptation and a corresponding one in the short-statured component, responses over mixed and pure stands will tend to be more linear than in Figure 2a. Hence, similar values of accumulated *Pnlli* could apply to canopies of a given species where the leaves of the different canopies are regularly illuminated at differing levels.

If indeed a single proportionality factor were to describe the dependence of growth (ΔW) on quantity of light intercepted in each component over a series of pure and intercropped stands, the growth of each component of an intercrop could be predicted simply by multiplying the amount of light it intercepted in the period by an empirically determined value of AW///. This idea is close to that proposed for sole crops by Monteith (1972). However, although this concept of a proportional response could be useful in understanding and managing competition for light in intercrops, there seems as yet to be no suitable set of growth and interception data to provide a test of its validity.

In an attempt to find whether this idea is likely *to* apply in mixed stands, simulations were

1. In Baker and Meyer's study (1966), where results for a range of light fluxes are plotted on the same graph as results for a range of LAI and plant arrangements, it might be expected that data points for stands with low LAIs should lie on curves like those in Figure 2c. Surprisingly, there is no indication of this in the data as published. However, in another similar set of data (Hesketh and Musgrave 1962), curves *can* in fact be discerned.

carried out, using a detailed model of canopy *Pg* (Trenbath 1972, modified from that of Duncan et al. 1967), of competition for light during a day in theoretical tall and short sole crops and a 1:1 mixture. LAI was constant at 4 in all three stands. The species had the same leaf inclination but differed slightly in Pg^{∞}; Pg^{∞} values in the canopy layers declined linearly from the species maximal Pg^{∞} in the top layer to one-quarter of this in the bottom layer. The results of these simulations .will be reported fully elsewhere, but the main finding was that the proportional increase in the per-plant *Pn* of the taller component in the mixture over that in its sole-crop was the same as the proportional decrease in the per-plant *Pn* of the shorter component below that in its own sole-crop. The Relative Yield Total (RYT; de Wit and van den Bergh 1965) was therefore unity. This was true irrespective of whether *Pn* was calculated from *Pg* using Eq. 3 or, alternatively, the relationship *Pn* = 0.6 *Pg* (as in rice; Cock and Yoshida 1973). When Eq. 3 was used, daily canopy Pn//ivaried for each species between sole crop and intercrop so that Monteith's (1972) model did not apply. However, in the second case, daily *Pnlli* was near to constant in each species over the two kinds of stand, so that the Monteith model did indeed apply to the intercrop (Fig. 2h). It seems likely that an analogous proportional-response model applies also when other environmental factors are the subject of competition (Trenbath 19746, 1976); if true, this would help to explain why RYTs are usually close to unity. As where the Land Equivalent Ratio (IRRI 1974) is unity, an RYT of unity implies that there is no advantage to be gained from a mixed stand.

These simulations therefore suggest the not-surprising conclusion that, when soil factors are nonlimiting, the intercropping of species of different height but similar canopy characteristics will lead to no mixture advantage in terms of daily canopy net photosynthesis. Less trivial is the finding that compensating changes in per-plant photosynthesis in intercrop are proportional to sole-crop performance rather than additive (Trenbath 1978). Whether or not the Monteith (1972) model is predicted to apply to mixed stands seems to depend on the plants' respiratory behavior. The effects of combining species differing in more than just height characteristics is explored in the next section.

Determinants of Incident Light-Use Efficiency and Potential for Improvement through Intercropping

The overall light-use efficiency (LUE) is related to canopy light-conversion efficiency *(Pnlli)* by:

LUE = (////o)(Pn//i) (4)

where/*i*//o is the proportion of the incident light intercepted by the crop canopy. For some purposes it might be useful to resolve the second term into further components:

Pnl/i=(la/li) *(Pnl/a)* (5)

where /a is the quantity of light, which, after being intercepted by the crop, is actually absorbed rather than being lost by reflection and transmission (Anderson 1966a, p. 87). All these terms refer to instantaneous measurements, but, in principle, they can be calculated from totals accumulated over periods of time. We now examine ways in which LUE may be raised by increasing the values of the components given in Eq. 4. Intercropping can make a contribution with respect to both of these components.

Light Interception *(li/lo)*

The value of *lillo* is low during a large proportion of the life of many sole crops (Watson 1952; Wilson 1977). The accumulated value of *lillo* for a crop is increased by more rapid leaf-area production when the plants are young, and by the leaves being held prostrate (or following the sun) without shading each other; when the plants are mature, long retention of the leaves has an effect on overall interception similar to that of rapid early growth. In a sequence of sole crops, the periods of low interception early and late in the growth periods of individual crops represent serious losses of potential productivity. Indeed, Allen et al. (1976) showed that the potential productivity of a sequentially cropped region of Florida could theoretically be doubled if the four crops per year were replaced by a single, continuously growing crop.

To increase accumulated *lillo* the periods of low leaf area can be "filled in" by relay planting each new crop of a sequence between the maturing plants of the previous crop. Thus, where sweet potato is relay planted into maturing rice (Chao 1975), the new crop already has a significant leaf area at the time when the old crop is removed. Potentially complementary combinations can be suggested by a comparison of the time courses of LAI plotted for a range of species and cultivars. Indeed it seems likely that the high RYTs of intercrops of early and late potato cultivars are due to increased light interception (Schepers and Sibma 1976).

The earliest stage of the previous crop at which successful relay planting can be carried out is determined by several factors. For the present discussion, the relevant ones seem to be the time course of light penetration through the old crop to the point on the soil where plants of the new crop are to be planted or sown, and the maximum shade that the young plants can endure.

Light penetration through the old crop can be manipulated by the farmer to some extent by choice of crop species or cultivar, by plant density, planting pattern, and other cultural factors. The pattern of leaf-area duration in the old crop will affect the rate of alleviation of shading at the soil surface after it has reached its maximum LAI. Apart from the LAI of the old crop, the inclination and degree of aggregation of its leaves will affect light penetration to the seedlings of the new crop and so determine their potential growth rate (Trenbath and Angus 1975; Trenbath 1976).

Since the pattern of planting of both shorter and taller components can so greatly affect light penetration to undersown species (Santhirasegaram and Black 1968), the choice of planting pattern may be crucial in relay planting. If constraints such as the need for adequate walkways leave some freedom of choice, theoretical experiments with a mathematical model of light penetration and photosynthesis may be used to provide a preliminary assessment of the value of various planting times and patterns (Trenbath et al. 1977). For this, it is necessary to have information on the size and shape of the types of plant, the average leaf inclination and leaf area within the plant volumes, and estimates of the photosynthetic light responses of the seedlings' leaves. Such an assessment would be specific for the latitude and time of year used in the simulations. The time course of LAI, and, hence of light transmission, by the old crop can also be influenced directly, as, for example, by the progressive harvesting of leaves of tobacco in Laos, which allows the earlier relay planting of soybean, peanut, or mung (Phommasthit 1975).

The second factor affecting the earliest date of relay planting is the shade tolerance of young plants of the new crop. The degree of shade tolerated by crop species depends strongly on their native habitat before domestication (e.g., Maestri and Barros 1977; Moraes 1977), although even within typical sun species, relatively tolerant genotypes or lines can be found (Wilson and Cooper 1969; IRRI-IDRC-UPLB 1976). Since degrees of shade tolerance are likely to be selected for in most short-statured relay- and interplanted species, it is important that the breeder should be aware of the main characteristics associated with shade tolerance (see Bainbridge et al. 1966).

As Grime (1966) pointed out, some of the characteristics of shade-tolerant species or ecotypes put them at a disadvantage in a high light environment. Hence, if harvest of the old crop will later expose the new crop to full light, it is important not to select specialized shade forms for earlier relay planting because of the likely inhibitory effect of the high light on photosynthesis (BjOrkman and Holmgren 1963). On removal of overhead shade, their leaves may further suffer from moisture stress (Cunningham and Burridge 1960), heat stress (Hadfield 1974/?), and apparent nutrient stress (Murray and Nichols 1966), unless special precautions are taken. Accordingly, genotypes should be selected for tolerance of the specific pattern of shading and other cultural conditions that they will experience in the period of crop overlap combined with tolerance of the sudden reduction of shading when the old crop is removed. Capacity to adapt quickly to changes of light level would seem desirable in cultivars to be relay planted.

The proportion of incident light that is intercepted by crops can also be increased by growing short-lived intercrops to occupy the space later taken up by longer-lived types. This also imposes requirements for light adaptation. Where the shorter-statured component is longer lived, as, for example, in a sorghum/pigeonpea intercrop, it must tolerate shade and then sudden exposure to high light, as in relay planting. Where the shorter-statured component is much shorter lived, as where vegetables are grown under young coconut palms (Bourke

1976), a succession of relatively ephemeral intercrops is needed, each able to tolerate progressively increasing shade (Gallasch 1976, 1977). There is evidence from an experimental sorghum/pigeonpea intercrop that at least pigeonpea tolerates a sudden increase in light level: a comparison of AW/// between the intercrop pigeonpea and a pigeonpea sole crop showed that after the sorghum was harvested, the conversion efficiency of the legume had not suffered any detectable reduction in spite of prolonged shading by the sorghum (Willey and Natarajan 1978). However, in this experiment, the pigeonpea showed a disappointingly slow increase in I_i/I_o after the sorghum harvest.

In those intercropping systems where plants of the tallest component dominate the stand so completely that they are effectively a sole crop, understorey components intercept light that is otherwise wasted (Fisher 1975a): From the point of view of light-use efficiency, such intercrops simply increase *hllo* without necessarily affecting *Pnlh.* The increase in interception at some point in growth due to the addition of a short-statured intercrop can be estimated for sunny conditions from a full series of sun-eye views of the stand, such as those in Figure 1. A series of estimations through a sunny period could indicate approximately how thetotal light receipt has been partitioned between the components of an intercrop, or whether a further component might possibly be added.

Light-Conversion Efficiency (p_n/Ii)

For a given leaf light-response curve, the graph of leaf *Pnllt* plotted as a function, of // rises steeply from zero at the light compensation point to a maximum at a fairly low value of illuminance, *l*r,* as illuminance is increased beyond/*, Pn///declines with a gradually lessening gradient (Fig. 2 a). It is of interest to see how individual leaf responses can be used to generate theoretical canopy configurations that maximize the *Pnlliof* the whole canopy.

If it is assumed, for example, that all leaves of a canopy have the same light response curve and all light comes from the zenith, the pattern of leaf inclination required to illuminate all leaves at their optimal values of /*i can be calculated to be one with leaves steeply inclined at the top, becoming more horizontal with depth (Warren Wilson 1961). In such a theoretical canopy there is no excessive interception in the upper layers leading to light saturation; instead, light is shared evenly over all leaves. While this configuration maximizes canopy *Polli* if the LAI is low the inevitably low value of *hllo* limits the LUE (Eq. 4). A theoretical maximum LUE can nevertheless be attained with this same LAI by a general reduction of the leaf inclinations to a point where the advantage of greater /il/o just balances the disadvantage of lower *Pnlh.* Under constant light conditions, as the LAI grows, to maintain optimality such a canopy has to gradually increase the inclination of its leaves (Verhagen et al. 1963).

If, as is normally found, the values of leaf Pg^{∞} decline with depth in a pure stand (Fig. 3a, de Wit 1965; Horie and Udagawa 1971), perfectly even sharing of light between all leaves will result in some loss of conversion efficiency (Nilson 1968). In this case, canopy *Pnlli* will be maximized by a configuration that allows penetration of light to various layers such that each layer is illuminated at its own /*i (Fig. 3b; Tooming 1970).

Although these and other analytical studies usefully clarify some of the issues involved in maximizing LUE, to make the problem mathematically tractable the authors have usually needed to assume that all leaves of a layer are uniformly lit and that the position of the light source is fixed. In fact, in all canopies at a given moment the uneven penetration of light results in the illuminance of the leaves in a layer being extremely variable (Kumura 1968a). This variability is greater under sunny conditions and with larger leaves. Furthermore, on a clear day the calculated optimal configuration is changing hourly with the sun's position in the sky (Fig. 4a; Nilson 1968).

Because the detailed geometry of light sources and canopy elements has been incorporated into complex simulation models, it seems wise to use such models to check the realism of predictions based on simpler "static" approaches. A relevant series of results had been reported (Duncan et al. 1967) for the photosynthesis of dense maize canopies of differing canopy configuration during a whole sunny day in midsummer at latitude 38°. A canopy resembling that of pineapple (Fig. 4b) showed a predicted 23% advantage over the poorest type (which was judged to be the same canopy but with the inclination pattern re-

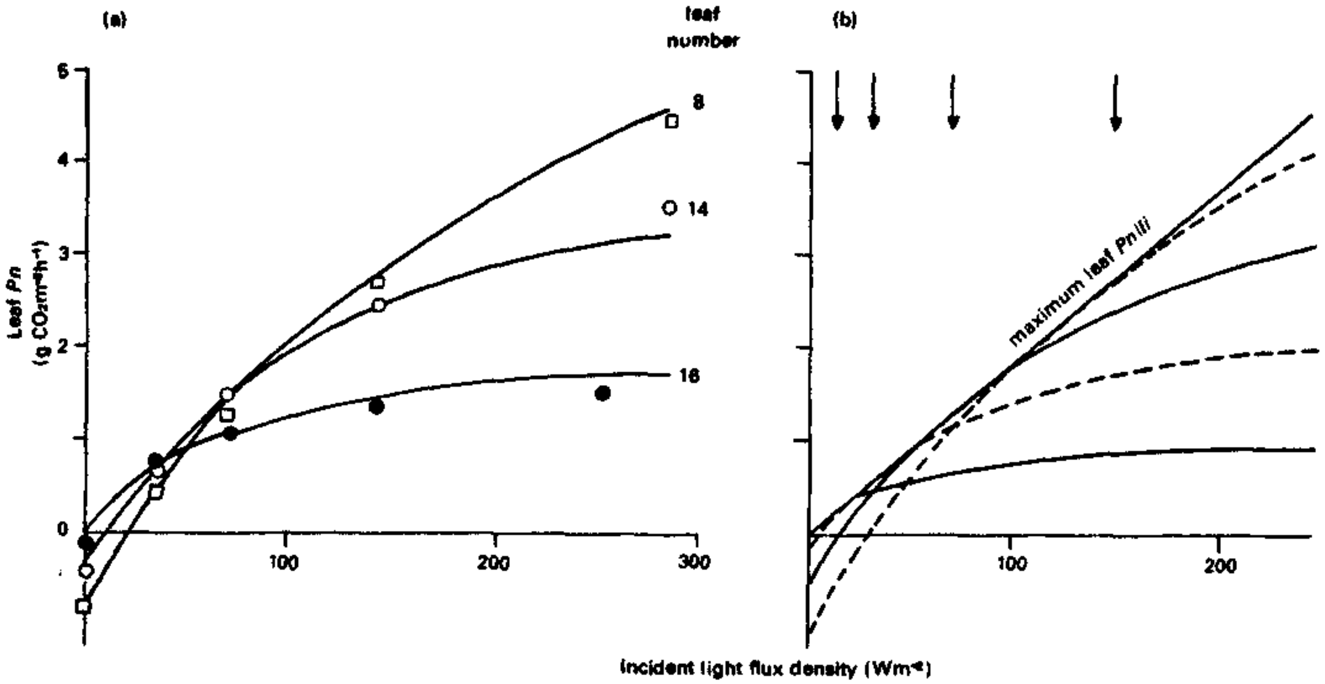

Figure 3. (a) Change of leaf net photosynthesis Pn response to incident tight (equivalently Pn or li) with increasing depth in a canopy of hybrid sugar beet, (b) Idealized representation of fa) showing the illuminance needed (marked by arrows) to bring four theoretical leaves to the points on their Pn: li curves where P_n/l_i values reach a common maximum [Tooming 1970, 1977].

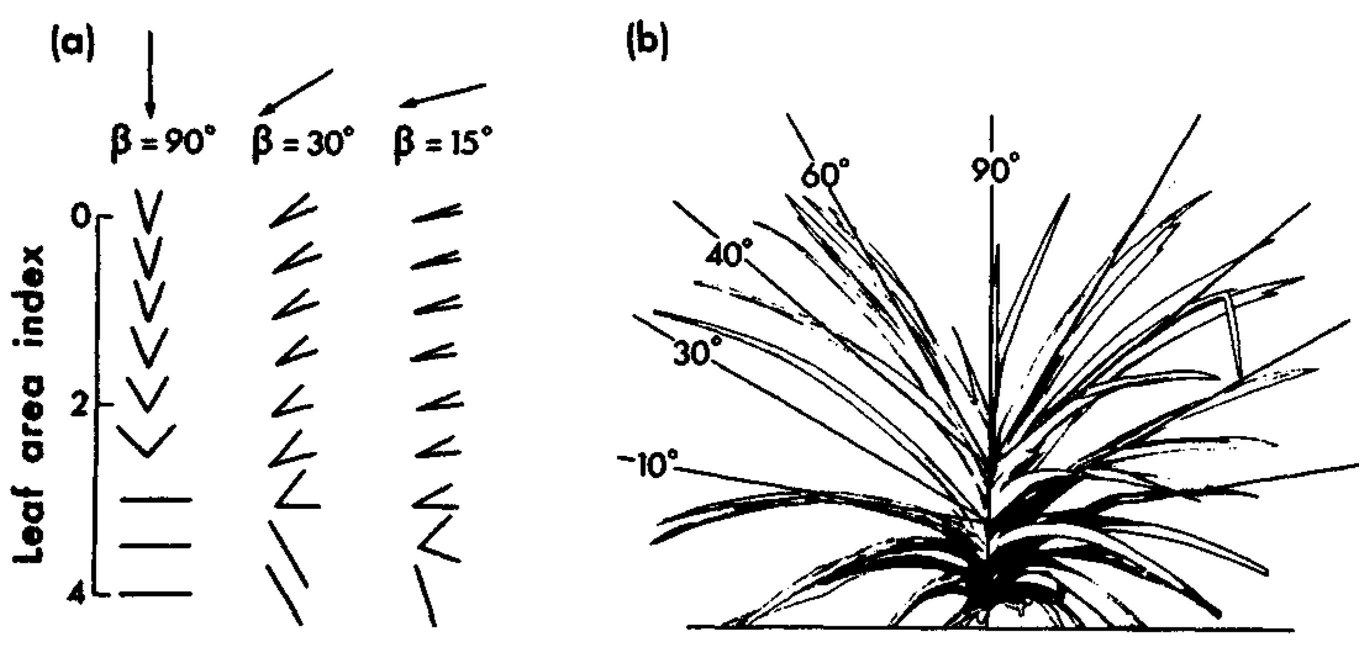

Figure 4 Optimization of canopy function, (a) Pattern of leaf inclination calculated to maximize canopy Pg. assuming direct sunlight only (at 3 solar inclination β) and a constant leaf P_g:l at all levels in the canopy; LAI - 4 [Nilson 1968]. (b) Pineapple plant fcv Smooth Cayenne) showing spirally arranged leaves and the changing pattern of leaf inclination with depth in canopy [redrawn from Bartholomew and Kadzimin 1977].

versed). Results from the complex model thus confirm the early predictions based on very simple models. More significant, however, is the considerable body of evidence obtained, mostly using rice, which suggests that leaf inclination is as important as predicted in determining crop growth rates in the field (Trenbath and Angus 1975).

Little effort has been aimed specifically at increasing P_n/I_i by using mixed stands. Assuming always that soil factors are nonlimiting, the characteristics of shade-tolerant species make it possible to add them to crops of sun species without interfering with the growth of the original crop. They are then able to grow using light intercepted from light fluxes that are too weak to support growth of other species. If a short-statured "shade" species is added to a stand of a tall "sun" species, the LUE will be increased by a rise in I_i/I_o; however, it seems that the conversion efficiency P_n/I_i of the canopy may also change somewhat. The relatively high P_n/I_i of shade forms at very low light fluxes is likely to cause the extra amount of light intercepted to be used with especially high efficiency. However, since only a rather small amount of extra light is involved, canopy P_n/I_i is not expected to rise greatly.

To explore in a preliminary way the effect on total canopy *Pn* rate and P_n/I_i of combining widely differing types of canopy, a simple model has been used to simulate the rate of net photosynthesis of a two-canopy stand representing a tall component intercropped with a short one. The model of canopy gross photosynthesis was that of Saeki (1960) and respiration was calculated using Eq. 3. The results will be reported in detail elsewhere, but the main conclusions were:

a. More light is intercepted by the upper component, and so the choice of this component has the stronger effect on predicted total *Pn* and P_n/I_i.
b. Under the conditions assumed and parameter ranges tested, the best upper component had *K* = 0.5 and $P_{g\infty}$ = 10 g CO_2 m^{-2} h^{-1}, while the best lower components had K = 1.5 and $P_{g\infty}$ values between 4 and 1 g CO_2 m^{-2} h^{-1} depending on the density of the shade cast by the upper canopy.
c. If possible, cultivars with high values of *b* should always be used.

Subsequent analysis of leaf light-response curves and light-extinction properties of a wide range of crop species and cultivars showed that the leaf and canopy properties measured for maize are closest to the predicted optimum for the upper canopy (under the conditions used). For the lower canopy, as the shade cast by the upper canopy was increased, the best character sets were approached by first sunflower, then rice, and finally by sweet potato (or possibly cocoa). Some tropical pasture legumes (Gulf Desmodium and calopo; Ludlow and Wilson 1971) would be good lower components on account of their apparently high *b* values.

The above choice of components for intercropping was made objectively using the results of the simulations and published measurements of leaf and canopy characteristics. If the list is taken as providing recommendations for advantageous species combinations, it is interesting to observe that these species are mostly already in use in the ways recommended (Harwood and Price 1976; Okigbo and Greenland 1976). Nevertheless, since the named species are only those so far found to be closest to optimal, the simulations may be able to suggest ways in which the overall LUE and canopy *Pn* of such intercrops can be further increased. For instance, with a total LAI of 4, there would in all cases have been predicted advantage from the lower components having values higher than those actually measured in field stands of the species. This could be achieved if their leaves were more regularly distributed and/or more horizontal.

Although this approach seems to offer a rational way of choosing intercrop ideotypes which will together maximize canopy conversion efficiency, there are difficulties to be overcome before the approach can actually be used to increase yields:

1. The yield of each crop canopy must be known to be limited by its photosynthesis rate, which, in turn, must be well enough predicted by the model.
2. Since measurements of leaf parameters are influenced by previous shading, a knowledge of this dependence for each character of the potential lower-canopy species or genotypes is necessary to show how they compare with the calculated optimum under the shade regime expected.

3. Because the simulation referred only to specific conditions of incident light and LAI, the effects of canopy growth, fluctuations of light level through time, etc., would have to be integrated over a series of simulated "snapshots," simultaneously taking account of progressive shifts in leaf parameters.

A formal way of carrying out such an integration of the effects of changing conditions through time is to use a dynamic simulation of the growth of the intercrop components. A simple model consisting of just two differential equations concerning leaf area has been used by Tooming (1972) to simulate the course of the interaction between two species with contrasting *Pn:li* curves. The "sun" form grew faster than the "shade" form, but finally an equilibrium was established. Using a whole-plant growth model, Trenbath (1974a) studied the possible advantage of an "ideal," pineapple-type configuration with a mixture of two varieties of sun species. Figure 5 shows no expected advantage for the "ideal" configuration and indicates, in addition, how an attempt to optimize canopy structure could end in the death of the shorter, prostrate-leaved variety. Although theoretical experiments like this can provide useful insights into the possible behavior of intercrops, for them to have predictive value, they must be based on considerable quantities of data. Even based on incomplete data, they may nevertheless have some potential, through sensitivity analyses (e.g., Brylinsky 1972), either for identifying the crucial characters which breeders should include in their selection criteria or for shortening the list of possible plant or management factors that should be studied.

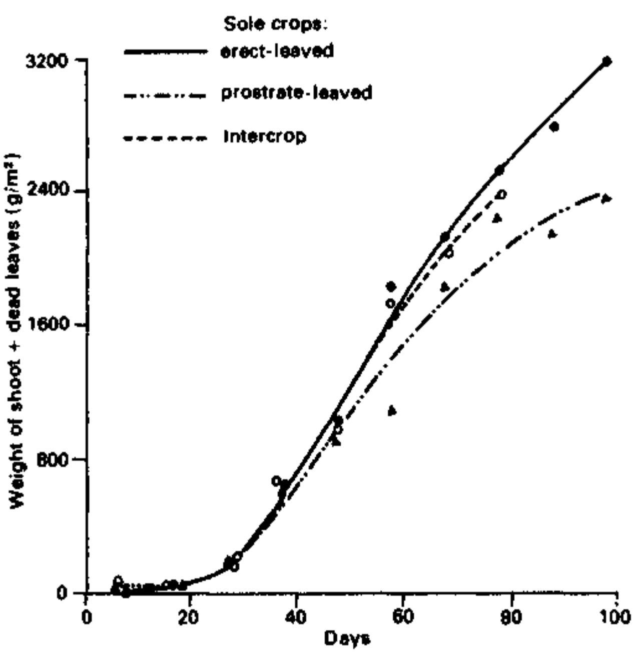

Figure 5. Course of growth of vegetative wheat crops simulated using GRODEV model [Trenbath 1974a]. Nonlimiting soil conditions are assumed. The mixed intercrop (dotted line) contains a tall, erect-leaved cultivar and a short prostrate-leaved one; it represents an unsuccessful attempt to create an improved canopy configuration by mixing types differing insufficiently in canopy properties.

Discussion and Conclusions

The efficiency with which light is used by mixed stands depends on the outcome of the whole interaction between plants of the various components. Apart from the light effects discussed above, this interaction involves many sorts of effects, ranging from microenvironmental influences involving wind speed, temperature, humidity, allelopathic substances, and competition for water and nutrients to possible mycorrhizal, disease, and pest influences. All of these are able to change light-use efficiency (Eq. 4) by affecting one or both of its components, light interception and the canopy light-conversion efficiency. Interception will be affected mainly by the light-extinction coefficient and the rates of growth and death of LAI, and canopy conversion efficiency will be affected mainly by the changes of LAI and leaf ***Pn:li*** curves.

Crop light-use efficiencies defined in units of dry matter or yield produced per unit of incident light are likely to be positively related to the LUE defined earlier in terms of CO_2 fixation, but the exact relationship will be determined by aspects of the physiology of the individual species concerned. If the yield is some specialized storage organ (e.g., tuber, fruit, or seed), there may well be parts of the growth period during which final yield is not much affected by shading (Evans and Wardlaw 1976). During this period, net photosynthesis could be low but yield remains high. Awareness of a crop's insensitivity at a certain phase can therefore allow intercrops to be added which dominate the mixed canopy at that time but which lower the yield of the first crop relatively little. Conversely, if a short-statured intercrop is especially sensitive at a certain phase, it may be profitable to thin or prune any taller component before the phase is reached. The success of the sorghum/pigeonpea intercrop from the standpoint of seed yields (Willey and Natarajan 1978) is probably partly due to insensitivity during the prereproductive phase of the pigeonpea. A similar suggestion applies to the profitable maize/rice intercrop investigated in the Philippines (IRRI 1974). Such cases illustrate advantageous deviations from a strict proportionality between economic yield and net photosynthesis. However, in cases where a component experiences a more constant light regime, near-constant harvest indexes suggest there may be strict proportionality (Fisher 1975a; Francis et al. 1976b).

The way intercropped species change each other's environments and their physiological responses to these changes are closely interwoven. Thus, the disadvantage of one component in competition for nutrients may increase its root/shoot ratio so that the extra respiratory load per leaf area will reduce its efficiency of conversion of light to dry matter or yield. Compensating increases in the same conversion efficiencies are likely to occur in the other mixture component(s). However, where the components are contrasting crop species, perfect compensation seems unlikely. Unfortunately, in the present state of knowledge, it is usually impossible to predict whether, in a given case, the overall effect of the "whole interaction" will be to the advantage of the farmer. Since complications of this type are probably common, it seemed here sensible to start an analysis of light use in intercrops with a consideration of the canopy net photosynthesis only.

Where similar canopy types are growing in a 1:1 intercrop, simulations predict that daily *Pn* per plant will show almost perfect compensation, and that possibly the conversion efficiency of each component will bethe same in intercrop as in sole crop. If the *Pnlli* values are indeed constant, then, as in sole crops (Monteith 1977), the *Pn* of a component will be calculable from a knowledge only of its (pure stand) *Pnlli* and the quantity of light it is intercepting in the intercrop (Fig. 2h). If found to be true, these propositions would provide a valuable set of baseline expectations against which to compare the performance of actual potential components of mixtures. Where no increased plant population pressure in the intercrop can be tolerated, it is only by virtue of deviation in the. right direction from the simple RYT = 1 pattern of Figure 2h that there is any possible photosynthetic advantage in growing mixtures of species. The methods for measuring // of individual components of intercrops exist (Kumura 1968a; Smart 1974), as also do the methods for making corresponding measurements of *Pn* (Angus et al. 1972), and so it is to be hoped that these basic propositions can soon be tested.

In a theoretical exploration of the effect of combining canopies differing markedly in photosynthetic light response and light extinction coefficient, sets of parameter values were found for the components which would maximize the predicted total canopy *Pn* under various conditions. The crops that, according to published data, came closest to being ideal, were identified as species already in use in the ways suggested to be appropriate by the simulations. RYT values based on canopy *Pn* ranged from 0.7 to 1.2 when the lower canopy was varied with identical //in all stands and from 0.9 to 1.3 when the upper canopy was varied in the same way. These values suggestthat there may be a considerable elasticity in ***Pn/Ii***. This could lead to useful photosynthetic advantages in well-chosen combinations and considerable penalties in poorly chosen combinations.

To achieve high canopy ***Pn/Ii*** in sole crops, light should be distributed more or less evenly over all photosynthetic surfaces. Models can be used to estimate the loss of canopy *Pn* due to uneven distribution arising from factors such as sunflecking on sunny days or leaf aggregation in row crops (Kuroiwa 1965; Fukai and Loomis 1976). The conclusions from these simulations are supported by experimental results showing markedly higher canopy *Pn* when a certain incident light flux arrives as diffuse light rather than as sunlight (Kumura 1968a). To favor even light distribution between components, upper canopies should therefore be uniform horizontally and should have steeply-inclined leaf surfaces and leaves that are very small to cast a shadow as diffuse as possible (Hadfield 1974a).

With the same objective, lower canopies should similarly be uniform and have near-horizontal leaves arranged in mosaics.

The P_n calculations also suggested "ideal" P_{g}^{**} values for the upper and lower components. The values chosen as ideal, however, are strongly influenced by the conditions used and by the value of the little-researched respiratory loss factor. It is interesting and possibly reassuring that the well-established maize + rice mixture should emerge as a possible ideotype combination. The success of this and similar C_4 and C_3 intercrops has so far been shown to be associated with complementarity in time and the possibility of higher plant population pressure, both of which result in greater light interception (Fisher 1975a; Willey and Natarajan 1978). However, the calculations reported here suggest that if plant breeders can select suitable canopy types, canopy P_n/I_i can also be improved. To raise the LUE of crop stands, intercropping has a proven potential, for it can increase light interception beyond that profitable in sole crops. The promise of higher LUE from increased light-conversion efficiency now urgently needs evaluation.

Acknowledgments

I thank I. R. Cowan and S. Powles for suggesting improvements in the manuscript.

Evaluation of Plant Interactions and Productivity in Complex Mixtures as a Basis for Improved Cropping Systems Design

Bede N. Okigbo*

Abstract

Intercropping of more than two crops in mixtures as is practiced in traditional cropping systems of tropical Africa results in a complex agroecosystem involving complex interactions among crop plants of the same species, varieties, and ages. Competition for various factors may be involved but there are also adaptive manifestations of crops in response to competition for light, space, nutrients, etc. Growth analysis in complex intercropping systems is useful in the study of crop plant competition and in the development of a strategy in cropping systems research. It is possible with detailed observations and their analyses to (1) select crops that are compatible in mixtures with minimum changes in sole crop plant population and planting arrangement for optimum performance, (2) determine what factors should be factorially superimposed on selected crop mixtures to enhance identification of suitable management practices for efficient crop performance in mixtures and (3) predict to what extent relay intercropping, spatial arrangements and use of crop plants possessing certain canopy structures and other characteristics can enhance efficiency of production in mixtures.

Although several indices are presently used in evaluating crop productivity in mixtures, indices such as LER, competition coefficient, relative yields, calorie equivalent, and gross returns can be reliably used to select efficient mixtures for relay and simultaneous intercropping. In a complex intercropping experiment involving yam, corn, melon and cowpea, highest calorie yields and returns were obtained in mixtures containing yams and corn. Where these crops are not involved in the mixture, it may be best to grow the crops separately. Most stable yields were obtained in mixtures of four crops.

A study of crop and weed competition has indicated possible changes in weed control strategy in which crop mixtures may be specially designed to minimize weed infestation and attendant losses.

Preliminary results of complex intercropping experiments indicate that the current strategy at IITA of aiming at crop combinations and sequences centered on certain major staples such as cassava, yam, corn, rice, and plantains is a sound one vis a vis thousands of mixtures that are possible with the numerous major and minor crops that can be grown in the humid tropics.

The main objective of IITA's Farming Systems Program is the development of more efficient crop production systems for sustained yields on small farms of the humid tropics. This involves improvements in cropping patterns (i.e., crop combinations and sequences) and their associated soils, as well as crop, pest, weed, and overall resource management to increase productivity per unit area per unit time and reduce risks while ensuring that the subsistence needs and increasing cash requirements of small farmers are satisfied. It calls for studies of existing or traditional farming systems and the practices and principles of experimental cropping sys-

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terns, with respect to their biological stability, productivity per unit area and time, returns on cash inputs, and labor utilization in relation to various crop characteristics and crop plant interactions in different cropping patterns (Okigbo 1974; Banta and Harwood 1975).

Intercropping is widely practiced among farmers in Asia and Africa (Andrews and Kassam 1976; Harwood and Price 1976; Okigbo and Greenland 1976). Reasons for intercropping include (1) increased efficiency in the utilization of environmental factors (light, nutrients, water, etc.); (2) more efficient utilization of labor; (3) reduction of the adverse effects of diseases, pests, and weeds; (4) insurance against crop failure; (5) higher gross returns; and (6) protection of the soil against erosion and so on (Norman et al. 1974; Banta and Harwood 1975; Okigbo 1978). Despite the widespread use of intercropping in traditional farming systems of tropical America, Asia, and Africa, intercropping is not understood by researchers (Banta and Harwood 1975), and the principles involved in it are only just beginning to be subjected to scientific study and elucidation.

There are complex interspecific, intervarietal, and interplant interactions (annidation, alleleopathy, etc.) that occur in intercropping, depending on various combinations of the effect of plant species, plant density and spacing, planting patterns, canopy types, root systems, differential demands on environmental factors at different growth stages, and so on (Trenbath 1976). Moreover, in cropping patterns involving simultaneous intercropping or multiple cropping sequences in oneyear or cropping season, there is alwaysthe problem offinding a suitable index for comparison of land-use efficiency, crop diversity, and crop intensity and productivity of different cropping patterns. For example, where more than one crop species is intercropped or grown in multiple cropping sequences, it is not always meaningful to pool dry weight yields of root crops with those of grain legumes or cereals. This is because the total dry-matter yield does not adequately reflect the land-use efficiency, economic returns, or nutritional value of component crops grown on a given area in a specified period even if it constitutes a meaningful measure of total dry economic material produced. Consequently, various criteria have been used in the evaluation of efficiency, economic returns, and productivity of multiple cropping systems. These include the land equivalent ratio (LER), land utilization index (LUI), calorie equivalent, protein equivalent, gross returns, net returns, diversity index (DI), multiple cropping index (MCI), harvest diversity index (HDI), simultaneous cropping index (SCI), cultivated land utilization index (CLU), and crop intensity index (CII) (IRRI 1974; IITA 1975; Strout 1975; Trenbath 1976; Francis 1978; Meneyey et al. 1978). Competition in mixed cropping is also difficult to measure or quantify. This paper reviews the results of two complex intercropping experiments designed to test principles of intercropping — development of approaches for the study of crop competition and evaluation of data on crop mixtures as a basis for cropping patterns design.

Two complex intercropping experiments were conducted at Ibadan and Ikenne (1) to test the principle of intercrop yields of component crops approaching sole-crop yields, as the competition gap increases, as demonstrated by Andrews (1970) and Kassam and Stockinger (1973), and (2) to study crop competition and interactions in complex intercropping involving traditional crop mixtures of yam, maize, melon, and cowpea.

Principles of Competition Gap

Experiments were started in the early season (April) of 1974 at Ibadan and the late season (June) of 1975 at Ikenne, southwestern Nigeria. Table 1 shows the environmental characteristics of these two locations. The test crops were bitter melon *(Colocynthis vulgaris* Schrad) usually grown in Nigeria for its nutritious seeds, cassava *(Manihot esculenta* Crantz), and corn (*Zea mays* L.)

Treatments

There were 18 sole-crop and relay-intercrop treatments of melon (planted on 6 April 1974 at Ibadan and on 9 June 1975 at Ikenne), corn (planted sole or with melon 10 days after melon), and cassava (planted through corn or corn/melon at 0, 4, 8, 12, and 16 weeks after planting (WAP) of corn (Table 2), with each main plot split into two fertilizer level subtreatments and laid out in four replications. Plot size for each subtreatmentwas 32 m^2. Each subplot was surrounded by 1-m guard rows and each main plot by 2-m guard rows with 3-m guard rows on the edges of the field. Spacings used were 2 x 1 m for melon, 20 cm x 1 m for corn, and 1 x 1m for cassava on 1-m ridges. Corresponding plant populations were 5 000, 50 000, and 10 000 plants/ha for melon, corn, and cassava, respectively. These constitute the current recommended sole-crop populations and planting pattern. Observations were made on general crop performance and yields of component crops.

Results and Discussion

Cassava

At Ibadan, significant differences were observed among thecassava dates of planting and crop combination treatments in plant population, rootfresh and dry weightyields, number of roots, and dry weight of tops (Figs. 1, 2). In all these observations, significant differences were observed among planting dates and crop mixtures. There was a general tendency of yields of root and tops to decrease with delay in cassava relay intercropping dates. Significant differences were observed between sole-crop cassava and intercropped cassava, but, while sole-crop top yields exceeded those of intercrop yields at all planting dates (Fig. 2), this was not necessarily the case in root yields (Fig. 1). No significant differences were observed between cassava in cassava/corn intercrops as compared to cassava in cassava/corn/melon intercrops, except in number of roots in which, for most planting dates, root numbers in the former exceeded the latter. Significant interactions between dates and crop mixtures were observed due to relative yields and other values for sole cassava, cassava/corn, and cassava/corn/melon not maintaining the same trends at all planting dates. No significant differences were observed between fertilizer treatments, perhaps due to the already high level of fertility of the plots used.

Similar results were obtained at Ikenne (Fig. 3), and significant differences were also observed in lodging of cassava, which decreased with delay in planting date but was highest in the cassava/corn mixtures followed by cassava/corn/melon. This was due to cassava plants developing top-heavy canopies after

Table 1. Environmental characteristics of Ibadan and Ikenne.

Observation	Ibadan	Ikenne
Latitude	7°30"N	6°55"N
Soils	Alfisol (Oxic Paleustalf)	Alfisol (Oxic Paleustalf)
pH	6.3	6.5
Effective CEC (meg/100g)	6.2	5.6
Mean annual rainfall (mm)	1250	1632
Radiation (g cal/cm^2/day)	330.6-469.9	—

Table 2. Main and subtreatments[a] used in the corn/caasava/melon intercropping experiment, Ibadan and Ikenne, 1974.

	Planting dates, Ibadan					Planting dates, Ikenne					
Main treatment	18 Apr	26 May	16 Jun	17 Jul	16 Aug	11Jun	21.Jun	24 Jul	23 Aug	26 Sept	25 Oct
Melon atone	X			X		X					
Corn alone	X			X			X				
Cassava alone	X	X	X	X	X		X	X	X	X	X
Corn + melon	X					X					
Corn + cassava	X	X	X	X	X	X	X	X	X	X	X
Corn + cassava + melon	X	X	X	X	X	X	X	X	X	X	X

a. Subtreatments:
High fertilizer level: 100N/80P/40K; Low fertilizer level: 40N/20P/0K.

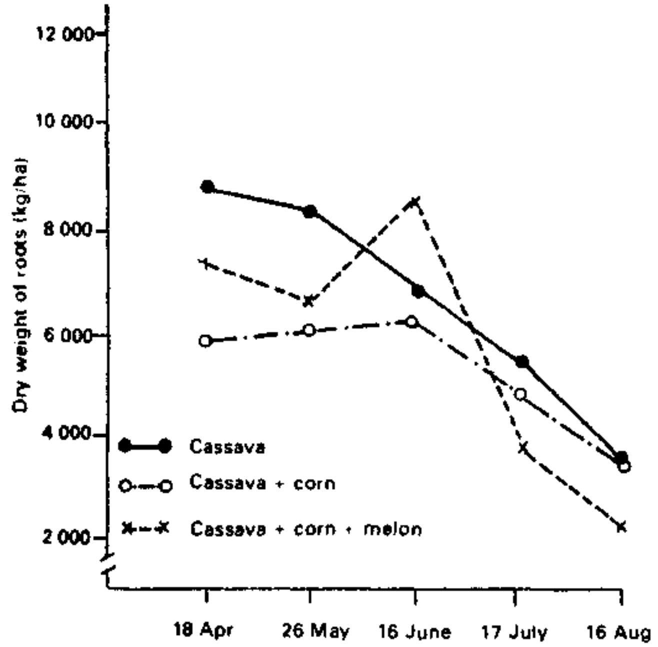

Figure 1. Mean dry weight of cassava root yields in relation to cropping patterns at Ibadan, 1974.

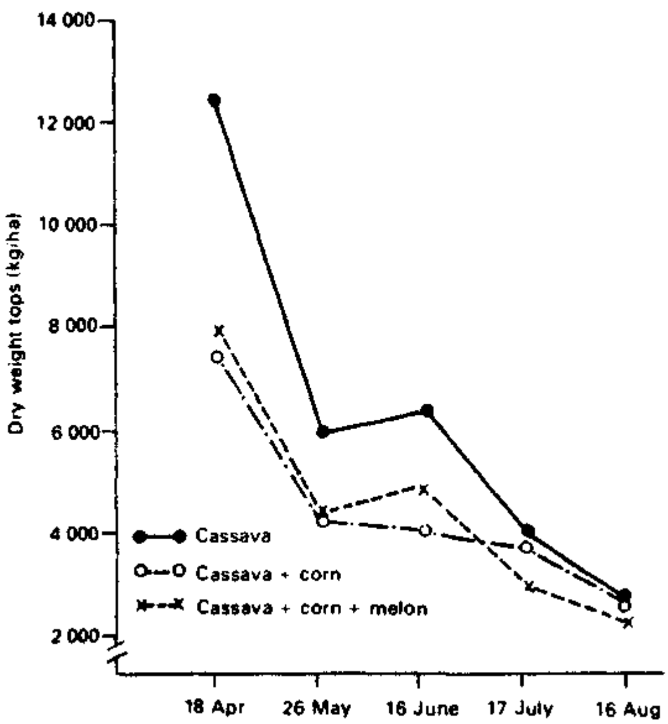

Figure 2. Mean dry weight yields of cassava tops in relation to cropping patterns at Ibadan, 1974.

senescence of the corn, the competition effect of which was most pronounced in corn/cassava mixtures. Moreover, cassava heights tended to decrease with delay in planting date.

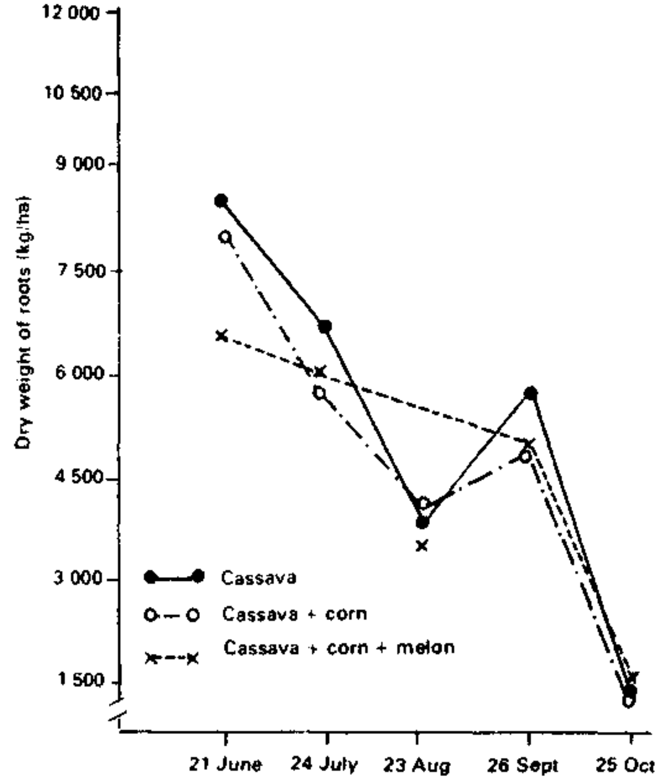

Figure 3. Mean cassava root dry weight yields in relation to cropping pattern at Ikenne, 1975.

Corn

Significant differences were observed in plant population, percentage and number of lodged plants/plot, and stover yields at Ibadan, but in grain yield only at Ikenne (Table 3, Fig. 4, 5). No significant differences in grain yield were observed at Ibadan, but there was a significant difference in crop mixture x fertilizer x number of fertilizer applications due to some plots at low fertilizer levels exhibiting higher grain yields in corn/melon plots than in corn/melon/cassava plots in which corn/melon was relay interplanted with cassava in June and August. At Ikenne, there were significant differences in grain yield among dates of planting and crop mixtures but not between fertilizer treatments (Fig. 5) Lodging was slightly lower in plots where cassava was planted earlier and in corn alone and corn/melon than in corn/cassava or corn/cassava/melon treatments. Thus it would appear that early cassava relay interplanting through corn reduced lodging in corn.

Table 3. Mean values[a] of various observations on early corn intercropped with melon and relay interplanted with cassava at 0, 4, 8, 12, and 16 WAP of corn and melon.

Treatment	Planting date	Plant population per plot	Total lodging (%)	Total lodging No/plot	Stover yield (t/ha)	Grain yield (t/ha)
Corn sole crop		138.62ab	11.5	16.0ab	5.39ab	4.49a
Corn/melon		140.50ab	14.9	20.9ab	5.36ab	5.65a
Corn/cassava	April	138.75ab	10.2	14.1ab	4.77a	4.60a
Corn/melon/cassava	April	133.00ab	13.9	18.5ab	4.26a	4.19a
Corn/cassava	May	135.63ab	13.6	18.5ab	5.59ab	4.84a
Corn/melon/cassava	May	129.88ab	15.0	19.5ab	4.70a	4.26a
Corn /cassava	June	130.50ab	12.7	16.6ab	6.59b	4.74a
Corn/melon/cassava	June	142.38ab	11.4	16.3ab	4.81a	4.59a
Corn/cassava	July	123.25a	27.3	33.6c	5.53ab	4.59a
Com/melon/cassava	July	145.75b	10.6	15.5	5.46ab	4.97a
Corn/cassava	Aug	124.38ab	20.6	25.6bc	5.92ab	4.50a
Corn/melon/cassava	Aug	130.25ab	14.0	18.3ab	5.02ab	4.43a

a. Values with common letter are not statistically different.

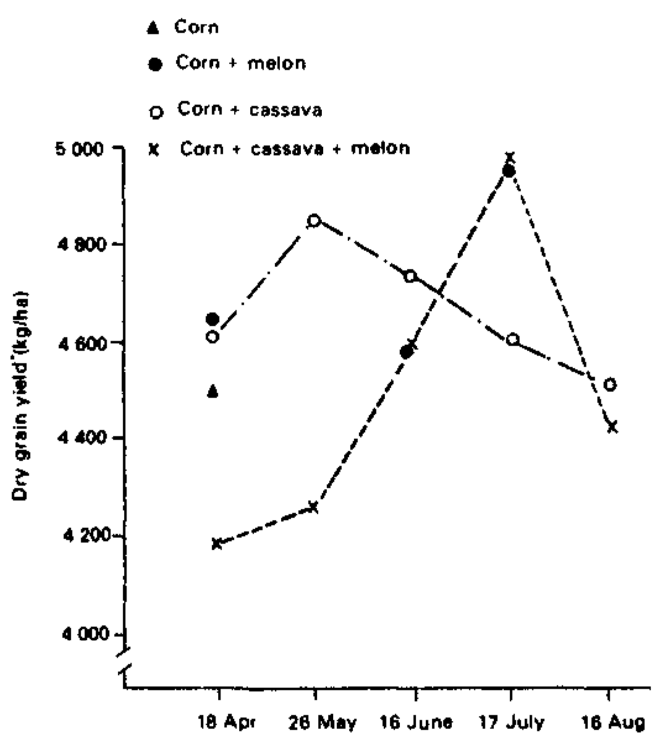

Figure 4. Mean dry-grain corn yields in relation to cropping patterns at Ibadan, 1974.

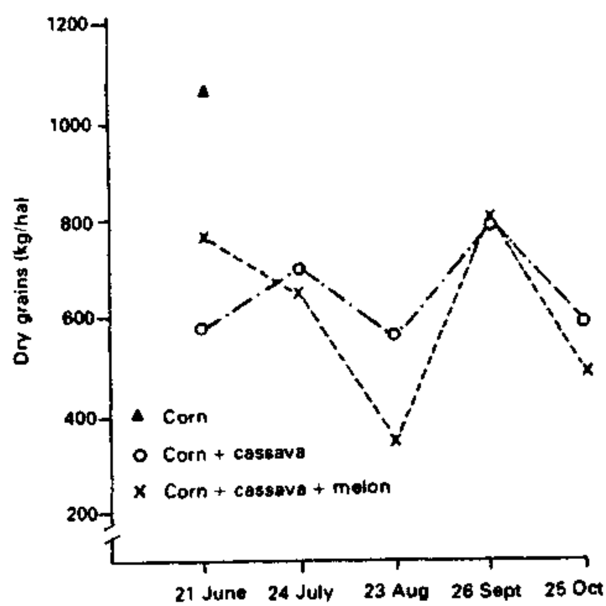

Figure 5. Mean dry-grain yields of corn in relation to cropping pattern at Ikenne, 1975.

Melon

The late melon crop at Ikenne completely failed and did not produce any mature fruits. In the early melon crop at Ibadan, number of fruits, fresh fru It weight, and seed yield of melon were all drastically reduced by intercropping (Fig. 6). The ratio of yields of melon in sole as compared to intercropped plots was higher than 20:1, and there were no significant differences among melon intercrop treatments. Most of the melon harvest was located in the guard row than inside the experimental plots proper. This supports the widespread practice of very wide spacing of corn when melon is intercropped. The melon appeared to slightly benefit the cassava crop in dry weight of tops and roots at both Ibadan and Ikenne, but not in fresh weight of roots.

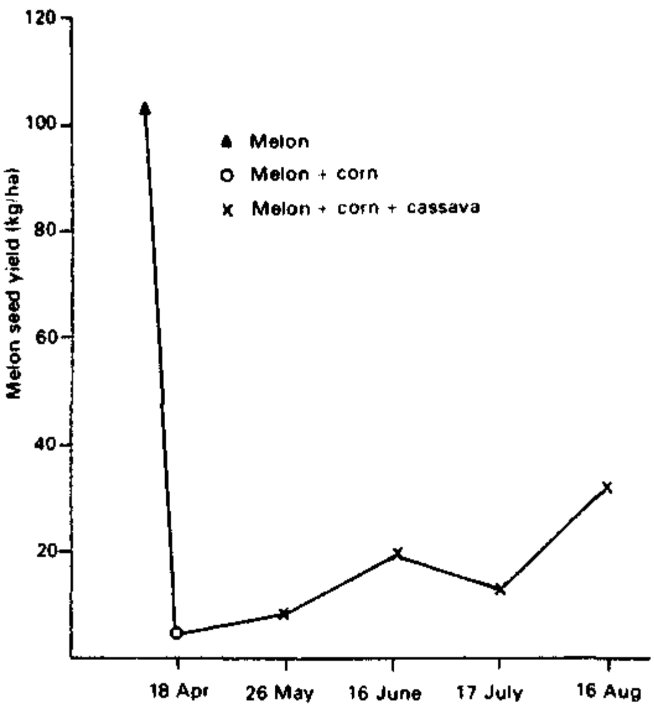

Figure 6. Mean melon seed yields in relation to cropping patterns, 1974.

Bivariate Analysis of 1974/75

Pearce and Gilliver (1977) used data from this experiment as an example in a bivariate statistical analytical procedure for evaluating intercropping data involving two crop species and arrived at conclusions similar tothose indicated above — (1) any beneficial effect of melon was obtained without any effect on yields of corn and cassava; (2) the time of planting cassava did not have any systematic effect on the corn, but later planting of cassava appeared to have reduced the yields of roots; and (3) when corn and cassava are planted at the same time, the caloric values were similar, but later planting of cassava resulted in about a 30% reduction in caloric values.

Productivity of Intercrops

The productivity of the various mixtures can be evaluated by comparison of caloric equivalents, land equivalent ratios, and gross returns (Table 4, 5). AH these indicate that it is more profitable

Table 4. Calorie equivalents, gross returns, and land equivalent ratios in melon/corn/cassava intercropping experiment, Ibadan, 1974/75 (early season).

Treatment	Planting date	Calorie equivalents (1×10^6/ha)	Total gross return (N/ha)	Land equiv. ratio (LER)
Corn alone	April	16.03	992	1.00
Melon alone	"	0.53	72	1.00
Cassava alone	"	39.77	2000	1.00
Corn/melon	"	16.63	1031	1.10
Corn/cassava	"	44.54	2433	1.74
Corn/melon/cassava	"	46.79	2533	1.87
Cassava alone	May	42.00	2116	1.00
Corn/cassava	"	45.98	2515	1.85
Corn/melon/cassava	"	46.38	2520	1.81
Cassava alone	June	31.49	1587	1.00
Corn/cassava	"	48.44	2635	2.00
Corn/melon/cassava	"	67.35	3586	2.03
Cassava alone	July	27.85	1403	1.00
Corn/cassava	"	41.82	2295	1.94
Corn/melon/cassava	"	38.90	2167	1.90
Cassava alone	Aug	19.84	1000	1.00
Corn/cassava	"	35.30	1963	1.97
Corn/melon/cassava	"	31.51	1782	1.77

Table 5. Calorie equivalents, gross returns, and land equivalent ratios of corn and cassava intercropped together, Ikenne, 1975/76 (late season).

Treatment	Planting date	Calorie equivalents (1×10^6/ha)	Total gross returns (N/ha)	Land equivalent ratio (LER)
Corn alone	June	4.498	277	1.00
Cassava alone	June	24.113	2322	1.00
Corn/melon	June	2.780	172	0.62
Corn/cassava	June	22.585	2078	1.50
Corn/melon/cassava	June	26.799	2462	1.80
Cassava alone	July	20.267	1952	1.00
Corn/cassava	July	21.623	1983	1.63
Corn/melon/cassava	July	21.117	1928	1.64
Cassava alone	Aug	14.373	1384	1.00
Corn/cassava	Aug	16.251	1471	1.55
Corn/melon/cassava	Aug	16.563	1528	1.45
Cassava alone	Sept	18.136	1746	1.00
Cassava/corn	Sept	20.519	1849	2.00
Corn/melon/cassava	Sept	20.068	1807	1.98
Cassava alone	Oct	9.235	889	1.00
Cassava/corn	Oct	21.208	1945	1.67
Cassava/corn/melon	Oct	11.498	1022	1.52

to grow cassava with corn than to grow corn or melon as sole crops or corn/melon mixtures, especially during the early season when moisture is not limiting.

Although yields of component crops (corn and cassava but not melon) approximated those of the sole crops, delay in cassava relay intercropping, which increased the competition gap, did not result in increased yields of both cassava and corn. Some of the interesting interactions among components included the reduction of lodging in corn in the presence of cassava and increased lodging in cassava after the corn plant was harvested. Melon yields were drastically reduced by shading, and it would be interesting to study melon/cassava intercropping alone or with another low-growing crop in the mixture in addition to the effects of spacing and spatial arrangement in melon intercropping experiments. With the results available, a 2-year rotational sequence in which melon/corn/cassava or corn/cassava followed by a suitable sole-legume or a legume/nonlegume intercrop sequence is suggested for increased yields and maintenance of continuous soil cover. Additional studies suggested include both determination of the most suitable time for cassava relay intercropping and evaluation of different canopy types of cassava in relation to varying populations and spatial arrangements with short early and tall late corn varieties. Fertilizer practices under such intercropping systems merit attention after compatible mixtures and planting patterns are determined.

Crop Competition, Interactions, and Performance in Complex Crop Mixtures

Treatments

This experiment involved 22 treatments in a randomized complete block design in four replications consisting of the white Guinea yam *(Dioscorea rotundata* Poir), corn *(Zea mays* L) bitter melon *(Colocynthis vulgaris* Schrad), and climbing cowpea *(Vigna unguiculata* [L.] Walp) grown as sole crops and in various intercrop mixtures of two or four crops in different row intercropping patterns on the same plots at IITA in 1975 and 1976. The crops used in this experiment are dominant major and minor crops in traditional cropping systems in most of southern Nigeria. Characteristics of the crops used in the experiment are shown in Table 6, and the details of the treatments are listed in Table 7. Plot size is 40 m^2 with guard rows of 2 m between plots and 5 m on the outside edge of all replicates to facilitate destructive sampling for growth analysis. Spacings and plant populations used are presented in Table 8. All crops were grown on 1-m ridges, and the spacings used were those recommended for sole crops, which constitute deviations from local practice. All crops were planted on tops of 1-m ridges except for melon and staggered corn, which were planted halfway down the sides of the ridges. The growing of crops in rows and high sole-crop densities *are* modifications of traditional practices.

The experiment was first carried out in 1975 and repeated in 1976. Melon was first planted on 25 April 1975 and on March 27 1976, followed 10 days later by other crops. In 1976, about half the melon stands failed to germinate as a result of drought, and replanting was done on 26 March 1976. Yam plant population in intercrops was three-fourths of the sole-crop plants in 1975 and the same as the sole crop in 1976. Cultural operations carried out included supplying of missing stands; thinning of melon, corn, and cowpea; pest control involving applications of insecticides (gammaline 20 and rogor against leaf insects of cowpea and corn and seven 85 wettable powder to melon); weeding (using preemergent herbicides and manual methods up to five times for yams to observe effects of crop mixtures on weeds); staking for yams and climbing cowpea; and fertilizer application. Rates of fertilizer applied amounted to 120:90:60 kg/ha, respectively, of N, P2O5, and K2O in split doses for corn; single-dose applications at planting of 30 kg K2O and 20 kg P2O5 per ha for cowpea; and 30 kg N, 20 kg P2O5, and 40 kg K2O5/ha for yams. Urea was the N source; singlesuperphosphate was the P source; and muriate of potash was the K source.

In addition to various observations on crop

Table 6. List of test crops and their major characteristics.

Crop	Species/Variety	Source	Characteristics
White Guinea yam	*Dioscorea rotundata* Pior. mar. Awudu	Seed yams from Otu-ocha in Anambra State	Stout climber, heavy foliage on 1-2 main vines, branching profusely. 6-8 months maturity.
Corn	*Zea mays* L. TZB Composite	Developed at IITA	High yielding (50-100%); higher than local tall maize variety adapted to humid and savanna areas of Nigeria; white-grained, medium to late maturity.
Cowpea	*Vigna unguiculata* L. (a) TVU 1190 (used in 1975)	IITA Selection	High yielding; large leaved; slightly photosensitive red-seeded cowpea; moderately resistant to disease and pests.
	(b) Ife Brown (used in 1975)	Developed and released by University of Ife	Early maturing; day-length insensitive erect; determinate brown winkled testa; and acceptable seed type.
	(c) Sitaopole (Syn. *V. sesquipedalis)*	Introduction supplied by IITA Grain Legume Improvement Program	Robust climber; large leafed; long dangling pods; vegetable cowpea, seeds speckled.
Melon	*Colocynthis vulgaris* (bitter melon)	Purchased from local market	Viny cucurbitateous herb; short leaved; 3 months maturity; usually grown for its nutritious seeds.

Table 7. Treatments used in the yam/corn/melon/cowpea intercropping experiment in Ibadan in 1975 and 1976.

1	Yams alone
2	Maize alone
3	Melon alone (earlier planting)
4	Cowpea (semierect, 1st year planting; erect, 2nd year planting)
5	Climbing cowpea (Sitaopoie) alone
6	Maize alone 2 plants per stand
7	Yams + maize 2 plants per stand staggered
8	Yams + maize 2 plants per stand same row
9	Maize 2 plants per stand + melon
10	Maize 4 plants per stand + melon
11	Yams + cowpea (semierect/erect)
12	Yams + climbing cowpea
13	Maize 2 plants per stand + climbing cowpea
14	Maize 2 plants per stand + cowpea (semierect/erect)
15	Maize 4 plants per stand + cowpea (semierect/erect)
16	Maize 4 plants per stand + climbing cowpea
17	Melon + cowpea (semierect/erect) same rows staggered
18	Melon + cowpea (semierect/erect) alternate rows
19	Melon + climbing cowpea same rows
20	Melon + climbing cowpeas alternate rows
21	Yams + maize 2 plants per stand + climbing cowpea + melon
22	Yams + maize 4 plants per stand + cowpea (semierect/erect) every 2 rows alternating with melon

performance, samples were taken from wide guard rows at 2, 4, 6, 8, 10, and 12 weeks after 50% emergence (WAE) for corn, cowpea, and melon and at 4, 8, 12, 16, 20, and 24 WAE for yams. Determinations of leaf dry weight, leaf area index (LAI), net assimilation rate (NAR), relative growth rate (RGR), dry matter yields, and harvest index were based on samples of two corn and cowpea plants and one melon and one yam plant from each replicate. Observations at maturity and harvesting were based on the net plot.

Results and Discussion

Growth Analysis

LEAF AREA (LA). Marked differences were observed in leaf area development at each sampling time, rate of LA development, and maximum LA attained (Figs. 7, 8). Rate of LA development was highest in melon, which was also the earliest crop to attain the maximum LA. Sequence in time of maximum LA attainment was: melon < corn < climbing cowpea-erect cowpea < yam. Yam attained the highest LA, but the general trend in maximum LA developed was: yam > climbing cowpea > melon > corn > erect cowpea. Viny crops attained higher LA than nonviny ones. Intercropping affected LA, but its effects varied with the crop. For example, yam LA was reduced by intercropping which varied with the crop and number of crops (Fig. 8). No pronounced reduction in LA resulting from intercropping was observed in the same manner at different sampling dates in other crops which would appear to have exhibited adaptive changes to intercropping. Only in the two cowpea varieties did the time of attainment of maximum leaf area overlap, but LA development curves indicate that maximum shading occurred detween the 8th and 12th WAE. All these indicate that possibilities of reduction of shading and competition exist through changes in relative planting dates.

LEAF AREA INDEX (LAI). The LAI at each sampling time varied with crop species, with rates of development and decrease in LAI being highest in melon which exhibited the earliest senescence (Fig. 9). Rate of increase in LAI was lowest in yam and erect cowpea but was in general related to the time of maturity of each crop. Sequence in time of maximum LAI attainment which was similar to that of LA was: melon < corn < climbing cowpea = erect cowpea < yam. Trend in magnitude of LAI attained was: melon > climbing cowpea > corn > yam > erect cowpea, which d iffers markedly from that of LA except for erect cowpea. Crops with highest LA did not necessarily exhibit the highest LAI, which was probably due to differences in spacing. In general, intercropping reduced LAI of the two viny climbing crops (yams and climbing cowpea) but tended to increase it in melon and corn. At certain sampling dates, LAI of sole crops exceeded those of intercrops; however, at other times, the reverse was true. Number, species, and arrangement of crops in the mixture had marked effects on the rate of change and value of LAI attained at different

Table 8. Test crop spacing and plant population.

Crop		Spacing	No. of stands/plot	Plant population
Corn	1 plant/stand	20 x 100 cm	200	50 000, 1 per stand
	2 plants/stand	40 x 100 cm	100	50 000, 2 per stand
	4 plants/stand	80 x 100 cm	50	50 000, 4 per stand
Yam		1 x 1 m	1975: 40 sole, 30 intercrop	10 000, 1 plant/stand 7 500,
			1976: 40 sole and intercrop	10 000,
		1 x 1 m	40 sole and intercrop	10 000, 3 plants/stand thinned to 1 plant/stand
Cowpea	1975 & 1976 TVU 1190	20 x 100 cm	200	50 000, 1 plant/stand
	Ife Brown	"	"	" "
	Climbing cowpea (Sitaopole)			
	1975	25 x 100 cm	160	40 000
	1976	30 x 100 cm	133	35 000

sampling dates (Figs. 10,11). Yam intercropped with corn exhibited higher LAI at the early sampling periods than both sole-crop yam and yam intercropped with three other crops. Melon intercropped with one or three crops had higher LAI at most sampling dates than the sole crop. Times of maximum leaf area attainment were similar to those of LA and indicate potentials for manipulation of relative times of planting and spatial arrangement of the crops in mixtures to reduce competition.

MEAN RELATIVE GROWTH (RGR). Relative growth rate (RGR) decreased with theage of the plant (Fig. 12). Negative values were observed at later stages of growth in melon, climbing cowpea, corn, and yam. At most times of sampling, intercropping tended to reduce RGR in melon, corn, and yams, but increased it in erect and climbing cowpea with differences at different sampling times, and the species and number of crops in the mixture affected the RGR observed (Table 9).

NET ASSIMILATION RATE (NAR). NAR was highest at the early stages of growth but varied with the crop, stage of growth, intercropping pattern, and number of crops in the mixture (Table 10). Negative values of NAR at later stages of growth were observed in yam and corn, and, in most cases, NAR increased during periods of grain filling or tuber development. Intercropping markedly affected NAR, depending on the crop and intercropping treatment. While intercropping three crops with melon, yam, and erect cowpea resulted in the lowest NAR in these crops, it resulted in highest value for corn, when yam, melon, and cowpea were intercropped with it (Table 10). Intercropping climbing cowpea with three other crops resulted in the same NAR value as the sole crop. Highest NAR in Ife Brown erect cowpea (used only in the 1976 trials) was obtained when it was intercropped with corn. Although low NAR exhibited by melon when intercropped with staked or taller crops as compared with erect cowpea is understandable, it is not as obvious why yam exhibited low NAR when it was intercropped with erect cowpea except perhaps as a result of weed infestation after the cowpea had stopped growing. NAR may, to some extent, be used to determine crop compatibility in intercropping.

DRY-MATTERYIELD. Dry-matter yields of component crops varied significantly in relation to time of sampling and treatment, rate of dry-matter accumulation, and time taken to attain

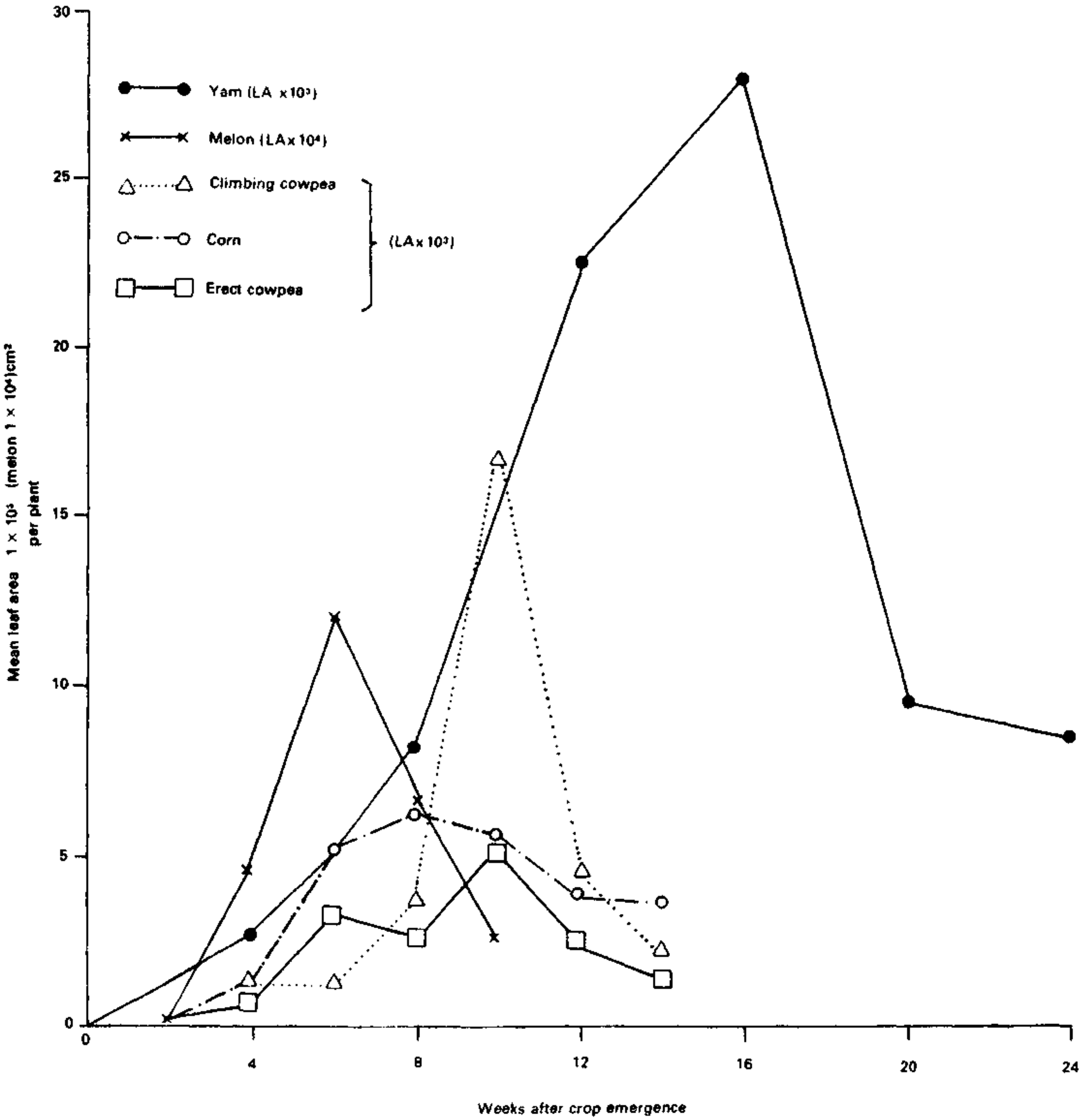

Figure 7. Leaf area development in five test crops showing extent of overlap in periods of maximum leaf area.

the highest dry-matter yield (Fig. 13). Rate of increase in dry matter was highest in melon and lowest in erect cowpea according to the trend: melon > corn > yam > climbing cowpea > erect cowpea. Sequence in the time of attainment of maximum dry matter was: melon > climbing cowpea > corn > erect cowpea > yam. The highest amount of dry matter attained followed the trend: melon > yam > corn > climbing cowpea > erect cowpea.

Intercropping reduced total dry weight yields per plant, but this varied with the crop and number of associated crops in the mixture and was most pronounced in yams and melon. Reduction in yam dry weight yield per plant was most pronounced when yam was intercropped

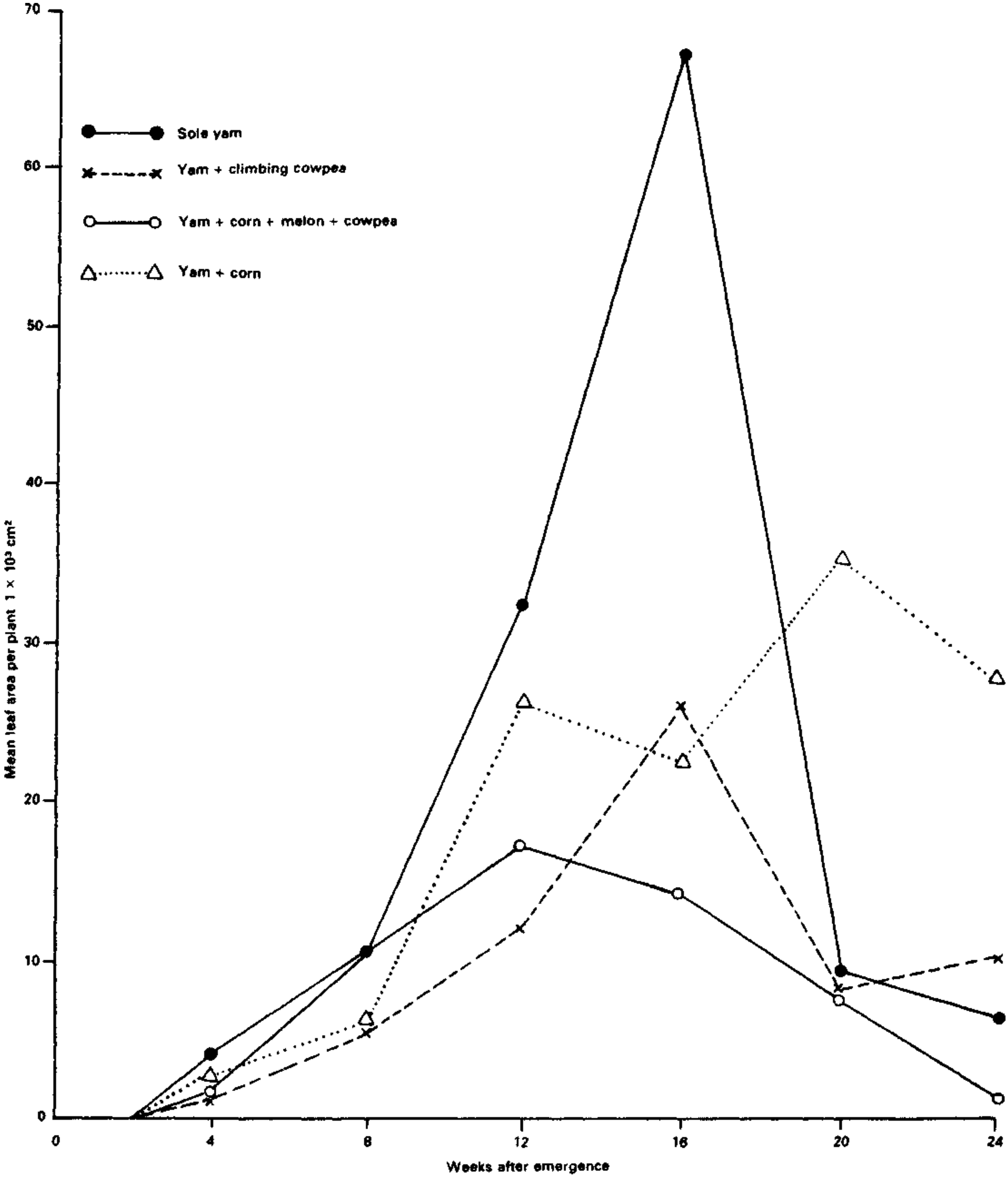

Figure 8. Mean leaf area development in relation to associated crops in the mixture.

with climbing cowpea and least when intercropped with corn and erect cowpea, but the relative effects of associated crops varied with time of sampling (Fig. 14). Melon dry weight yield per plant was most drastically reduced in association with corn and climbing cowpea and least when in association with erect cowpea (Fig. 15). It is interesting to note that melon dry weight yield was not as much reduced when grown with yam, corn, and cowpea as com-

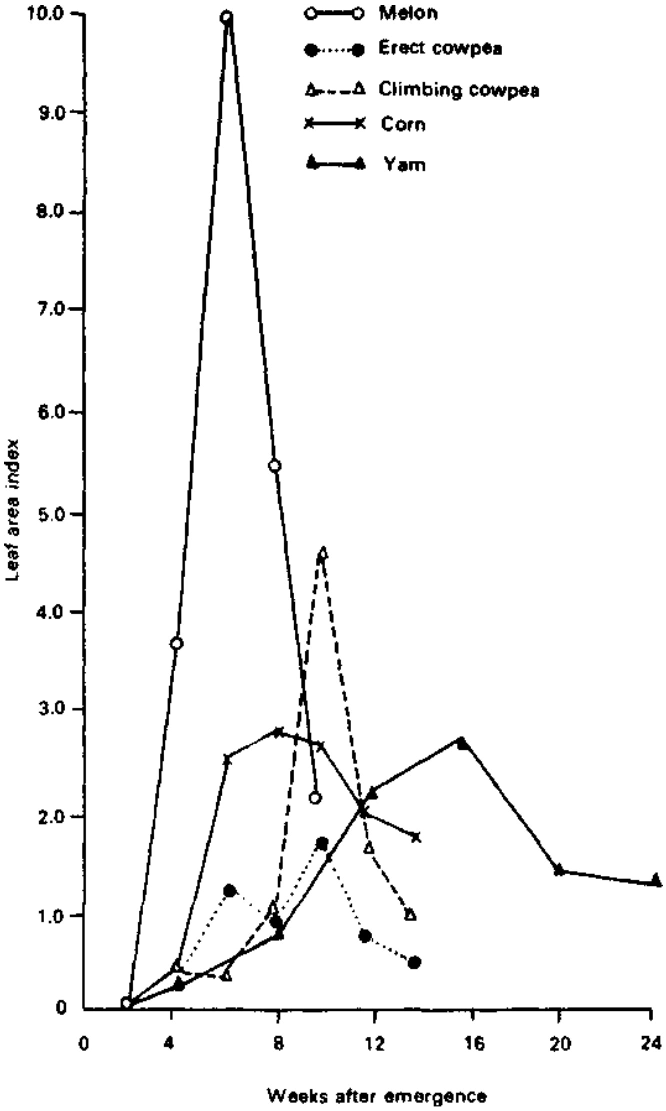

Figure 9. Leaf area index in five test crops showing peaks of leaf-area development.

pared to yields in its association with only one other crop. Spatial arrangement also affected melon dry weight yield per plant, with the melon intercrop in alternate rows resulting in greater reduction than in alternate rows probably due to interplant competition.

Dry weight yields of different parts of the crop were significantly affected by intercropping treatments. Thus, tuber yield in yams was reduced by intercropping with the extent of reduction increasing with the increase in number of crops in the mixture (Fig. 16). Yams intercropped with three other crops exhibited much earlier maturity and premature senescence. Highest dry weight yields of grain, seed or tubers were observed in corn and yam both of which also exhibited the least reduction from intercropping. Yield reductions due to intercropping in these crops were highest when they were associated with tall or climbing crops such as climbing cowpea and yams (in the case of corn) or corn and climbing cowpea (in the case of yams). Reduction resulting from intercropping was most pronounced in melon. Both types of cowpeas produced the lowest dry weight yields. Dry weight yields in a given crop were highest when, for example, corn was associated with erect cowpea or melon, yam with erect cowpea or corn, melon with climbing cowpea or erect cowpea, erect cowpea with melon, climbing cowpea with melon, and yams with erect cowpea and to a lesser extent with corn (Fig. 17). Erect cowpea yield in intercrop with melon exceeded the sole-crop yield.

Dry weight yields of various crops in mixtures gives a rough indication of their compatibility. Melon leaf dry weight per plant was differentially affected by intercropping and spatial arrangement. Melon leaf dry weight for the sole-crop was significantly lower than when melon was intercropped with either yam or erect cowpea. Similarly, melon leaf dry weight was higher in intercrops on the same row than in the sole crop except at 8 WAE. Thus, the melon plant under shading appears to exhibit an adaptive behavior under intercropping by developing higher LAI and leaf dry weight as compared to the sole crop.

HARVEST INDEX (HI). Harvest indices of all crops were significantly affected by the crops in the mixture and planting arrangement (Fig. 18). The highest values were not necessarily observed in the sole crop except in yam and melon. In erect cowpea (Ife Brown), the highest HI was observed when it was intercropped in two alternating rows with melon in association with yam and corn. In corn, the highest value was observed when it was intercropped with yam, cowpea every two alternating rows, and melon. From these observations, there is an indication that the cowpea produced higher proportions of *economic* yields in mixtures with certain crops than as a sole crop. This may be due to interactions related to pest damage or to other beneficial effects such as may occur when they share the same supports with yams. More detailed observations are needed to clarify these interactions.

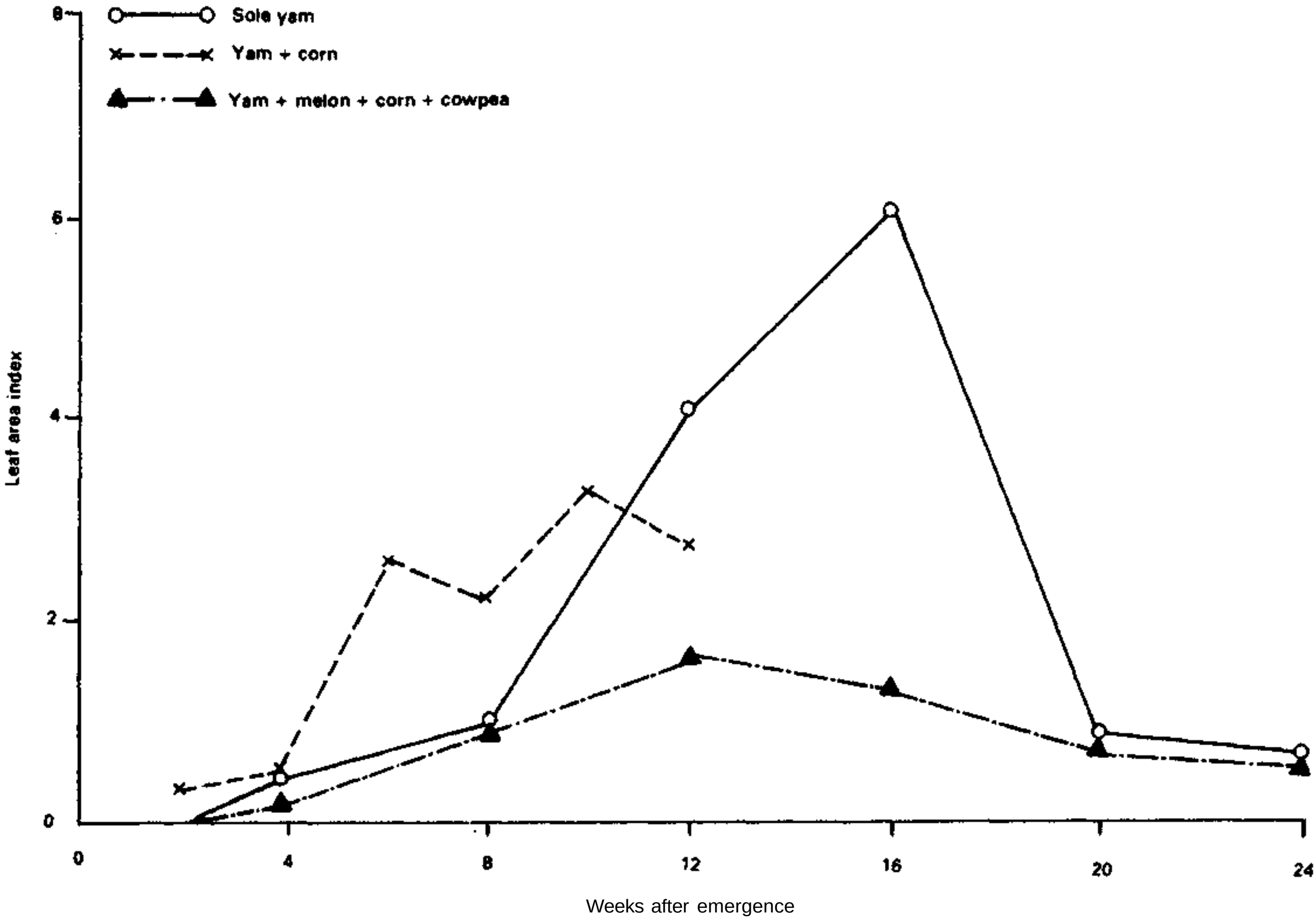

Figure 10. Leaf area index in yams as affected by associated crops in mixtures.

Evaluation of Competition and Productivity

Evaluation of competition and productivity in this experiment is based on LER, relative yields (RY), competition coefficient (C), calorie equivalents (CE), and gross returns (GR).

LAND EQUIVALENT RATIO (LER). This is the sum of the ratios of dry weight yields of each crop in a mixture over its yield in pure culture and is a measure of the area of pure stands that is required to produce the same yield as the intercrop under the same management. Mixtures are more efficient when their LER is greater than 1. On the basis of LER, the best crop mixtures in 1975 and 1976 were corn/yam/melon/cowpea; yam/erect cowpea; corn/yam; erect cowpea/melon; and corn/erect cowpea. The least efficient combinations were corn/climbing cowpea, climbing cowpea/melon, corn/melon, and yam/climbing cowpea. LER also varied with treatment. The best treatments were yam/corn at two plants per stand/climbing cowpea/melon, yam/corn at four plants per stand/erect cowpea every two rows alternating with melon, melon/erect cowpea, yams/corn *at* two plants per stand staggered, yam/corn at two plants per stand same row, and yams/erect cowpea (Table 11).

RELATIVE YIELDS (RY). According to van den Berg (1968), relative yield is the ratio of the yield of a species in mixtures to its yield in pure stands. RY of corn was highest when intercropped with yams, and yams and three other crops followed by erect cowpeas but very low in climbing cowpeas (Table 12). The RY of yams was consistently high in all mixtures used but relatively lower when grown with climbing cowpea. The RY of melon, erect cowpea, and climbing cowpea were low (<0.5) when each is in association with corn, indicating their low competitive ability and adaptation to intercropping with a tall corn variety. Erect cowpea when

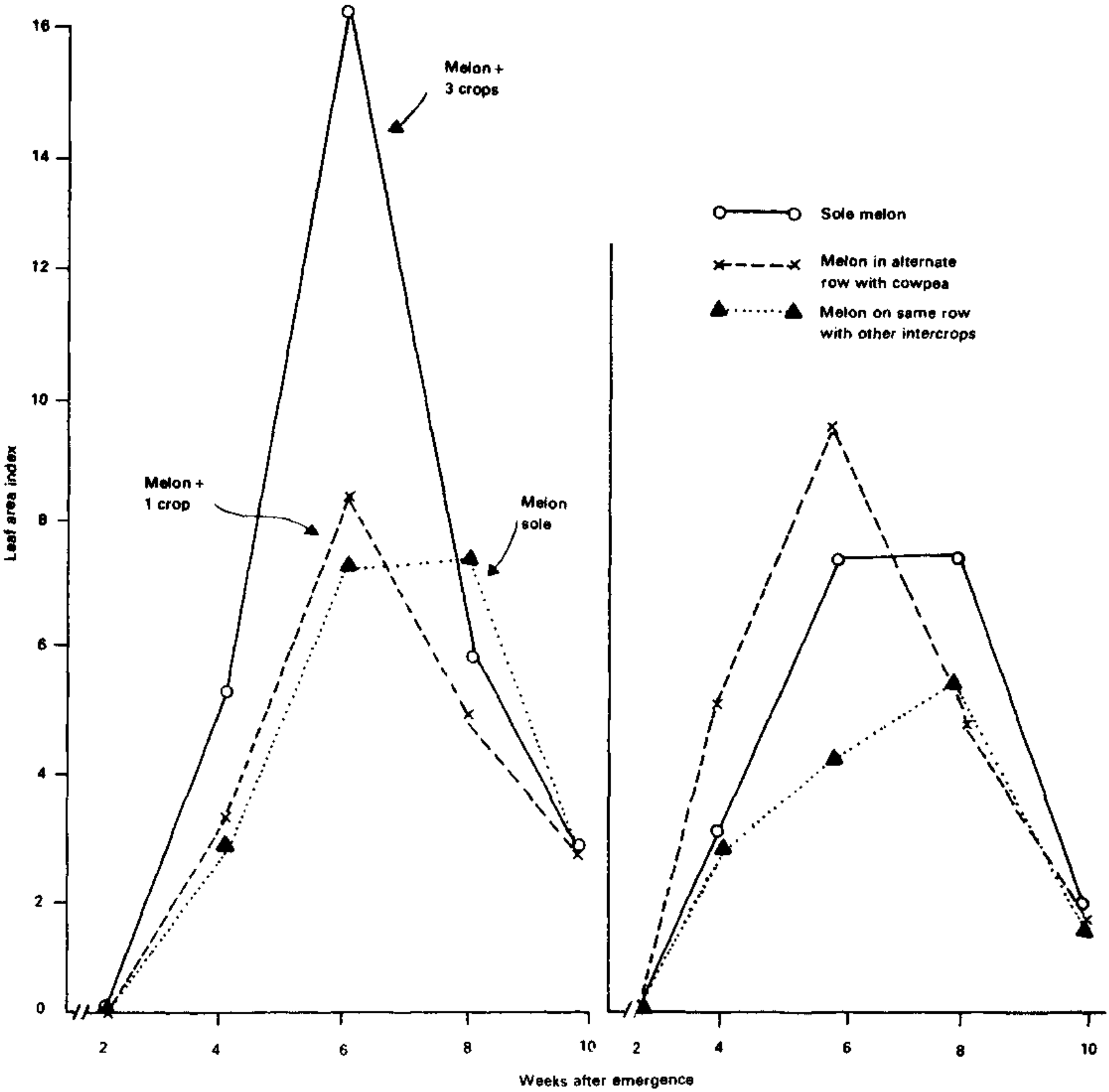

Figure 11. Leaf area index in melon in relation to crops in association in mixtures and arrangement of crops intercropped.

intercropped with melon gave the highest RY (>1.2) in both years, indicating compatibility of erect cowpea and melon. RY figures indicate that erect cowpea is the best companion crop for all the test crops and treatments used in the experiment.

RY also varied with year and treatment. Thus corn and erect cowpea RY was up to 0.5 in 1975 but below 0.5 in 1976. In general, it is beneficial to intercrop when the sum of the RY of any two crops is *over* 1. RY is a fairly reliable index for determining competition and compatibility of crops in mixtures.

RELATIVE CROWDING COEFFICIENT (RCC) AND COMPETITION COEFFICIENT. The relative crowding coefficient (RCC) of de Wit (1960) is the ratio of the yield per stand of component crops in a mixture over their yields in pure stand at standard density. Where proportions of populations

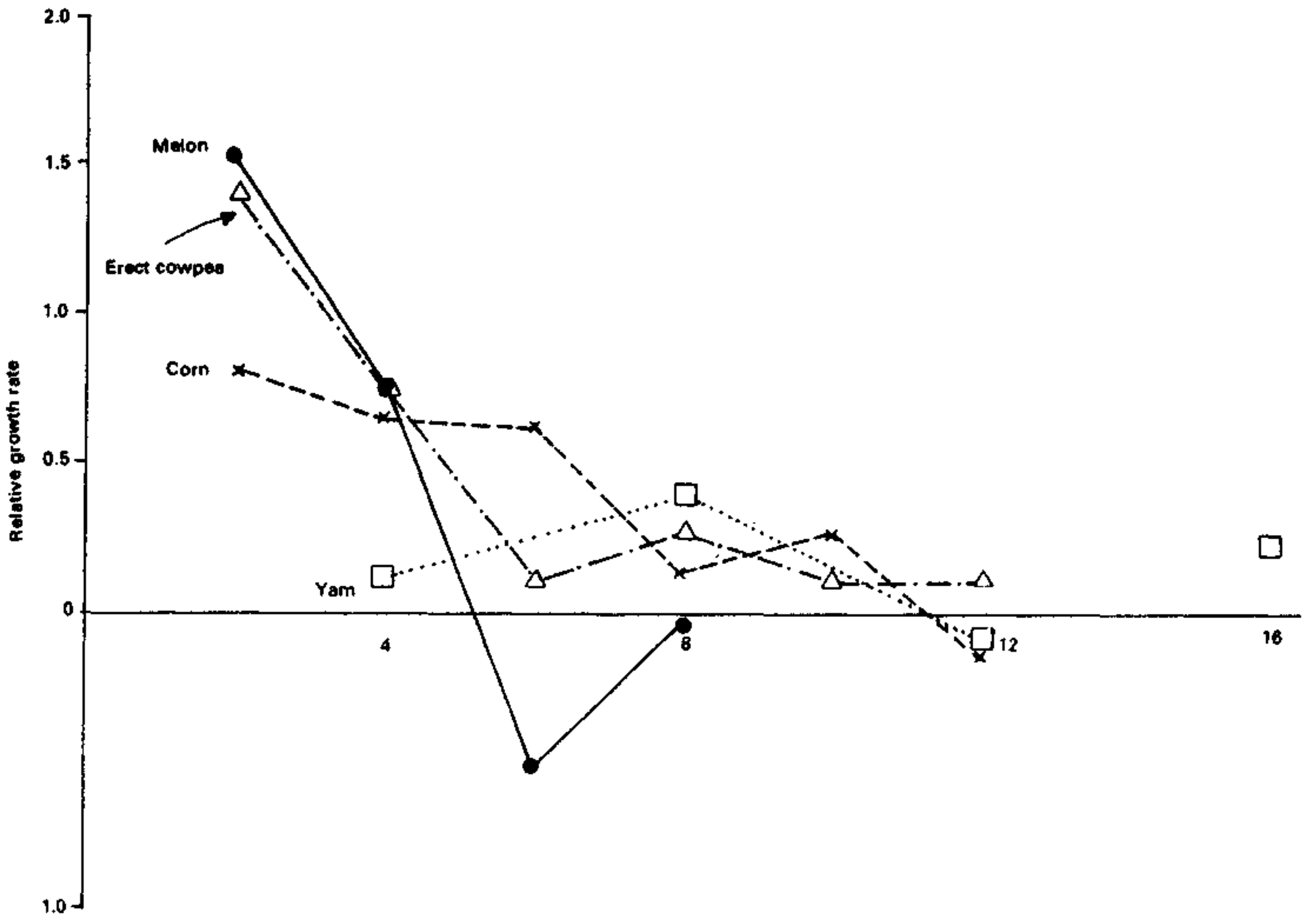

Figure 12. Mean relative growth rate changes of test crops used in an intercrop experiment.

in the mixture do not add up to unity and are not kept constant, RCC is not an adequate measure of competition. The competition coefficient (C), which is the ratio of the RCC of a given species in the mixture to the sum of RCC for all crops in the mixture, constitutes a more reliable measure.

For corn in 1975 and 1976, the C values, except when grown with yams or other four crops and melon in 1976, were higher than 0.5, indicating that corn in combination with melon, erect cowpea, and climbing cowpea, was the aggressor species. (Table 13). When corn was grown with only yams or with yam and other crops, the corn suffered greater competition stress. The low C value for corn when grown with melon in 1976 was due to a faster takeoff by the melon before corn was planted, indicating the importance of relative planting dates in intercropping. When melon was intercropped with erect cowpea, the melon had a lower competition coefficient of 0.032 in 1975 and 0.434 in 1976 as compared to 0.968 in 1975 and 0.566 for cowpeas. The higher C for melon in 1976 was due to a change from more photosensitive and less determinate cowpea TVU 1190 (used in 1975) to Ife Brown (used in 1976) which is more determinate and photoperiod insensitive. This indicates the importance of canopy types in determining the extent of competition and compatibility in mixtures. In combinations with corn, melon, and yams, climbing cowpea always exhibited a lower C value than associated crops, indicating its low competitive ability in the mixtures used. Yam, on the other hand, had high C values and a competitive advantage over the other crops since it is usually staked. In four crop mixtures with yam in 1975, C was 0.901 and in 1976 it was 0.729 as a result of higher plant population in 1975, indicating that the higher the plant population in the mixture the higher its competitive ability.

GROSS RETURNS (GR). Since calorie values do not reflect the differences in monetary values of

Table 9. Mean relative growth rate in g/m^2 par week of different crops grown sola or In association with one or three crops at Ibadan in 1976.

Crop component	Associated crop(s)	Weeks after emergence (WAE)			Mean
		2 (or 4)[a]	4 (or 8)[a]	6 (or 12)[a]	8-12 (24)[a]
Melon	Sole	1.62	1.09	-0.54	0.604
	Erect cowpea	1.48	0.95	-0.70	0.434
	Climbing cowpea	1.53	0.62	-0.53	0.420
	Corn	1.69	0.76	-0.33	0.494
	Yam/corn/cowpea	1.45	0.71	-0.55	0.381
Yam	Sole	0.18	0.33	0.04	0.137
	Erect cowpea	0.05	0.50	-0.13	0.120
	Climbing cowpea	0.11	0.36	-0.04	0.090
	Corn	0.10	0.47	-0.17	0.112
	Melon/com/cowpea	0.17	0.32	-0.08	0.098
Erect cowpea	Sole	1.34	0.95	0.07	0.440
	Melon	1.35	0.61	0.26	0.459
	Yam	1.49	0.82	0.29	0.490
	Yam/corn/melon	1.35	0.92	-0.09	0.544
	Corn	1.52	0.79	-0.02	0.468
Climbing cowpea	Sole	1.47	0.79	0.03	0.450
	Melon	1.54	0.88	0.09	0.480
	Yam	1.36	0.53	0.07	0.410
	Corn	1.54	0.69	0.17	0.510
	Yam/corn/melon	1.60	0.55	0.06	0.410
Corn	Sole	0.78	0.81	0.69	0.400
	Melon	0.74	0.70	0.75	0.410
	Erect cowpea	0.83	0.63	0.68	0.400
	Climbing cowpea	0.88	0.56	0.53	0.430
	Yam	0.91	0.63	0.55	0.410
	Yam/melon/cowpea	0.77	0.85	0.59	0.410

a. Refers to yam only.

unit weights of cereals as compared to roots and tubers or grain legumes, gross returns based on prevailing market prices is a meaningful index for comparison of yields and economic returns of mixtures. On the basis of GR in both years, the best cropping patterns were sole yam, yam/corn/melon/cowpea, yam/corn, yam/erect cowpea, and yam/climbing cowpea (Table 14). The lowest GR were observed in sole-crop climbing cowpea and climbing cowpea/melon.

CALORIE EQUIVALENTS. This is a meaningful index for comparing mixtures in relation to their food and energy values. On this basis, the best mixtures or cropping patterns were yam/corn, sole corn, yam/melon, yam/corn/melon/cowpea, yam/erect cowpea, corn/erect cowpea (Table 15). Gross returns varied with treatments, but it is obvious that while yam/corn mixtures gave reasonably high economic returns in both years, sole yams and sole corn also gave equally high or higher gross returns and calorie equivalents. However, they involve greater risk for small farmers and do not give them the opportunity of constant harvests as do intercrops.

WEED INFESTATION. In 1975 no significant differences among treatments were observed in

Table 10. Net assimilation rates ($g/m^2/day$) of various crops at 2 or 4 weekly intervals in relation to crops in the mixture.

Crop component	Associated crop(s)	Weeks after emergence (WAE) 2 (or 4)[a]	4 (or 8)[a]	6 (or 12)[a]	Mean 8-12 (24)[a]
Melon	Sole	0.1219	0.1927	-0.0467	0.0399
	Erect cowpea	0.1101	0 0960	-0.0259	0.0442
	Climbing cowpea	0.1351	0.0449	-0.0864	0.0225
	Corn	0.1058	0.0467	-0.0327	0.0286
	Yam/corn/cowpea	0.0725	0.0363	-0.0246	0.0209
Yam	Sole	0.1173	0.0230	0.0008	0.0212
	Erect cowpea	0.0501	0.3852	-0.1660	0.0395
	Climbing cowpea	0.1481	0.2565	-0.0564	0.0568
	Corn	0.2072	0.2992	0.0457	0.0987
	Melon/corn/cowpea	0.0481	0.1421	-0.0653	0.0222
Erect cowpea	Sole	0.0394	0.0643	0.0053	0.0246
	Melon	0.0606	0.0155	0.0069	0.0219
	Yam	0.0173	1.0054	0.0155	0.0272
	Corn	0.0285	0.0303	-0.0057	0.0144
	Yam/corn/melon	0.0381	0.0115	-0.0170	0.0078
Climbing cowpea	Sole	0.0180	0.0290	0.0060	0.0110
	Melon	0.0240	0.0550	0.0040	0.0060
	Yam	0.0170	0.0270	0.0010	0.0090
	Corn	0.0310	0.0240	0.0030	0.0120
	Yam/corn/melon	0.0240	0.0340	-0.0920	0.0110
Corn	Sole	0.0320	0.0290	0.0290	0.0180
	Melon	0.0270	0.0190	0.0520	0.0160
	Erect cowpea	0.0710	0.0190	0.0110	0.0190
	Climbing cowpea	0.0440	0.0170	-0.0570	-0.0030
	Yam	0.0350	0.0160	0.0350	0.0240
	Yam/melon/cowpea	0.0330	0.0240	0.0290	0.0260

a. Refers only to the yam crop.

the dry weight of weeds removed during the first weeding, as was observed during the second, third, and fourth subsequent weedings. During the first weeding, the highest weed weights were observed in the yam/corn (at two plants per stand) followed by melon/erect cowpea in alternating rows. Lowest weed growth was observed in the sole yam, yam/corn (at two plants per stand)/climbing cowpea/ melon, and sole-crop melon. Since most crops were only developing canopy and ground cover during this period, the differences in weed growth can only be justifiably partly attributed to treatments. During the second weeding, the highest quantity of weeds were observed in the sole melon, sole yam, and yam/climbing cowpea plots, but the lowest were from corn/ erect cowpea, melon/erect cowpea, and sole erect cowpea treatments. At the third weeding, highest weed weights were observed in sole melon followed by melon/climbing cowpea, and the lowest weed weights were observed in the melon/erect cowpea, yam/erect cowpea, and corn/erect cowpea plots. Similar results were obtained during the fourth weeding. In 1976, first weeding was done with a herbicide (paraquat) and during the first manual weeding the highest weed infestation occurred in corn (at four plants/stand)/climbing cowpea, corn (four plants/stand)/melon, and sole-crop corn,

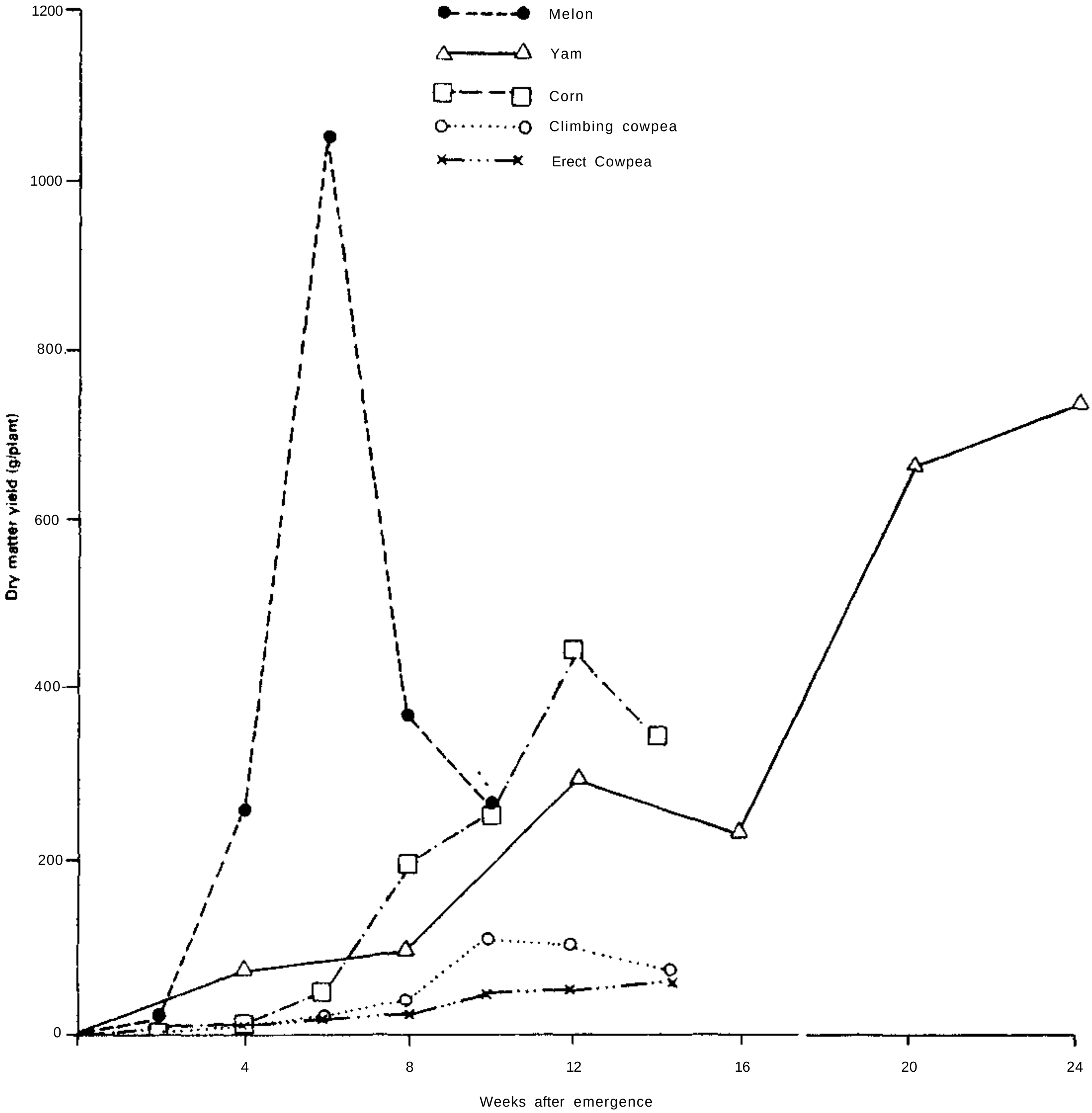

Figure 13. Mean dry-matter yields of test crops at specific intervals during plant growth.

but the lowest weed infestations were observed in corn (at two plants/stand)/climbing cowpea, yam/climbing cowpea, yam/corn (at two plants/stand)/climbing cowpea/melon, and corn (at two plants per stand) melon. Although sole melon plots had relatively low weed infestation during the first weeding, they exhibited the highest weed growth during the second and subsequent weedings.

After 2 years of observations, it was determined that the extent of weed infestation was related to the amount of soil cover and crop canopy development. During the first 2 weeks, weed infestation on all plots was almost the same but after this, suppression of weeds was most pronounced on plots of erect cowpea and melon, which were the first to develop canopies and provide soil cover. The yam and climbing cowpea canopy development occurred much later, and weed growth was not effectively suppressed until much later. During the second and subsequent weedings, the highest weed

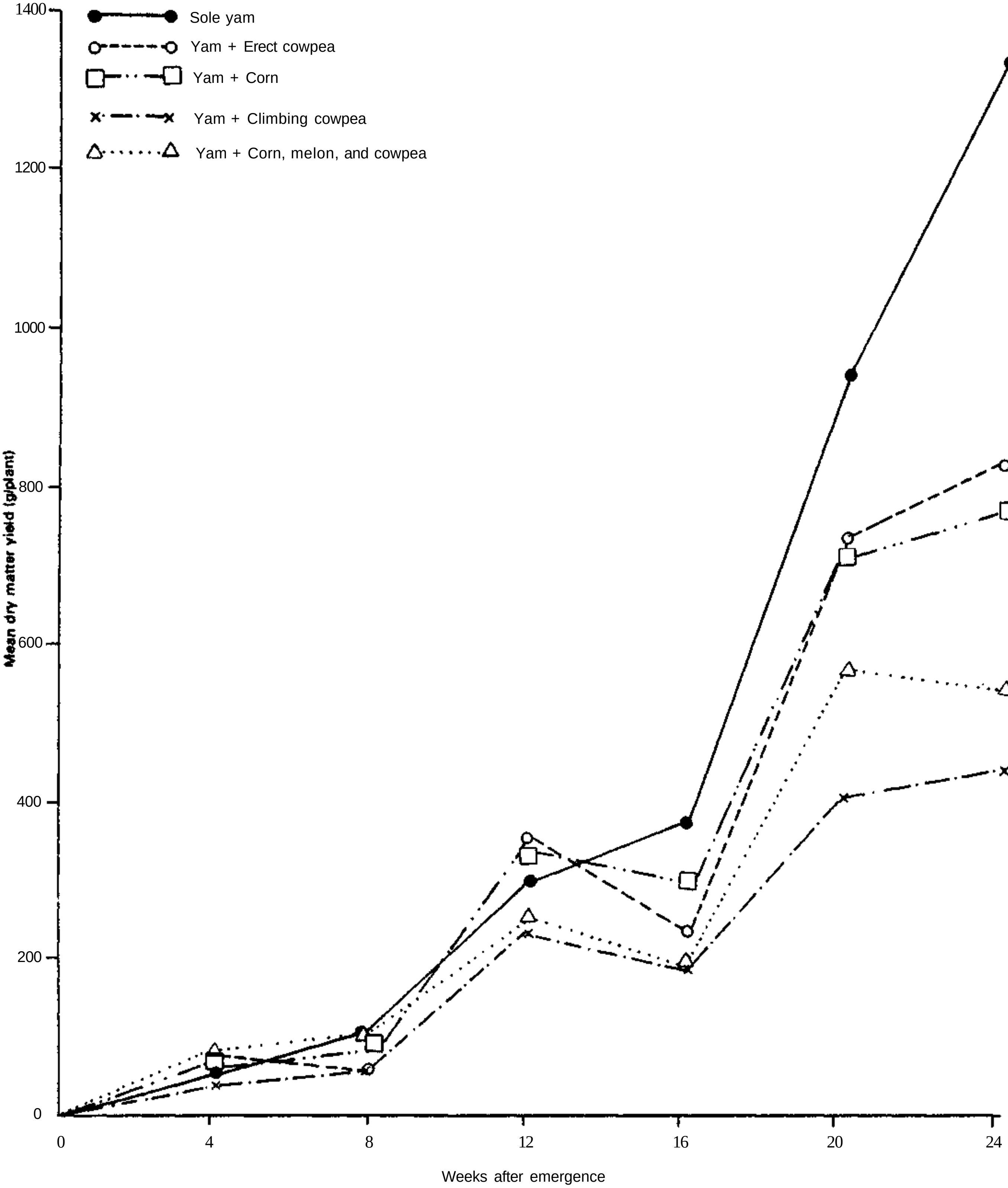

Figure 14. Changes in yam mean dry-matter yield in relation to the associated crop in the mixture.

weights were obtained from sole melon plots and, to some extent, from some melon intercrops due to early senescence of the melon, the residues of which decompose quickly and probably release nutrients which support heavier weed growth. On sole yam and corn plots, where canopy development was relatively slower, third and fourth weedings re-

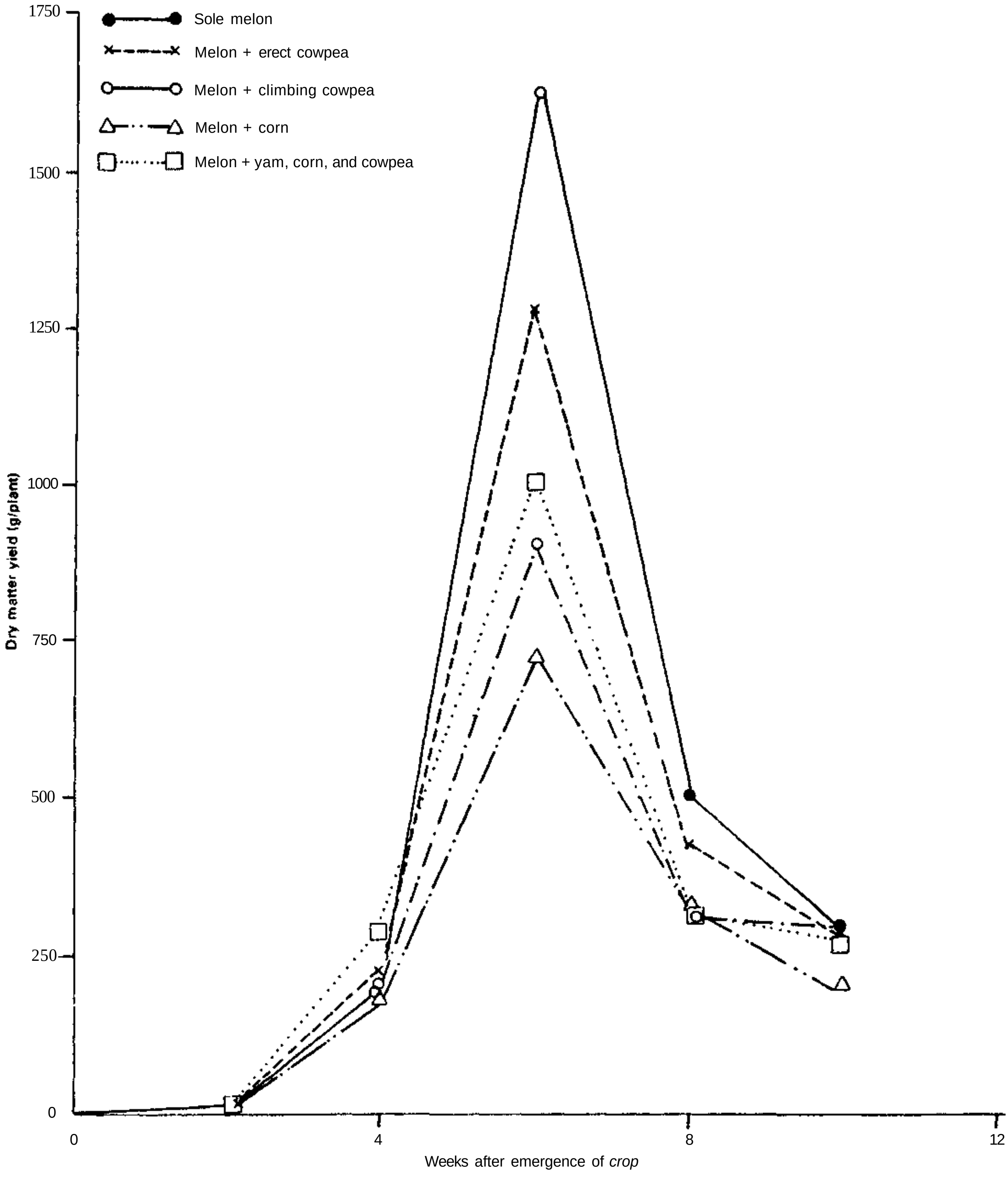

Figure 15. Changes in melon mean dry-matter yield in relation to the associated crop in the mixture.

suited in lower weed growth than sole melon. In general, intercropping suppressed weed growth after the first one or two weedings, provided that the crops in the mixture were tall, climbing, or with more persistent canopies than melon.

Thus, weed suppression was most pronounced in plots with four crop mixtures Plant-

Table 11. Land equivalent ratios (LER) observed In different intercrop treatments in 1975 and 1976.

Treatment	LER 1975	LER 1976
Yams + corn, 2 plants per stand, staggered	1.41	1.27
Yams + corn, 2 plants per stand, same row	1.28	1.32
Corn, 2 plants per stand + melon	0.90	1.12
Corn, 4 plants per stand + melon	0.91	1.14
Yams + cowpea (semierect/erect)	1.30	1.49
Yams + climbing cowpea	1.07	0.98
Corn, 2 plants per stand + climbing cowpea	0.91	0.82
Corn, 2 plants per stand + cowpea (semierect/erect)	0.96	1.21
Corn, 4 plants per stand + cowpea (semierect/erect)	1.11	0.99
Corn, 4 plants per stand + climbing cowpea	0.99	0.87
Melon + cowpea (semierect/erect), same rows staggered	1.25	1.82
Melon + cowpea (semierect/erect), alternate rows	1.09	1.29
Melon + climbing cowpea, same rows	0.91	1.19
Melon + climbing cowpea, alternate rows	1.02	0.79
Yams + corn, 2 per stand + climbing cowpea + melon	1.41	1.28
Yams + corn, 4 per stand + cowpea (semierect/erect), every 2 rows alternating with melon	1.46	1.52

Table 12. Relative yields of different crop mixtures In 1975 and 1976.

Crop mixture	Relative yields 1975	Relative yields 1976
Corn + yam	0.51	0.65
Corn + climbing cowpea	0.26	0.23
Corn + erect cowpea	0.50	0.24
Corn + melon	0.10	0.28
Com/yam/melon/cowpea	0.59	0.69
Yam + climbing cowpea	0.55	0.44
Yam + erect cowpea	0.83	0.65
Yam/corn/melon/cowpea	0.56	0.42
Melon/erect cowpea	1.13	1.23
Climbing cowpea + melon	0.34	0.34

ing patterns significantly affected weed growth. Alternate-row arrangement of melon intercropped with cowpea suppressed weeds less than melon intercropped with staggered planting of cowpea on the same ridges as the melon. It follows that cropping patterns can be selected with the objective of not only increasing yields of components in the mixture but also for effectively minimizing weed infestation and losses.

Conclusions

Intercropping of more than two crops in mixtures, as is practiced in traditional cropping systems of tropical Africa, results in a complex agroecosystem involving complex interactions among crop plants of the same species, varieties, and ages. As suggested by Trenbath (1976), competition for various factors may be involved, but there are also adaptive manifestations of crops in response to competition for light, space, nutrients, and so on. Increases in leaf dry weight, more growth and development in guard rows of melons planted inside experimental plots, differential rates of leaf-area development and dry-matter accumulation under shading, and related intercrop environment and other aspects of crop performance in complex mixtures can be utilized as a basis for crop manipulations for efficient performance in mixtures. Growth analysis in complex intercropping systems is useful in the study of crop plant competition and development of strategies for cropping systems research. It is possible with detailed observations and their analyses to (1) select crops that are compatible in mixtures with minimum changes in sole-crop plant popu-

Table 13. Competition coefficients of various crops in relation to associated crops and planting pattern in 1975 and 1976.

Crop combinations or associations and arrangements	1975	1976	Mean
Corn (2/stand staggered) + yam	0.018	0.043	0.031
Corn (2/stand same row) + yam	0.015	0.032	0.029
Corn (2/stand) + melon	0.385	0.429	0.407
Corn (4/stand) + melon	0.940	0.833	0.887
Corn (2/stand) + erect cowpea	0.729	0.903	0.866
Corn (4/stand) + erect cowpea	0.431	0.901	0.666
Corn (2/stand) + climbing cowpea	0.790	0.816	0.803
Corn (4/stand) + climbing cowpea	0.733	0.686	0.710
Corn (2/stand) + climbing cowpea + melon + yam	0.018	0.088	0.053
Corn (4/stand) + erect cowpea alternated with melon + yam	0.010	0.078	0.040
Yam + corn (2/stand staggered)	0.982	0.957	0.969
Yam + corn (2/stand same row)	0.985	0.968	0.977
Yam + erect cowpea	0.973	0.963	0.968
Yam + climbing cowpea	0.954	0.955	0.955
Yam + corn (2/stand) + climbing cowpea + melon	0.963	0.778	0.871
Yam + corn (4/stand) + erect cowpea + melon	0.839	0.681	0.760
Climbing cowpea + corn (2/stand)	0.210	0.184	0.197
Climbing cowpea + corn (4/stand)	0.268	0.314	0.291
Climbing cowpea + yam	0.046	0.045	0.046
Climbing cowpea + melon (same row)	0.403	0.252	0.328
Climbing cowpea + melon (alternate rows)	0.148	0.243	0.196
Climbing cowpea + melon + corn (2/stand) + yam	0.010	0.076	0.043
Erect cowpea + corn (2/stand)	0.271	0.097	0.184
Erect cowpea + corn (4/stand)	0.569	0.099	0.334
Erect cowpea + yam	0.028	0.037	0.033
Erect cowpea + melon same row staggered	0.961	0.558	0.759
Erect cowpea + melon alternate rows	0.976	0.574	0.725
Erect cowpea + melon + corn (4/stand) + yam	0.006	0.137	0.072
Melon + corn (2/stand)	0.615	0.571	0.593
Melon + corn (4/stand)	0.060	0.167	0.114
Melon + erect cowpea	0.039	0.442	0.241
Melon + climbing cowpea (same row)	0.597	0.749	0.673
Melon + yam + corn (2/stand) + cowpea	0.010	0.059	0.035
Melon + yam + corn (4/stand) + erect cowpea	0.010	0.105	0.056

lation and planting arrangement for optimum performance, (2) determine what factors should befactorially superimposed on selected crop mixtures to enhance identification of suitable management practices for efficient crop performance in mixtures, and (3) predict to what extent relay intercropping, spatial arrangements, and use of crop plants possessing certain canopy structures and other characteristics can enhance efficiency of production in mixtures.

Although at present several indices are used in evaluating crop productivity in mixtures, indices such as LER, competition coefficient, relative yields, calorie equivalent, and gross returns can be reliably used to select efficient mixtures for relay and simultaneous intercropping. In a complex intercropping experiment involving yam, corn, melon, and cowpea, the highest calorie yields and returns were obtained in mixtures containing yams and corn. Where these crops are not involved in the mixture, it may be best to grow them separately as sole crops. Most stable yields were obtained in mixtures of the four crops.

Study of crop and weed competition has indicated possible changes in weed control strategy in which crop mixtures may be specially designed to minimize weed infestation and attendant losses.

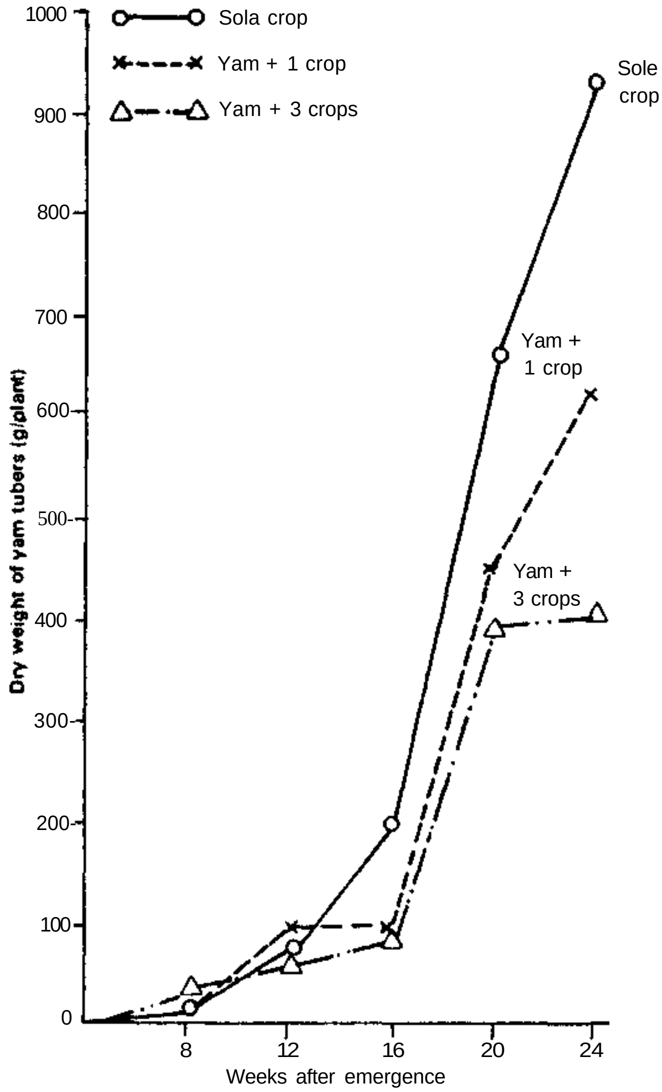

Figure 16. Dry weight yields of yam tubers in relation to number of crops in mixture and sampling time.

Finally, results of these preliminary complex intercropping experiments indicate that the current strategy at IITA of aiming at crop combinations and sequences centered on certain major staples such as cassava, yam, corn, rice, and plantains is a sound one vis a vis thousands of possible mixtures that are tenable with the numerous major and minor crops that can be grown in the humid tropics.

Table 14. Gross returns (₦) of the different crop components under sole cropping and Intercropping mixtures.

Treatments	1975	1976
Yams alone	3001.38	2734.15
Corn alone	643.50	1281.50
Erect cowpea alone	657.75	115.65
Climbing cowpea alone	222.75	162.00
Corn alone 2/stand	650.65	1125.85
Yams + corn 2/stand, staggered	1940.83	2469.83
Yams + corn 2/stand, same rows	2193.48	2651.24
Corn 2/stand + melon	609.50	1251.90
Corn 4/stand + melon	592.50	1208.13
Yams + erect cowpea	1965.50	2680.88
Yams + climbing cowpea	1670.00	1536.19
Melon + climbing cowpea, same rows	331.25	412.00
Yam + maize 2/stand + melon + climbing cowpea	1988.25	1949.60
Yams + maize 4/stand + erect cowpea in 2 alternate rows with melon	2410.35	2156.99

Table 15. Calorie equivalents per ha of the different crops grown **alone or in Intercrops.**

Treatments	1975	1976
	(In 1 x 10^6 calories/ha/day)	
Yams alone	16.39	14.94
Corn alone	10.44	20.80
Erect cowpea alone	7.41	1.30
Climbing cowpea alone	2.50	1.83
Corn alone, 2/stand	10.56	18.27
Yam + corn, 2/stand, staggered	17.35	21.91
Yam + corn, 2/stand, same row	16.86	22.60
Corn, 2/stand + melon	8.69	18.94
Corn, 4/stand + melon	9.33	17.30
Yam + erect cowpea	13.90	13.44
Melon + climbing cowpea alternate rows	4.21	2.63
Yam + maize, 2/stand + melon + climbing cowpea	15.73	19.50
Yam + corn, 4/stand + erect cowpea in 2 alternate rows with melon	17.89	21.22

Acknowledgments

I hereby acknowledge the work and assistance of Dr. A. A. Fagbamiye, who did most of the field work, tabulated the data, and wrote the thesis on which part of this work was based; Mr. B. Gilliver, who assisted with analysis of the data; and Professors A. A. Fayemi and V. Bartholomew, who assisted with suggestions in the analysis and interpretation of the data.

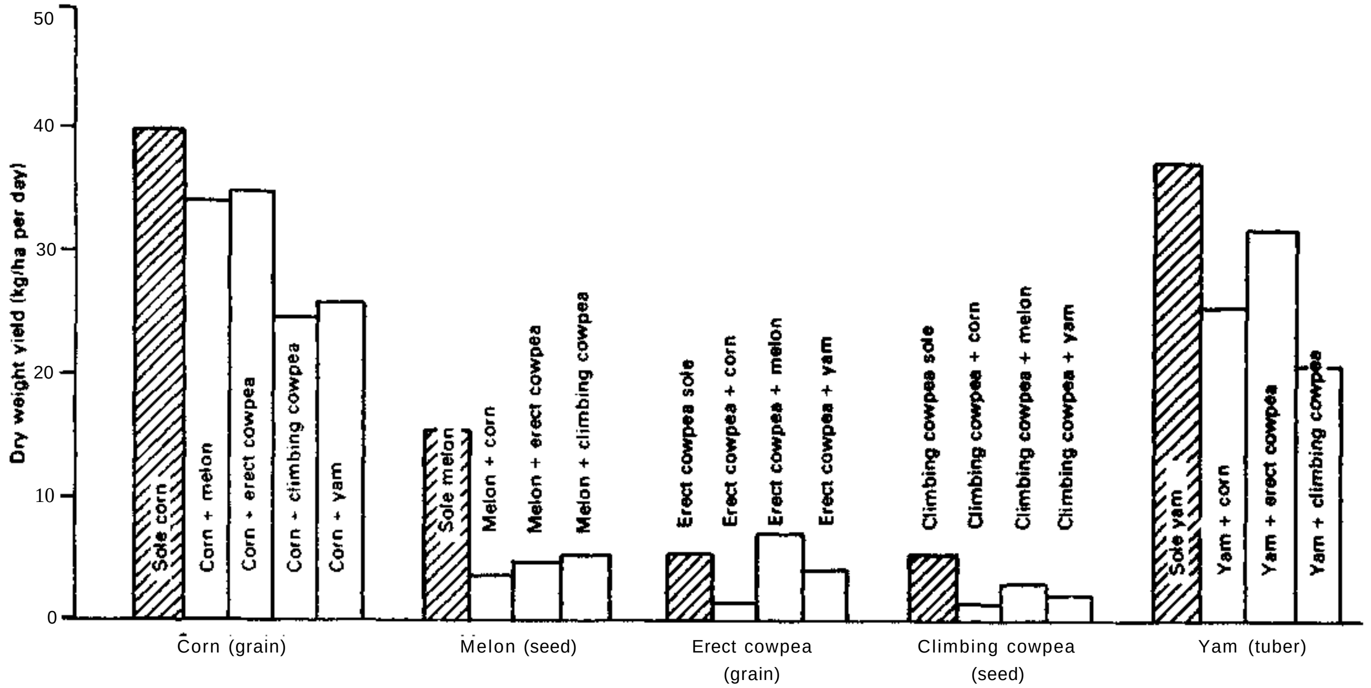

Figure 17. Dry weight yields of grain or tuber for different crop mixtures.

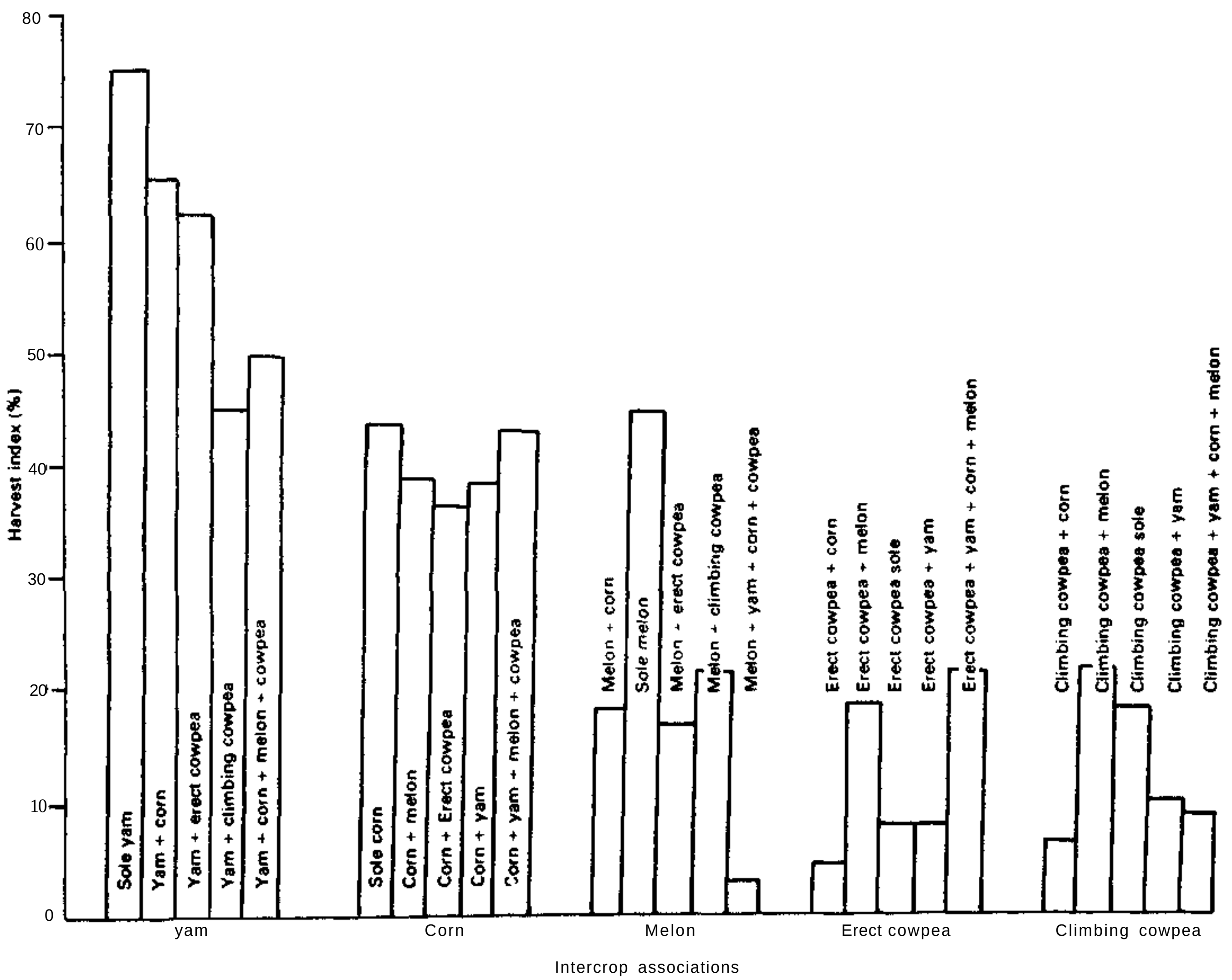

Figure 18. Harvest indices of sole crops as compared to those of mixtures.

Growth Studies in Sorghum/Pigeonpea Intercropping with Particular Emphasis on Canopy Development and Light Interception

M. Natarajan and R. W. Willey*

Abstract

Two experiments were conducted at ICRISAT Center on a medium deep Vertisol during 1977 and 1978 to study in detail the growth and resource use by the sole crops and intercrops of sorghum and pigeonpea. In the first experiment, growth and yield of sorghum in an intercropping pattern of 2 rows sorghum: 1 row pigeonpea was similar to that of sole sorghum. The pigeonpea intercrop experienced considerable competition from sorghum, but after the sorghum harvest it compensated for the initial slow growth and produced seed yield equivalent to 70% of the sole crop. Light use by the intercrop canopy was efficient except for a period of very low interception during the period immediately after sorghum harvest. In the second experiment (stiff being conducted), attempts were made to improve fight interception during this period by changing the row arrangement to a 1: 1 pattern and increasing the pigeonpea population. Data so far available indicate that both factors have increased the light interception; in general, this has produced a dry-matter response, but final seed yields are not yet available.

Many recent investigations have shown that intercropping can give genuine and often very substantial yield advantages. The main physiological reason for such advantages would appear to be that, when grown together, the component crops complement each other and make better total use of environmental resources than when grown separately.

Intercropping is reported to be particularly beneficial when it involves two component crops which are of very different growth cycles because this allows the greatest scope for making better temporal use of resources (Kassam and Stockinger 1973; Willey and Lakhani 1976). An early-maturing sorghum (e.g., about 90 days) with a later-maturing pigeonpea (e.g., about 180 days) is such a combination and one in which several workers have shown very substantial yield advantages (AICRPOA 1976; ICRISAT 1977c, 1978; Krantz et al. 1976; Sheike 1977).

In most intercropping experiments, better use of resources is simply assumed because of higher yields, and there is a need for a better understanding of exactly how the resources are used. This understanding should help to provide a basis for further yield improvement besides indicating howtheyield advantagesare likely to be affected by growing conditions. This paper presents some of the findings from ICRISAT studies conducted to obtain this basic information on resources use by sorghum/pigeonpea.

Experimental Methods

Experiment I (1977)

This experiment was sited on a medium deep Vertisol with an available water-holding capacity of approximately 200 mm in the top 150 cm

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of the profile. Rainfall during the growing season was 575 mm, well distributed during early growth, but September was very dry with a long dry spell of 27 days. Some good showers occurred in early October.

The experiment comprised 11 treatments, which included the two sole crops at what is considered to be their respective optimum populations (180 000 plants/ha for sorghum and 40 000 plants/ha for pigeonpea). The other nine treatments were intercrop treatments consisting of the full factorial of three population levels each of sorghum and pigeonpea. The medium population (S_2 and P_2) in both the crops was the same as the sole-crop optimum; the lowest (S_1 and P_1) and highest (S_3 and P_3) were equal to half and double the optimum, respectively. In sorghum, the S3 population (360 000 plants/ha) could not be achieved, so the plant population at the time of first sampling (320 000 plants/ha) was considered as the established population. The cultivars used were CSH-6 sorghum and ICP-1 pigeonpea.

All the treatments were grown in 45-cm rows. All intercrop treatments were grown in a standard row arrangement of two rows of sorghum to one of pigeonpea, and different populations were achieved by altering within-row spacings. This 2:1 row arrangement was adopted because of the considerable evidence that this could help ensure the "full" sorghum yield (i.e., equal to the sole crop) usually desired by farmers.

Sampling for growth analysis was carried out at 2-week intervals for all the treatments on harvest areas of 2.43 m^2. In the sole plots and the S_1P_1, S_2P_2, and S_3P_3 intercropping treatments, further detailed studies were made, which included light interception, moisture use, nutrient uptake, and some preliminary work on rooting patterns. Light interception was measured using tube solarimeters. Two solarimeters per plot were placed at ground level, and the difference between these and a "control" solarimeter recording incident light was measured as integrated daily totals on every third day in each plot. Soil moisture was monitored at 15-day intervals using a neutron probe; four access tubes were monitored in each intercrop plot and two in each sole plot. The top 22.5 cm of the profile was monitored gravimetrically. In this paper, only the yield, leaf area index and light interception data are discussed in detail.

Experiment II (1978)

This experiment was planned as a result of the findings from Experiment I. Data from this experiment are not yet fully available, but some information on light interception and dry-matter production in a selected few treatments of particular interest are discussed. These treatments were:

Pigeonpea populations:
- P_1 (40 000 plants/ha)
- P_2 (80 000 plants/ha)
- P_3 (120 000 plants/ha)

Row arrangements:
- 2:1 (2 sorghum rows: 1 pigeonpea row)
- 1:1(1 sorghum row: 1 pigeonpea row)

Other aspects were as for Experiment I, except that sorghum was sampled for dry matter and LAI at weekly intervals and the sampling area was 2.99 m^2.

Soil of the experimental site was similar to the one described above, but the rainfall during the growing period was abnormal. A total of 995 mm rain was received during the season, of which 542.5 mm was received during August. September received 79 mm rain, which was distributed fairly uniformly.

Results and Discussion

Experiment I

Performance of the two crops in sole and intercrop systems

Initial comparisons between intercrops and the sole crops are presented at a constant population of each crop, so that the intercropping performance indicates the direct competitive effect of *adding* the other crop. Figure 1 illustrates the cumulative dry matter per unit area in these treatments throughout the season. The typical rapid accumulation of dry matter by the sole sorghum crop and the much slower accumulation of dry matter by the sole pigeonpea crop are evident. In intercropping, sorghum was the dominant component, and it grew at a rate comparable to that of sole sorghum. There was no sign that it experienced any competition from pigeonpea and the grain yields of sole and intercrop sorghum were not statistically different.

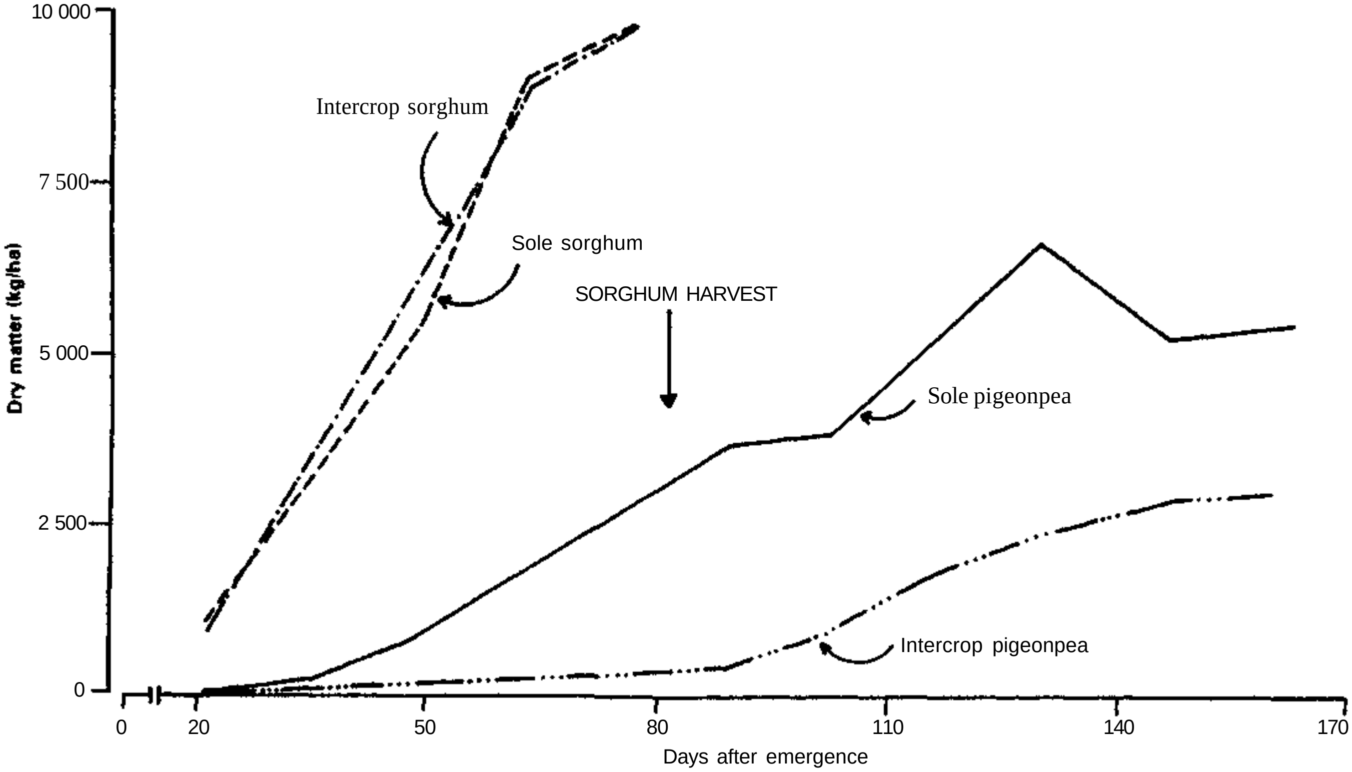

Figure 1. Dry-matter accumulation in sole sorghum and pigeonpea and in sorghumIpigeonpea intercrop on Vertisols at ICRISAT Center (Experiment I, 1977).

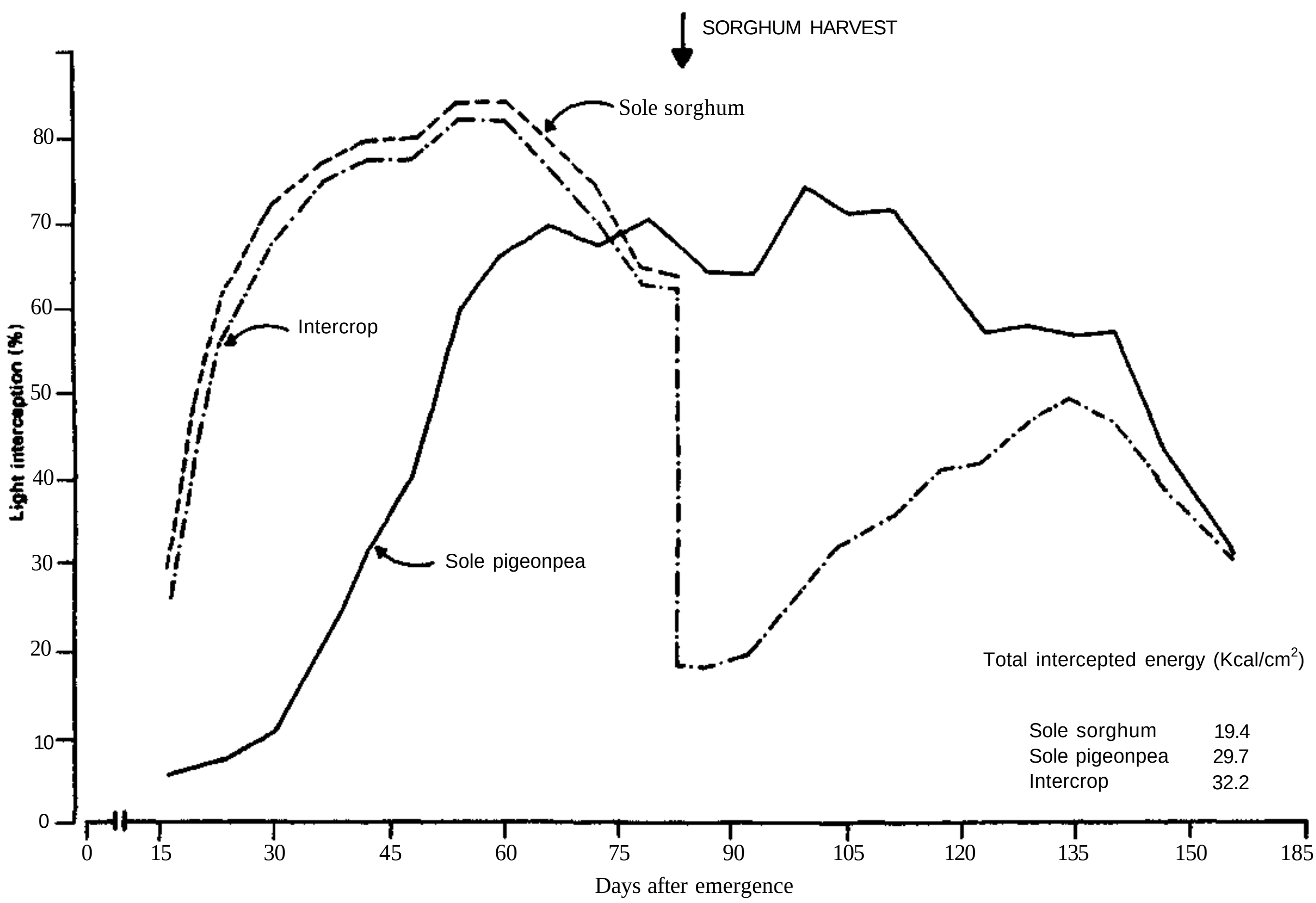

Figure 2. Light interception by sole sorghum and pigeonpea and sorghum Ipigeonpea intercrop on Vertisols at ICRISAT Center (Experiment I, 1977).

In contrast, pigeonpea in the intercrop experienced severe competition from sorghum; its growth was considerably reduced and the onset of flowering was delayed by approximately 18 days. At sorghum harvest, which was about 85 days after sowing, the dry-matter yield of intercrop pigeonpea was only 14.5% of that of the sole pigeonpea. After the sorghum was removed, the intercrop pigeonpea was able to compensate to some extent, but at the final harvest it had produced still only the rather low total dry-matter yield of 3050 kg/ha, which was equivalent to 42% of the sole crop.

The harvest index, however, was 31.9% for intercrop pigeonpea compared with only 18.8% for the sole crop. This occurred presumably because sorghum competition mainly suppressed early vegetative growth. It resulted in intercrop pigeonpea seed yield being as much as 69.7% of the sole-crop seed yield (Table 1).

Canopy development was very rapid in sole sorghum. As Figure 2 illustrates, at 30 days after emergence, it had already intercepted more than 70% of the incident radiation and by about 55 days the peak interception of 84% was achieved. Canopy development in sole pigeonpea was much slower: at 30 days, this crop had intercepted only 10% of the incident light, and at 60-65 days, it had reached a near maximum value of 70% which was more or less maintained until about 110 days. The peak level of interception in sole pigeonpea was 77% at 100 days. At sorghum harvest, the cumulative energy intercepted by sole sorghum and sole pigeonpea was 19.4 and 11.2 $Kcal/cm^2$, respectively, which indicates relative efficiency; however, at final harvest, pigeonpea had intercepted 29.7 $Kcal/cm^2$.

In the intercrop, it was not possible to measure the amount of light intercepted by the sorghum and pigeonpea components separately. Figure 2 shows the combined interception by both crops prior to the sorgum harvest; this was surprisingly high because the contribution from pigeonpea was very low and, although the intercrop had just as high a sorghum population as the sole crop, the sorghum plants in the intercrop occurred in only two rows out of each three rows. At sorghum harvest, the total energy intercepted by the intercrop was 18.6 $Kcal/cm^2$ compared with the 19.4$Kcal/cm^2$ intercepted by sole sorghum.

Immediately after sorghum harvest, the interception by the remaining pigeonpea fell to only 19% and reached a maximum of only 50% at about 135 days. This was a particularly inefficient period of interception; nevertheless, the total light energy eventually intercepted by the intercrop was 32.2 $Kcal/cm^2$, which was still greater than the 29.7 $Kcal/cm^2$ intercepted by the sole pigeonpea.

Figure 3 illustrates the efficiency with which the intercepted energy was converted into dry matter throughout the growing period. Comparing the sole crops, the fitted regression lines show that the sorghum at 6.3 mg/Kcal was much more efficient than the pigeonpea at 2.6 mg/Kcal. Presumably this was mainly because of the difference between a C_4 and C_3 crop. The intercrop converted the intercepted light energy before sorghum harvest at a rate of 7.0 mg/Kcal, which was more efficient than sole sorghum. After the sorghum harvest, the efficiency of conversion of the intercrop pigeonpea reverted to a value virtually identical to that of sole pigeonpea.

Data on soil-moisture use showed that the net moisture loss from the profile over a given

Table 1. Mean effect of yield and yield components of pigeonpea in sole cropping and at different populations of either pigeonpea or sorghum in intercropping, Experiment I.

Treatment	Seed yield (kg/ha)	Stalk yield (kg/ha)	Harvest index (%)
Sorghum population			
S_1	748	1705	30.7
S_2	671	1376	32.9
S3	650	1331	33.0
Pigeonpea population			
P_1	630	1212	34.3
P_2	709	1529	31.9
P_3	732	1673	30.5
SE(m)	34	63	0.67
LSD (0.05)	101	186	1.99
Intercrop	690	1472	32.2
Sole crop	1017	4382	18.8
Sole crop vs. intercrop			
LSD (0.05)	143	274	2.65
CV (%)	15.2	12.1	6.7

period of time was independent of the degree of canopy cover and that the cropping patterns simply altered the proportions of transpiration and evaporation from the soil surface. Thus the yield advantages of intercropping were achieved not at the expense of making greater overall demand on soil moisture but simply by channelling a greater proportion of the evapotranspiration through the crop. The implication of this is that the intercropping situation could be improved by increasing canopy cover and light interception after sorghum harvest and this would not affect water demand. Ideally this means having a better pigeonpea canopy at the time of sorghum harvest and a more rapid further development thereafter.

Table 2. Mean effects of sorghum and pigeonpea population on land equivalent ratios (LERs) in sorghum/pigeonpea intercropping, Experiment 1.

Treatment		Sorghum	Pigeonpea	Total
Sorghum				
population	S_1	0.93	0.74	1.67
	S_2	0.97	0.66	1.63
	S_3	0.92	0.64	1.56
Pigeonpea				
population	P_1	0.97	0.62	1.59
	P_2	0.90	0.70	1.60
	P_3	0.95	0.72	1.67
Mean		0.94	0.68	1.62

Response to Plant Population in Intercropping

There was a positive dry-matter response to increase in sorghum populations in intercropping. This was not reflected in the grain yield however, and the grain yields from all the three populations were not significantly different. There was also surprisingly little effect of sorghum population on pigeonpea except that at the lowest sorghum population (S_1), pigeonpea dry matter and seed yield were higher than at S2 and S3.

Pigeonpea population had a much greater effect on pigeonpea dry matter, and there were consistent positive responses between all population levels, but especially between P_1 and P2. This pattern was also repeated in the leaf area data, which show that increased pigeonpea population produced a higher and somewhat earlier peak of LAI. However, these differences in LAI patterns were not reflected in the light interception measurements. Part of the reason for this was probably that higher populations were achieved by increasing the plant number within the row, whereas the real constraint to improved light interception was the inability of the poorly branched intercrop pigeonpea to intercept light between the relatively wide 135-cm rows. The growth responses at higher populations were partly affected by a decrease in harvest index, but final seed yield still showed a positive response, the response between P_1 and P_3 almost reaching statistical significance.

The overall results of these population effects are given in Table 2, in terms of LER values. There was relatively little difference between treatments, but there was still evidence of a positive response in total LER with an increase in pigeonpea population and a negative one with an increase in sorghum population.

Experiment II

Experiment I showed that the sorghum/pigeonpea system was a very efficient one, producing a full crop of sorghum and approximately a 70% yield of pigeonpea. Further improvement in this system must be in increasing the pigeonpea contribution, and indications from Experiment I were that this might be achieved by improving the pattern of light interception just after sorghum harvest. In Experiment II this was attempted by (a) growing the intercrop in alternate rows so that the effective row width of pigeonpea was 90 cm compared to the earlier 135 cm, and (b) increasing pigeonpea population to a much higher level. Data from this second experiment are not yet fully available, but some aspects of light interception and dry-matter accumulation are briefly presented.

At a pigeonpea population of 40 000 plants/ha (approximately equal to the sole crop optimum), the intercrop pigeonpea in the 2:1 pattern achieved a light interception value of 30% at the time of sorghum harvest (Fig. 4),

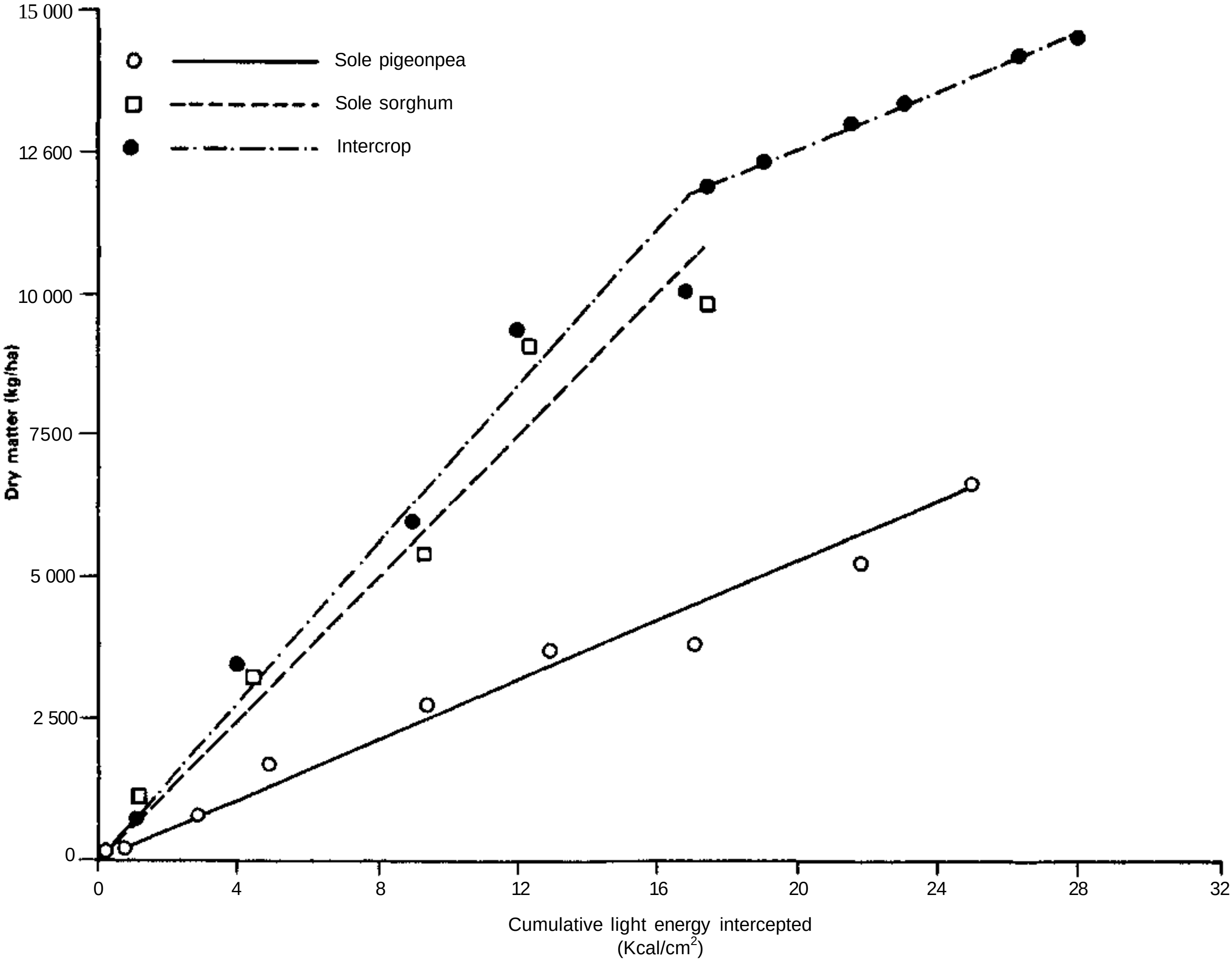

Figure 3. Efficiency of conversion of intercepted light energy into dry matter on Vertisols at ICRISAT Center (Experiment I, 1977).

which was somewhat higher than the comparable treatment in the previous year. This was probably because pigeonpea growth was in general much better this year, perhaps because of the wetter August and September. But the alternate-row pattern gave a substantially higher level of interception after sorghum harvest. This started at approximately 48% interception and reached a peak value of 71%; in total energy terms, this pattern intercepted 18% more light after sorghum harvest than the 2:1 pattern. It can also be seen that this greater interception was initially reflected in an appreciable dry-matter response, though by the time of the later harvests, dry-matter yields were little different (see Fig. 6a).

At the higher pigeonpea population of 120 000 plants/ha, both row patterns gave a higher initial light interception after sorghum harvest than at the lowest pigeonpea population; actual values were 51% and 61% for the 2:1 and 1:1 patterns, respectively (Fig. 5). Thereafter, difference between the patterns diminished, and they both reached a similar peak value of about 76%. Again, these higher values of interception were reflected in higher dry-matter yields compared to the lowest pigeonpea population (Fig. 6).

Thus, the preliminary indications are that, compared with the treatments tried in Experiment I, light interception by intercrop pigeonpea after sorghum harvest can be improved quite substantially by an improved row arrangement and by a higher pigeonpea population. As described in Experiment II, this improved interception was in general reflected in higher dry-matter yields; only final pigeonpea harvest will show to what extent they are also

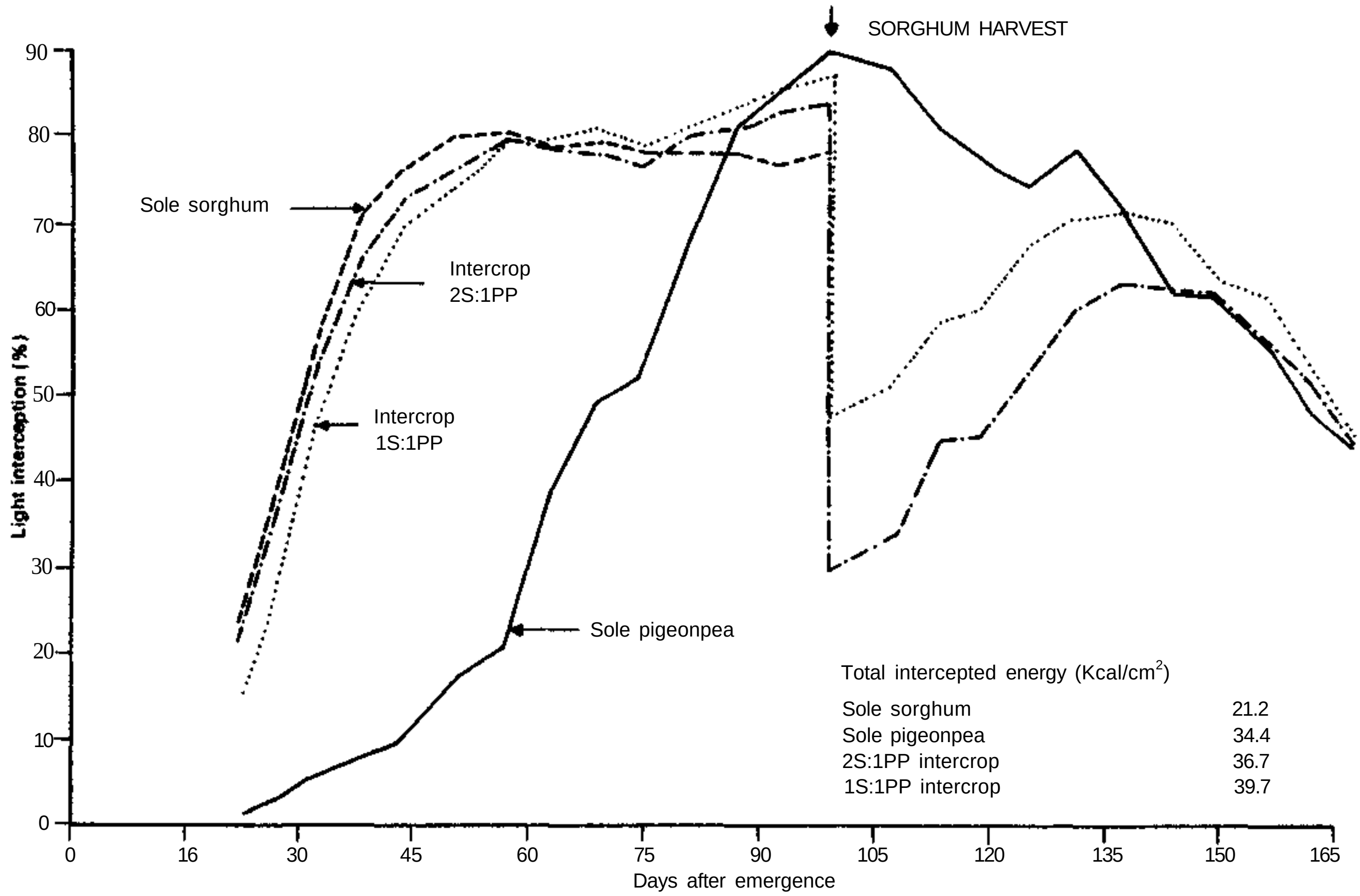

Figure 4. Light interception by sorghumlpigeonpea intercrop at two row arrangements and 40 000 pigeonpea p/antslha on Vertiso/s at ICRISAT Center (Experiment II, 1978).

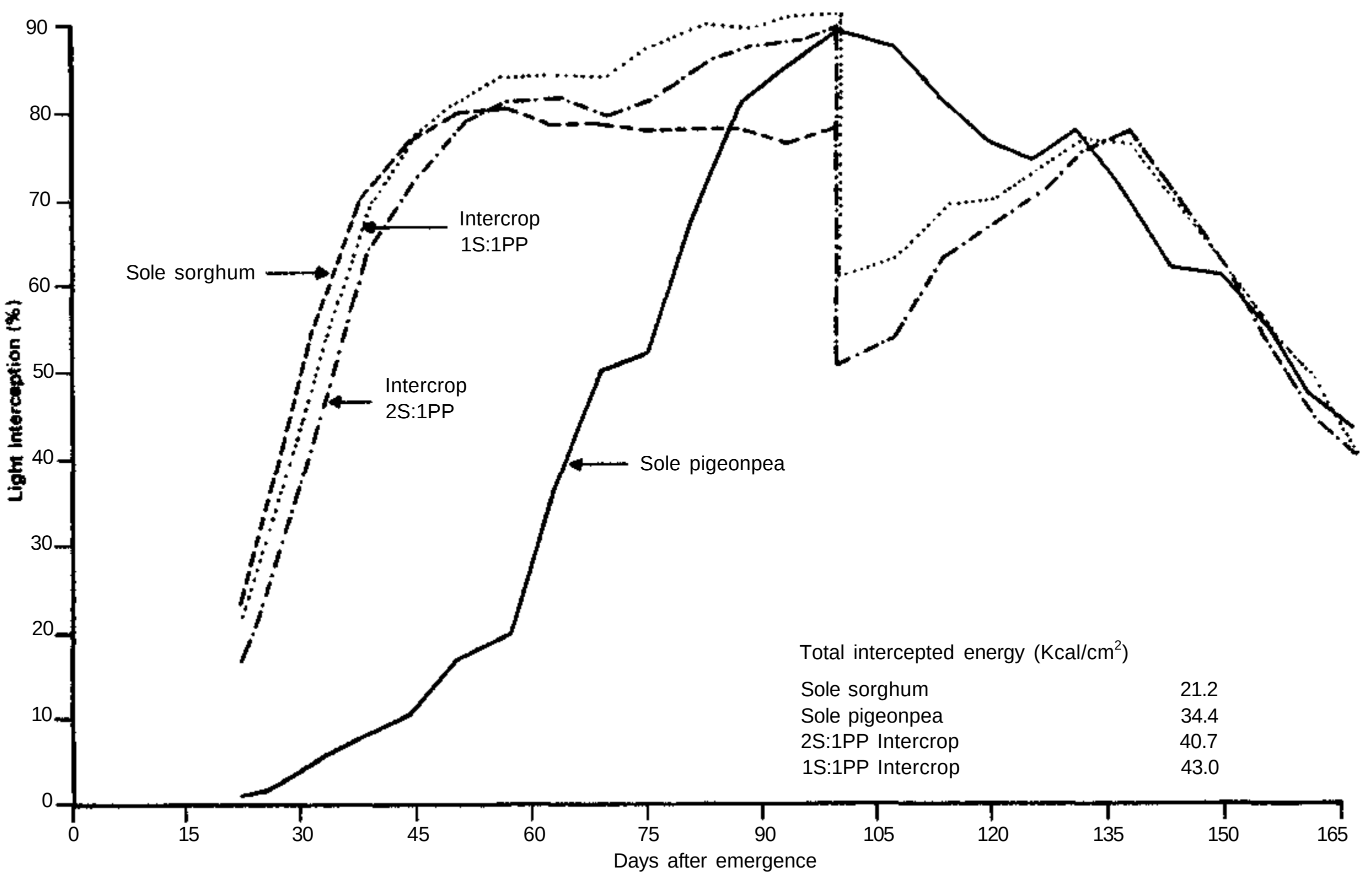

Figure 5. Light interception by sorghumlpigeonpea intercrop at two row arrangements and 120 000 pigeonpea plants/ha on Vertisols at ICRISAT Center (Experiment II, 1978).

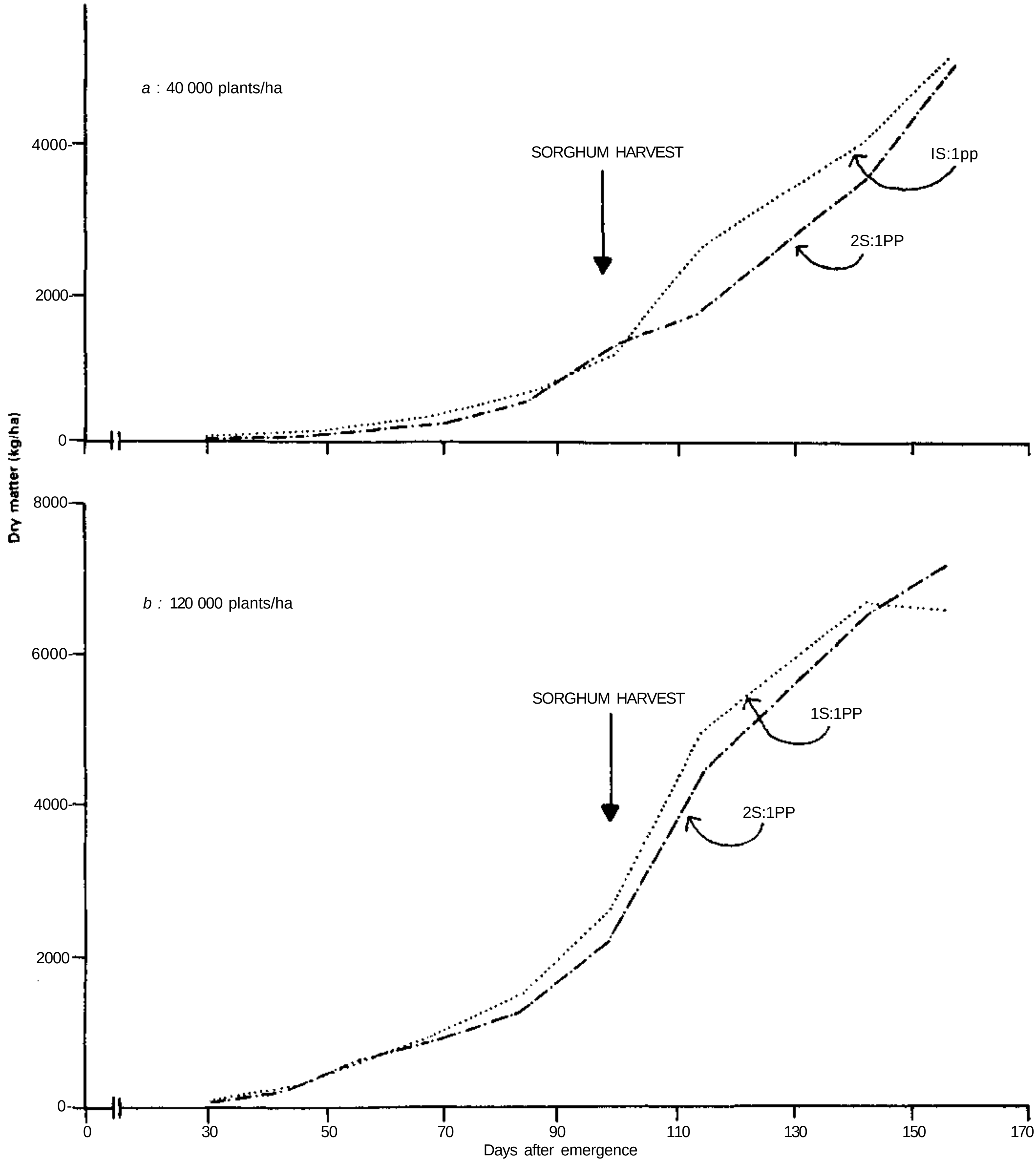

Figure 6. Dry-matter accumulation by intercropped pigeon pea at two row arrangements and two plant populations on Vertiso/s at ICRISAT Center (Experiment II, 1978).

reflected in seed yields. It is also important to emphasize that these improvements were brought about by little or no sacrifice in sorghum yield. Increased pigeonpea population had virtually no effect on sorghum yield, and the mean reduction in sorghum yield from the 2:1 pattern to the 1:1 pattern was only 4.8%.

Acknowledgments

We acknowledge the cooperation of Mr. Piara Singh in providing data on moisture use and the help of Mr. A. A. H. Khan in the light measurements.

Interactions Belowground—The Use of Nutrients and Water

R. W. Snaydon and P. M. Harris*

Abstract

We have classified the various mechanisms of intercropping that might lead to more effective use of limiting resources, and so to yield advantages. Cases where intercropped species compete fully are first separated from those where competition is only partial; further subdivisions are then made.

The necessary conditions for all these mechanisms to function are commonly found in the soil. In particular, soil resources (water and mineral nutrients) are most commonly the limiting factors in agricultural production; therefore, there is scope for more effective utilization of these resources.

Experimental evidence shows that plant interactions belowground are normally more intense than those aboveground, though the particular limiting resources and the mechanisms involved have rarely been studied in detail.

Both direct and indirect evidence indicates that belowground interactions often give rise to yield advantages in intercropping. The most common and largest advantages occur when legumes and nonlegumes are intercropped. The advantage is usually due to the use of different resources (N_2 and NO_3), only one of which (NO_3) is limiting, though other mechanisms may also be important in some cases. In mixtures of nonlegumes, zonation of the root systems may lead to the more effective use of nutrients or water, and so to intercropping advantage.

There is, as yet, too little evidence to clearly define which environmental conditions, and which plant attributes, are likely to give most advantage from intercropping. In general, the advantage is likely to be greatest when nutrients are deficient, and when species differ in their temporal or spatial use of soil resources.

Various experimental techniques are considered, which may improve our understanding of belowground interactions and their effects on intercropping. Most of these require more intensive study than has been common in the past, and they benefit from a team effort that involves agronomists, crop physiologists, soil scientists, and statisticians.

In most studies of intercropping, attention has been focused on the interactions that occur between the component species aboveground. This emphasis on interactions aboveground is probably because the effects are visible, and so more apparent, and because it is easier to measure such attributes as leaf area and light interception than it is to measure the size and activity of the rooting system or the abundance and distribution of water and nutrients in the soil. This paper attempts to put belowground interactions into perspective, by considering the theoretical, experimental, and practical evidence.

Trenbath (19746) and Willey (1979) have reviewed the various methods of assessing the yield advantage of intercropping. For simplicity, in this study, the advantage will normally be assessed relative to the mean of the component species, unless otherwise stated; reasons for

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this will be given later. Other methods of comparison will be used when information is available, or when those methods are more appropriate.

Two main mechanisms have been suggested (e.g., Trenbath 19746; Willey 1979), that may account for the many recorded cases of intercropping advantage. Firstly, mixtures of species and cultivars are said to reduce the damage caused by pests and pathogens (Browning and Frey 1969; Dempster and Coaker 1974). This mechanism is active belowground, as well as aboveground, but is not considered further here. Secondly, mixtures of species and cultivars are said to exploit environmental resources more effectively than pure stands (Trenbath 1974b; Willey 1979). This is the mechanism that will be explored here. We shall consider the theoretical reasons why intercropping might give greater yields than single (or sole) cropping. We shall then review the experimental evidence and briefly consider the practice of intercropping. On the basis of all these considerations, we shall argue that interactions between plants belowground are apparently more important than those aboveground in causing yield advantages in intercropping, though they may also cause lower yields in some circumstances.

Theoretical Considerations

Only one aboveground resource, light, is amenable to more effective capture in intercropping; on the other hand, a series of belowground resources, e.g., water and a variety of mineral nutrients (N, P, K, S, Ca, Mg, etc.), might be more effectively captured in intercropping. It therefore follows that, by the laws of probability, belowground interactions should more often lead to intercropping advantage than do aboveground interactions. Further, it might be expected that the more effective use of a resource would be greater the more deficient the resource. Although shading can reduce the yield of both grain (e.g., Moss and Stinson 1961; Fischer 1975; Evans 1978) and herbage (e.g., Blackman and Black 1959; Cooper and Tainton 1968; Ludlow 1978), there seems little evidence that light is a major limiting factor over much of the world's agricultural area, and certainly not in the tropical and subtropical areas, where intercropping is commonly practiced. In most agricultural areas, the most limiting factors are soil, water, and mineral nutrients. In many areas, light supply is in surfeit, leading to excessive use of already deficient water and to deficiencies of nutrients. Not until other deficiencies (e.g., water and nutrients) have been alleviated would light become a limiting factor.

There are several mechanisms, involving more effective use of environmental resources, that could lead to greater production from intercropping than from single-species stands. Surprisingly, none of the previous reviews of intercropping, with the possible exception of Trenbath (19746, 1976), have systematically considered these, though such an approach is an essential starting point for a rational consideration of the nature of intercropping. We propose a classification of possible mechanisms (Table 1) and go on to consider whether the necessary conditions exist for each mechanism to function where root systems interact. Further experimental evidence of such function is considered in a following section.

It is possible, first of all, to separate the possible mechanisms of intercropping advantage into those where species compete only partially and those where they compete wholly. Each of these broad categories can then be subdivided (Table 1).

Partial Competition

Partial differences in the time of utilization of resources (Table 1, 1ai) have long been recognized as being important in intercropping; however, most workers have assumed that the effects are due to greater capture of light, and many have measured both the seasonal pattern of leaf area (e.g., LAI) and light interception and the total leaf area (i.e., leaf area duration, LAD) and total light intercepted. It would be just as relevant to consider the seasonal pattern of uptake and total uptake of nutrients (e.g., N, P, or K), or of water since, in most cases, these are the limiting resources. Such considerations would only be relevant, however, where the resource was renewable; several of these resources (e.g., water and N) sometimes function as nonrenewable resources. A cropping system based on a limiting supply of nonrenewable water — i.e., soil-stored water with no further rainfall — would be less likely to benefit from

Table 1. Classification of possible machanisms, involving mora affactiva use of environmental rasources, that could lead to greater production from intercropping than from sole cropping.

1. Intercropped species compete only partially for limiting resources.
   - (a) Same limiting resource, but different sources:
     - (i) partially different times of use (i.e., semiconcurrent crops);
     - (ii) partially different zones of use (i.e., different root or shoot zonation);
   - (b) different limiting resources:
     - (i) same requirement met by different resource (e.g., N_2 & NO_3 for legumes and nonlegumes);
     - (ii) different requirements (e.g., light, various mineral nutrients, water).
2. Intercropped species compete wholly; the most productive component is most competitive and the outcome of competition is unpredictable.
   - (a) The environment is spatially variable (i.e., mosaic environment).
   - (b) The environment is temporally variable (i.e., seasonal and year-to-year).

semi-concurrent cropping than one based on a continuous supply of soil water from rain or irrigation. Similarly, a system based on N supplied from an initial store would benefit less than one supplied from a continuous supply (e.g., by fixation or decomposition). Nutrients such as P and K are usually released from fixed forms, or exchange sites, as the solution phase is depleted, and are therefore renewable resources in the soil.

The possible importance of root zonation in intercropping (Table 1, 1aii) has been recognized, but has generally been given less attention than leaf stratification, leaf angle, and light interception. The zonation of nutrients and water in soils is also widely recognized. The pattern of zonation in the soil varies greatly, depending on the particular resource considered, on the particular environmental conditions (soil, climate, and biotic) existing, and on the management practices conducted. Immobile nutrients, such as P, are most stratified in the soil, especially where there has been little disturbance of the soil. Soluble anions (e.g., $N0_3$ and SO_4), mobile cations (e.g, K and Na), and, most of all, water are more freely distributed. However, even in these cases strong zonation can develop. For example, N tends to occur mainly in the superficial layers when applied as fertilizer or released from superficial deposits of litter; water occurs mainly in the superficial layers of soils in semi-arid areas (e.g., Snaydon 1972), but most of the water may be below 0.5 m in summer in temperate regions, after plants have extracted the superficial water (e.g., Garwood and Williams 1967). Parallel to these differences in the zonation of resources, there are differences in the root distribution pattern of crops, weeds, and pasture species (e.g., Welbank et al, 1973; Parrish and Bazzaz 1976). There ought to be opportunities, therefore, for the complementary use of soil resources by component species.

All plants have requirements for the same factors (light, CO_2, O_2, water, nutrients, etc.). They may differ, however, either in the way that the requirement is satisfied — i.e., the resource that is used (Table 1, 1bi) — or in their limiting requirement for the resource (Table 1, 1bii). There are relatively few examples where different resources are used to satisfy the same requirement (Table 1, bi). The most obvious example is for N supply, where most species use NO_3 from the soil solution, but some are able to use NH_4^+, and some species, especially legumes, are ableto fix N_2 by symbiotic associations with microorganisms. There is also some evidence that crop species may extract different forms of P (e.g., Russell et al. 1958; Kalra 1970). In the case of N, P, and perhaps Fe, the species may not only use different sources but also, under some circumstances, one species may make additional supplies available to the other. There are, of course, innumerable examples of this for N, in mixtures of legumes and nonlegumes, and rare examples for P and for Fe (Kashirad and Marschnar 1974).

The most common examples of intercropping advantage occur when legumes and nonlegumes are grown together. It would seem, therefore, that utilization of different resources (Table 1, 1bi) is the most effective mechanism. However, several workers have attributed the advantage of some mixtures of legumes with nonlegumes to other factors, such as semi-concurrent growth (e.g., Osiru and Willey 1972, 1976).

There should be cases where intercropped speciesdiffer in their requirement for a resource (Table 1,1bii), since crop species (and cultivars) differ considerably in response to various mineral nutrients and to water. The available evidence has not been fully reviewed, though Epstein and Jefferies (1964) and Epstein (1972) have made partial reviews of the differences, while Andrews and Johansen (1978) and Robson and Loneragan (1978) have reviewed differences between pasture species. Crop species differ considerably in their response to P (e.g., Loneragan and Snowball 1969). Few comparisons have been made of differences between crop species in response to N, but large differences exist between grass species (e.g., Bradshaw et al. 1964) and crop cultivars (e.g., Gardner and Rathjen 1975). The various crop and pasture species also differ in the critical concentration or "functional nutrient requirement" within the plant material — i.e., the internal concentration necessary to sustain unrestricted growth. There are fourfold differences between species for calcium concentration (Loneragan and Snowball 1969), twofold differences for potassium concentration (Asher and Ozanne 1967) and phosphate (Ozanne et al. 1969), and threefold differences for nitrogen concentration (Gladstones and Loneragan 1975).

In cases where the species which respond least to the external supply of the nutrient also have the lowest "critical concentration" (e.g., for Ca and P, though notfor K), then it is possible that a mixture of two species with different limiting resources may be more productive than either alone. Each species would extract less of the resource that is limiting to the other, yet not be itself inhibited by this. Similar relationships between species might exist for water versus some nutrient, and perhaps for some soil factor versus light.

Full Competition

It is not generally appreciated that it is possible to obtain intercropping advantage even if the components are in full competition. Intercropping advantage will occur if, on the one hand, the environment is unpredictably variable in space and/or time and, on the other hand, the most competitive component in each set of conditions is also the most productive.

Imagine first a spatial mosaic (Table 1, 2a) of two environments (a and b) sown to a mixture of two species (A and B). Species A is most productive and also most competitive in environment a, and similarly species B in b. Even if we set relative yield totals (RYT) at 1.0 in each of the two environments, then it is possible for the mixtureto exceed the yield of both components and for RYT > 1.0 over the whole mosaic (Table 2). The size of the intercropping advantage depends, of course, upon the magnitude of the difference in response of the two species to the two environments, on the magnitude of the difference in competitive ability in the two environments, and on the correlation between yield and competitive ability. If the nature of the mosaic is known and is sufficiently large, and if the response of the species (or cultivars) to the variation is known, it would be possible to sow the "best" species in each area. However, the nature of the variation is rarely known, the size of mosaic is usually too small, and the responses of species (and cultivars) are unknown, so that intercropping would be better than sole cropping, given the above assumptions.

There is usually considerable spatial variation within a single cropped area (Beckett and Webster 1971); indeed, variation seems to be greater within cropped areas than in undisturbed areas (Beckett and Webster 1971). Much of the variation exists over distances of a few meters (Beckett and Webster 1971), so that it is not possible to sow each species in the most suitable environment, and intercropping may therefore be more advantageous (Table 2). By contrast, the aboveground environment, and especially light intensity, is much more uniform laterally, so the same advantages are unlikely to hold aboveground.

Environmental conditions also vary with time, both within and between years, so that the hypothetical results in a spatial mosaic (Table 2) are also relevant to year-to-year variation for crops and to harvest-to-harvest variation for pastures. There can thus be intercropping advantage and RYT > 1.0 over a series of years (or

Table 2. Hypothetic case of two species (A and B) grown alone and Intarcroppad in a mosaic of two environments (a and b). The RYT is 1.0 In each environment. The two environments (a and b) may also represent 2 years (see text).

	Pure stands yield		Intercropping				
			%		yield		
Environment	A	B	A	B	A	B	Total
Type a	120	80	70	30	84	24	108
Type b	80	120	30	70	24	84	108
Mean	100	100	50	50	54	54	108

harvests), even if RYT = 1.0 in each year (or harvest period). This comes about because no single species (or cultivar) is "best" in every year, or every environment — i.e., there is a large species x environment (or cultivar x environment) interaction. Such interactions normally occur and usually exceed overall differences between species and cultivars. These interactions are particularly relevant where the environment varies from year to year. Under these conditions it is not possible to predict, in any one year, which species (or cultivar) will perform best, since the environmental conditions cannot be predicted, nor are the responses of species (or cultivars) to those conditions known with any certainty. This highlights a common fallacy in studies of intercropping; the mixture is often compared with "best" component grown alone; however, the "best" component is determined *after* the experiment is completed and might not have been predicted before it started. The farmer has to select the best component before sowing, without knowing future conditions during the growing season, and often with very limited information on the relative performance of the components in the range of likely conditions. As a result, unless one component is consistently superior to the other, it is usually more relevantto compare the mixture with the mean of the purestands.

In considering the variability of environments in time (Table 1, 2b), the importance of soil factors should not be underestimated. We tend to think of the variation as climatic, but often it has its effect via the soil. The most obvious effects are on soil water content; water supply affects crop yields over a remarkably wide range of crops and regions (e.g., Gangopadhyaya and Sarker 1965; Smith 1967; Robertson 1974; Gilloby and Dyer 1977). Conversely, crop yields seem to be rarely correlated with light (or radiation) receipt, except insofar as radiation affects temperature, or affects transpiration and so reduces soil water content, and so usually *reduces* yield. Climatic variation also affects the mineral nutrient status of the soil. Detailed studies have shown large seasonal variations in N, P, K, Mg, and Ca contents of soils (e.g., Gupta and Rorison 1975) and in soil pH (van der Paauw 1962). Those variations *can* lead to variations, as great as twofold, in the yield of crops (van der Paauw 1962). Ittherefore seems that climatic variation within and between years could have important direct effects upon belowground interactions in intercropping, as well as any indirect effects resulting from aboveground interactions.

Experimental Evidence of Belowground Interactions

Most experimental studies of species mixtures have been carried out to investigate the effect on the component species, rather than to study the total yield of the mixture. In addition, most have been carried out under artificial conditions, in pots or boxes, in glasshouses or controlled-environment chambers, and on heavily fertilized soils. However, many of these studies provide information that is useful in analyzing the nature of interactions between species (and cultivars) in mixtures in the field, or in assessing the possible mechanisms of intercropping advantage.

Several techniques have been used to analyze the nature of interactions between species. In several cases, the effects of aboveground and belowground interactions have been directly compared, using partitions aboveground and belowground, similar to the technique first used by Donald (1958). The more common technique, which is indirect, is to vary the supply of the resource(s) thought to be in limiting supply. In each of these two cases, the effects are measured on the yield of the component species, in single-species stands and mixed-species stands. In addition to these studies, the ability of the species to exploit limiting resources has been investigated, in single-species and mixed-species stands, by measuring the amount and distribution of the resource (e.g., light, water, or P) in the proximity of the plants. The rate and location of uptake of nutrients or water has sometimes been measured, usually by radiotracers, or light interception measured, and the total uptake and location of nutrients within the plants have been determined. None of these various techniques gives a complete understanding of the nature of the interactions that occur between species in intercropping, but together they give some indication of the mechanisms involved.

It is important to recognize that the outcome of any experiment is highly dependent upon the particular conditions used. In many of the experiments on species interactions, the results have tended to be predetermined, in favor of aboveground interactions, by the fact that adequate water and mineral nutrients were added, so that soil factors were no longer limiting. In a few cases, however, exceptionally deficient soils have been used. In addition, the boxes and pots used in many studies have abnormally restricted root systems, especially in depth. In spite of these restrictions, most of the studies indicate the importance of belowground interactions, relative to aboveground interactions, in determining the outcome of interactions between species and cultivars.

There have been more than ten published studies in which the two forms of interaction have been directly compared, using various techniques, mostly modifications of a technique by Donald (1958); all but two (Wilkinson and Gross 1964; Schreiber 1967) showed that belowground interactions were more intense than those aboveground (e.g., Donald 1958; Aspinall 1960; King 1971; Snaydon 1971; Eagles 1972; Litav and Isti 1974; Newbery and Newman 1978). Further, five unpublished studies also showed that belowground interactions were greater than aboveground interactions.

The importance of soil factors in interspecific interaction has also been demonstrated indirectly by adding more of the resource thought to be in limiting supply. Few studies have been made of intercropping, though Kurtz et al. (1952) concluded that various crops competed with maize for N and water, when intercropped. Similarly, weeds compete with other crops for N (e.g., Niets and Staniforth 1961). Other studies indicate that pasture species compete for K (e.g., Blaser and Brady 1950; Mount and Walker 1959; Paden 1962; Hall 1974), for P (e.g., Mount and Walker 1959; Jackman and Mount 1972; Harries et al. 1974), and for water (e.g., Wilkinson and Gross 1964; Jackman and Mount 1972). In some of these studies there were indications that competition occurred for light, as well as for soil factors, and that these effects interacted (e.g., Donald 1964).

These numerous studies show conclusively that belowground interactions are extremely important in determining the relative success of component species in mixed stands. However, this does not necessarily imply that belowground interactions can cause intercropping advantage. In most of the studies it is not possible to assess intercropping advantage, because the relevant sole-crop treatments have not been imposed. In addition, many of the studies have been carried out in pots and boxes, and in other artificial conditions, so that the results may not be validly extrapolated to field conditions.

Mechanisms of Intercropping Advantage

Few studies of intercropping have been designed to elucidate the mechanisms involved in intercropping advantage. This seems to be due, firstly, to the size and complexity of intercropping experiments, which makes the imposition of other treatments unwelcome. Secondly, it is probably due to unpredictability of the outcome of experiments, and lack of information on what factors to vary and what measurements to make. Thirdly, there are the difficulties of measuring many of the necessary attributes, especially those belowground (e.g., root distribution and activity, distribution of nutrients, and water in the soil). As a result, most assessments of the mechanisms involved are made post hoc, after the experiment has been completed, and on insufficient information. Most of the information that has been collected has been concerned with the shoot system (e.g., leaf area, leaf stratification, leaf inclination, light interception). As a result, most interpretations have been in terms of the shoot system, in spite of the apparent importance of belowground interactions. In addition, the results of many studies of intercropping tend to be biased toward the importance of aboveground interactions, because of large inputs of nutrients and water which reduce the usual deficiencies for these factors; these inputs are often vastly in excess of the inputs used in those farming conditions where intercropping is likely to be used.

Most of the available information has been obtained from experiments in which likely limiting factors (e.g., N, P, or water) have been varied. Some additional information has been obtained where species (or more often cultivars) with different morphological or physiological attributes have been grown together in various combinations. Finally, studies of nutrient and water uptake have sometimes indicated the nature of the interactions between the component species (or cultivars). Because of the likely differences in the mechanisms of interaction involved in mixtures of legumes with nonlegumes, these mixtures will be considered separately from those involving only nonlegumes. In both cases, the various mechanisms will be considered in the order listed in Table 1.

Mixtures of Nonlegumes

There is considerable evidence that partially different timing in the use of resources (Table 1, 1ai) is one of the major causes of intercropping advantage in mixtures of nonlegumes. It is also important in mixtures of legumes with nonlegumes where more intensive studies have been made (e.g., Osiru and Willey 1976).

Most of the evidence is indirect, incomplete, and based upon observation. Palvakul et al. (1973), however, grew all possible paired mixtures of eight barley cultivars, which differed in height, maturity date, yield, and morphology. They found that the mixtures were most advantageous when the components differed most in maturity date. There is also some evidence that the greater yield of some mixtures of ryegrass cultivars (Rhodes 1970) may be caused by differences in the period of regrowth after cutting, since the yield advantage depended on the frequency of cutting. Most of the other evidence is circumstantial, based upon post hoc assessments of experimental results either by the authors or others (see Trenbath 1974*b*). The yield advantage of mixtures of oats and barley (Syme and Bremner 1968), of sweet potatoes and rice(Chao 1975), of flax and linseed (Harper 1968), and of early and late cultivars of potatoes (Schepers and Sibma, 1976; P. M. Harris unpublished) are among the examples that have variously been attributed to differences in time of resource use. Assuming that the yield advantages of mixtures are due to differences in time of resource use, it is as likely that they are due to differences in time of use of mineral nutrients or water as to use of light. It is difficult to see how these effects could be disentangled, or indeed whether this knowledge would lead to any more effective management of intercropping.

More direct evidence is available on the use of resources from different zones, both aboveground and belowground, in intercropping (Table 1, 1aii). However, the importance of this in causing intercropping advantage is usually only circumstantial.

Several studies (e.g., Whittington and O'Brien 1968; Ellern et al. 1970; Harries et al. 1974; Trenbath 1975a) have shown that, when species (or cultivars) *are* grown together, they may extract mineral nutrients from different zones of the soil. There is rather less evidence that species may also extract water from different zones, though stratified root systems should be able to extract both nutrients and water. Unpublished evidence (Fig. 1; Willey and Lakhani 1976) indicates that intercropping may exploit the soil profile more fully, so using the soil water content more effectively. In several of these cases where either nutrients or water were more effectively utilized, the yield of the species mixtures was greater than either com-

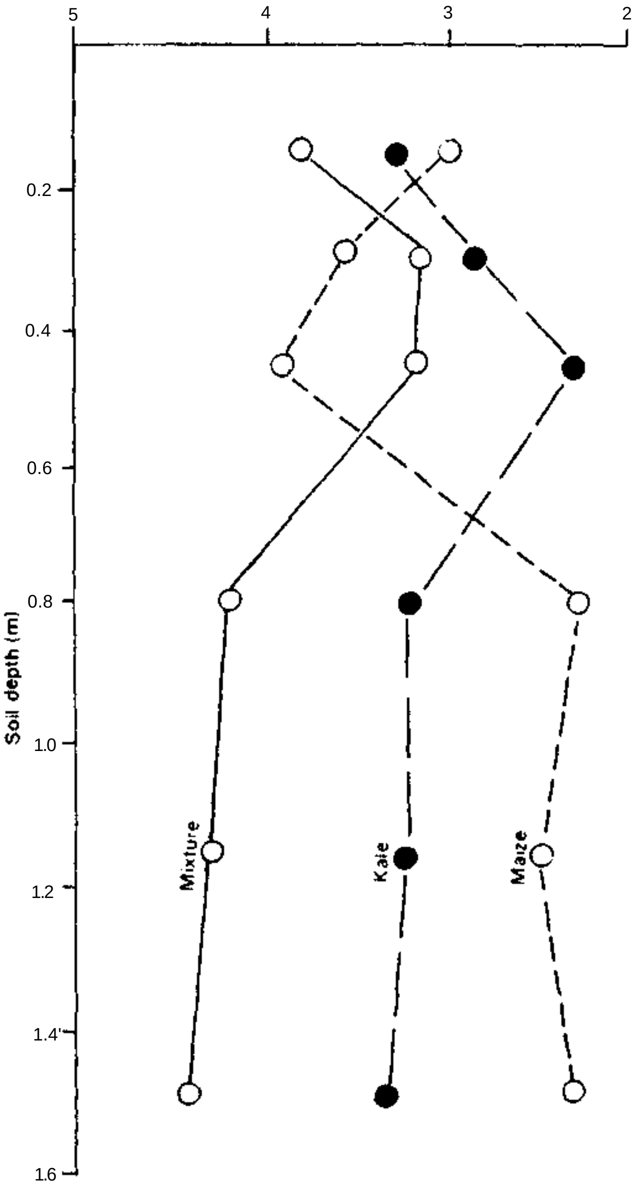

Figure 1. Soil water content beneath maize, kale, and their mixture (Mazaheri 1979).

ponent (e.g., Whittington and O'Brien 1968; Trenbath 1975a; Willey and Lakhani 1976; Table 3). As yet there is no fully convincing experimental evidence that this was cause or effect.

Many cases of intercropping *advantage* have been attributed to shoot zonation and consequently more effective light capture; theoretical models have also been constructed which demonstrate this possibility (Trenbath 1976). However, the experimental evidence (Palvakul et al. 1973; Williams et al. 1978) shows little indication of advantage from either differences in height or leaf form. In view of the known deficiencies of mineral nutrients and water in many areas where intercropping is practiced, the known cases where intercropping has led to more effective use of these limiting resources, and the apparent effects of this on yield, it seems that the more effective use of soil resources, by root zonation, is at least as likely to lead to intercropping advantage as is more efficient capture of light.

Table 3. The total dry-matter yield (t/ha) of pure stands of kale (*Braaalca oleracea*) and maize (*Zea mays*), grown at two or three densities, and of mixtures of those two species, grown at two densities (Mazaheri and Harris, unpublished).

Maize density (plants/m^2)	Kale density (plants/m^2)			
	0	11	22	44
None	—	—	8.4	9.3
5.5	7.8	—	—	—
11.0	9.8	—	11.5	—
22.0	10.8	11.6	—	—

Few examples exist of cases where intercropped, nonlegume species have been shown to have different limiting resources (Table 1, 1bi and ii). Indeed, it is difficult to imagine an experiment that would satisfactorily demonstrate such a case.

Surprisingly few cases have been published which might demonstrate cases where intercropped species fully compete — i.e., RYT = 1.0 — yet intercropping gives higher yields than does pure stands (Table 1, 2a and b). Herethe difficulty isthatthe spatial variations in yield and species composition within experimental plots are rarely measured (Table 1, 2a), though variations between replicated plots usually are, but are rarely considered separately. Similarly, experiments are rarely repeated over several years (Table 1,2b). One of the best examples of such a study is by Daniel (1955), who grew pure stands and mixtures of oats and barley at various sites in Britain during 5 years, giving a total of 26 site/year combinations. Neither crop was consistently better in pure stands. Barley yielded more than oats on 14 occasions, sometimes more than twice as much (8 occasions $P< 0.05$), while oats yielded more than barley on 11 occasions (7 occasions $P<0.05$); on the average, barley yielded 9% more than oats. The 50:50 mixture of the species yielded more than the highest-yielding component on seven occasions (3 occasions $P<0.05$), and only yielded less than the mean of the components on three occasions, and then not significantly. When averaged over all sites and years, the mixture yielded 11% more than the mean of the components and 7% more than barley, which on an average was the highest-yielding component. There was a significant correlation ($r=0.54$, $P<0.01$) between the percentage of barley in the harvested seed of the mixture, at each site/location, and the yield of barley, relative to oats, in pure stands at each site/location. This example therefore approximates the hypothetical case in Table 2, except that RYT > 1.0 in some years/location. There is no way of telling to what extent competition for soil factors, and differences in response to those factors, were responsible for these results. Such large species x environment interactions are not unusual under field conditions; for example, the relative performance of barley and beans, in different years and with different irrigation and N applications (Martin and Snaydon, unpublished), varies at least as much as that of barley and oats in Daniel's study. This large variation and its implications for the advantage of intercropping have not been adequately recognized in the past.

Legumes with Nonlegumes

When legumes and nonlegumes are intercropped, the yield may often exceed that of either of the components grown alone, and the RYT may exceed 1.5 (Trenbath 1974b)). The most likely reason for this is that the two components do not compete for N, which is often the most limiting soil resource. In addition, if the intercropping is continued for sufficiently long (> 3-6 months), available N may be released by the legume and so further increase the yield of the nonlegume. However, this does not seem to be the only mechanism involved, for example, Willey and Osiru (1972) and Osiru and Willey (1972) obtained large intercropping advantage from mixtures of legumes with nonlegumes, even when 130 kg N/ha was applied. They attributed the effect to differences in the time of utilization of environmental resources (Table 1, lai). The advantages of intercropping legumes with nonlegumes may also result, in part, from differences in rooting pattern (Robson and Loneragan 1978) and in ability to utilize P from different sources (Andrews and Johansen 1978).

Studies by Bakhuis and Kleter (1965) indicate that the intercropping advantage of *Trifolium repens,* when grown with several grass species, was largely due to interactions belowground. Martin and Snaydon (unpublished) have investigated the effects of N supply and growing period on the RYT of mixtures of barley and beans, separating the effects of above- and belowground interactions by using partitioned boxes. Intercropping advantage was observed only when the root systems of the two species interacted (Table 4), and was greatest when *only* the root systems interacted. Addition of 80 kg N/ha significantly reduced RYT, but the effect was not large. The RYT was greatest when barley was sown before beans, especially if only the root systems interacted. Further information would be needed on the total uptake and on the location of the uptake, of N, of other nutrients (e.g., P and K), and of water to fully define the actual mechanism involved.

It will be apparent, from this review of the evidence, that many mechanisms might lead to intercropping advantage; only in a few cases is there strong circumstantial evidence that any particular mechanism has led to intercropping advantage. In no case is there strong direct evidence of any particular mechanism, though there is strong evidence that belowground interactions are most important. The actual mechanism(s) involved in each case will depend upon the particular environmental conditions (e.g., the limiting resources), the particular species (e.g., legumes and nonlegumes), and the way the crop is managed (e.g., planting data).

Factors Affecting Intercropping Advantage

Surprisingly few studies have been designed to define the conditions under which intercrop-

Table 4. The relative yield totals (RYT) off mixtures off barley (*Hordeum distichon*) and field beans (*Vicia faba*), grown with either 10 kg N/ha or 80 kg N/ha. The mixtures were sown with the barley either sown early (3 weeks before beans) or sown late (3 weeks after beans). The mixtures were allowed to Intermix only belowground, only aboveground, or both below- and aboveground. Data are based on total plant weight after approximately 3 months.

	Species interacting			
Treatment	Belowground only	Aboveground only	Belowground and aboveground	Mean
(a)				
10 kg N/ha	1.35	1.02	1.21	1.19
80 kg N/ha	1.24	0.98	1.20	1.14
(b)				
Barley sown early	1.35	0.91	1.36	1.21
Barley sown late	1.24	1.08	1.05	1.12
Mean	1.30	1.00	1.21	

LSD (P = 0.05) of Individual values = 0.05.
LSD (P = 0.05) of mean = 0.03.

ping might be most advantageous. In theory, it might be possible to define them by observing the conditions under which intercropping is (or has been) most frequently practiced. In general, the extent of intercropping seems to be more closely correlated with the intensity of agriculture (e.g., extent of mechanization) and with social conditions, rather than with particular environmental conditions. However, intercropping is usually associated with suboptimal soil conditions (e.g., deficiencies of mineral nutrients and, perhaps, water); conversely, there is no evidence that it is associated with suboptimal conditions of light receipt — indeed, the opposite seems to be true. These associations, however, may not be causal and may merely reflect social conditions.

We shall review the limited amount of experimental evidence on the factors that affect intercropping advantage, treating mixtures of legumes with nonlegumes separately from those with nonlegumes only.

Mixtures of Nonlegumes

Intercropping advantage, with mixtures of nonlegumes, sometimes seems to be greatest when mineral nutrients are deficient. For example, Syme and Bremner (1968) found that, when oats and barley were grown together without N fertilizer, the mixture yielded more grain than either of the component species; at intermediate applications (53 kg N/ha), the mixture yielded less than the highest-yielding component but more than the mean of the components. With large applications (105 kg N/ha), however, the mixture yielded less than the mean of the components. Similarly, Remison and Snaydon (1980) found that when two grass species (*Lolium perenne* and *Dactylis glomerata*) were grown with only their root systems intermixing, the RYT only exceeded 1.0 when N fertilizer was not applied (Fig. 2). The RYT was also greater when no P fertilizer was applied. When neither N nor P was applied, the RYT exceeded 1.5 in some cases (Fig. 2); such high values are usually only found in mixtures containing legumes. On the other hand, Chestnutt (1970), in a very extensive study of mixtures of three grass species, found no effect of N fertilizer on intercropping advantage, while Morris and Reese (1962) found a large intercropping *disadvantage,* when no N fertilizer was applied to mixtures of rye cultivars, and an intercropping advantage only at intermediate applications (120-180 kg N/ha).

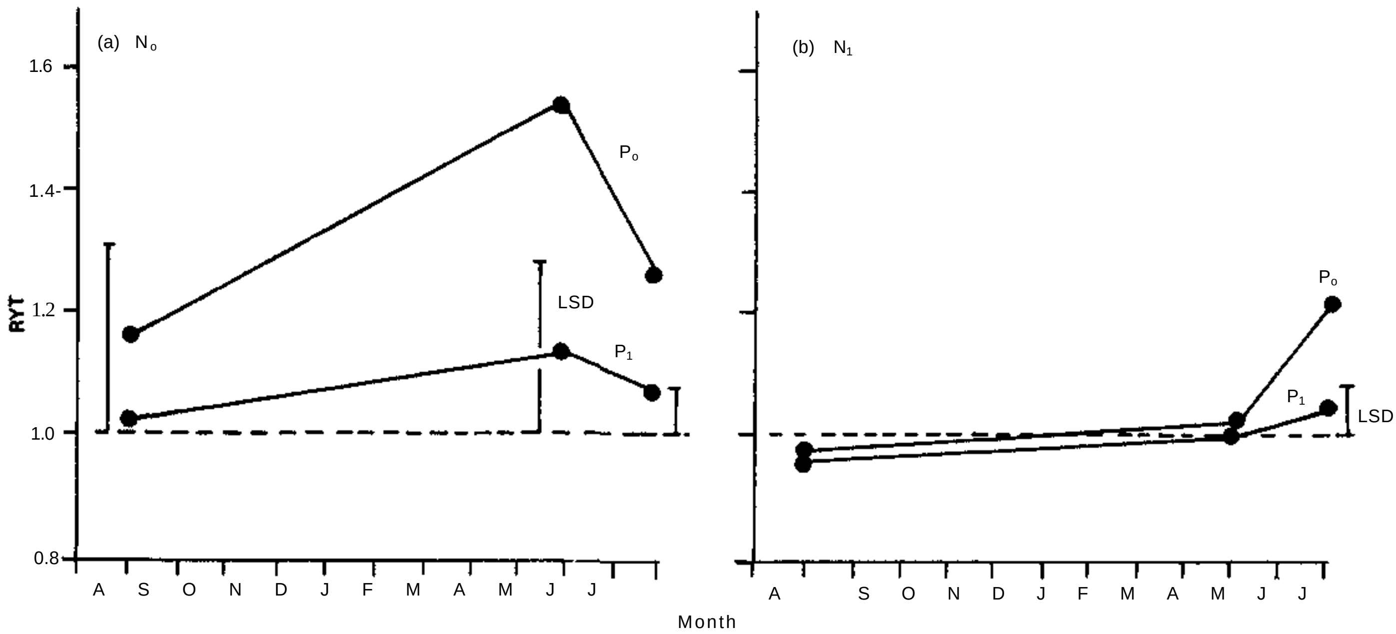

Figure 2. Relative yield totals (RYT) when L. perenne *and* D. glomerata *were grown with only their roots intermixed (Remison and Snaydon 1979).*

Syme and Bremner (1968) found that the intercropping advantage of oats with barley was greatest when rainfall was supplemented by irrigation. Fisher (1977a) also found that the intercropping advantage of maize with potatoes (and maize with beans) only occurred in wet seasons. These seem to be the only relevant data on water supply, and it would be dangerous to draw general conclusions from them.

Mixtures of Legumes and Nonlegumes

Various factors seem to affect mixtures of legumes with nonlegumes mainly by their effect on the ability of the legume components to fix N. For example, when the N-fixing microorganism (*Rhizobium*) is absent, there is no intercropping advantage, i.e., RYT = 1.0, but the RYT may exceed 1.5 when the *Rhizobium* is present (e.g., de Wit et al. 1966). Similarly, when N fertilizer is added, the advantage is reduced (e.g., de Wit et al. 1966). On the other hand, when some other nutrient (e.g., K or S) is in limiting supply, additions of the deficient nutrient usually increase intercropping advantage, by increasing the proportion of the legume in the mixture and so increasing N fixation. For example, additions of K fertilizer can greatly increase RYT (Hall 1974). Additions of S and P also appear to increase the intercropping advantage of legumes with nonlegumes (e.g., Jackman and Mount 1972) though in most cases, valid comparisons cannot be made because pure stands of both components have not been grown. Similarly, deficiency of soil water reduces the legume content of the mixture and N fixation, and so reduces intercropping advantage (de Wit et al. 1966).

It is difficult to draw general conclusions from the available evidence, especially for mixtures of nonlegumes, where the evidence is limited and often conflicting. This is perhaps not surprising, in view of the many potential mechanisms (Table 1), and the large differences between environments and between species combinations. In the case of mixtures of legumes with nonlegumes, a single mechanism is mainly involved (Table 1, 1bi) and most factors which increase N fixation, whether by increasing the legume content or the efficiency of N fixation, generally increase intercropping advantage. These factors include increasing the supply of mineral nutrients (except N) and of water, and also increasing the light intensity (e.g., Ennik 1960).

So far we have concentrated attention on belowground interactions, and on factors that modify the belowground environment. However, belowground interactions are affected by aboveground conditions and by aboveground interactions (e.g., Donald 1958). It is therefore not possibleto totally divorce aboveground and belowground interactions from each other.

Future Studies

In the past, systems of intercropping have mainly been based on trial and error. If the advantages of intercropping are to be fully exploited, and the less frequent disadvantages are to be minimized, then the conditions that favor intercropping must be defined. The physiological, ecological, and morphological attributes of crop species that lead to productive coexistence must also be defined. To achieve this, there must be systematic studies of intercropping and a greater emphasis on the mechanisms that give rise to intercropping advantage.

No single experimental technique can be used to obtain all the necessary information, nor will any single specialist (crop physiologist, soil scientist, statistician, agronomist, or ecologist) be able to design or execute the necessary experiments, or collect and analyze the resultant data. A variety of techniques must be used and a diverse team of researchers is needed to obtain and interpret the necessary data.

We consider that two main types of experiment are needed, the first to investigate the effects of various factors on intercropping, under field conditions, and the second to define the mechanism involved, mostly under more controlled conditions. Neither of these broad categories are mutually exclusive, as will be seen later.

Relatively few systematic studies have been made of the effects of various factors on intercropping advantage, mainly because of the large size of the necessary experiments. Two main types of experimental design are now available, which partially overcome this problem (Mead and Stern 1979). Firstly, various methods of partial confounding make it possibleto reduce the number of plots without loss of essential data, as long as the priority of data is carefully defined beforehand (Mead and Stern 1979). Secondly, various systematic designs are now available that produce the maximum amount of data in the minimum area (e.g., Huxley and Maingu 1978; Mead and Stern 1979). A further example of a design which allows the investigation of a wide range of relative densities of component species, over a wide range of overall densities, is shown in Fig. 3. Density can be varied either by varying row width (Fig. 3a) or within-the-row spacing (Fig. 3b).

These types of experiment should be exploited as fully as possible, by collecting the maximum amount of useful data. In the past, too little attention has been paid to belowground conditions. Techniques are now available to collect the necessary data with greater ease than previously. Neutron scatter equipment (Wu 1965) and various tensiometers allow rapid and accurate measurement of soil water content, but in situ measurements of mineral nutrients in the soil are still difficult or impossible; ion-specific electrodes may make such measurements possible in the future. At the moment, the most valuable method is to measure nutrient uptake at various depths by various tracers. So far, radiotracers have mainly been used, but these are expensive, and require skilled and careful handling. Nonradioactive tracers such as Li (Snaydon and Martin unpublished) and Sr (e.g., Fox and Lipps 1964) are highly effective, cheap, and easily measured by standard flame-photometry. Unfortunately ^{14}N and Tr require expensive equipment.

Chemical analysis of the plant material can often provide valuable evidence of nutrient deficiencies and of the mechanisms involved in intercropping advantage (e.g., Hall 1974).

The mechanisms of intercropping advantage may often be inferred from the types of experiments just considered, especially when supported by studies of nutrient and water uptake, and of plant chemical composition. However, more direct evidence can be obtained by first isolating the effects of belowground and aboveground interactions. This is best done under more controlled conditions, e.g. in boxes, but is also possible in thefield (e.g., Bakhuis and Kleter 1965). Various methods have been devised since that of Donald (1958). Those involving rows (e.g., Schreiber 1967; Eagles 1972) have advantages of simplicity and constant

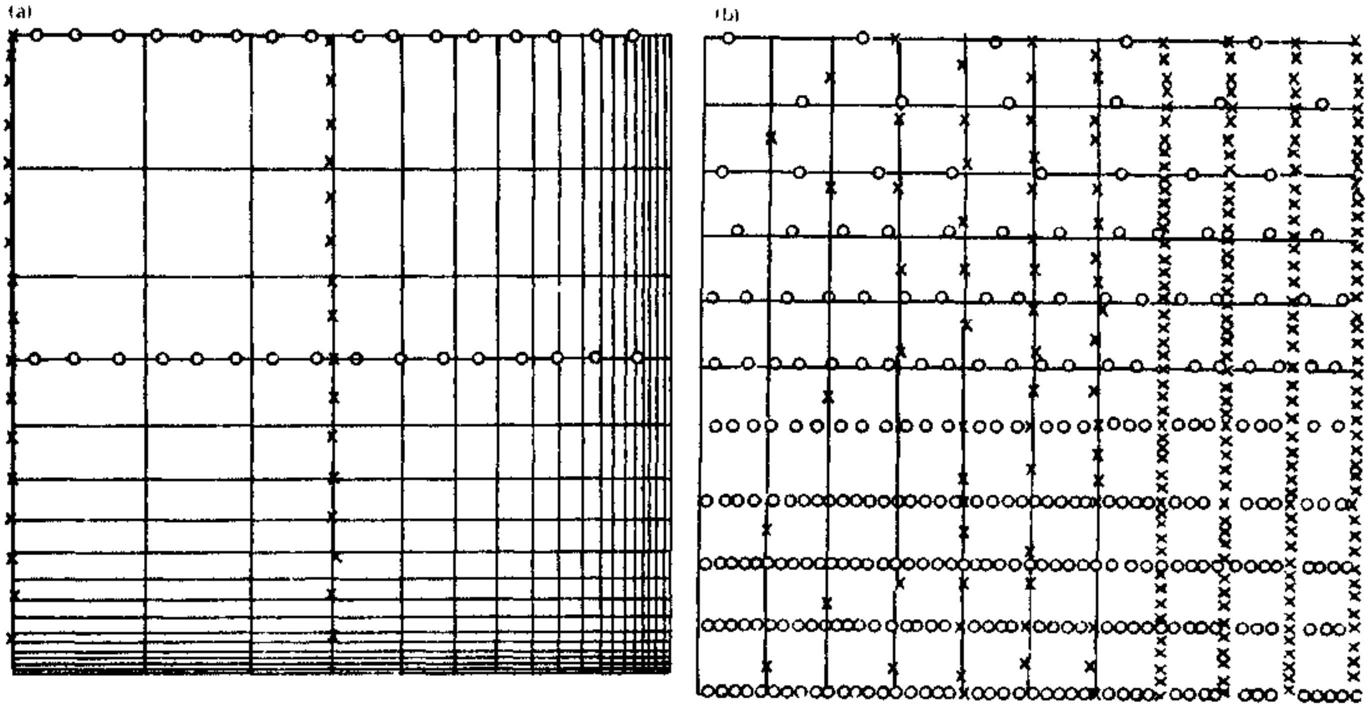

Figure 3. Suggested design for investigating wide range of relative densities of component species over a wide range of overall densities by varying (a) row width, and (b) withfn-the-row spacing.

effective density; the new technique described in Figure 4 has further advantages in that the relative density of the components can be varied and the density above- and belowground can be varied independently (Snaydon 1979). These row methods can be used in the field, where corrugated iron sheets driven into the soil (Snaydon and Odion, unpublished) are easier to use than, and are preferable to, the plastic sheets used by Bakhuis and Kleter (1965). Similarly, aluminium-faced, reinforced paper (Sisalcraft) is preferable to other materials (e.g., hessian and plywood) that have been used previously. Once again, measurements of nutrient and water uptake and of the chemical composition of plant material will add valuable, indeed essential, information that will allow a more critical analysis of the mechanisms involved. It is also important that the supply of nutrients, water, light, and other important factors be varied where possible in these studies.

Obviously, such intensive yet wide-ranging studies will require the skills of various specialists (e.g., crop physiologists, soil scientists, and statisticians) as well as agronomists and ecologists. More is likely to be achieved by detailed planning, close collaboration, and teamwork than by the small-scale, one-man, "one-off" experiments that have been the pattern of intercropping studies in the past.

Finally, a note of caution: the yield advantages of intercropping, compared with pure stands, are usually quite small (5-15%); yield advantages greater than 20% are rare, except in the case of mixtures of legumes with non-legumes or, perhaps, crops with very different growth periods. These advantages are quite small compared with the yield increases that can be achieved by other agronomic practices (e.g., improved cultivation, fertilizer use, irrigation, pest and disease control), or perhaps by the use of better cultivars. These various practices are not necessarily mutually exclusive, but, firstly, careful thought should be given to research priorities in these various areas, bearing in mind the research costs, the cost of the practices, and the potential benefits of the practices. Secondly, some of the practices may negate each other — e.g., use of fertilizer and intercropping in some conditions; though in other conditions the practice may act

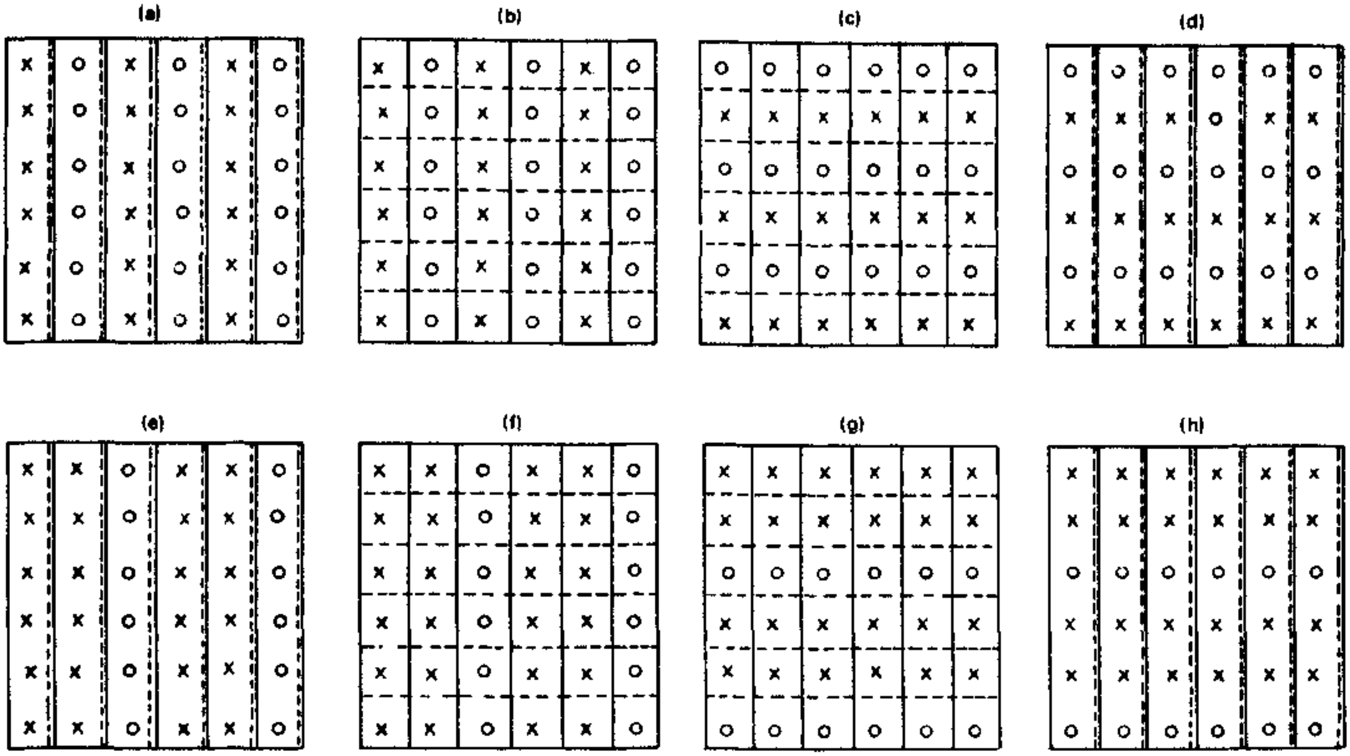

Figure 4. Planting arrangements of two species (o and x) giving 1:1 ratios (a-d) and 1:2 ratios (e-h). The arrangements give: no interaction between species (a and e), root interaction only between species (b and f), shoot interaction only between species (c and g), both root and shoot interaction between species (d and h). Aerial partitions are shown as full lines and soil partitions as dashed lines. Soil partitions are slightly displaced in (a), (d), (e), and (h) for clarity.

synergistically — e.g., the use of K with legume intercropping. Similarly, breeding for sole cropping may produce cultivars less beneficial for intercropping, and vice versa. Care must therefore be taken that the various practices complement one another, where possible, and that intercropping be considered in the context of possible improvements in other practices.

A Study of Pearl Millet/Groundnut Intercropping with Particular Emphasis on the Efficiencies of Leaf Canopy and Rooting Pattern

M. S. Reddy and R. W. Willey*

Abstract

A detailed study was carried out on pearl milletlgroundnut intercropping at ICRISAT Center during the rainy season of 1978. Sole crops were grown in 30-cm rows, and a single intercropping treatment was examined in a 1 millet: 3 groundnut row arrangement with the same within-row spacings as the sole crops.

The intercrop produced a yield advantange of 28% for total dry matter (LER = 1.28) and of 26% for seed and pod yields (LER = 1.26). LERvalues were also computed for leaf area index and rooting density, and these gave "advantages" up to 30% and 18%, respectively. There was no real evidence that the intercrop root system was any more efficientthan the root systems oftheso/e crops. Considering the leaf canopy, however, it was concluded that the dry-matter yield advantage of the intercrop was produced by improved efficiency of conversion of light and not by the interception of more light.

Research during recent years has provided sufficient evidence to suggest that substantial yield advantages can be achieved from intercropping compared to sole cropping. But even though the emphasis on intercropping research has increased during the last few years, there have been few detailed growth studies (Kassam and Stockinger 1973, Lakhani 1976, Willey and Natarajan 1978). And yet there is an obvious need for a better understanding-of the competitive effects between component crops and their response to environmental factors such as light, soil moisture, and nutrients.

A number of research workers have found that crop combinations having shade-tolerant legumes with a nonclimbing habit — such as groundnut, cowpea, soybean, and phaseolus bean — with maize, sorghum, millet, cotton, or castor bean have given greater overall yield from intercropping compared to sole cropping (Bodade 1964, Enyi 1973, Evans 1960, Evans and Sreedharan 1962, Osiru 1974, Schilling 1965, Willey and Osiru 1972). These yield advantages have beer, attributed to differences between crops — e.g., in height, rooting pattern, or maturity period — which can enable better spatial and/or temporal utilization of light, soil moisture, and nutrients.

In the ICRISAT intercropping program, the pearl millet/groundnut combination has been chosen as a typical representative of this nonlegume/low-growing legume situation because of its importance in many areas of the African semi-arid tropics and because it comprises two ICRISAT crops. Initial agronomic studies at ICRISAT have shown thatthis mixture is capable of producing yield advantages up to 25-30%. This paper briefly reports some of the findings from a pearl millet/groundnut intercropping experiment carried outto obtain some basic information on growth and resource use.

Experimental Methods

The experiment was conducted during the monsoon season of 1978 on a medium-deep Alfisol with an available water-holding capacity of approximately 100 mm in the top 90 cm of the profile. Rainfall during the growing period was 968 mm, which was above normal and also well distributed during the season. There were three treatments in four randomized blocks:

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Sole pearl millet

Sole groundnut

Intercrop of 1 row pearl millet: 3 rows groundnut

In this experiment, a replacement series technique was employed, in which the one-fourth millet/three-fourths groundnut proportion was achieved by replacing every fourth row of sole groundnut by a row of millet. This kept a standard within-row spacing for each crop, whether in sole cropping or intercropping, and it attempted to maintain a constanttotal population pressure for both sole crops and the intercrop. This was done to facilitate comparisons between the sole crops and the intercrop, although it was appreciated that in practice the intercrop might have a somewhat higher optimum population requirement than the sole crops. All treatments were on 30-cm rows, and within-row spacing was 10 cm and 15 cm for millet and groundnut, respectively. A fertilizer application of 50 kg/ha of P_2O_5 was applied to all treatments, and both sole and intercrop millet were top-dressed with nitrogen at a rate of 80 kg/ha. Both crops were sown on 25 June; millet was harvested on 16 September and groundnut on 8 October. Cultivars were BK 560 millet and Robut 33-1 groundnut.

Dry-matter and leaf-area sampling were carried out at weekly intervals, starting from 20 days after sowing. Sampling areas were 1.8 m^2 for sole crops, and a total of 2.4 m^2 (two rows of millet + six rows of groundnut) for the intercrop. Light interception was measured using tuoe solarimeters (Szeicz et al. 1964). One solarimeter per plot in the sole-crop treatments and two solarimeters per plot in the intercrop were placed at ground level, and the difference between these and a "control" solarimeter recording full incident light was measured as integrated daily totals.

Rooting patterns were examined by coring on seven occasions, at weekly intervals initially and at 10-day intervals later. Core samples of 6.8 cm in diameter were taken on the crop rows and also midway between the rows. This gave two coring positions in the sole crops but five different positions to cover the full intercrop pattern (Fig. 1); these five positions were necessary because of the likelihood of growth being different in the middle groundnut row compared with those next to the millet.

These cores were divided into sections representing depths of 0-10, 10-20, 20-30, 30-40, 40-50,50-70, and 70-90 cm. The sections were soaked in water overnight, and then the roots were washed out using a 0.5-mm sieve. Root length was estimated in each section by the "line intersect" method (Newman 1966) by spreading the roots out randomly on a piece of graph paper with 1-cm squares.

Mean root density (cm root/cm^3 soil) across all sampling positions was then calculated at each profile depth for each sole-crop and the intercrop. For the sole crops, the two sampling positions were averaged; for the intercrop, the

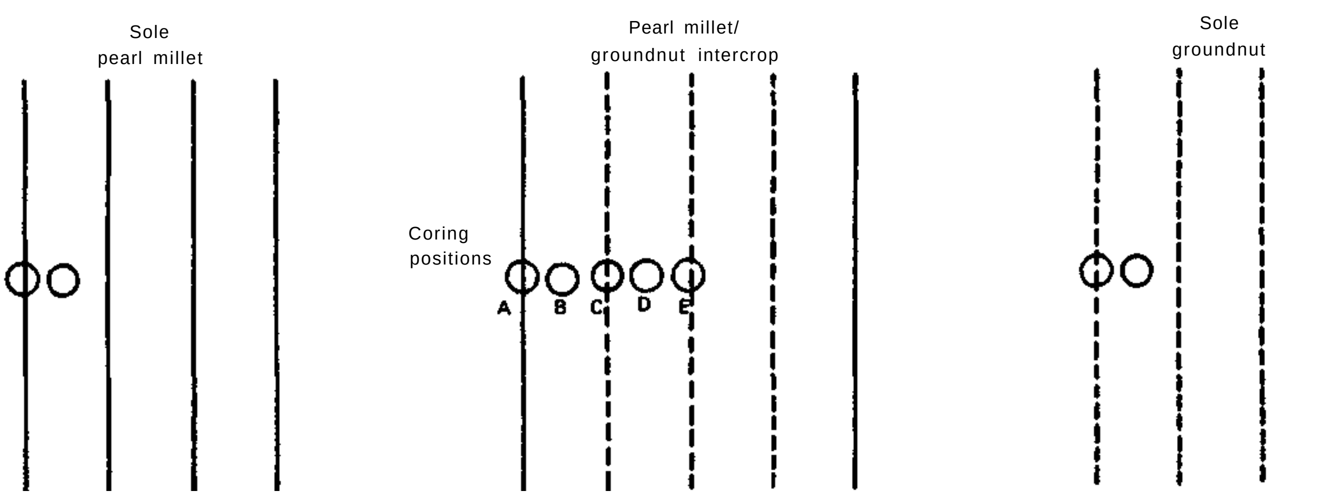

Figure 1. Soil coring positions for root sampling. Coring positions A to E were weighted in the ratio of 1A:2B:2C:2D:1E to give a measure of the average rooting density over the full intercrop pattern.

different sampling positions had to be given different weightings so the intercrop pattern was correctly represented (Fig. 1).

Soil moisture, nutrient uptake, nitrogen fixation, and crop conductance studies were also conducted in this experiment, but only the data on dry-matter accumulation, leaf area index, rooting patterns, and light utilization are reported here.

Results and Discussion

The patterns of dry-matter accumulation in the sole crops and the intercrop of millet and groundnut throughout the growing season are shown in Figure 2. One striking feature is the time difference in crop growth between the two sole crops, although they were both sown at the same time. It is evident that millet establishes early, and initially has a faster growth rate than the slower establishing groundnut. Sole millet had a consistently higher rate of dry-matter accumulation than sole groundnut. At final harvest, the dry matter accumulated by sole millet was 8134 kg/ha compared to 4938 kg/ha produced by sole groundnut. In the intercrop, it can be seen that the growth of groundnut was only slightly less than the "expected" level (i.e., the level that would have been achieved if the millet row had produced exactly the same degree of competition as a groundnut row). On an average, the groundnut produced a dry-matter LER of between 0.7 and 0.8, which compared to the "expected" LER of 0.75. On the other hand, millet suffered less competition in intercropping and produced dry-matter LERs of between 0.5 and 0.6, compared with an "expected" LER of 0.25. The partitioning of dry matter clearly indicates that the additional dry matter of millet in intercrop was due to an increased number of tillers per plant.

Grain or pod yields, total dry matter at final harvest, and harvest index are shown in Table 1. Sole millet produced 2226 kg/ha grain yield, and the intercrop millet 1227 kg/ha, giving an LER for millet grain yield of 0.55. Sole groundnut pod yield was 1185 kg/ha compared to 840 kg/ha for the intercrop, giving an LER for groundnut pod yield of 0.71. This gave an overall intercropping advantage for grain or pod yield of 26% (i.e., a total LER of 1.26) compared to a 28% intercropping advantage obtained for total dry matter at final harvest. Harvest index of the intercrop of both species was only 1% higher than the sole crops.

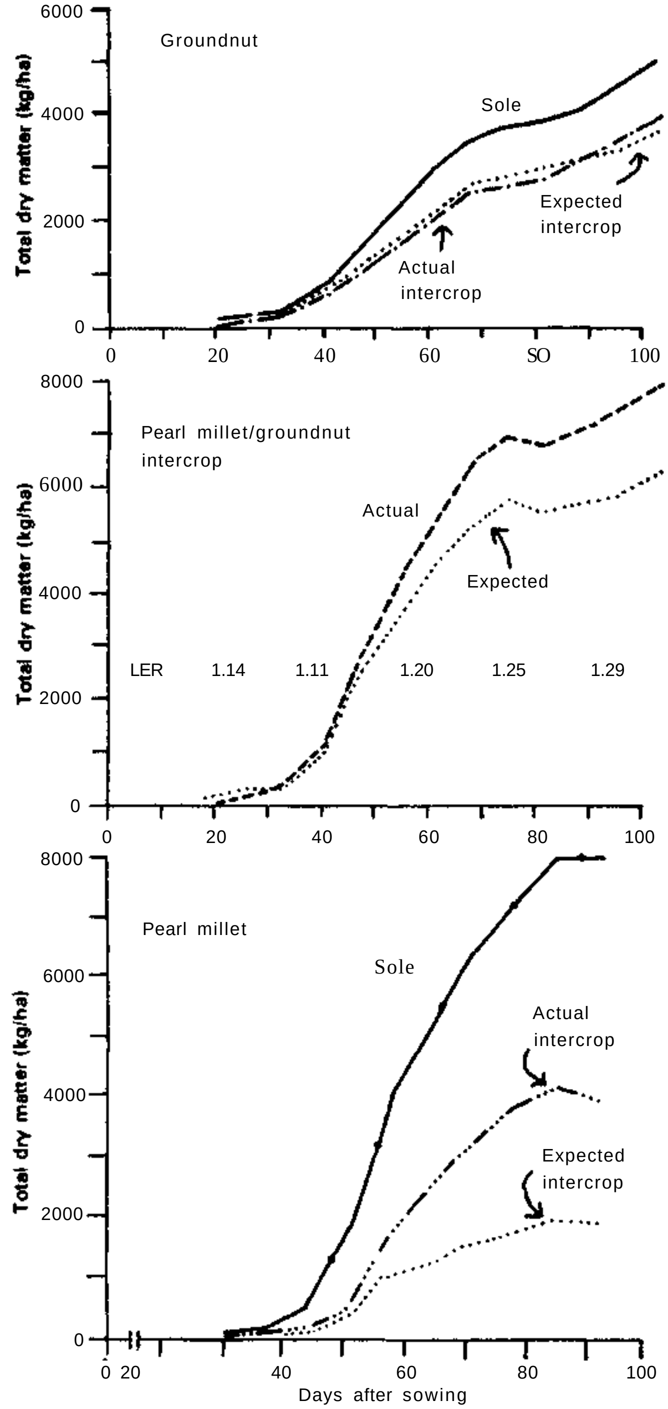

Figure 2. Dry-matter accumulation in sole groundnut and pearl millet and in a groundnutlpearl millet intercrop on Alfisols at ICRISAT Center, rainy season 7978.

Leaf area index (LAI) of sole and intercrops is shown in Figure 3. Maximum LAI in millet was reached at about 45 days after sowing and was

Table 1. Grain *or* pod yields, total dry matter, and harvest index in millet/groundnut intercropping on Alfisols, ICRISAT Center, rainy season 1978.

Crop	Grain or pod yield (kg/ha)	Total dry matter (kg/ha)	Harvest index (%)
Sole groundnut	1185	5617	21
Intercrop groundnut	840	3900	22
LER	0.71	0.69	
Sole millet	2226	8085	25
Intercrop millet	1227	4775	26
LER	0.55	0.59	
Total LER	1.26	1.28	

2.62 and 1.49 for sole and intercrop, respectively. Maximum LAI in groundnut was achieved at about 60 days after sowing and was 3.09 and 2.32 for sole and intercrop, respectively. LAI values showed patterns in agreement with those of the other growth factors. LER values based on LAIs were calculated and showed that the LER for millet LAI was between 0.5 and 0.6 throughout the active growing period. The LER for groundnut LAI was about the expected value of 0.75 until millet was harvested, but after the millet harvest it even reached 0.89. Thetotal intercropping advantage in terms of increased LAI during most of the growing period averaged about 30%, but around 70 days, when the millet was senescing, it even reached 39%. This suggests a beneficial interaction between the canopies, since the intercrop was able to support much *more* leaf than expected.

Light interception patterns are presented in Figure 4. As expected, sole millet established ground cover most rapidly and reached approximately 80% light interception at about 40-45 days after sowing. Subsequently a peak interception of 86% was achieved at about 50 days, but this dropped back to 60% near final harvest. The much slower development of the groundnut canopy was particularly apparent, as, at 40 days after sowing, this crop had intercepted only 45% of incident light. At about 65 days it had reached a near maximum value of about 85%, and this was more or less maintained until the final harvest. A similar time difference between the two species was observed for achieving maximum leaf area development, and, in fact, the peaks of light interception and leaf area development coincided.

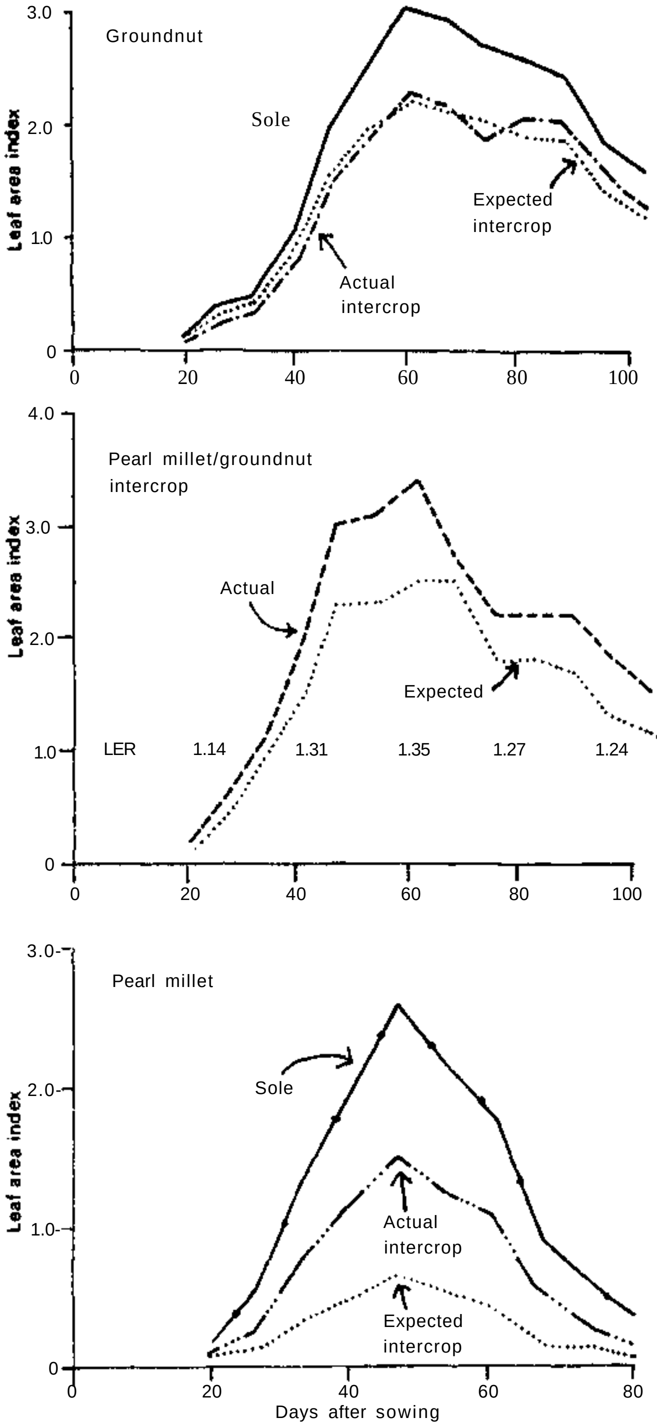

Figure 3. Leaf area index in sole pearl millet and groundnut and in a pearl milletl groundnut intercrop on Alfisols at ICRISAT Center, rainy season 1978.

In the intercrop, attempts were made to measure the amount of light intercepted by each individual crop, but this was possible only during the middle of the season, and by that

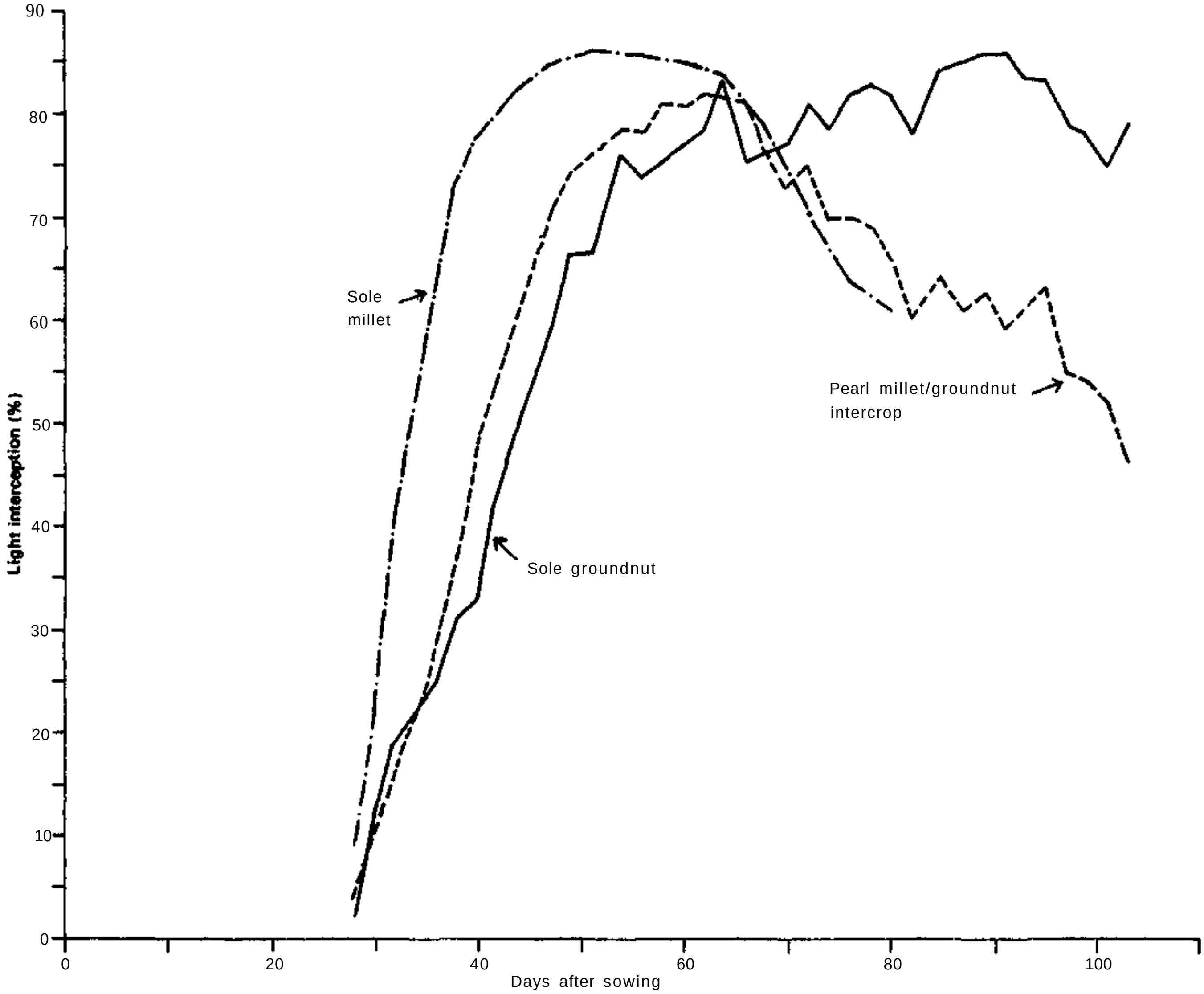

Figure 4. Light interception by sole pearl millet and groundnut and by a pearl millet/groundnut intercrop on Alfisols at ICRISAT Center, rainy season 1978.

time peak interception values were already achieved. Thus the curves in Figure 4 show the total interception by both crops. The level of interception by the intercrop was intermediate between the two sole crops, as expected, until millet was harvested; it was then reasonably constant until the groundnut senesced. The maximum interception of 82% by the intercrop was achieved 60 days after sowing.

The efficiency with which the intercepted light energy was converted into dry matter during the growing period is illustrated in Figure 5. Although groundnut matures 20 days after millet, at final harvest it had intercepted 19.25 Kcal/cm^2 compared to 14.26 Kcal/cm^2 by the millet. At millet harvest, the total energy intercepted by the intercrop was 12.5 Kcal/cm^2 compared with 12.64 Kcal/cm^2 intercepted by the sole groundnut. At final harvest of groundnut, the total amount of light energy intercepted by the intercrop was 17.3 Kcal/cm^2, which was only slightly lessthan 19.25 Kcal/cm^2 intercepted by the sole groundnut. Considering the efficiency with which the intercepted light energy was converted into dry matter, millet was much more efficient than groundnut. Millet produced 5.7 mg of dry matter per kilocalorie intercepted, whereas groundnut produced only 2.57 mg. These different efficiencies of light energy conversion were presumably due to differences in photosynthetic rates of the two species—i.e., C_4 as compared to C3. The efficiency of the intercrop to convert intercepted light energy into dry matter was slightly but consistently higher than sole millet up to 60 days, but once millet started senescing, the

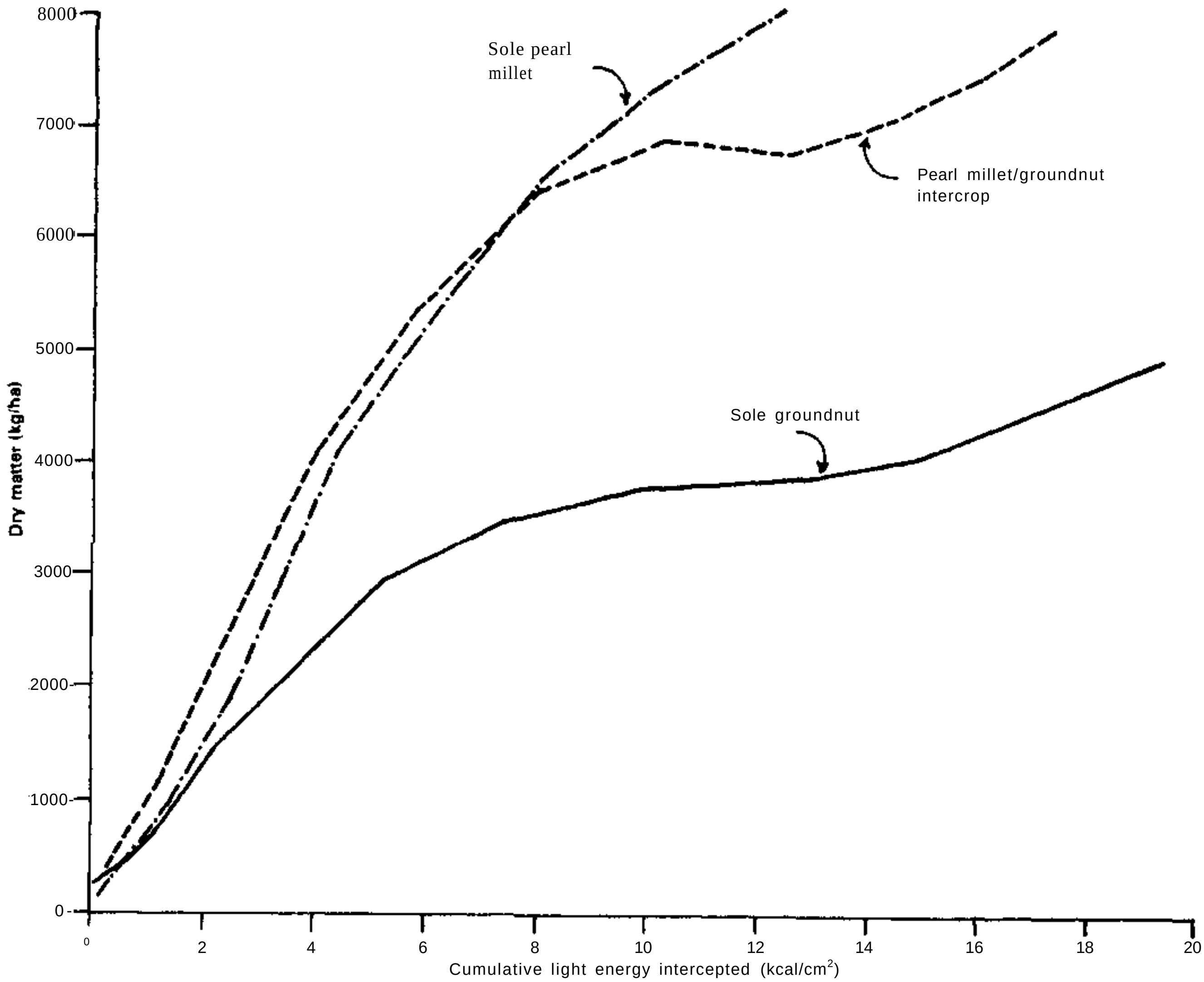

Figure 5. Efficiency of conversion of intercepted light energy into dry matter in sole pearl millet and groundnut and in a pearlmilletlgroundnut intercrop on Alfisols at ICRISAT Center, rainy season 1978.

efficiency fell and followed the pattern of groundnut. At final harvest, the intercrop had produced 4.6 mg of dry matter per kilocalorie intercepted.

This efficiency of light energy conversion by the intercrop is of particular interest because this must indicate to what extent the greater dry matter yield of the intercrop was due to the interception of more light or more efficient use of light. In fact, if the dry-matter yield of each component in the intercrop had been produced at the same efficiency as the comparable sole crop, the total "expected" interception would have been 22.14 Kcals compared to the actual interception of 17.25 Kcals; also the "expected" rate of efficiency would have been 3.59 mg/ Kcals compared with the actual of 4.6 mg/Kcal. So, clearly, the intercrop was converting light more efficiently, and calculation shows that it was actually 28% more efficient. This closely matches the dry-matter LER of 1.28. The inference, therefore, is that the dry-matter yield advantage from the intercrop was due entirely to improved efficiency of conversion of light rather than to the interception of more light. Considering the increased LAI of the intercrop, which compared closely with the increased dry matter, this improved efficiency of conversion must have been partly due to the fact that light was better distributed over more leaves. There also remains the possibility, of course, that some of the increased efficiency was due to a combination of a C_3 crop below a C_4 one, although whether this can actually cause greater efficiency still seems to be a matter of conjecture.

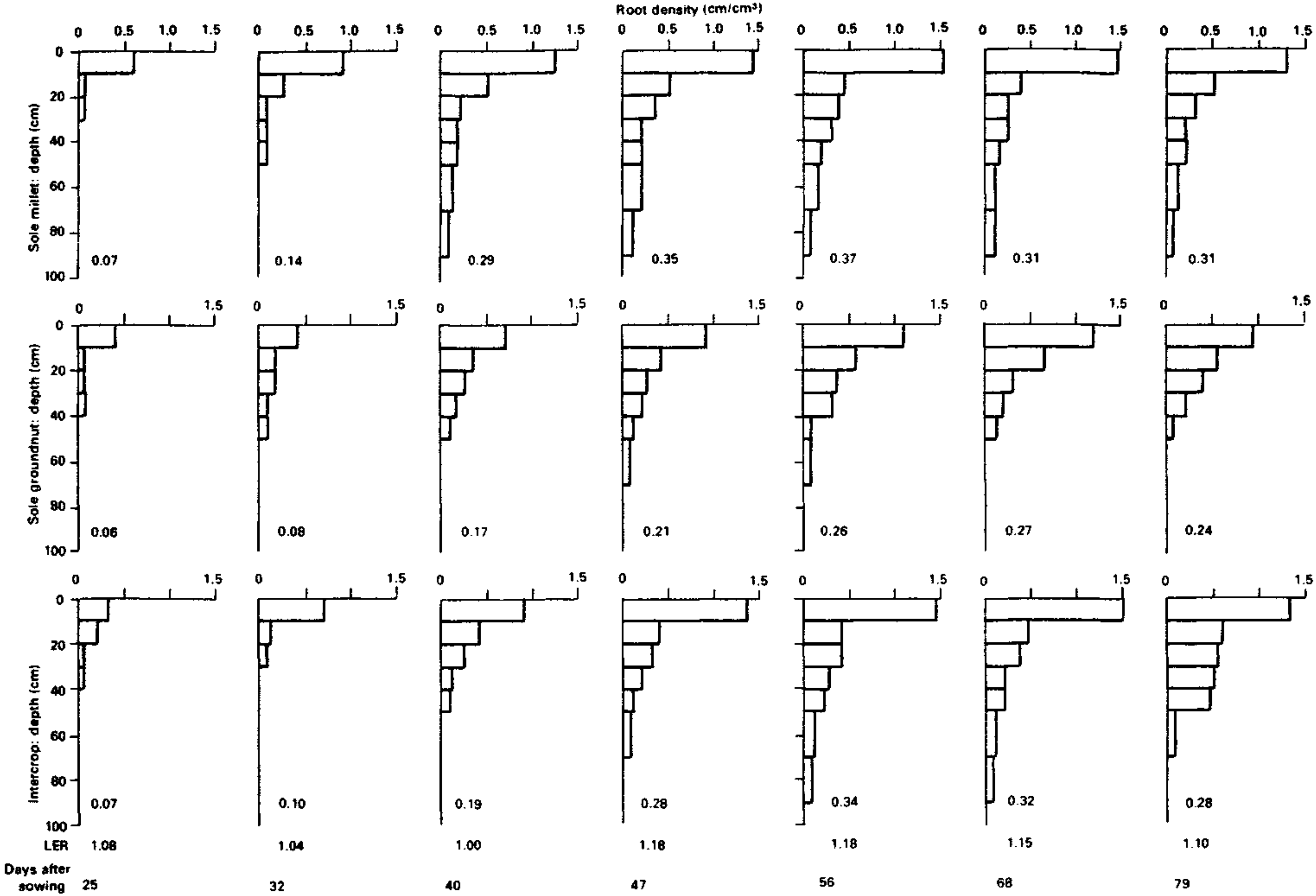

Figure 6. Rooting patterns in sole pearl millet and groundnut and a pearl millet/groundnut intercrop in Alfisols at ICRISAT Center, rainy season 1978.

Figure 6 shows root densities of sole crops and intercrop at different profile depths investigated on seven occasions during the growing season. In the intercrop, it was found that the component crop root systems could not be distinguished. Hence, attempts were only made to have some comparison of the total intercropping root system with the respective sole crops. It was found that millet exhibited a rather different rooting system from that of groundnut. It was clearly evident that groundnut had a more ramified and very active rooting system concentrated mostly in the top 40 cm of the soil, whereas millet had a deeper rooting system distributed even up to 90 cm depth. The total root density values of the intercrop were intermediate between the two sole crops.

An attempt was also made to calculate LER values for rooting density patterns. The intercrop total root density was partitioned according to the proportion of each crop in thetotal dry matter; this, of course, assumes that the shoot/root distribution is not affected by intercropping. With this assumption, it was found that the intercrop total root density gave LER values up to 1.18. These values were more or less in line with dry-matter effects. Soil-moisture measurements during the growing period indicated no appreciable differences in moisture use by sole crops and intercrop, although the above normal rainfall produced wet conditions throughout the growing season. Nutrients were also considered adequate. These results suggest that, although intercropping produced a greater root density than that which would have been "expected" if there had been no intercropping effects, this greater density was reasonably in accordance with the greater dry matter produced. There thus seems little reason to suggestthatthis rooting effect was the cause, rather than simply the effect, of greater dry matter. There was also no particular evidence to suggest that the intercropping root system was any more efficient in producing greater growth per unit of root length.

Acknowledgments

We gratefully acknowledge the valuable advice of Dr. P. Gregory and Dr. B. Marshall, University of Nottingham, U. K., on the measurement of rooting patterns and light interception, respectively. We also acknowledge the help of Dr. Sardar Singh in root sampling and Mr. A. A. H. Khan in light measurements.

Nitrogen Response Studies of Intercropped Sorghum with Pigeonpea

T. J. Rego*

Abstract

To study the N response of intercropped sorghum with pigeonpea, three experiments were conducted during 1977 and 1978 in Vertisols at ICRISAT Center. In Experiment I, sole sorghum (180 000 plantsIha), sole pigeonpea (40 000 plantsIha), and three intercrop population treatments (40:40,80:80, and 120:120% of sole optimum) were sown as main plots with four levels of N (0, 40, 80, and 120 kgIha) only to sorghum as subplots. In Experiment II, sole sorghum at optimum plant population (180 000 plants/ha), intercrop sorghum at 33, 67, and 100% optimum population with constant pigeonpea population (40 000 plantslha) with the same levels of N as in Experiment I, and sole pigeonpea (40 000 plantslha) were grown in a randomized block design. In Experiment III, a constant sorghum (150 000 plantslha) and pigeonpea population (40 000 plantslha) were planted as sole crops at 45 and 90 cm and as intercrops in alternate rows at 45 cm with three levels of N (0, 60, and 120 kgIha) applied only to sorghum in a randomized block design. In all three experiments, sorghum variety CSH-6 and pigeonpea ICRISAT-1 were grown.

Based on the results of these experiments, it can be concluded that intercropped and sole sorghum responded similarly to applied N. Different sorghum populations in the intercrop performed similarly. Pigeonpea did not seem to be contributing any N to its companion sorghum. Sorghum at higher N levels had a greater effect on pigeonpea yield. Sorghum as well as pigeonpea did equally well at 45 cm and 90 cm when grown as sole crops.

Intercropping of a nonlegume with a legume crop is a common practice among the semi-arid tropics (SAT) farmers of India. In a subsistence farming situation with uncertain and erratic rainfall, which is characteristic of the SAT region, very little attention has been paid in the past to improving the soil productivity. Even though N is the most limiting plant nutrient in these soils, intercropped legumes might have been responsible for maintaining soil productivity, at least at a subsistence level. Meager data are available on the response of a nonlegume to N in the presence of a legume. Enyi (1973) reported an intercrop system where maize and other legumes were grown: crops such as bean or cowpea had a more adverse effect on maize grain yield than did pigeonpea. He attributed this to the high rates of nutrient absorption by those two legumes, which coincided with that of the maize crop, whereas pigeonpea had the greatest nutrient demand after the harvest of maize. For the experiments described here, a typical sorghum/pigeonpea intercrop system was chosen to compare the N response to intercropped and sole-crop sorghum.

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Materials and Methods

Field experiments were conducted in 1977 and 1978 during the kharif (monsoon) season on a medium-deep Vertisol at ICRISAT Center under rainfed conditions. These soils are low in organic matter, available N, and available P, but high in exchangeable K. The dominant clay mineral is montmorillionite. The physical composition of the soils and the initial fertility status of the experimental sites are given in Table 1. The total amount of rainfall during the 1977

Table 1. Some physical and chemical characteristics of medium-depth Vertlsols at ICRISAT Canter.

	Depth (cm)	Org.C. (%)	pH	CEC (m.e./100g)	Gravel	C.sand	F.sand	Silt	Clay
General characteristics	0-155	0.30	8.3	43	8.3	11.3	13.7	17.7	57.3

	Depth (cm)	Available N (ppm)	Available P (ppm)	Exchangeable K (ppm)
Specific characteristics				
Experimental site I	0-30	79	6.5	195
Experimental site II	0-30	62	7.0	144
Experimental site III	0-30	81	5.3	168

growing period was 571 mm, which was below normal but well distributed. However, during the 1978 growing period, the total amount of rainfall exceeded the average rainfall (715) by 373 mm. During 1978 there were many continuous rainy days, resulting in short periods of temporary waterlogging.

Experiment I

In 1977, a 5 x 4 split-plot design of five populations (100:0, 0:100,40:40,80:80, and 120:120% of sorghum and pigeonpea sole optimum plant population, considering 180 000 and 40 000 plants as optimum for sole sorghum and pigeonpea, respectively) as main plots and four levels of N (0, 40, 80, and 120 kg N/ha applied only to sorghum) as subplots were replicated four times. These varying populations were chosen because earlier evidence showed that the intercrop responded to increasing populations and there is a likelihood of interaction between populations and N levels. Before land preparation, 20 kg P/ha was uniformly broadcast and incorporated. Sorghum cultivar CSH-6 and pigeonpea ICRISAT-1 were planted manually in 45-cm rows, both in the sole as well as in the intercrop. A 2:1 sorghum/pigeonpea row-planting pattern was followed for the intercrops, and varying plant populations were achieved by changing the intrarow spacing. Both crops were sown at a higher than normal (5-6 times) seed rate and thinned to the desired plant population 14 days after germination. After final thinning (and except for zero N plots), 20 kg N/ha as ammonium sulfate was placed by the side of sorghum rows about 10 cm away and about 5 cm deep; the remaining N, as urea, was placed by the side of sorghum rows as mentioned earlier at 28 days after germination. The subplot had 12 rows of 9-m length (5.4x9 m). The central four rows of sorghum and two rows of pigeonpea were harvested at maturity. During the entire growing period, only two hand weedings were given, one in the second week after planting and one in the fifth week. A research level of plant protection was given against shoot fly and stemborer of sorghum and against pod borer of pigeonpea. Sorghum was harvested after 96 days and pigeonpea was harvested after 158 days.

Experiment II

In 1978, a similartrial was conducted with slight modifications based on the results of experiment I. There were 17 treatments in all, replicated three times in a randomized block design. The treatments consisted of one sole sorghum at optimum population (180 000 plants/ha) plus three sorghum/pigeonpea intercrops (at 33:100, 67:100, and 100:100% of optimum populations in a 2:1 row proportion) with four levels of N (0, 40,80, and 120 kg/ha) applied only to sorghum, and one sole pigeonpea at optimum population (40 000 plants/ha). Land preparation, P fertilization, and other operations were similar to those of Experiment I, but planting was done by a seed drill. At the time of writing, only sorghum had been harvested (after 98 days).

Experiment III

During 1977, another sorghum/pigeonpea intercrop experiment was conducted with a constant population of 150 000 sorghum plants/ha and 40 000 pigeonpea plants/ha in a 1:1 row pattern in 45-cm rows. In addition, both crops were grown as sole crops in 45- and 90-cm rows but keeping the population constant. These planting patterns were tried with three levels of N (0, 60, and 120 kg/ha) applied only to sorghum. These nine treatments were replicated four times in a randomized block design. The planting was done manually and all other operations were done as in Experiment I. Sorghum and pigeonpea were harvested 95 and 159 days after sowing, respectively.

Results and Discussion

Experiment I

There was a significant grain yield response of sorghum (Fig. 1) to N up to 80 kg N/ha, whereas

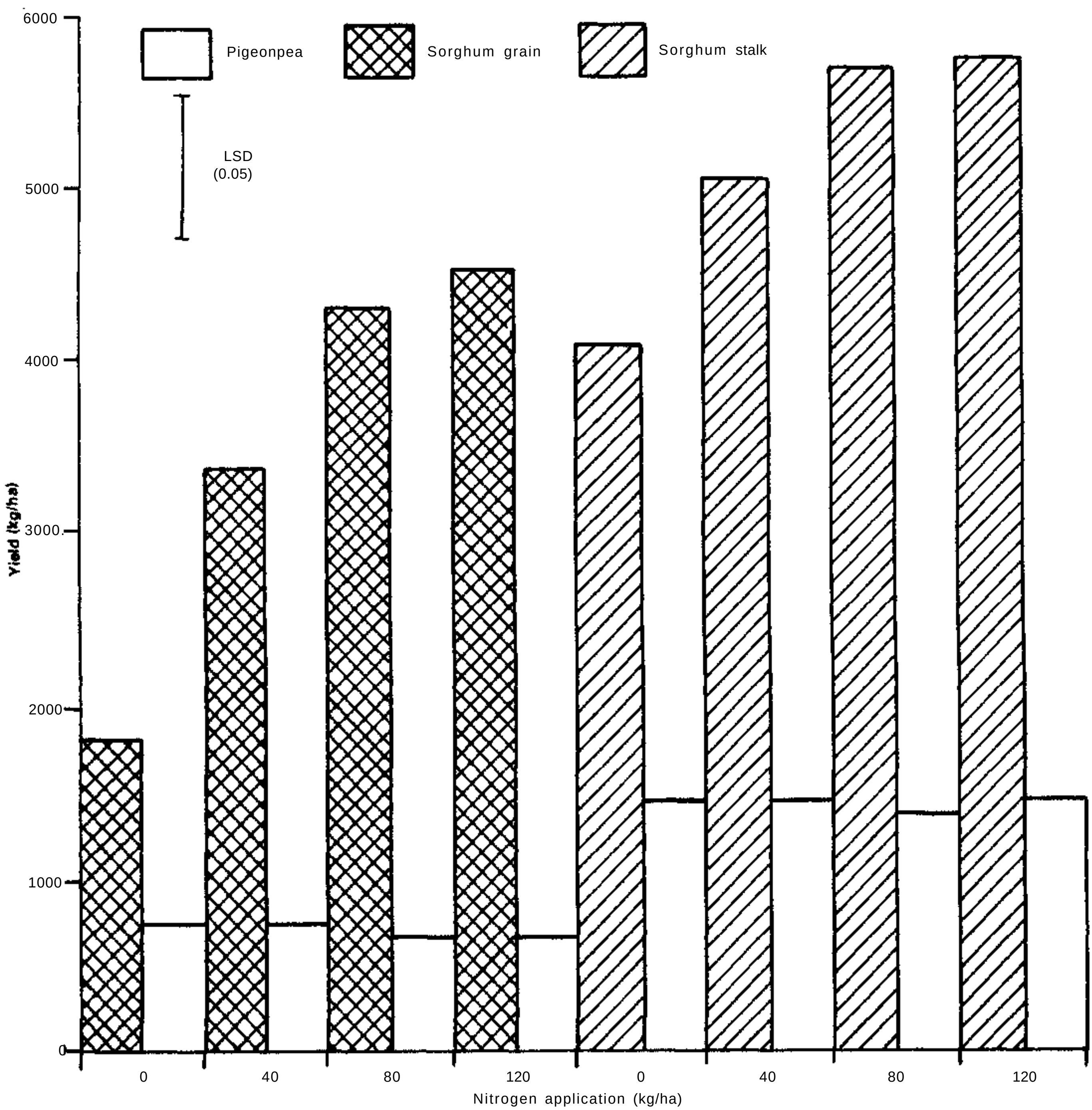

Figure 1. Effect of nitrogen on grain and stalk yields of intercropped sorghum and pigeonpea on Vertisols at ICRISAT Center, 1977.

yields at 80 kg and 120 kg N/ha were similar. Interestingly, in the intercrop situation, all three populations performed equally well and their grain yields did not significantly differ from each other. However, sole sorghum yielded more grain yield than intercrop sorghum at any level of N and more so at higher levels of N. On an average, the intercrop yield was nearly 20% less than the sole. The interaction between population and N levels was not significant. The increase in grain yield with increasing N levels was mainly due to an increase in grain weight/ear and an increase in 1000-grain weight, whereas, as the population increased, grain weight/ear decreased, especially from 80 to 120% population. This character might have been responsible for compensation of yields of different sorghum populations.

The response of sorghum populations at different levels of N (Fig. 2) reveals that near-optimum sorghum populations (80 or 120% of optimum) behave more or less as sole optimum population, although at a lower grain yield level; but low population (40% of optimum) at higher N (120 kg/ha) still responds to N. The sorghum fodder yield also more or less followed the same trend, except that the fodder yields at different populations did not differ significantly.

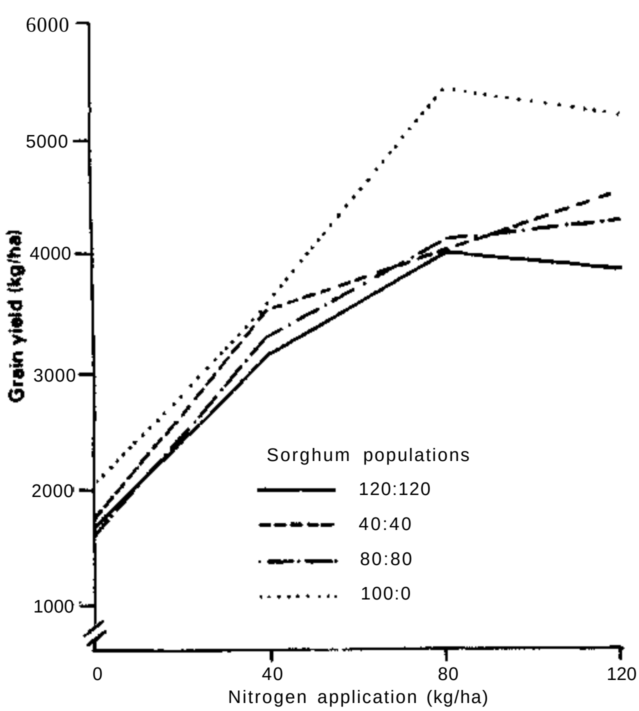

Figure 2. Nitrogen response of sole sorghum and different populations of sorghum intercropped with pigeonpea on Vertisols at ICRISAT Center, 1977.

The pigeonpea grain as well as stalk yields in the intercrop were not influenced by either the N applied to its companion sorghum or by varying populations. Even though a reduction in the pigeonpea yield might be expected, especially at higher levels of N and at higher sorghum population, these effects might have been countered by simultaneous increase in pigeonpea population. The Cropping Systems group at ICRISAT, on similar soil and during the same period working in 2:1 sorghum/pigeonpea intercrop system, found a positive response to pigeonpea population whereas sorghum populations at 90 000 and 360 000 plants/ha performed equally well (ICRISAT 1978). On an average, pigeonpea yields were about 65% of the sole pigeonpea grain yields and about 60% of stalk yields.

The total N uptake (Fig. 3) in sorghum increased with increasing levels of applied N. On an average, sole and all intercrop populations were similar in N uptake. The different levels of N applied to sorghum in intercrop did not influence the N uptake by pigeonpea. The total P uptake by sorghum was similar for the 40, 80, and 120 kg N/ha treatments, but this was higher than zero N treatment. As in the case of N uptake, the total P uptake by pigeonpea was not influenced by different N levels.

Experiment II

Only the sorghum crop in this experiment has been harvested, and the data are presented in Table 2. Unlike the previous year, both the sole and the intercrop sorghum responded up to 120 kg N/ha. This may be mainly because of excess rain resulting in more N loss compared to the previous year. The sorghum in intercrop was as good as sole in 0 and 40 kg N/ha, but at 80 and 120 kg N/ha it yielded about 90% of sole sorghum. During the previous year, a similar trend had also been observed.

Experiment III

There was no significant difference in sorghum grain yield between 45- and 90-cm row spacing as a sole crop at all levels of N (Table 3). The sorghum grain yields both in sole as well as in

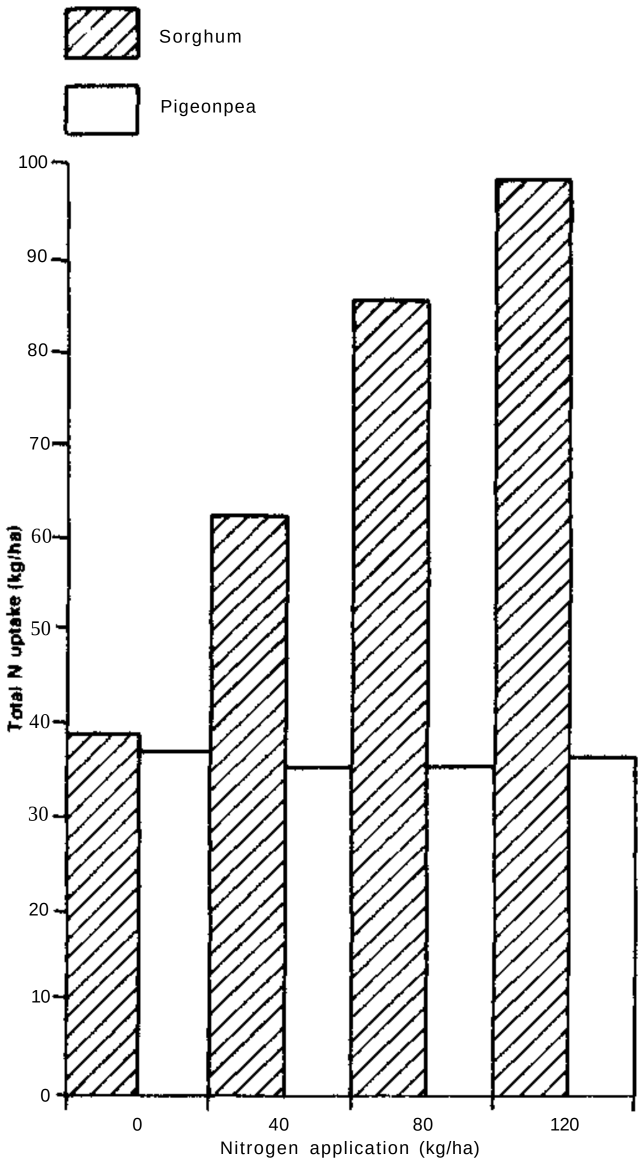

Figure 3. Effect of nitrogen on the total N uptake of intercropped sorghum and pigeonpea grown on Vertiso/s at ICRISAT Center, 1977.

intercrop responded up to 120 kg N/ha. The intercropped sorghum yielded significantly lower grain when compared to sole cropping at 60 and 120 kg N/ha, but they were not significantly different at zero N treatment. The increase in grain yield of sorghum with increase in N level is mainly due to increase in grain weight/ear and increase in 1000-grain weight. The reduction in intercrop sorghum grain yield compared to sole at the same level of N is mainly due to reduction in grain weight/ear.

Pigeonpea grain yields from 45- and 90-cm row spacings were similar. The pigeonpea yields were significantly lower in intercropping than in sole cropping. The different levels of N applied to companion sorghum did not influence the intercrop pigeonpea, since pigeonpea yields were similar at different N levels. The advantages of intercropping were 68, 39, and 47% for the 0, 60, and 120 N treatments, respectively. This may be in agreement with the work of Liboon and Harwood (1975), but in the 2 : 1 system of Experiment I, the LER was more or less the same at ail levels of N—1.46, 1.58, 1.34, and 1.41 at 0, 40, 80, and 120 kg N/ha, respectively. Although the LERs for the 60 and 120 N treatments were lower than the zero N treatment, the total absolute yield or total value was far greater in the 60 and 120 N treatments.

The data for fodder yields of sorghum and stalk yields of pigeonpea show a pattern similar to that of their grain yields. The total N uptake by sorghum {Fig. 4) shows that at 0 and 60 kg N/ha, the sole and intercrop sorghum were similar, but at 120 kg N/ha, the intercrop sorghum had a lower uptake than the sole. As expected, with increasing levels of N, the N uptake of sorghum also increased. In contrast, pigeonpea at all three levels of N to sorghum had more or less the same amount of N uptake. This emphasizes that whether its companion sorghum is fertilized with N or not, the uptake remains more or less constant. Dalai (1974) had clearly shown that in a maize/pigeonpea alternate-row arrangement, at the end of maize harvest (16 weeks), the intercrop pigeonpea had taken only 5.7 kg N, whereas the sole pigeonpea had taken 17.1 kg N/ha. At pigeonpea harvest, however, sole and intercrop pigeonpea had taken 119.4 and 126.8 kg N/ha, respectively, which was similar. In Dalal's trial, sole and intercropped pigeonpea yielded similarly, but intercropped maize yielded only 80% of sole maize. From the data of sorghum-N uptake at the zero N level, it can be concluded that there was no current transfer of N from intercrop pigeonpea to sorghum as sole, and intercrop sorghum had almost the same quantity of N uptake. There was also no evidence of transfer at a low fertility level of 60 kg N. Henzell and Vallis (1977), in an extensive review on transfer of N in grass/legume forages, found no evidence of current transfer of N from legume to its companion nonlegume. Dalai and Quilt (1977), in a study of response of pigeonpea to N, clearly showed that pigeonpea did not respond to applied N. This response holds here also, because even though pigeonpea did not receive directly any

Table 2. Effects of nitrogen and population on grain yield (kg/ha) of sorghum (Experiment II, 1978).

	Population (% of sole optimum)				
	Sole crop	Intercrop			
Applied N	100:0	33:100	67:100	100:100	Mean
0	1293	1621	1394	2082	1598
40	3192	3542	3288	2986	3252
80	4293	4261	3920	3944	4104
120	4967	4593	4656	4448	4666
Mean	3436	3504	3314	3365	
			Population	N	Population x N
LSD (0.05)			NS	298	NS
CV (%) 10.5					

Table 3. Effects of row spacing and nitrogen application upon grain and straw/stalk yields of sole and intercropped sorghum and pigeonpea (Experiment III).

		0 N on sorghum		60 N on sorghum		120 N on sorghum	
Crop	Row spacing (cm)	Yield (kg/ha)	LER	Yield (kg/ha)	LER	Yield (kg/ha)	LER
Grain yield							
Sole sorghum	45	930		2890		4590	
Sole sorghum	90	1330		3140		4240	
Sole pigeonpea	45	1390					
Sole pigeonpea	90	1370					
Intercropped sorghum	a	1240	1.10	2410	0.80	3710	0.84
Intercropped pigeonpea	a	800	0.58	820	0.59	870	0.63
Total LER			1.68		1.39		1.47
LSD (0.05): Sorghum 571	Pigeonpea 401	CV (%) Sorghum 14.3		Pigeonpea 22.9			
Straw/stalk yield							
Sole sorghum	45	4110		5640		6750	
Sole sorghum	90	4110		4390		5360	
Sole pigeonpea	45	2740					
Sole pigeonpea	90	2440					
Intercropped sorghum	a	3420	0.83	4250	0.85	4690	0.77
Intercropped pigeonpea	a	1760	0.68	1440	0.56	1900	0.74
Total LER			1.51		1.41		1.51
LSD (0.05) Sorghum 770	Pigeonpea 111	CV(%) Sorghum 11.1		Pigeonpea 33.6			

a Alternate row, 45 cm.

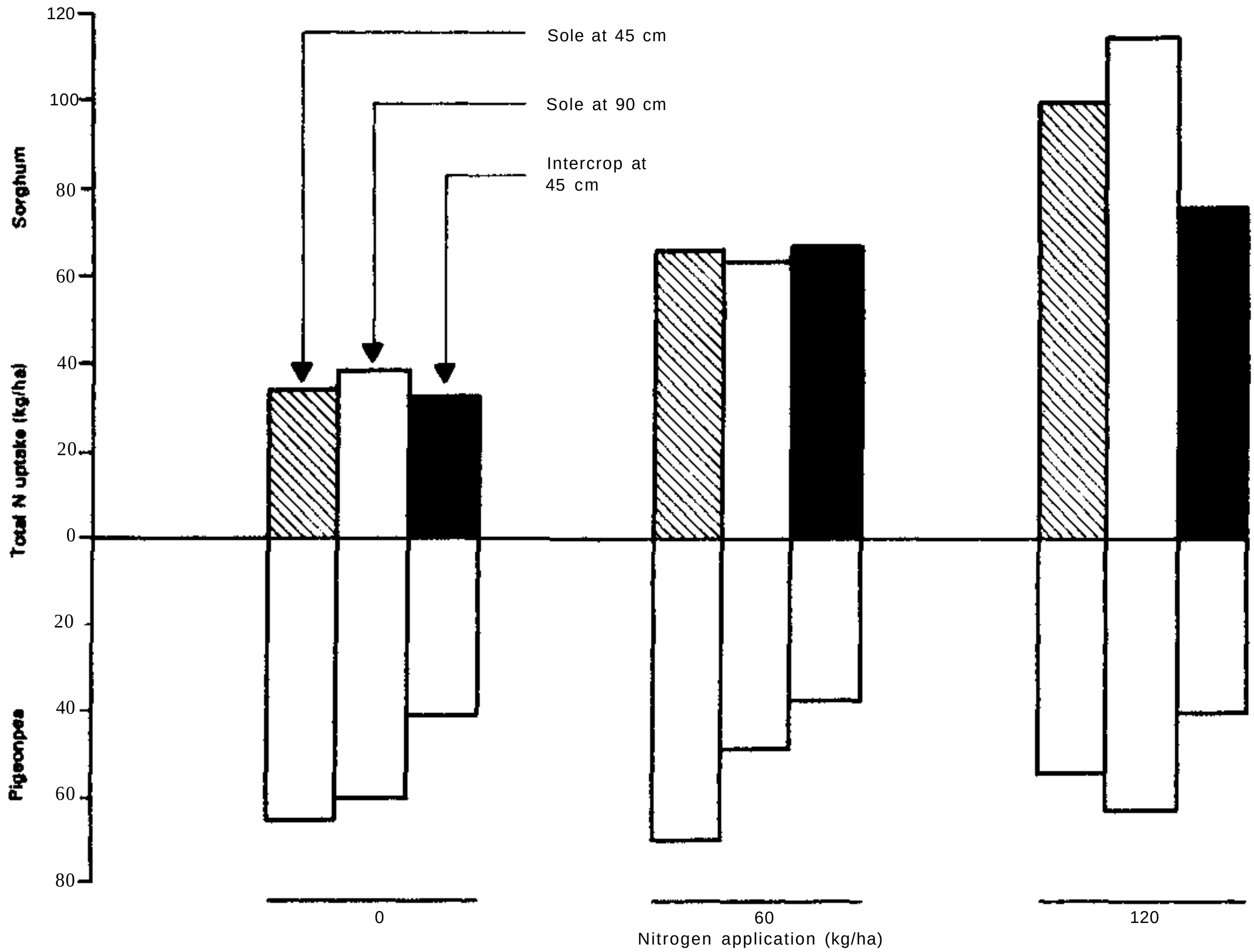

Figure 4. Effect of nitrogen on total N uptake of sole and intercropped sorghum and pigeonpea grown on Vertisofs at ICRISA T Center, 1977.

applied N, its companion sorghum received up to 120 kg N/ha. The total P uptake more *or* less followed the same pattern as N uptake but at a very low magnitude.

Conclusions

Based on the results of these experiments, the following conclusions can be drawn.

In a sorghum/pigeonpea intercrop system, the sorghum response to applied N is more or less similar to sole-sorghum response. The sorghum crop seems to be very plastic with regard to population response. At high levels of N (80 or 120 kg/ha), there is a slight reduction in sorghum LER, which causes a small reduction in total LER.

Indirect evidence reveals that pigeonpea in a 2:1 sorghum/pigeonpea system may suffer a little at higher levels of N applied to its companion sorghum, and in such a situation, a response to pigeonpea population might be expected.

At low levels of N fertility, sorghum planted in rows at 45 and 90 cm performs equally well.

Acknowledgments

I thank Drs. B. A. Krantz and R. W. Willey for their continuous support and advice during the study.

Sorghum/Chickpea Intercropping Trial at Morogoro, Tanzania

M. S. Chowdhury and R. N. Misangu*

Abstract

Sorghum was intercropped with uninoculated or inoculated chickpea at varied soil-fertility levels in a field experiment using a randomized block design. Chickpea was inoculated with a commercial inoculant (Nitrogerm -chickpea) under three levels of soil fertility: (a) no fertilizer (control), (b) 20 kg Nlha as ammonium sulfate, and (c) 20 kg Nlha plus tOO kg Plha as ammonium sulfate and triple superphosphate, respectively. Nodulation, dry matter, and N content of chickpea were examined at various stages of growth. Results indicated the absence of indigenous rhizobia for chickpea. Inoculation significantly increased dry matter and N content of chickpea, but failed to cause a significant grain yield increase. Intercropping greatly decreased the dry-matter content and grain yield of chickpea but had no effect on yield of sorghum. Variation in the soil fertility levels had no effect on nodulation, dry matter, N content, or grain yield of chickpea but significantly increased the grain yield of sorghum.

Intercropping, or mixed cropping, is a common feature in traditional farming of tropical Africa. At the subsistence level, intercropping of cereal(s) and legume(s) is one of the most popular crop husbandry practices. The reasons for its popularity among small farmers have been discussed by some workers (Bains 1968, Norman 1971, Finlay 1975). Systematic research on intercropping has begun only recently. At the Faculty of Agriculture, Forestry and Veterinary Science of the University of Dar es Salaam, in collaboration with the International Development Research Centre, Canada, a coordinated research program has been under way since 1973 to study the various aspects of intercropping in an attempt to understand and to improve upon the system on a scientific basis. Studies on crop combination in terms of compatibility of species and varieties; planting configuration with varied populations; pest control (including insects, weeds, and pathogens); breeding of new cultivars to suit crop combination; and management of soil, water, and fertility under intercropping are some of the important aspects of this program.

In a cereal/legume intercropping, yields of either or both of the component crops have been lower than in sole crops, and this is attributed to competition for nutrients, water, light, or space (Kurtz et al. 1952, Pendleton et al. 1963, Enyi 1973). An increase in the cereal yield when intercropped with legume has also been recorded (Agboola and Fayemi 1971, Keswani et al. 1977), in which case the contributing factor has been assumed to be the supply of biologically fixed N from the legume (Agboola and Fayemi 1972) and, perhaps, the influence of rhizosphere microflora (Keswani et al. 1977). The contribution of rhizobia or their fate in cereal/legume intercropping, however, is not yet well defined.

The present report is based on the results of a field trial on sorghum (*Sorghum bicolor* L.) and chickpea (*Cicer arietinum* L.) intercropping at Morogoro, Tanzania. The aim of this study was to find the effect of the cropping system, with or without rhizobial inoculation of chickpea, at varied soil fertility levels, on the nodulation, N content, and yield of chickpea, and on the yield of sorghum. These crops were selected because Morogoro is in a semi-arid region of Tanzania and is characterized by a bimodal and unreliable rainfall pattern, most of the mean annual

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rainfall of 837 mm being concentrated between March and April.

Experimental Methodology

Sorghum Dwarf Lulu variety and chickpea cultivar BEG 482 with and without rhizobial inoculation were grown in the field as sole crops and intercropped at three levels of soil fertility. The treatments included: (a) two cropping systems — sole crop and intercrop; (b) chickpea uninoculated and inoculated; and (c) three levels of soil fertility. The three levels of soil fertility were obtained by adding (i) no fertilizer (control); (ii) 20 kg N/ha as ammonium sulfate (applied N); and (iii) 20 kg N/ha as ammonium sulfate plus 100 kg P/ha as triple superphosphate (applied N and applied P). Triple superphosphate was applied in the row 10 cm below the surface before planting, and ammonium sulfate was applied as a side dressing 1 month after planting. The experiment was laid out in a randomized block design. All chickpea seeds were surface-sterilized with 0.1% mercuric chloride, washed repeatedly in sterilized water, and dried in air prior to inoculation and sowing. The seeds were inoculated with the prescribed dose of "Nitrogerm-chickpea" (Root Nodule Pty. Ltd., Australia) using 40% neutralized gum arabic solution as the adhesive (Vincent 1970). Both crops were planted in seven rows per plot, each 5-m long, using 60 x 20-cm spacing. In intercropping, sorghum and chickpea were sown alternately at a distance of 10 cm in the same row. All plots containing inoculated chickpea were separated from the uninoculated ones by a distance of 2 m, and separate manpower and tools were used for nodule collection and weeding. The crops were grown under rainfed conditions and weeded twice at about 4-week intervals after sowing.

The experiment was conducted on a moderately acid (ph 6.4), sandy clay loam containing 2.01% organic matter, 0.15% total N, 39 ppm available N (ammonical and nitrate-N), 20.5 ppm available P (Bray and Kurtz No. 1), and 146 ppm exchangeable K (NH_4DAC pH 7.0 extractable).

Nodulation of chickpea was examined at weekly intervals from 7 DAP (days after planting) to 35 DAP. For nodule collection, 10 chickpea plants were carefully uprooted with entire root systems at 40, 55, and 75 DAP. The middle three rows of plants in each plot were used for grain yield data, while the plants from the outer four rows were randomly selected for nodulation study. The uprooted plants were washed clean in running tap water to remove the soil; the nodules and the tops of plants from each plot were separated, dried to a constant weight initially at 70℃ for 48 hours, and finally dried overnight at 105℃. The results are expressed as oven-dry weight per plant. A portion of the dry top from each plot was ground in a ball mill, and 0.1 g of the ground material was used for N determination by the Kjeldahl method.

Results and Discussion

There was no nodulation in the uninoculated chickpea plants up to 75 DAP, indicating the absence of chickpea rhizobia at the experimental site. First nodulation in the inoculated plants was detected at 21 DAP, and measurable quantities of nodules appeared at about 35 DAP. Nodulation data on the inoculated chickpea collected at 40, 55, and 75 DAP are presented in Table 1. There was a great variability in the nodule mass, but no significant effect of either applied fertilizer or cropping system was observed on the nodules collected at 40 and 75 DAP. Intercropped chickpea, however, had sig-

Table 1. Nodulation of inoculated chickpea (mean of three replicates, oven-dry basis).

Soil fertility level	Cropping system	Dry nodule mass (mg/plant) 40 DAP	55 DAP	75 DAP
Control	Sole crop	44.3	82.3	25.0
	Intercrop	13.7	8.0	10.7
Applied N	Sole crop	17.3	63.3	20.0
	Intercrop	20.3	15.7	16.3
Applied N and P	Sole crop	11.3	58.7	36.7
	Intercrop	34.3	33.7	26.0
S.E. of cropping system and inoculation means		±7.31	±8.47	±6.21
CV (%)—cropping system and Inoculation		58.78	44.07	52.53

nificantly fewer nodules than the sole-crop chickpea at 55 DAP. In general, applied fertilizers depressed nodulation in the sole-crop, but a slight increase was observed in the intercropped chickpea. Similar observation was made with the nodulation of soybeans when intercropped with maize (Chowdhury, unpublished). The lowering of nodule mass in sole-crop chickpea at 75 DAP, when the crop was at 50% flowering, indicates the senescence of the nodules. Such senescence, however, was not apparent in intercropped chickpea (Table 1).

Both dry-matter (Table 2) and N content (Table 3) of chickpea plants were significantly increased due to inoculation but decreased in the intercropping system. Soil fertility had no significant effect on either dry-matter or N content of chickpea plants.

The grain yield of intercropped chickpea was markedly low by comparison to that of sole crop (Table 4), indicating that chickpea is not particularly suitablefor intercropping. Neither inoculation nor the fertilizers affected the grain yield of chickpea significantly under either sole crop or intercrop (Table4), despite thefactthat effective nodulation occurred due to inoculation (Tables 2 and 3). *Rhizobium* inoculation of chickpea has resulted in varied kinds of response — from lowering to markedly increasing yields in India (Subba Rao 1976). The lack of inoculation response is usually associated with the presence of effective native strains in soil (Saxena and Yadav 1975) or other factors limiting symbiosis (Dart et al. 1975). In the present case, native chickpea rhizobia were absent, and N fixation did occur up to the flowering stage. The possible reason for the lack of grain yield response may be due to senescence of the chickpea nodules at flowering time (Table 1) resulting in low N fixation during pod fill when the plants required rapid N uptake, as reasoned by Chopra and Subba Rao (1967). However, Dart et al. (1975) noted that N fixation of nodulated chickpea was not affected by flowering, but senescence of nodules is likely to lower the N-fixation rate. Further, it was observed that the chickpea plants started yellowing at the pod fill stage. The nodules harvested at 55 DAP already showed greening at the base, and those harvested at 75 DAP were green, almost 50% by volume, indicating reduced symbiosis. A detailed study on N fixation at various stages of the field-grown chickpea and the redistribution of the symbiotically fixed N in different plant

Table 2. Chickpea dry matter per plant (mean of three replicates, oven-dry basis).

Soil fertility level	Inoculation	Cropping system	Dry matter (g/plant)		
			40 DAP	55 DAP	75 DAP
Control	Uninoculated	Sole crop	3.46	3.19	7.83
		Intercrop	0,93	1.22	2.36
	Inoculated	Sole crop	3.24	6.26	7.89
		Intercrop	1.28	2.05	3.83
Applied N	Uninoculated	Sole crop	1.88	5.62	7.34
		Intercrop	1.09	1.57	3.32
	Inoculated	Sole crop	2.88	6.24	9.77
		Intercrop	1.70	3.55	4.82
Applied N and P	Uninoculated	Sole crop	3.10	4.78	9.39
		Intercrop	1.25	1.96	2.85
	Inoculated	Sole crop	3.78	6.61	10.47
		Intercrop	1.27	1.43	2.89
S.E. of cropping system and inoculation means			+ 0.16	± 0.30	± 0.26
CV (%) — cropping system and inoculation			27.43	28.51	20.54

Table 3. Nitrogen content of chickpea plants (mean of three replicates, oven-dry baste).

Soil fertility level	Inoculation	Cropping system	Total N content (mg/plant)	
			55 DAP	75 DAP
Control	Uninoculated	Sole crop	85.33	234.33
		intercrop	26.00	49.67
	Inoculated	Sole crop	191.67	240.67
		Intercrop	50.67	96.00
Applied N	Uninoculated	Sole crop	152.67	228.00
		Intercrop	35.67	93.67
	Inoculated	Sole crop	188.33	303.67
		Intercrop	101.00	113.67
Applied N and P	Uninoculated	Sole crop	141.00	302.00
		Intercrop	45.33	80.00
	Inoculated	Sole crop	191.00	387.00
		Intercrop	42.00	67.00
S.E. of cropping system and Inoculation means			± 9.32	± 11.70
CV (%) — cropping system and inoculation			29.91	25.28

Table 4. Chickpea grain yield (mean of three replicates, oven-dry basis).

Soil fertility level	Inoculation	Grain yield of chickpea (kg/ha)	
		Sole crop	Intercrop
Control	Uninoculated	854	119
	Inoculated	848	115
Applied N	Uninoculatec	924	136
	Inoculated	788	107
Applied N and P	Uninoculated	814	091
	Inoculated	1046	70
8.E. of cropping system and Inoculation means		± 16.7	
CV (%) cropping system and inoculation		18.40	

parts may offer some insight into the symbiosis in chickpea.

The intercropped chickpea had a comparatively poorer canopy than sole chickpea, but sorghum plants showed no visible difference in growth under the two cropping systems. This indicates superior competitive ability of sorghum over chickpea. Although data were not taken for sorghum dry-matter content, application of fertilizers, particularly N and P combined, improved the growth of sorghum. This was reflected by the grain yield data of sorghum (Table 5). Application of N and P almost doubled the grain yield of sorghum, whereas chickpea yield was not affected by fertilizers. Response to applied N and P fertilizers by sorghum has been recorded in Nigeria (Goldsworthy 1967). The lack of chickpea response to P application in this experiment is in contrast to the findings of Sinha (1972) and Saxena and Yadav (1975). It may be possible that environmental factors — e.g., soil temperature and soil moisture — limited the utilization of nutrients in chickpea.

Table 8. Grain yield of sorghum with unlnocu-latad and inoculatod chlckpaa (mean of three replicates, ovan-dry basis).

Soil fertility level	Grain yield of sorghum (kg/ha)		
		Intercropped	
	Sole crop	Uninoculated chickpea	Inoculated chickpea
Control	1557	1721	1927
Applied N	1919	1837	2250
Applied N and P	3430	3418	3067

S.E. of soil fertility means ± 178
CV (%)—soil fertility 3182

Favorable response to applied fertilizers may be obtained by altering the planting date.

Lowest yield of chickpea was obtained when both N and P were applied under intercropping (Table 4); conversely, sorghum yield was maximum with applied N and P, but it was not affected by intercropping (Table 5). Such results indicate that either nutrients were not limiting for competition between the cereal and the legume or the enhancement of the cereal growth due to applied nutrients induced or aggravated the competition for other limiting factors, such as light and water.

Conclusions

Intercropping markedly reduced the yield of chickpea, irrespective of rhizobial inoculation and applied fertilizers. Sorghum yield was greatly increased by applied fertilizers but was not affected by chickpea inoculation or inter-cropping. The adverse effect of intercropping on chickpea was most serious when fertilizers were applied and cereal growth was improved.

When chickpea was grown as a sole crop, nodulation, dry-matter content, and N content up to the flowering stage were improved due to inoculation. However, the grain yield of chick-pea was not increased by inoculation, possibly due to the rapid senescence of nodules at the flowering stage.

Acknowledgments

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Discussion

Leaf Canopies and Utilization of Light

Snaydon

At least two of the mechanisms that Dr. Trenbath suggests might increase LER of intercrops might not give an agronomic advantage. First, Dr. Trenbath's model indicates that the highest LERs should occur when Pmax of the lower species is close to zero. Under these conditions, the intercrop yield would be identical to that of the dominant species, so there would be no agronomic advantage. Thus, LER does not always indicate agronomic advantage. Second, the highest LERs should also occur with low extinction coefficients for the dominant component, but these are the conditions that are likely to lead to low productivity.

Trenbath

I think I did point out as an aside that I was more interested in Pn than in LER. I think I said that you can in effect eat Pn but you cannot eat LER. So I think the indications given by the Pn were the more important ones and certainly there were parts of my graphs in which there were strange things happening. You may have noticed that in thefirst series there were some negative Pns; these occurred with a very high photosynthesis maximum in the lower canopy and with very little light from the upper canopy. But with this high Pmaxyou have to pay a high respiration tax. This is why you do not often have good intercropping if you have C_4S down in the bottom of the canopy.

Willey

I would also like to refer to Dr. Trenbath's paper. I must say I thought this had tremendous implications for intercropping research, because I think that the efficiency of light use in intercropping is rather like the efficiency of nitrogen fixation that we discussed at length earlier. I think that Dr. Trenbath has shown that in this light utilization field, at least in theoretical terms, there appears to be some potential for getting better light use. This is important to agronomists in the field.

It seems to me that one of our combinations — millet/groundnut, which we work on a good deal — seems to fulfill a number of the characteristics that are theoretically desirable. If this is so, what sort of increased efficiency in terms of increased dry matter do you think we might be talking about? Are we, for example, talking about the possibility of a further 5%, 10%, or 20% increase in dry matter?

Trenbath

Well, certainly this combination has some desirable characteristics with a nice erect C_4 plant above and a rather compact C_3 plant below. But the calculations I showed were of instantaneous Pn, and the incident light level which I used for all the calculations was something of a medium level of 200 watts/m^2 (400 watts/m^2 is about full sunlight). So in those calculations we are looking at instantaneous rates, which are in a sense relative growth rates; and small changes in relative growth rates — i.e., in compound interest terms — can have large effects on the accumulated dry matter. So I would not really like to guess without a model that could integrate these snapshots over time and I would not really like to guess at the overall effect of what might be small increases in instantaneous growth rates. I am sorry I am not going to commit myself further on that. And I would add that there are some snags. For example, you may aim at a very efficient canopy structure but your lower component may then die. Thus you get nothing or at least very little from your lower component. Similarly, you may say that by lowering the leaf inclination you may intercept more light. But in fact if your leaves intercept more light you are going to produce a higher root/shoot ratio which will mean that you have a higher respiration. So in fact your rate of dry matter production may not be increased at all.

There was a reference earlier to some sorghum/millet combinations which are of course two C_4 plants, and it was said that advantages could have something to do with a better distribution of the young leaf tissue throughout the canopy. I would notexpectthis theoretically; if anything, I think I would expect an LER less than 1 because you have highly respiring young leaves low in the canopy and they will pay a high respiration tax.

S. J. Reddy

Does the same extinction coefficient hold good during the period of leaf area development and leaf area senescence?

Trenbath

No, the extinction coefficient does not remain constant during growth, and certainly with cerealsthey can change their leaf inclination in just a few days quite markedly.

Wein

As the overstorey grows, the light becomes less and less for the canopy underneath. Can we expect changes in the efficiency of light use by the crop growing underneath? I think changes in gross photosynthetic rate have been shown before; as plants grow under lower light environments they do tend to adapt to the lower light levels. Can we expect, because of the differences in light quality which occurs, red light generally being more plentiful in the lower layers, that this can bring about some adaptive changes?

Trenbath

Ithink Dr. Okigbo showed with hismelonsthat the leaf area index was higher when the crop was shaded. On a related aspect to this, I have seen some information that the shift to far red in the lower parts of the canopy is in fact a specific inhibitor of nitrogen fixation and nodulation. So if you are relying on a lower legume to fix nitrogen, then there may be this effect of a spectoral shift on the rate of fixation.

Snaydon

Dr. Natarajan plotted dry matter accumulation against light interception. Has this been done for accumulated water loss, or accumulated nitrogen? If you do this, you will presumably get exactly the same linear relationships as was obtained for light. It is in fact very dangerous to say that, simply because one has got a straight line relationship between growth and light, it is a cause-and-effect relationship. It could equally well be argued that the light interception was a result of the growth and it may well be some other factor which is responsible for the growth.

S. P. Singh

Our own experience in the All India coordinated Sorghum Improvement Project is that even if we go to 180 000 plants of sorghum, if we widen sorghum rows as far as 90 cm, the decrease in sorghum yield is tremendous — upto 25 to 30%, for example. When we have pigeonpea as an intercrop this decrease becomes even greater. So I would suggest that this effect be studied very carefully.

Natarajan

The experiment we have described here was also repeated on the red soil where the loss in sorghum yield in the 1:1 situation was even less.

Sivakumar

Concerning the way in which we present the water-use efficiency in sole crops and in intercrops, it has been suggested that it does not differ between intercrop and sole crop. But as the LERs have shown that there can be quite large increases in dry matter over sole crops, it might be better for us to talk about water-use efficiency in terms of kilograms of dry matter per centimeter of water and not just cm of water used.

Natarajan

When I said there was not much difference in the soil moisture loss due to different degrees of canopy cover, it was because when we had a better canopy most of the moisture loss was channelled through the canopy. Where the canopy was poorer a bigger proportion of the moisture loss occurred by evaporation from the soil surface.

Nutrient Interactions and Rooting Patterns

Willey

I thought Dr. Snaydon's paper helped us to keep in perspective the importance of these different growth factors. In terms of rooting pattern, where are we likely to get the biggest effects from? Does it mean that we have to have spatial separation between the root systems, or can we get some of these effects by having different roots demanding different things even in the same horizon next to each other?

Snaydon

The answer is that we do not know. There is no evidence whatsoever on this kind of thing. All I can say is that we can definitely find different species with different root distributions, and we can also find different species with different temporal distributions of nutrient uptake. We can also get species that are limited by different resources so, for example, one is limited by nitrogen and the other is limited by phosphorus. So all of these are possible, but it just is not possible to say which is more important, because there is no experimental evidence.

Russell

I am very much in agreement with Dr. Snaydon in terms of the possible importance of the belowground factors. But, let us remember that we are dealing with a system. In some cases it may be dominated by one component. For example, this last summer water was in excess and the factor controlling growth was possibly light. This current season it is of course an entirely different thing. I also agree that whether the extinction coefficient is the cause or the effect of leaf development is questionable. The same thing applies to root development. It all suggests to me that we are dealing with a highly dynamic interactive system in which all the primary environmental and genetic elements are functioning. And to try to sort them out without some kind of conceptual model, and to attempt to put some response functions on these different interactions, is not desirable. You comment that water is obviously the controlling environmental factor, but you are here at this (postrainy) season of the year, whereas in summer time (the rainy season) the problem is to get rid of water. For example, the root patterns that were shown by millet and groundnut this last season were entirely different from the patterns that were shown in millet the previous postrainy season. We should think in terms of a comprehensive system and try to measure as many components as possible. Then, perhaps, we can try to overcome this problem of site specificity by putting this in stochastic terms on the basis of the long term probability of the weather.

Snaydon

I would agree wholeheartedly on your suggested need for a model, but before we can build the model we need to know the size of the various parameters involved. And I would like to make the point that it is going to be a very complex system. So perhaps our first approach should be to eliminate the less important parameters as we see them.

Laxman Singh

I would prefer to see us talking about measuring and exploring complementary effects rather than talking about competition. Dr. Osiru indicated thatto a certain level there was a neutral effect in the competition, then after this level there was a compensatory effect and production increased. At a further level again, production was reduced and there was a competition effect. Do you think that we should concentrate on this type of terminology of effects?

Snaydon

Yes, complementary effects are perhaps what we are looking for. But of course there is still a lot of very straightforward competition occurring between any two crops growing together.

Snaydon

My interpretation of Dr. M. S. Reddy's data is that this is probably a nutrient, especially a nitrogen, effect. In this arrangement we have removed three quarters of the cereal and replaced it by a legume. The legume, being a nitrogen fixer, needs no nitrogen; so as a result of this we have multiplied the nitrogen available to the cereal crop by 4. We therefore expect the cereal crop to do better. It is also relevant that the groundnuts remain equally productive under intercropping as in sole cropping. If there had been intense competition for light, i would have expected yields to be reduced. I have also calculated from some of the experiments that we have seen, that the cereal was probably removing about twice as much nitrogen as was applied in fertilizer. This again would suggest that we were operating in a nitrogen-deficient system.

Shivashankar

I noticed that the ICRISAT experiments we have seen were all carried out at a relatively high level of nitrogen. This could obviously suppress nitrogen fixation by the legume. I think there is a need for this kind of study at low levels of nitrogen more equivalent to the farmer's situation.

Rego

As far as possible we place all the nitrogen near the cereal rows so that as little as possible gets near the legume or the pigeonpea crop.

Burford

Dr. Snaydon has attached a good deal of importance to nitrogen in intercropping but I am not sure that this explains some of the differences that he has been talking about. For example, in Figure 2 of Dr. Rego's paper, at higher nitrogen levels there was a difference between sorghum and pigeonpea and in intercropping the sorghum yield levels out. If nitrogen was the limiting factor in that experiment, that difference should not occur. Then, if we look at Dr. Reddy's paper, the results were attributed to improved efficiency of conversion of light and they considered light interception was the same in both sole crop and intercrop. So could not those results be due to some effect of the geometry of the intercropping situation? For example, could not one have an improved flow of carbon dioxide to the millet plants, because it was in fact the millet that was giving the big response rather than the groundnut?

Snaydon

When sorghum was grown sole it went on responding up to 80 kg N/ha but when it was grown with pigeonpea it responded only upto 40. So it still seems to me that there was a nitrogen effect. But I have stressed earlier that these belowground effects do not have to be entirely nitrogen; there could be phosphorus or other nutrients involved, or even water.

Trenbath

We should perhaps remember Dr. Shivashankar's point that at the level of nitrogen used in those experiments there may have been some suppression of N fixation.

Willey

I think it is terribly misleading, even in this environment, to say that light is a nonlimiting factor. At a given level of interception, which may not necessarily be full interception, I think it is still possible to get more efficient use of light. And I think that is what we were trying to point out. If we contrast the two experiments we have looked at, in the sorghum/pigeonpea I think the effects were because we were getting greater use of most things. We reported this as light, but there was also more moisture going through the plant, and I am sure that when we getthe nutrient analysis we will find that there were more nutrients taken up. So it is very difficult in that circumstance to say that one is the cause rather than the effect. But in the millet/groundnut situation, the intercrop canopy was able to support 30% more leaf area index and it achieved this without any greater interception of light. The simple explanation therefore is thatthe canopy was more efficient, with a C4 at the top and a C3 at the bottom, a sparse canopy at the top in the high light situation and a dense canopy in the bottom in the low light situation. These are the sorts of characters which we would imagine could create an improved light-use efficiency. So it seems to me that we are going to great lengths to find a more unlikely explanation; for example, better CO_2 utilization, better nitrogen fixation, etc. What is wrong with a light effect?

Chairman

This has been a most interesting morning. The first session emphasized the importance of light, and this second session has emphasized the importance of belowground factors. This latter emphasis is one which I support. It is becoming clear that we *are* possibly ignoring some of the important basic factors such as nutrients and water. We should perhaps remember that the intercropping system is one which has been designed to fit into situations where water and nutrients are limiting. And light is not generally the limiting factor. I do hope that we have opportunity later in the workshop or even afterwards to go into some of these factors in more detail.

N Fixation

S. L. Chowdhury

Was the environment in Morogoro, Tanzania, suitable for chickpea? Often, where the environment is suitable for sorghum, it is not suitable for chickpea. Normally the chickpea likes a cool situation. The northern part of India is more suitable for chickpea than the southern part.

M. S. Chowdhury

The chickpea was planted at a temperature of around 28℃ but at the time of flowering the temperature was probably about 5° less.

S. L Chowdhury

I have a feeling that chickpea is probably not well adapted and this is why the combination did not do well.

M. S. Chowdhury

Chickpea is in fact grown as a cash crop, not for local consumption. Few farmers grow chickpea.

Laxman Singh

If you see the magnitude of the yields, sorghum sole crop was around 1500 kg/ha, chickpea uninoculated was around 1700 kg/ha, and chickpea inoculated around 1900 kg/ha. This is quite a big difference. So presumably the CV of the experiment was quite high?

M. S. Chowdhury

Yes, it was high.

Shivashankar

I would like to know what can best be done in India when nodulation is unsatisfactory. Even when we do not have sufficient nodules, we do not have the right culture being supplied to the farmers. This is a big problem.

Dart

This question has two aspects to it. First, whether nodulation is in fact poor. A few of our analyses using acetylene reduction suggest that it is poor and one could assume that nitrogen fixation in these situations is limiting. But until we have some quantitative measure of the amount of nitrogen fixed, I do not think we can be certain. For example, with chickpeas in our environment, the fixation time is relatively limited compared with other crops such as groundnut which are better adapted. But it is very difficult to examine nodulation on some plants such as pigeonpea. It is possible to get a nitrogen response in pigeonpea provided you add sufficient nitrogen and this may suggest that nodulation is limiting.

The second aspect relates to inoculation and this is a difficult one. I am not sure that inoculation will put right the difficulties you are referring to. It may not be a lack of the appropriate *Rhizobium.* It may be other environmental factors which are limiting. In due course we may be able to identify strains which are more drought resistant, but we are a long way off from that.

Rajat De

Many of the legumes when grown in intercropping *are* adversely affected. And yet there are other legumes that are not so adversely affected. This again points to the need for specific cultivars or genotypes for intercropping, for example, as I have indicated earlier, genotypes which can grow under low light situations.

Chairman

We have benefitted from taking the system apart, looking at each of the factors which may be limiting, and looking at the final yield of the system. I think we urgently need to look more at the methodologies required to examine the different parts of the system. This came out particularly clearly when we were discussing the light factor and the water and nutrient factor. But in terms of determining which factors are most limiting — the aboveground factors or the belowground factors — we still having a long way to go.

Session 3

Plant Protection Aspects

Chairman: B. R. Trenbath

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Weed Management in Intercropping Systems

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Abstract

Weed management research in intercropping is limited. Many authors claim that one of the reasons for intercropping is weed suppression, but there is little experimental evidence to support this conclusion. The few experiments on weed management that have been conducted in an intercropping system indicate that many factors—including the specific component crops, crop cultivars, plant population, spatial arrangement, and soil fertility—determine the weed competitive ability of intercrops.

The main methods of controlling weeds in intercrops are manual or mechanical. According to some authors, intercrop combinations require less input for weed control, but the quantitative evidence does not support this statement. Mechanical weeding may be difficult or even impossible in certain spatial arrangements. It has been difficult to find suitable broad-spectrum herbicides as the herbicides are often crop specific. The more complex the system, the less the likelihood of finding suitable herbicides. A review of past experiments on weed management in intercropping systems indicates that concerted and coordinated weed research approaches are necessary to determine the implications of intercropping on weeds and to develop effective and economical weed-management methods. The authors suggest that ecophysio/ogical studies to understand "how" the weeds respond and agronomic studies to evaluate "what" should be done to manage them need to be intensified.

In the past, no distinction has been made between the terms "intercropping" and "mixed cropping," or they have been used interchangeably. In this paper, "intercropping" implies that two or more cultivars of the same or different crops are grown simultaneously on the same piece of land without taking spatial arrangement into consideration.

Numerous authors (Enyi 1973, Geertz 1963, Walters 1971, Webster and Wilson 1966) have stated that the more complete cover provided by intercropping reduces weed growth by competition. This results in a reduction in the amount of labor required for weeding (Webster and Wilson 1966).

Evans (1960) observed that for corn (*Zea mays* L.) and peanut (*Arachis hypogaea* L.), weeds in the crop row caused approximately the same reduction in yields as that caused by another crop. The percentage of reduction in yield caused by weeds or by an intercrop was approximately twiceas great in peanut as it was in corn. On the basis of these results, he speculated that the best weed was another crop. Raheja (1973) stated that the growing of intercrops prevents usurpation of space by weeds and instead substitutes a profitable crop. De (1974) suggested that planting an early-maturing crop of either mung bean [*Vigna radiata* (L.) Wilczek] or cowpea [*Vigna unguiculata* (L.) Walp.] as an intercrop in cotton (*Gossypium hirsutum* L.) may help in effectively utilizing the vacant spaces between the cotton rows without detriment to the yield of the crop components. The fast initial growth of the legume crop keeps the weeds under control.

Moody (1978) observed that the growing of a number of crops in close proximity to one another so that the plant density is greater than in sole cropping should result in greater competition against weeds and thus reduce the need for weeding. However, if the plant density of the intercrop is the same as for the component crops when grown alone, or if both are planted at their optimal densities, there may be

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little advantage with respect to weed suppression from intercropping. In fact, weed growth in the intercrop may be as great as in the sole crop (Moody 1978).

The weed-suppressing ability of intercrops is dependent upon such factors as the component crops selected, the cultivars selected, the plant density used, the proportions of the component crops in the intercrop, their spatial arrangement, and the fertility and moisture status of the soil (Moody 1978, Shetty and Rao 1977).

Comparative Ability of Intercrops and Sole Crops in Competing with Weeds

Intercrop Superior to all Component Crops

Numerous authors (Bantilan and Harwood 1973, Bantilan et al. 1974, Castin et al. 1976, Mahyuddin et al. 1976) have reported that the weight of weeds growing in association with a corn/mung bean intercrop is as low or generally lower than that growing in association with the sole crops. Castin et al. (1976) reported that the weed-suppressing ability of the intercrop was greater at higher levels of weeding. Bantilan et al. (1974) and Mahyuddin et al. (1976) reported that corn yield was greater in the intercrop than in the sole crop, and land equivalent ratios were highest under unweeded conditions, but Castin et al. (1976) observed the reverse.

Furoc et al. (1977) reported that when soybean *[Glycine max* (L.) Merr.] was intercropped with corn, the presence of the soybean reduced weed growth markedly. Forty days after sowing, 4.0 t/ha weed were harvested from the sole-crop plots, whereas only 0.5 t/ha were harvested from the intercropped plots.

Robinson and Dunham (1954) reported that wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), and peas (*Pisum arvense* L.) gave excellent weed control without affecting soybean yield when intercropped with soybean.

Rao and Shetty (1976) reported that intercropping systems based on sorghum [*Sorghum bicolor* (L.) Moench] reduced weed growth an average of 25% more efficiently than sole-crop systems. Hart (1974) reported that there were no statistically significant differences in the total dry-matter production from all the cropping systems that he studied. Weeds constituted 20, 25, and 83% of the total biomass in corn, cassava (*Manihot esculenta* Crantz), and bean (*Phaseolus vulgaris* L.) sole crops and 16% when these crops were intercropped.

Intercrop Superior to one of the Component Crops

Intercropping wheat or oats (*Avena sativa* L.) with flax (*Linum usitatissium* L.) made it possible to grow flax on land which was too weedy for flax when it was sole cropped. Even though fewer weeds grew in association with the intercrops than with sole-cropped flax, there were more weeds than in the sole-cropped wheat or oats. Thus intercropping was beneficial only for weed control in flax.

Bantilan and Harwood (1973) observed that corn was more effective than peanut or sweet potato [*Ipomoea batatas (L.)* Lam] in suppressing weeds. When corn was intercropped with sweet potato or peanut, weed growth was less in the intercrops than in the sole crops for sweet potato and peanut but greater than for the sole-crop corn (Bantilan and Harwood 1973). However, Mercado (1976) reported that peanut was more effective in suppressing weeds than corn, and weed growth in the intercrop was less than in the sole-cropped corn but greater than for sole-cropped peanut.

In Colombia (CIAT 1976), there were fewer weeds growing in sole-cropped bean than in intercropped corn and bean. There were, however, more weeds in sole-cropped corn than in the intercrop. Moraes (1975) observed more broadleaf weeds growing in association with a corn/bean intercrop and sole-cropped corn than in sole-cropped bean, the bean again being a more effective competitor. Rao and Shetty (1976) reported that when pigeonpea [*Cajanus cajan* (L.) Millsp.] was intercropped with sorghum, there were fewer weeds in the intercrop than in the sole-cropped pigeonpea but not in the sole-cropped sorghum.

No Difference between Intercrops and Sole Crops

Punzalan (1972) reported that weed growth in corn intercropped with peanut was no less than in sole-cropped corn.

Alfalfa (*Medicago sativa* L.), winter vetch (*Vicia villosa* Roth), timothy (*Phleum pratense* L.), bromegrass (*Bromus* sp.), and medium red clover (*Trifolium pratense* L.) were ineffective in weed suppression when they were intercropped in soybean (Robinson and Dunham 1954).

Rao and Shetty (1976) reported that pigeonpea-based intercropping systems did not improve their competitive ability over the respective sole crops primarily because of the poor contribution of pigeonpea to the system.

According to Kass (1976), the evidence for better weed control with intercropping is at best indirect because no diminution of weed growth was obtained when cassava was intercropped with corn or rice (*Oryza sativa* L.). However, crop dry matter was increased, the total dry-matter production was greater, and the proportion of the total dry matter that was weeds was less in the case of intercropping. Hence, according to Kass (1976), intercropping provides the farmer with a more effective means of utilizing available environmental resources especially if weeding is not practiced.

Effect of Different Factors on the Competitive Ability of Intercrops

Component Crops

Bautista (1918) observed that cowpea seemed to control weeds better than mung bean, soybean, and tepary bean (*Phaseolus acutifolius* Gray) when they were grown in association with corn. Robinson and Dunham (1954) reported that, at equivalent rates of sowing, a rye/soybean intercrop suppressed weeds more than a wheat/soybean intercrop.

Mung bean was superiorto peanut and sweet potato in suppressing weeds when the three crops were intercropped with corn. The superiority of mung bean to peanut appeared to be due to the more rapid early growth of the mung bean and differences in the leaf canopy. Even though peanut may intercept nearly as much light by mid-season, it has a broken pattern compared tothe more uniform interception pattern of mung bean (Bantilan et al. 1974).

At ICRISAT, intercrops of cowpea or corn with pigeonpea suppressed weed growth to a greater extent than mung bean or peanut (ICRISAT 1977s).

Crop Cultivars

Bantilan et al. (1974) observed that when mung bean cultivar MG 50-10a was grown in association with corn, there was less weed growth than when CES 14 was used. They reported that CES 14 exhibited an increase in height during the early growth at the expense of lateral growth, whereas the reverse was observed for MG 50-1 Oa. This indicated that early canopy closure is more important than rapid increase in height in suppressing weeds. Castin et al. (1976) also reported differences between mung bean cultivars in their weed-suppressing capabilities when grown as an intercrop with corn. They observed CES 55 to be superior to CES 14 and MG 50-10a (Y).

Rao and Shetty (1976) reported that when pigeonpea was sole cropped, a spreading cultivar, ST 1, was more competitive against weeds than a compact cultivar, HY 3a. However, when pigeonpea was intercropped with sorghum, no difference was observed between cultivars with respect to their weed-suppressing ability. In the following year, the advantage of the spreading cultivar was not apparent, primarily due to a change of the cultivar to ICRISAT 1.

Moody (1978) reported that when corn was intercropped with sweet potato, less competition occurred against weeds when DMR 2 was used as the corn cultivar than when Hickory was used.

Plant Population and Spatial Arrangement

Mung bean and corn were more effective in controlling weeds at low corn plant populations and at a wide corn row spacing, whereas corn and either sweet potato or peanut were better at high corn populations and at a close corn row spacing (Bantilan and Harwood 1973, Bantilan et al. 1974). However, Moody (1978) reported that when mung bean and cowpea were intercropped with sorghum, the intercrops were superior to the sole crops in their weed-suppressing abilities when one row of sorghum was intercropped with one row of legume. When two rows of legume were intercropped with one row of sorghum, the intercrop was inferior to the sole-cropped sorghum but superior to the sole-cropped mung bean.

Fortuity

Bantilan et al. (1974) observed that corn intercropped with sweet potato or peanut was less competitive against weeds at high N levels, whereas a corn/mung bean intercrop was more competitive. They also observed that the land equivalent ratios decreased as the N level increased for the mung bean/corn intercrop. Soria et al. (1975) reported that cassava intercropped with bean, corn, sweet potato, or bean plus corn was less competitive at a high fertility level than at a low fertility level. However, Hart (1974) reported that weed growth in a bean/corn/cassava intercrop was generally less at high fertility than at low fertility.

Soil Type

In trials conducted at ICRISAT (ICRISAT 1977a) on Alfisols and Vertisols, the weed infestation was about the same in the early part of the growing season on both soil types. However, late-season weed weights were two to four times higher on the Vertisol than on the Alfisol.

Weeding Requirements for Intercrops

Even though certain crop combinations may cause a reduction in weed weight compared to the component sole crops, there is still a need in most cases to do some weeding so that the weeds that are present do not cause yield reductions (Moody 1978). It is assumed in the literature, without empirical verification, that growing crops in mixtures results in a saving in labor (Norman 1973b). Norman (1973b) states that such reasoning has been based on the premise that weeding is less critical in intercropping and that some operations, such as planting of the second crop and weeding of the first, can be combined. In 1968, Norman reported that although, theoretically, labor should be saved by intercropping, the quantitative evidence does not support this statement. According to Harwood (1974), intercrop combinations require less input in weed control. This can only be so if there is a reduction in weed weight in the intercrop combination compared to the sole crops. On the other hand, Day (1978) states that the need for weed control in intercropping is as great as for sole cropping.

Paner (1975) reported that intercropping corn and mung bean under coconut reduced weed growth to such an extent that weeding was not needed. At the other extreme, Jereza and De Datta (1976) observed that despite a 40% reduction in weed weight in intercropped corn and mung bean compared to sole-cropped corn, weed competition was so intense that no yield of the intercrops was obtained.

Lagemann (1977) reported that a second weeding of a sole crop of corn resulted in a significant increase in yield, whereas no such relationship was found with traditional intercropping. For a pigeonpea/sorghum intercrop, Rao and Shetty (1976) reported that one less hand weeding was needed than when pigeonpea was sole cropped to obtain optimum yields of the crops involved. Moody (1978) reported that when one row of mung bean or cowpea was intercropped with one row of sorghum, no yield response to weeding was observed; however, for the sole crops, and when two rows of either of the legumes were intercropped with one row of sorghum, one weeding was needed to obtain yields that were not significantly different from the weed-free check. Sjarifuddin et al. (1975) reported that it took less time to weed crops grown in intercrop combinations than when the same crops were grown sequentially as sole crops.

Suppression of weeds in the intercrop compared to the sole crop may have a beneficial effect on the subsequent crop as well. A common practice in Nigeria and other parts of West Africa is to sow cowpea into established corn during weeding about a month after the corn has emerged (Moody 1977). Moody (1977) surmised that the presence of the cowpea would result in fewer weeds, and fewer weed problems, in subsequent crops. Deat et al. (1977, 1978) confirmed this theory. They reported that fewer weeds grew in association with a cotton crop when it was planted after a corn/cowpea intercrop than when it had been planted after a sole crop of corn (Deat et al. 1977,1978). Less time was required to weed the cotton crop following the corn/cowpea intercrop (Deat et al. 1977).

Shetty (1978) reported that the critical period of weed competition in the intercrop was longer than in the sole crop, so that weeding operations had to be continued for a longer period of time to obtain optimum yields of the crops involved. The sole-cropped sorghum needed to be maintained weed-free for only the first 4 to 5 weeks of crop growth, whereas for the sorghum/pigeonpea intercrop, the weed-free period had to be extended to 7 weeks (ICRISAT 1977a).

In Colombia (CIAT 1976), in sole- and intercropped corn and bean, one weeding was needed to give adequate control even though fewer weeds occurred in the intercrop compared to the sole-cropped corn. Therefore in terms of the number of weeding operations needed, there was no advantage to intercropping. In Brazil, the traditional weed-control practice for corn and bean in the Pernambuco Agreste is two hoeings during the crop cycle. However, field trials conducted in 1974 and 1975 demonstrated that one well-timed hoeing gave equally good yields in these crops when they were sole cropped as when intercropped.It was thought that farmers may perform two weedings to improve field aesthetics or possibly to facilitate harvest (Miller 1976).

Suryatna (1976) reported that significantly more time was required to weed a corn/cassava intercrop than a cassava sole crop, whereas in northern Nigeria, intercrops required 29% more labor input during June and July — the peak weeding period — than sole crops (Baker and Norman 1975). In India, there was less expenditure on weed control when chickpea (*Cicer arietinum* L.) was intercropped with sugarcane (*Saccharum officinarum* L.) than when sugarcane was grown alone (Lall 1977).

Methods of Weed Control

Bunting (1972) stated that regulation of harmful organisms is essential and must be based on methods that are (a) cheap and effective even if they are less than perfect in some respects, (b) not dependent on expensive mechanical equipment, and (c) not dependent on a sudden and dramatic technical change.

Weed control may be a greater problem in intercropping than when the component crops are grown alone (Moody 1978). The major methods of controlling weeds in intercrops are manual or mechanical. Mechanical weeding is difficult or even impossible in certain spatial arrangements, such as the random planting of legumes between rows of corn — a practice that is used when Mexican yam bean (*Pachyrrhizus erosrus* Rich) is intercropped with corn in Iloilo province, Philippines — or when the row spacings of the component crops are too close to each other. Erbach and Lovely (1976) stated that when crops are grown side by side in alternate rows, equipment must be operated more precisely to prevent damage to the adjacent crop. Cultivation is greatly facilitated if the component crops are planted in the same row or in rows that are spaced equidistant and are sufficiently far apart to allow passage of the cultivating implement and its power source (Moody 1978). Small, manually operated, engine-powered equipment or hand tools will allow closer spacing of the crop rows than will animal-powered equipment or equipment with large wheels (Erbach and Lovely 1976). Miller (1976) reported that weed-control methods utilizing mechanical cultivation or herbicides appeared less satisfactory for intercropped corn and bean than for the same crops when they were grown separately. This was caused by the problem of plant and row spacing in intercropping and by the scarcity and high cost of herbicides possessing acceptable selectivity for both corn and bean.

Herbicides are often crop specific. Thus it has been difficult to find compounds that will control a broad spectrum of weeds without causing damage to the component crops in the intercrop (Moody 1978). The spatial arrangement of different crops makes chemical control of weeds difficult (Anon. 1965). Young et al. (1978) stated that technical considerations severely restrict herbicide utilization in intercropping, while Moody (1978) noted that as the number of crops that tolerate a herbicide increase, so must the number of weeds that are not controlled. Thus, the more complex the intercropping system, the less the likelihood of finding herbicides that will effectively control weeds without causing crop damage (Moody 1973).

Experiments conducted primarily at research stations have identified some herbicides that are suitable for use in simple crop associations. Butachlor (N-butoxymethyl- α -chloro-2', 6'-diethylacetanilide) applied preemergence has been used successfully in corn/mung bean

(Bantilan and Harwood 1973, Bantilan et al. 1974, Castin et al. 1976, Pamplona and Imlan 1976) and corn/cowpea (Pamplona and Imlan 1976) intercrops to control many weed species. However, Pamplona and Imlan (1976) reported that it failed to control *Rottboellia exaltata* L.f. and *Boerhaavia erecta* L, and Castin et al. (1976) reported that it controlled only 35% of the broadleaf weeds. Pamplona and Imlan (1976) observed that when butachlor was applied, yields from the intercrop were equal to those obtained with a single hand weeding but significantly lower than those from the weed-free check.

Butralin [4-(1, 1-dimethyl)-*N*-methyl-propyl)-2, 6-dinitrobenzene amine] failed to control any of the broadleaf weeds and controlled less than 50% of the grasses in a corn/mung bean intercrop (Castin et al. 1976). In a corn/peanut intercrop, only trifluralin (2, 6-dinitro-/V/V-dipropyl-4-trifluoromethylaniline) was not toxic to both crops (Punzalan 1972); however, this herbicide failed to control *R. exaltata.* The most promising herbicides in a cabbage (*Brassica oleracea* L.)/tomato (*Lycopersicum esculentum* Mill.) intercrop were napropamide *[NN*-diethyl-2-(1-naphthyloxy) propionamide] and butralin applied alone and in combination (Begonia and Mercado 1974).

In India, alachlor (α - 2', 6' - diethyl - *N* - me thoxymethylacetanilide) has been used successfully for weed control in a corn/soybean intercrop. The same herbicide at 1 kg/ha gave 85% weed control when sorghum or corn were intercropped with cowpea and hyacinth bean *[Lablab purpureus* (L.) Sweet] (Damodaran and Sankaran 1974).

In a corn/pigeonpea intercrop, alachlor gave excellent control of weeds initially but retarded pigeonpea growth up to 4 months after treatment; however, the crop recovered completely later intheseason (ICRISAT 1977a). In Colombia (CIAT 1974), excellent weed control has been obtained in a corn/bean intercrop when alachlor and linuron [3-(3, 4-dichlorophenyl)-1-methoxy-1-methylurea] were applied alone or in combination at high rates. In another trial (CIAT 1976) in which bean was intercropped in corn 2 weeks after application of preemergence herbicides to the corn, acceptable grass control was achieved with chloramben (3-amino-2, 5-dichlorobenzoic acid), fluorodifen (4 nitrophenyl-2-nitro-4-trifiuoromethylphenylether), dinitramine (N'N diethyl 2, 6 dinitro 4 trifluoromethyl- *m* - phenylenediamine), Hercules 22234 [*N* chloro acetyl *N*-(2, 6 diethylphenyl) glycine ethyl ester], pendimethalin [*N* (1-ethylpropyl) 3,4-dimethyl-2,6 dinitrobenzenamine], trifluralin, butralin, and linuron. The herbicides used were slightly less effective in the control of broadleaf weeds. No crop injury was observed.

Triazine herbicides such as ametryn (2 ethylamino-4-isopropylamino-6-methylthio-1, 3, 5 triazine), prometryn [2, 4 di (isopropylamino)-6-methyl-thio-1, 3, 5-triazine] and terbutryn (2-*tert*-butylamino-4- - ethylamino-6 methylthio 1, 3, 5-triazine) have given good weed control without causing crop damage in a pigeonpea/sorghum intercrop (ICRISAT 19776).

Peng and Sze (1967) reported that a preemergence application of nitrofen (2,4 dichloro 4'-nitrodiphenyl ether) gave good weed control with little crop damage in sugarcane intercropped with peanut or soybean. Linuron and atrazine (2-chloro-4 ethylamino-6-isopropylamino-1, 3, 5-triazine) are used when sugarcane and corn are intercropped, whereas linuron and metribuzin (4-amino-6-tert-butyl-4,5-dihydro-3-methylthio-1, 2, 4-triazin-5-one) are used when the intercropping system involves sugarcane and potato (*Solatium tuberosum* L.) (Rochecouste 1978).

Young et al. (1978) observed that although limited progress has been made in identifying herbicides for use in intercrops, compounds that can be used effectively on a broad range of crops are not available. Peng and Sze (1967) suggested that the second crop be planted after the residual effects of the herbicide applied to the first crop have diminished or that two different herbicides might be applied separately as a band application to each of the crops in the intercrop to overcome the toxic effects of a herbicide which may occur when both crops are planted at the same time and sprayed with a broadcast application of a preemergence herbicide These suggestions may not be practical because of competitive effects of the first-planted crop against the second crop and the difficulty involved in precise application of herbicides.

In spite of the fact that some advances have been made in chemical control of weeds in intercropping; generally, the technology has not been adopted by farmers. Reasons given include the cost involved, unavailability of recommended herbicides, application difficulties, and the supposed availability of inexpensive labor (Moody 1978).

Weed-management research in intercropping is still in its infancy, probably because no systematic and coordinated research to improve the efficiency and productivity of intercropping has been undertaken. The study of plants growing in mixtures is a complex topic in itself, and an additional complexity is provided by considering weeds. There is little or no theory of weeds and their control in intercrops to which reference can be made in planning a research program. As intercropping is gaining importance, especially in tropical rainfed farming, and as weeds are one of the major factors in determining the success of a new cropping system, a well-directed weed-management research strategy for intercropping is absolutely essential. Two approaches need to be considered immediately:

1. Ecophysiological studies leading to the manipulation of intercropping systems to obtain better management of weeds.
2. Studies involving evaluation of various weed-control methods for a few selected intercropping systems.

Ecophysiological Studies

It is not clear whether or not intercropping suppresses weeds more efficiently than sole crops. There is a lack of coordinated research in experiments using similar intercropping systems with the same crop species or cultivars. In some cases there are conflicting results, for example:

a. Why were entirely different results obtained for corn/peanut intercrops by Bantilan and Harwood (1973), Mercado (1976), and Punzalan (1972)?
b. Why does an increase in soil fertility result in decreased weed growth in some instances and increased weed growth in others?
c. Why, in some cases, is there a reduction in the number of weedings required in intercrops compared to sole crops, in others no difference, and in others a greater number.

It is clear, however, that all weed-related aspects in intercropping revolve around "competition." Therefore, there is a need to investigate competitive ability of various intercrop systems in relation to the competitive ability of the component crops under sole cropping. Differential competitive ability is dependent on many physical, biological, and cultural factors. These factors should be identified and manipulated alone, or preferably in combination, to obtain better weed management. Constant monitoring of the system is also needed as the system is dynamic and there is a likelihood of "shifts" or buildups of certain weed types due to continuously practicing a particular type of intercrop system (e.g., shade-tolerant weeds in a good canopy-structured system). Some of the areas that need to be researched immediately are:

a. What is the weed-suppressive ability of the intercrop system? Does it favor or disfavor weed growth when compared to sole cropping?
b. What are the major weed problems of the system? Does the system encourage the buildup of particular weed species?
c. What are the physical or biological factors operating in the system?
d. Can we manipulatethese physical, biological, or cultural factors in order to increase the weed-suppressing ability of the system?
e. Which management practices affect which weeds? How?

One of the important physical factors that determines the nature and extent of weed growth in the intercropping system is light. There is, therefore, a need to determine the response of different weeds to different levels of shade. Weeds may have to be classified according to their shade tolerance. This would help us to predict changes in futute weed infestations.

To obtain answers to some of the above questions, there is a need for simultaneous research on component crops under both sole- and intercrop systems. Field trials should be conducted to determine the weed competitiveness of different component crops or cultivars, or both, and also the intercrops involving these crops. This initial screening process would help the production agronomists to select only those systems that are efficient in weed suppression and also to examine ways of manipulating the system to obtain better weed management.

As ICRISAT is already concentrating on a few representative systems, perhaps these systems should be selected initially as a basis for understanding the ecophysiology of weeds. Eventually, other crops, such as cowpea and mung bean, which have shown potentialities for weed suppression, will need to be included. One of the basic needs of "competition studies" is the availability of fairly uniform fields with uniform weed growth or fields where weed seeds can be planted along with the crop or intercrop.

Another approach is to study these representative systems under the farmers' present weeding regimes. This latter approach would also indicate the relative productivity of the systems under farmers' present weed control levels. Also, evaluation of these systems using the farmers' present management levels would provide true relative advantage figures for intercropping rather than often misleading advantage figures obtained against a background of good protection measures, which vary from crop to crop and from system to system.

Ecological studies should not only be aimed at investigating the importance of weed competition in a few selected systems but also should include the examination of increased weed suppression by manipulating other agronomic factors. This latter aspect should be studied in collaboration with other agronomists and physiologists engaged in intercropping research. Studies related to increasing weed suppression by including early-maturing, good canopy-structured crops need to be intensified.

Weed Management Studies

The methods of weed control that can be used in highly diversified intercropping systems become more difficult to apply, especially if more crops are involved in the system. Associated with this are:

a. The problems of doing weed research when dealing with intercrops;
b. The difficulty in developing suitable equipment for mechanical control in the intercrop;
c. The difficulty in using selective herbicides where crops of different plant families are grown together.

With a change in the cropping pattern, there is sure to be a change in the environment of the crops as well as the ecology of the weeds associated with them. Further, the planting pattern used in intercropping affects the yields of the component crops and the weeds, even though, in some cases, their populations (and proportions) may remain the same. Intercropping may eliminate some weed species that are not able to cope with such a system but, likewise, other weed species that do not occur under sole cropping may be favored by intercropping. Therefore, there is a continuing need to develop and evaluate improved weed-control methods for different intercrop systems. Some of the questions that need to be answered are:

a. What is the critical weeding time for intercrops? When, and how many times, and how long should we weed the intercrop system?
b. Do crop mixtures require more labor for weeding? Do crop mixtures help alleviate the labor problem?
c. Can mechanical weeding be practiced in intercrops as dene in sole crops? What modifications are necessary? How can we develop improved tillage systems for intercrops. When should we do interrow cultivation in the intercrop?
d. What is an "acceptable" level of weed competition? Which weeds must be controlled, and which weeds could be left alone?
e. By continuously practicing the same control methods, are we creating favorable conditions that encourage growth and dominance of certain species? What modifications in the present weeding systems are necessary to avoid this? What modifications in the cropping systems are necessary? Can we use crop rotations to avoid problem weeds?
f. Can herbicides improve the productivity of the system? Are they economical, at least in the long run? Which herbicides are useful? When and how should these be applied?

In improved intercropping systems, because of many factors — such as row arrangements, plant population, spacing, fertility, and land and water management — the weed-control methods presently being used by the farmer may need to be modified. It is essential to know exactly what the farmer is doing with respect to weed control in his present system and to highlight the differential weed-control requirements of the improved system. The essential modifications of the farmers' system and in the tools used for weeding or interrrow cultivation also need to be determined.

Herbicide research needs to be intensified in areas where herbicides can be used immediately (especially in the African semi-arid tropics) and where they can improve the productivity of the farming system in general (such as the deep Vertisols of India). As herbicides are generally crop specific, it may be difficult to identify herbicides that are safe for two or more component crops of the system. Herbicide studies should be concerned with reducing the cost of herbicide application by manipulating the rate and method of application. Selected herbicides also need to be tested along with other weed-control systems to develop alternative systems that areeconomical and feasible for farmer use.

One of the ways to determine the feasibility of improved weed-management systems (including herbicides) is to conduct operational research in the farmers' fields. This would not only help in observing the-success of the farmers' own methods in overcoming weed competition but also in building up information and understanding of the crop, soil, and socioeconomic situations in which improved weed management could have the greatest impact.

Weed research in intercropping is a relatively new field. The problem is made even more complex as there has been very little weed research done on the component crops of the intercropping systems, most of which are considered as "minor" crops. The best approach is to do research on both the individual crops and the intercrop systems at the same time, placing more emphasis on the sole crops initially and later on the interaction of these crops with one another with respect to weed control.

Some of the obstacles of greater understanding of weeds as they pertain to intercropping are the environmental and biological factors, which vary from situation to situation. There is a need to reduce these variables or eliminate them so that our task is made easier. Studies related to the ecophysiology of weeds in the intercrop system are highly complicated, and additional research is needed to evolve different methodologies for conducting weed research in intercropping. Because of the many practical and statistical difficulties currently being encountered, research should be oriented to develop improved techniques and experimental designs particularly to study weed ecology.

Complete weed control cannot be achieved by using any one method alone. Whenever possible, the most effective weed-control methods that are available should be used in combination. The end result has to be a system that is economic and feasible for the farmer to use. The basic weed-research philosophy in intercropping should be the manipulation of the environment in such a way that it favors a community of "crop" plants and not a community of "weed" plants. The broad research objective should be to identify weed-management problems and effective measures of weed control. To do this, we must concentrate more on the ecology of major weeds and obtain a greater understanding of the biology of each species in association with surrounding plants. This would not only assist us in managing our weed/crop community in the intercrop system but also enable us to predict possible future serious weed problems.

Weed-management Studies in Sorghum/Pigeonpea and Pearl Millet/Groundnut Intercrop Systems — Some Observations

S. V. R. Shetty and A. N. Rao*

Abstract

*Studies were initiated at ICRISAT Center to examine the competition between weeds and intercrop systems and the increased weed suppression by the inclusion of additional crops, in this paper, some preliminary observations on sorghum (*Sorghum bicolor *L.) pigeonpea (*Cajanus cajan *L.) and pearl millet (*Pennisetum typhoides *L.) groundnut (*Arachis hypogaea *L.) intercrop systems are highlighted, with particular reference to weed growth as affected by a few selected biophysical factors. With increase in density of a sorghum I pigeonpea system, there was rapid decrease in weed dry weights. The inclusion of additional "smother" crops like cowpea (*Vigna unguiculata *L.) and mung bean (*Vigna radiata *L.) minimized weed infestation. These crops could rep/ace one hand weeding without affecting the main crop yields. Cowpea was more efficient than mung in its weed-suppressing ability later in the season. In the pearl milletlgroundnut system, the row arrangement of one pearl millet with three groundnuts resulted in optimum weed suppression and maximum intercrop advantage. With the increase in groundnut rows, there was a rapid increase in total weed dry-matter weights. Digitaria and Celosia were found in increased density and biomass as the groundnut rows were increased. The relative composition of *Cyperus*, however, tended to decrease in groundnut systems.*

In this paper, some of these initial trends in weed growth, as affected by different factors operating in the complex plant mixtures, are discussed in the broader perspective of intercropping weed research in general.

From the available literature, it is evident that crop/weed competition in intercrop systems depends on various physical, biological and cultural factors (Moody and Shetty 1978). Research should be directed, therefore, toward manipulating these factors to minimize weed problems. At ICRISAT, weed research in intercropping is mainly aimed toward both examining the competition between weeds and crops and developing principles for management systems to minimize weed competition. Earlier results at ICRISAT (Rao and Shetty 1976, Shetty and Rao 1977) revealed that many biological and cultural factors — such as suitable crop species, crop varieties, plant population, and supplemental use of herbicides — should form the major components of integrated weed-management systems for a sorghum/pigeonpea intercrop system. Recently, it has been considered that more permanent and economically feasible weed-management technology can be developed by orienting the intercropping weed research more toward ecophysiological studies (Moody and Shetty 1978). At ICRISAT, two systems selected for detailed weed-related studies were sorghum/pigeonpea on Vertisols and pearl millet/groundnut on Alfisols. The main objectives of the studies were:

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a. To understand the competition between weeds and the crops involved, and the trends (both intensity and composition) in weed growth in sole vs intercrops; and
b. To examine the increased weed suppression by the inclusion of additional "smother" crops with a view to increasing the competitive ability of the crops.

In this paper, some preliminary observations from the results of 1977 and 1978 crop seasons are highlighted with reference to the above two objectives.

Methods

A series of field experiments on sorghum/pigeonpea and pearl millet/groundnut intercropping were conducted at ICRISAT Center. A brief description of the trials is given below.

Sorghum/Pigeonpea

Population Effect

A trial was conducted on deep Vertisols primarily to examine the effect of population of sorghum/pigeonpea intercrops on the incidence of weeds. The treatments included the proportional increase of relative plant populations of these two component crops. The normal populations considered were 180 000 plants/ha for sorghum and 40 000 plants/ha for pigeonpea. Only one initial hand weeding (3 weeks after planting) was given to all the treatments to keep weeds from dominating and suppressing crop growth. Crop- and weed-growth observations were taken to examine the relationships between crop density and weed growth.

"Smother" Cropping Effect

Two field trials were conducted during the 1977 and 1978 crop seasons to observe the influence of sole cropping, intercropping, and the inclusion of an additional low-growing legume "smother" crop on the intensity of weed infestation. The treatments also included varying levels of hand weedings mainly to examine whether the inclusion of additional "smother" crops could replace hand weeding(s). The cropping systems tested were sole cropping of sorghum and pigeonpea, and a sorghum/pigeonpea intercrop with or without the inclusion of a "smother" crop and with two, one, or no hand weedings. The smother crop was planted between the normal crop rows and removed at physiological maturity.

Pearl Millet/Groundnut

To examine the weed-competitive ability of a pearl millet/groundnut intercrop, trials were conducted on Alfisols during the 1977 and 1978 monsoon seasons. Treatments included different row proportions of pearl millet and groundnut (1:1 to 1:6) in the intercrop situations to observe the trends in weed infestation as affected by different row arrangements of component crops. Again, only one initial hand weeding (3 weeks after planting) was given uniformly to all the treatments to keep the weeds from dominating the crop.

In addition to observations on crop growth, phytosociological observations on weeds were recorded to detect and compare variation and change in weed community as affected by the above-modified environments. In addition to the study of the contribution of each species to the total biomass (total dry weight of weeds), a quantitative measure of density (number of weeds per unit area) was also employed. The relative density of each weed was calculated as follows:

$$\text{Relative density} = \frac{\text{density of the species}}{\text{total density of all the species}}$$

Density, relative density, and biomass were used as measures of detecting the trends in weed infestation as affected by various treatments.

Results and Discussion

Sorghum/Pigeonpea

Crop Density Effect

Earlier results at ICRISAT (Rao and Shetty 1976, Shetty and Rao 1977) indicated that higher plant populations necessary for a greater advantage in intercropping were also effective in suppressing weed growth. In the present experiment, there is a clear trend in the relationships between plant population and weed growth (Fig. 1). The contribution to weed suppression is more evident with increased population of sorghum than of pigeonpea. There was a rapid decrease in weed biomass as the sorghum population was increased from normal to two times normal; however, there was no substantial increase in crop yields (Table 1). The same trend

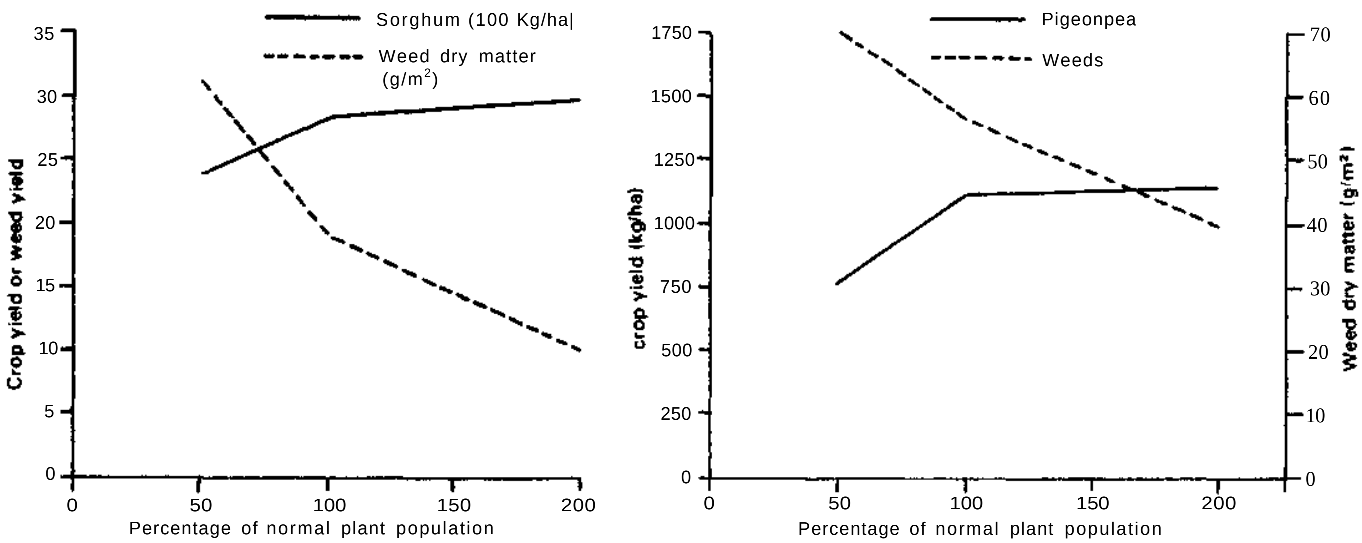

Figure 1. Influence of crop density on crop and weed yields in sorghumIpigeonpea intercrop on Vertisols at ICRISAT Center, 1977.

Table 1. The influence of crop density of sorghum/pigeonpea intercrop on weed growth, Vertisols, 1977-78.

Treatment[a]	Yield (kg/ha) Sorghum	Yield (kg/ha) Pigeonpea	LER	Weed counts/m of sorghum row	Weed dry matter (g/m²) at harvest Sorghum	Weed dry matter (g/m²) at harvest Pigeonpea
N-sorghum	4043	—	—	22	30	57
N-pigeonpea	—	1704	—	—	169	142
0.5N-sorghum + 0.5N-pigeonpea	2108	809	1.0	21	36	118
0.5N-sorghum + N-pigeonpea	2438	970	1.2	15	32	95
0.5N-sorghum + 2N-pigeonpea	2540	1002	1.2	17	25	43
N-sorghum + 0.5N-pigeonpea	2895	804	1.2	21	23	52
N-sorghum + N-pigeonpea	2615	1062	1.2	17	15	51
N-sorghum + 2N-pigeonpea	2913	1375	1.5	12	18	46
2N-sorghum + 0.5N-pigeonpea	2675	661	1.0	15	10	45
2N-sorghum + N-pigeonpea	3168	1295	1.6	16	10	26
2N-sorghum + 2N-pigeonpea	3118	1071	1.4	12	9	31
LSD (0.05)	902	517	—	—	39	15

a. N-sorghum = "Normal" sorghum population of 180 000 plants/ha; N-pigeonpea = "Normal" pigeonpea population of 40 000 plants/ha; 0.5N = 1/2 the normal; 2N = twice the normal.

of decrease in weed dry-matter weights was observed when the pigeonpea population was increased from half normal to two times normal. Further, the number of weeds per row of sorghum at sorghum harvest indicated that the increase in population tends to favor less weed survival in the crop row. This aspect needs further investigation.

The data further indicate that the maximum intercropping advantage was obtained with the combination of greater-than-normal sole populations of component crops. There also exists a trend of decreasing weed dry-matter weights as the intercropping advantage (LER) is increased due to the suppressing effect of higher plant population upon weeds.

Since plant population is an important agronomic aspect of intercropping research, there is a need to examinethe smothering effect of high crop density upon weeds. Increasing plant density beyond a certain level may not be practical because of interplant competition. It is important to consider, however, to what extent increasing plant population suppresses weed growth without a detrimental effect on individual crop yields.

Effect of "Smother" Crops

The results of 2-year studies (Figs. 2, 3) indicate that, in both years, the inclusion of the additional cowpea and mung crops showed promise in minimizing weed infestation and virtually replaced one hand weeding without significantly affecting the yields of main crops. There were no significant differences between sorghum yields in sole- and "smother"-cropping systems; therefore, the advantage of the "smother" crop is the additional yield of the "smother" crop and the elimination of one hand weeding. The same conclusion can be drawn in the pigeonpea system (Shetty and Rao 1977). However, in the sorghum/pigeonpea intercrop, both the pigeonpea and sorghum yields were affected when the additional crop was included. In the one-hand weeding treatment, there were indications of deleterious competitive effects on the main crops both by the "smother" crops and by the increased weed growth. The decline in main crop yield was noticed even during 1978 when the row spacing adopted was60 cm instead of 45 cm. Therefore, there does not seem to be any additional gain by replacing hand weedings completely and including additional "smother" crops in the sorghum/pigeonpea intercrop.

The weed dry-matter weights indicate the weed-competitive ability of different cropping systems. The inclusion of additional crops, cowpea and mung bean, resulted in less weed growth (Fig. 4) after one hand weeding. The weed suppression dueto these additional crops was about the same as obtained with two hand weedings. After the harvest of "smother" crops, a new flush of weeds again emerged, resulting in higher weed growth. However, these late-season weeds were not competitive with the main crop of sorghum as the crop was already well established. The yield data support this observation. Among the "smother" crops, mung is a quick grower and was more efficient in suppressing weed growth initially; later in the season, however, cowpea performed better, mainly because of its good canopy structure. There was a distinct difference in weed growth after the "smother" crop harvest. While there was a marked increase in total weed dry matter after mung harvest, the weed dry matter did not differ much in cowpea plots before and after cowpea harvest. The same observation was noticed earlier (Shetty and Rao 1977) when the residual effect of cowpea seemed to have a detrimental effect on further weed seed germination later in the season.

Pearl Millet/Groundnut

Earlier results (ICRISAT 1978) indicated that the row arrangement in pearl millet/groundnut intercropping influences the weed infestation. The data shown in Figure 5 further support this claim. When compared with respective sole croppings, groundnut suffered more because of competition by both pearl millet and weeds. As the groundnut rows were increased by replacing pearl millet rows, there was an increase in groundnut yields, whereas there was no significant change in pearl millet yields. This is perhaps due to the compensatory ability of the dominant pearl millet in the system. The row arrangement of 1:3 looked optimum as far as total advantage of the pearl millet/groundnut system was concerned. Further increase in groundnut rows did not help in increasing groundnut yields. The possibility of any increase in groundnut yields due to more

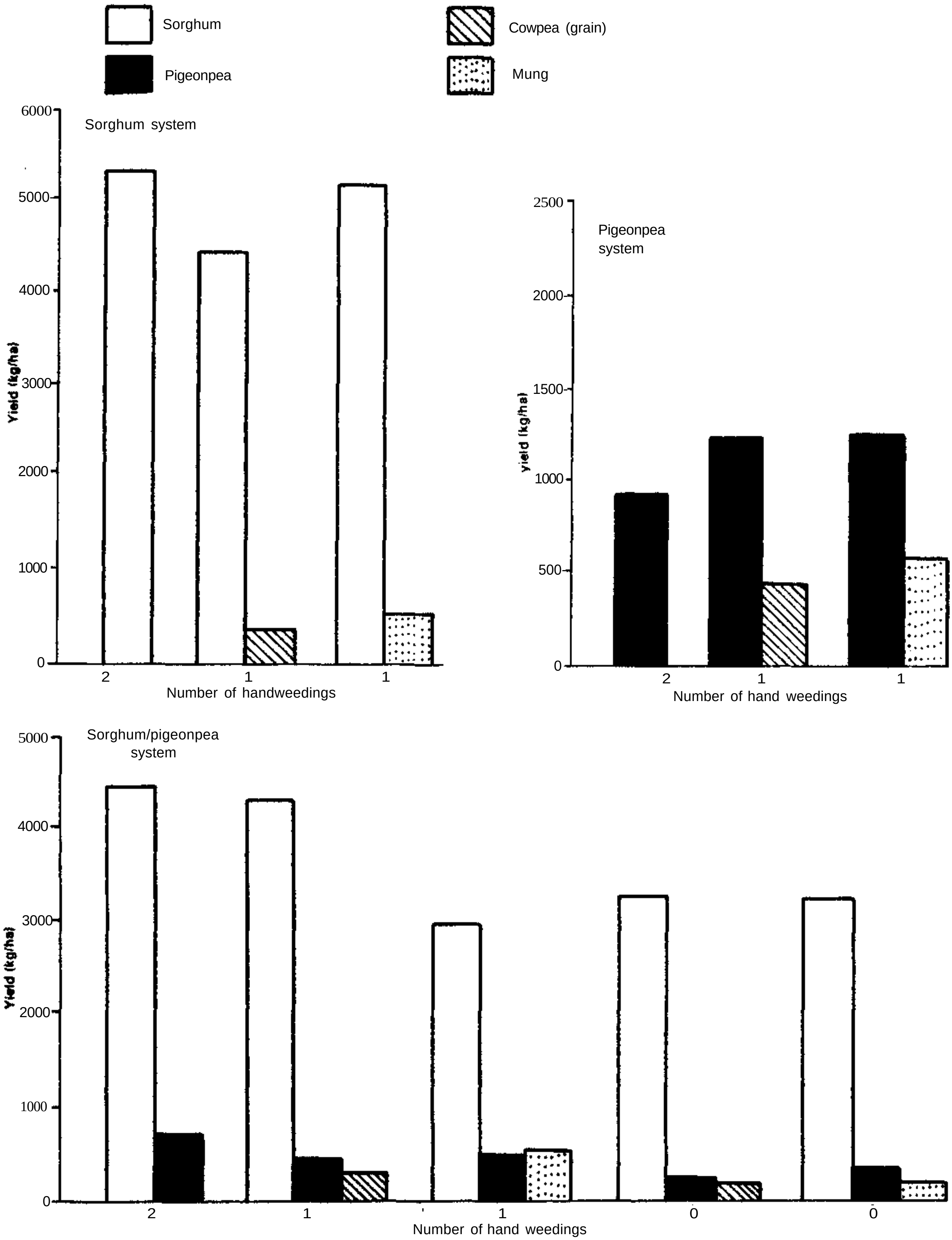

Figure 2. Influence of "smother" crops and number of hand weedings on crop yields on Vertisols at ICRISAT Center, 1977.

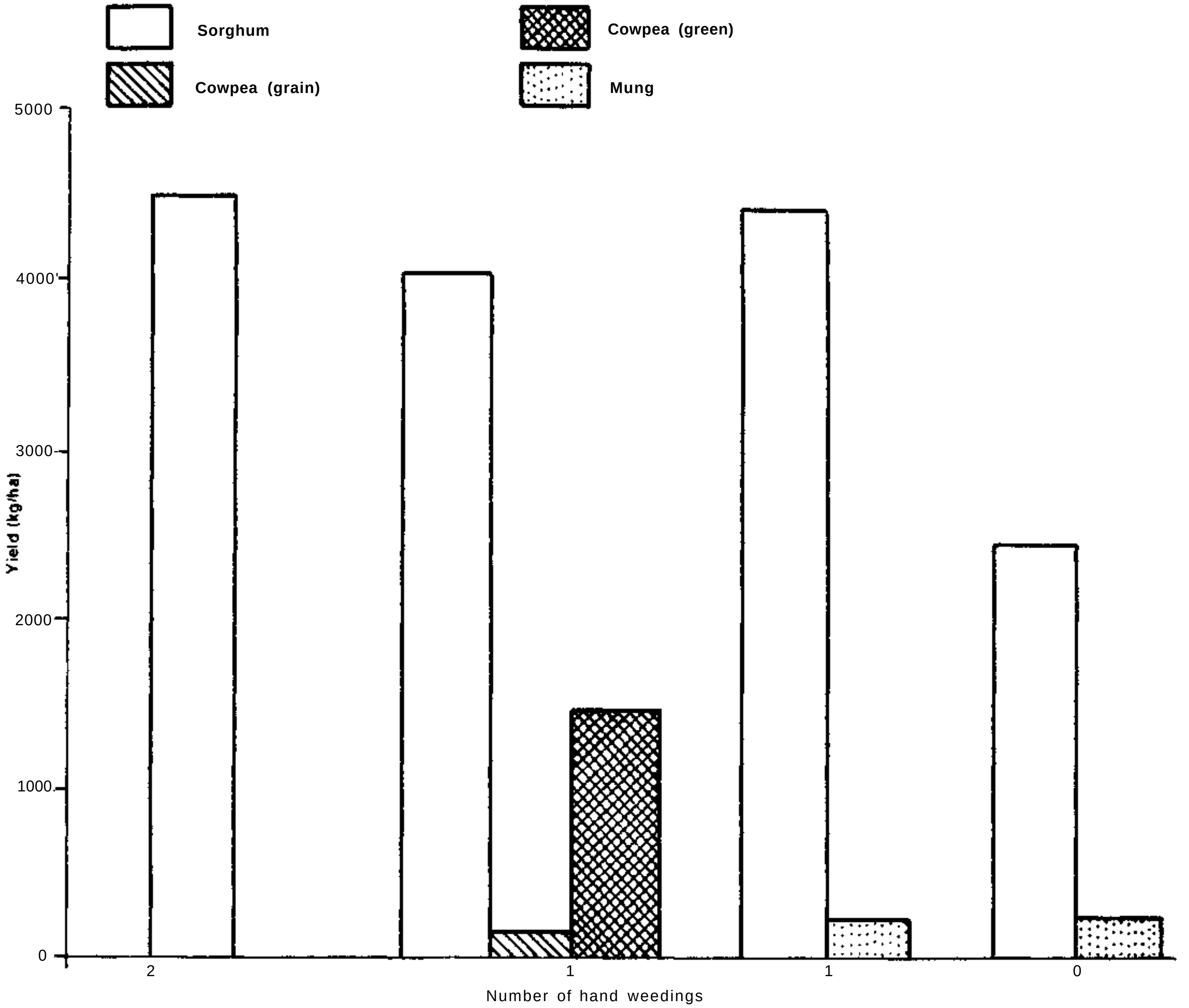

Figure 3. Influence of "smother" crops and number of hand weedings on crop yields on Vertisols at ICRISAT Center, 1978.

groundnut rows was nullified by increasing weed competition. The LER data indicate that a maximum of 15% advantage was obtained with a 1 pearl millet: 3 groundnut row arrangement. Further increase in groundnut rows resulted in lower LER values.

The weed dry matter taken during pearl millet harvest showed the least weed growth in the sole pearl millet. The sole groundnut and the 1 pearl millet:6 groundnut intercrop showed the highest weed dry-matter values. The highest weed-competitive ability of pearl millet was visible until the 1:3 row arrangement, and thereafter there was a rapid increase in weed dry-matter weights, mainly because of the introduction of more groundnut, which is a poor weed competitor.

The seriousness of weed growth in groundnut systems was evident not only in the quantity of weed growth but also in the composition of weed flora (Fig. 6). The relative composition of weed flora in different treatments indicates that the dominant weeds in the pearl millet/groundnut intercrops were *Digitaria, Celosia,* and *Cyperus.* In sole pearl millet, the flora was a mixture of many weeds, including

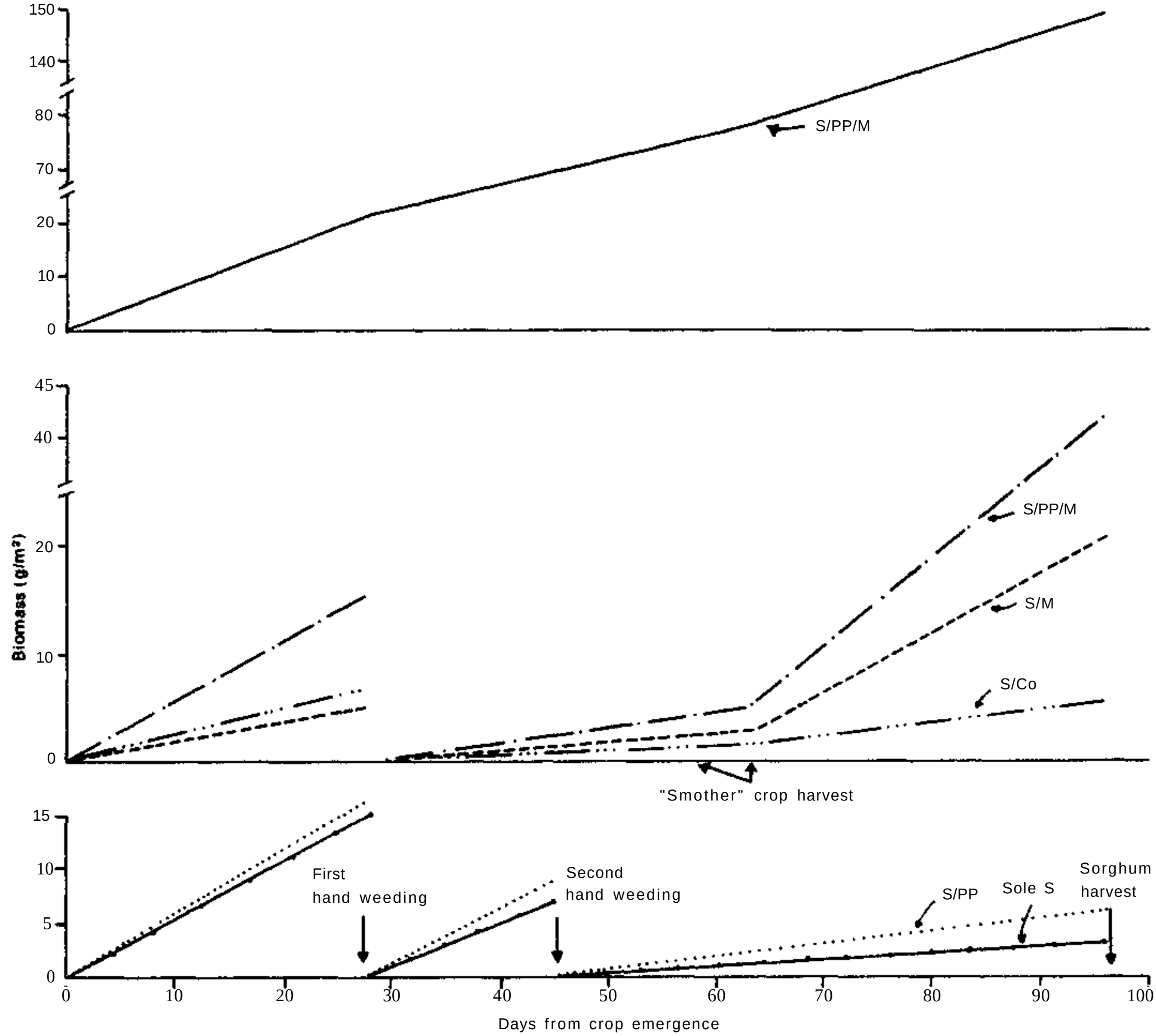

Figure 4. Biomass of weeds at different stages of crop growth as affected by different cropping systems on Vertisols at ICRISAT Center, 1978 (S = sorghum, PP = pigeonpea; M = mung; Co = Cowpea).

Digitaria, Cyperus, Celosia, Tridax, Phyllanthus, Eragrostis, and *Brachiaria,* whereas in sole groundnut, the predominant weeds were only *Celosia, Digitaria,* and *Cyperus.* As more rows of groundnuts were introduced in place of pearl millet rows, the relative proportion of *Digitaria* increased to a certain extent and then remained constant, while that of *Cyperus* went on decreasing. But the most striking observation was the build-up of more competitive and tall-growing *Celosia* in the groundnut-predominant systems. There appeared to be a shift in weed flora toward this particular weed as the groundnut rows were increased. These results have some practical significance in that a better weed-management practice, more suited to managing *Celosia* and *Digitaria,* should be a part of improved management technology for a pearl millet/groundnut intercropping system.

The data on relative density of different

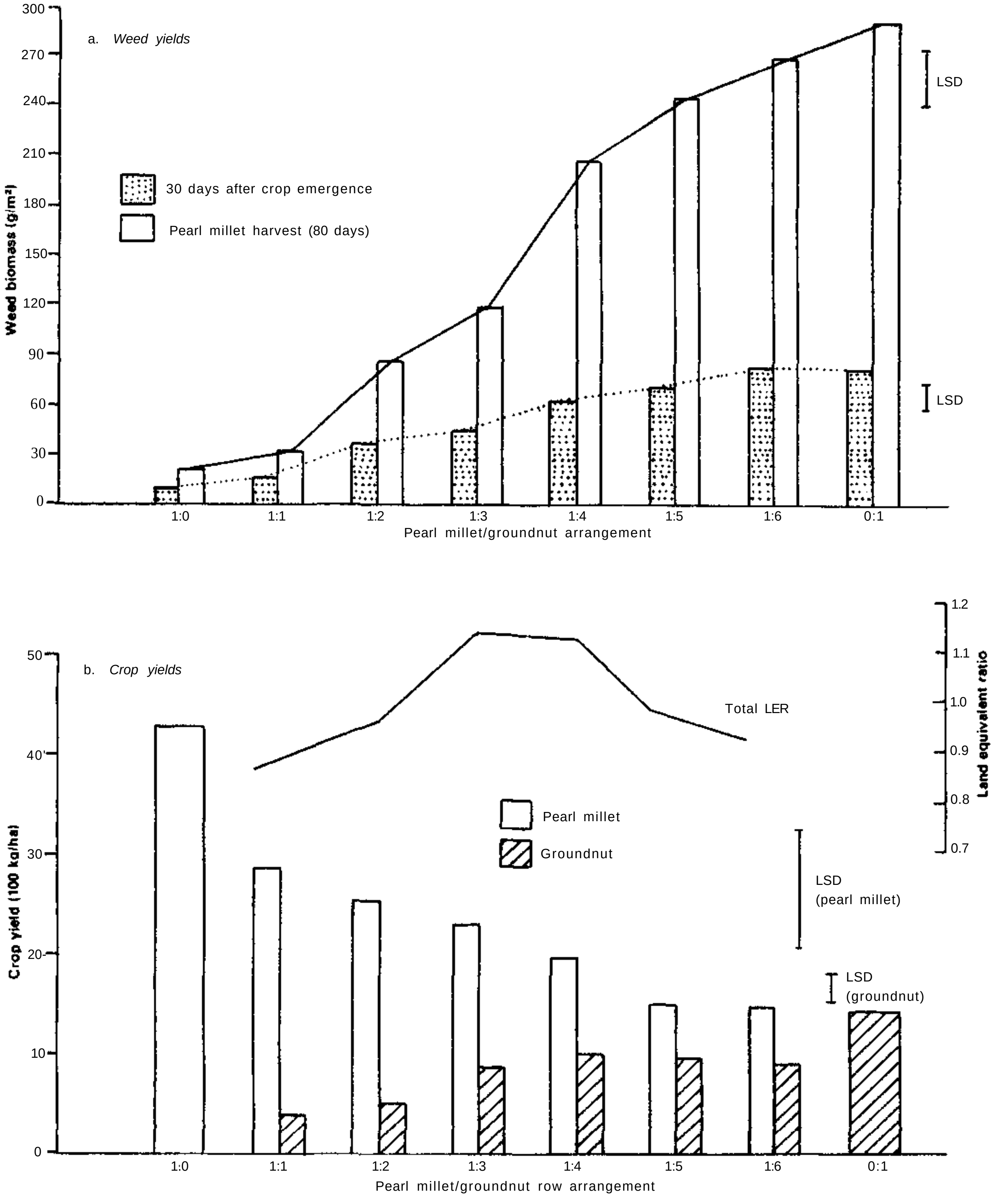

Figure 5. Effect of row arrangement in a pearl millet/groundnut intercrop on weed and crop yields on Alfisols at ICRISAT Center, 1978.

weeds in different treatments follow the same trend as that of weed dry-matter weights, except in the case of *Cyperus.* There was not much change in the density of *Cyperus* as the groundnut rows were increased, but the dry-matter weights decreased, as indicated earlier.

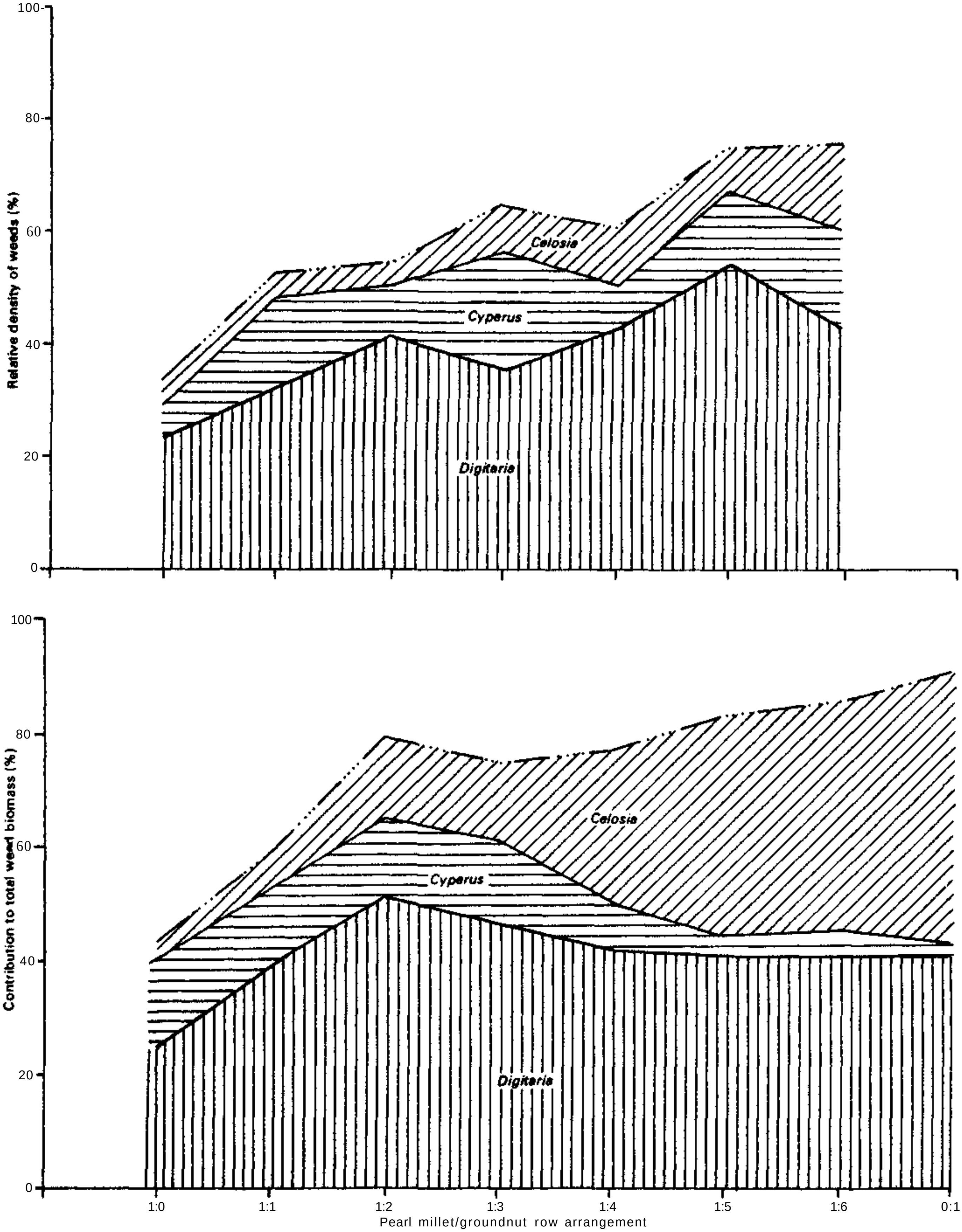

Figure 6. Percentage contribution of Celosia, Cyperus, Digitaria, *and other weed species to the total biomass and density of weeds at the time of pearl millet harvest on Alfisols at ICRISAT Center, 1978.*

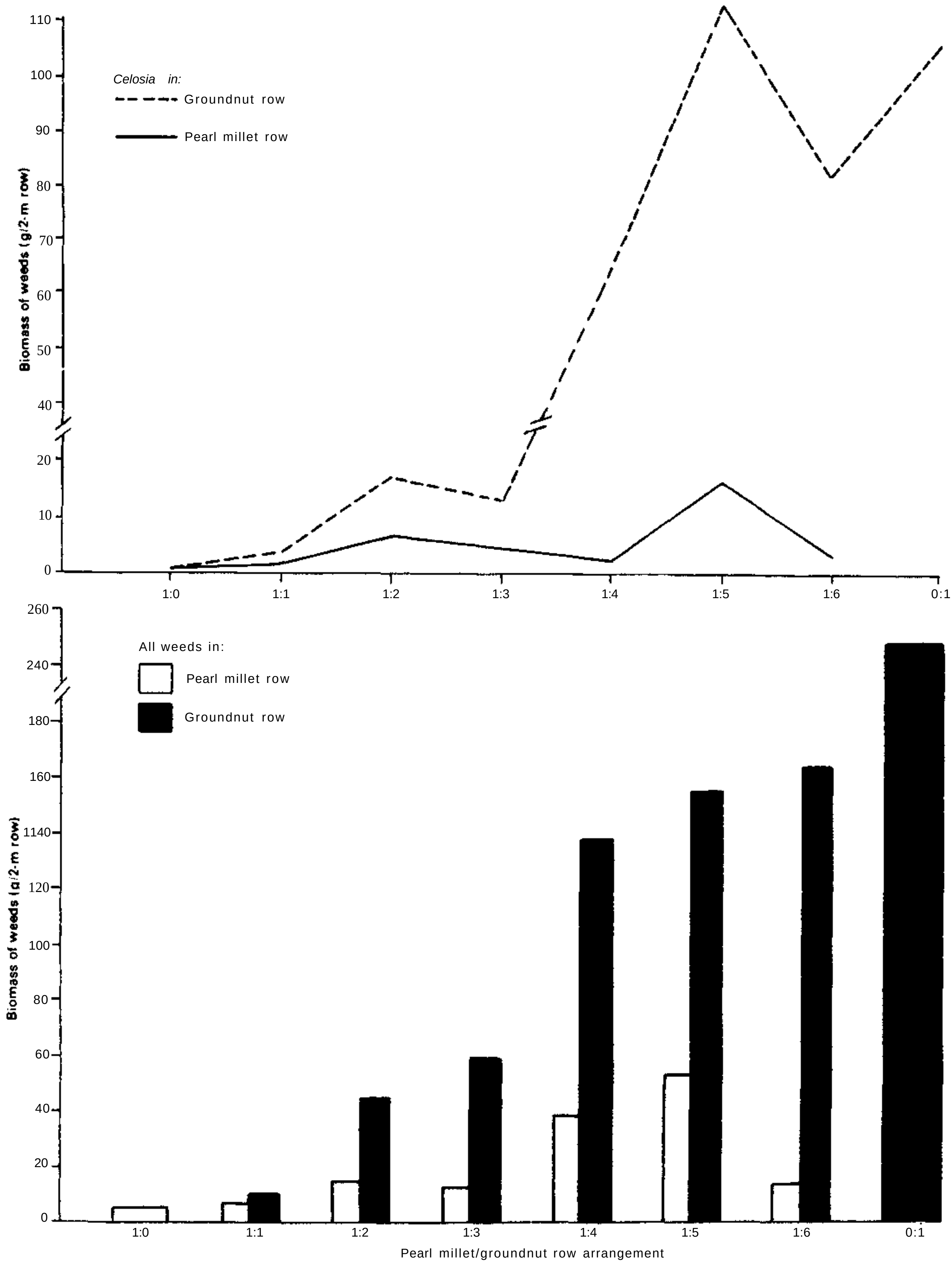

Figure 7. Effect of row arrangement in pearl milletlgroundnut intercrops on weed growth in the crop rows on Alfisols at ICRISAT Center, 1978.

This can be attributed to the shade sensitivity of *Cyperus.* As the groundnut rows were increased, the crop canopy provided a higher level of shading to *Cyperus* (which grows under the canopy), resulting in poor growth of *Cyperus.* However, *Digitaria* and *Celosia,* which are tall and usually grow above the groundnut canopy, did not suffer and hence had greater dry weights.

The data on number of weeds in the crop row (Fig. 7) further indicate that, as the intercrop system contains more groundnuts, the number of weeds in the crop rows tends to increase. As the ecosystem was changed due to the presence of groundnuts in place of pearl millet, there appeared to be a change in the environment more favorable to weeds. Likewise, as the groundnut rows were replaced by pearl millet rows, the number of weeds in the groundnut rows tended to decrease. Among the individual weeds, *Celosia* was found to be more associated with groundnut rows, whereas it was found in negligible numbers in and around pearl millet rows.

These studies indicate that intercropping can be a method of weed management if suitable component crops are grown with proper agronomic manipulation. Although all intercropping systems are not favorable for weed suppression, some systems can be manipulated to obtain better weed management. As the growth pattern of weeds changes due to a change in the environment, studies to identify suitable combinations of component crops and the resultant change in trends in weed growth need to be intensified. As the main factor operating in many systems is light, it is also essential to determine the response of different weeds to different levels of shading offered by different crop canopies.

These studies clearly underline the need for more ecophysiological studies in the field of intercropping weed management. As intercropping research is a fairly new discipline, simultaneous studies should be carried out to determine the implications of different intercropping systems on weeds. As brought out by the results of pearl millet/groundnut intercropping systems, weeds respond differently to different cropping systems. Ecological studies should be conducted mainly to answer questions like:

1. Which species of weeds contributes more?
2. At what stage?
3. How do different weeds behave with changes in the system?
4. What fluctuations in density occur in different weeds?

Answers to these questions should help in designing proper weed-management techniques.

Also, efforts should be oriented to manipulate intercropping systems to obtain better weed management; as the results of sorghum/pigeonpea/cowpea or mung intercrop systems reveal, additional crops can be grown mainly to obtain more weed suppression without offering serious competition to the main crops. Intercropping can thus be utilized as a method of weed management. Further studies are necessary to examine the weed-competitive ability of different crops/systems to design and develop systems which show increased weed suppression along with higher productivity. These studies would also help in predicting the seriousness of weed problems due to a change in the farming system.

Pest Management in Intercrop Subsistence Farming

V. S. Bhatnagar and J. C. Davies*

Abstract

Basic information on the entomology of intercrop systems in tropica/ areas, in particular from the small-farmer situation, is scant. This is due to past preoccupation with the entomology of sole cropping and the research emphasis on cash crops, which often meant that resources and staff were diverted to research on insecticides. There is a vital need to gather base data from properly replicated and representative trials in both the controlled research station situation and on farmers' fields. Initially work will have to be concentrated on a relatively small number of typical intercrop situations using large plot sizeandlocationalreplication. Results to date showthatthe pest level at research centers is very different from that on farmer's fields.

Data so far obtained at ICRISAT indicates that the situation with regard to yield losses in intercrop caused by insect pests and the pestlpredatorlparasite relationships are very complex. There appear to be demonstrable differences in pestlparasite relationships, based not only on crop combinations but also on factors such as cultivar, season, and soil type. These microeffects can be seriously affected by climatic effects, which result in large-scale immigration of major pest species. An example of migration in Heliothis armigera (Hubner) in India is given, 'which causes disequilibrium with native biotic control agents, leading to a rapid increase in larval numbers and heavy yield loss to intercropped chickpea and pigeonpea. Surveys carried out on small-farmer holdings, by and large, have supported detailed experimental work.

Suggestions are made for future courses of action to enable realistic pest-management strategies and implementation in intercrop subsistence situations. Entomologists have a vital role to play in furthering understanding of intercrops in the tropics and in enhancing their productivity, in ways this paper attempts to outline.

Intercropping is generally understood to mean the growing of a mixture or interpianting of different plant species on the same piece of land, at the same time. The number of crops grown in combination may differ and their maturity periods may vary. It is frequently practiced by small farmers in tropical countries, but, in spite of this, agricultural research workers in the tropics have tended generally to neglect the complicated intercropping systems and have concentrated on research on individual crop species, and more effort has been paid to "cash" as opposed to subsistence crops. The exact system of mixed/intercropped subsistence farming varies considerably from area to area, even within one country, depending on the farmer resources and needs. Under conditions of "low-level equilibrium" farming, as exists in much of the developing world (e.g., in the semi-arid regions of India and Africa), difficulties arise from low available capital, unfavorable price relations, unsophisticated markets, uncertain and unevenly distributed rain, and a rudimentary infrastructure. Thus, intercropping is traditionally a low-input agricultural system and an important characteris-

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tic of many developing countries. It matches the total resources available to the farmers in maintaining low but often adequate and relatively steady production. Agricultural practices at this level are often those handed down from generation to generation and which have been found by experience to present the least risk.

In a period when many developing countries are struggling to increase food production, the depredation of pests is an increasingly important problem. Through basic ignorance of the "total environment" of cropping systems and of the infrastructure which supports it, there have been many inappropriate attempts by research and extension workers to accelerate rural development by large-scale importation of modern technology. These were developed under conditions of "high-level equilibrium" farming in the countries of North America and Europe and required sophisticated and highly supportive technologies. The environmental disasters and pest outbreaks which sometimes followed in the wake of the Green Revolution, whereby widespread introduction of high-yielding cereal cultivars, especially in Southeast Asia, created monocultures with a narrow genetic base leading to increasing losses to pests, exemplify the hazards of radically disturbing the delicate ecological balance of subsistence farming in the tropics (Conway 1973, Frankel 1971, Pradhan 1971, Smith 1973).

Food is produced in the tropics both on large commercial farms (generally sole crops) and on more marginal small farms (generally intercrops). With political changes, many large land holdings have been broken up into smaller units, and it cannot be denied that the small peasant or subsistence farmers now feed the majority of both the rural and urban populations in the poorer third-world countries. Between 70 and 90% of the population in these countries are engaged in farming or are directly dependent on agriculture. A large proportion of their produce, mainly cereals, legumes, and root crops, is destroyed by pests before harvest. This further contributes to the fact that in large areas in these countries man's minimum caloric and protein requirements are not satisfied. About 200 million children under the age of five in these countries suffer from nutritional deficiencies which affect their ability to progress normally to adult life and to cultivate land effectively (World Food Conference 1974).

Tragardh (1925), comparing outbreaks of pests in the forests of Germany and Sweden, concluded that fewer outbreaks took place in Sweden because almost two-thirds of its forests are mixed tree species. Catastrophes have occurred in forests where man changed the environment to growth of single species. Rohrl (1928) and Friedrichs (1928) suggested, therefore, that the lack of diversity characteristic of mixed stands was responsible for these outbreaks. Monocultures are similarly ecologically unsound and are not sustainable for the long-term social and economic well-being of subsistence farmers. The pest problems are quite different in intercrop subsistence agriculture than in large-scale monoculture (Lamb 1978).

In the past, farmers have usually selected seeds from individual plants that survived best under native cultural conditions. The plants that yielded best under these conditions were genotypes that also naturally harbored alleles for resistance to pests (Pimentel 1976). Despite its obvious importance, intercrop subsistence farming has received inadequate attention. Clearly, increased and more coherent research and development in this area is a priority need. Since this has major implications on pest management in intercrop subsistence agriculture, field entomologists have a vital role to play in furthering the understanding and overall improvement of intercropping systems.

Entomology as a Component in Intercropping

In addition to syntheses of economic and social surveys (Binswanger et al. 1974, Norman 1976) and surveys of technical and human factors (Finlay 1976b), basic biological studies of pest disease incidence are essential for the improvement of present and proposed intercropping systems. Some work has been done in these areas (Rao and Willey 1978). Unfortunately, until the early 1970s, most base studies and screening of improved systems have been largely agronomic and have not considered the whole cropping system in a true biological sense. The belief that intercropping as traditionally practiced is outdated, unproductive, and only a transitional phase in the trend toward sole cropping is still so strong that agricultural scientists in national programs of most developing countries still do not give weight to research in intercropping. Entomologists are not immune from this and appear to suffer from the psychological notion that systems associated with subsistence farmers are not worthy of serious research endeavor, as noted by Norman (1974). The fact that the insect pest situation in intercrops is a highly dynamic one is conveniently ignored.

There has been delay in incorporation of the few specific inputs from pest-management specialists, despite the known importance of pests as a complex, major limiting factor to increased yields of virtually all tropical crops. There are already realistic studies to an extent in Nigeria, Tanzania, Costa Rica, India, and the Philippines, where the influence of particular crop mixtures and crop systems on pest incidence is being investigated with a view to designing systems that minimize pest damage but which retain an acceptable agronomic situation. Multidisciplinary research efforts have been initiated.

Pest/Parasitoid Situation in Intercropping Systems and Their Influence on Crop Losses

Monocultures, though thought to be often highly productive and efficient, have been criticized for their genetic uniformity and increased pest susceptibility. Unlike monocultures, the regulation of insect pests in multiple crop systems by physical means (protection from wind, hiding, shading, alteration of color or shape of the stand, etc.) and biological interference (production of adverse chemical stimuli, presence of predators/parasitoids, etc.) have been emphasized (Litsinger and Moody 1975, Nickel 1973, Pimentel 1961, Southwood and Way 1970, van Emden and Williams 1974). These workers included some examples of the behavior of insect pests in mixed/inter- and strip-cropping systems, but some of this has been of theoretical and academic interest.

In the tropics, intercropping has been an important component of small-farm agriculture (Lamb 1978), and one of the reasons for the evolution of these cropping patterns may be reduced incidence of insect pests (Altieri et al. 1978, Baker and Norman 1975, Batra 1962, Burleigh 1973, Crookston and Kent 1976, de Loach 1970, Dempster and Coaker 1974, Finlay 1974, Francis et al. 1975, Fye 1972, Guevera 1962, IRRI 1972, 1975, Stern 1969, Tahvanainen and Root 1972, Trenbath 1975b). Factors such as increased parasitoid and predator population, availability of alternative prey, decreased colonization and reproduction in pests, chemical repellency, masking, feeding inhibition by odors from nonhost plants, prevention of emigration in pests, and optimum synchrony in the relation between pests and their natural enemies are quoted as likely to be important in efficient pest regulation in intercropping systems. But there is much uncertainty.

Certain pests colonize one particular crop in a given ecosystem, which then serves as a diversionary host, protecting other more susceptible or economically valuable crops from severe damage (McBeth and Taylor 1944). In Nigeria, unsprayed cowpea is less subject to insect damage when intercropped with sorghum rather than sole cropped (Raheja 1977), and a similar situation prevails in maize/cowpea intercropping in Tanzania (Kayumbo 1975). Thus the preference of certain polyphagous pests for cereals may enable subsistence farmers to produce an economically viable yield of legumes. Similarly, okra appears to be a useful diversionary crop for flea beetles (*Podagrica* sp.) attacking cotton, which is usually the major crop in an intercropping system in Nigeria (Usenbo 1976).

Some pests can attack and feed on several plant species and can move from one host to another when one of the host plant species matures. It is generally considered that, along with the pest species, the parasitic and predatory fauna also move (Fye 1972, Stern 1969). In the more diverse environment of intercropping, the number and/or species of natural enemies may be increased (Prince and Waldbauer 1975) or decreased (Root 1973). Gavarra and Raros (1975) found more predatory spiders in a maize/groundnut system than in sole-cropped maize. This was partly attributed to improved supply of soil microfauna in the mixed planting to support early instar spiderlings.

Growing of several crops together may or may not mitigate for a stable interaction between pests and their enemies. The continuity of vegetative growth offers a chance for longer term stability of predatory/prey interaction — e.g., it is thought that this keeps *Heliothis* *armigera* (Hubner) a minor pest in southern Uganda (Coaker 1960). In an equable climate, *H. armigera* breeds throughout the year on a wide range of crops and wild plants, and the complex of native plants in a semiwild environment seemingly stimulates "perennial" stability, which ensures that the pest remains a minor pest even in unsprayed condition. However, in southern Tanzania, the dry season induces diapause in *Heliothis,* which limits successful biological control (Reed 1965). In these circumstances, therefore, the planting of maize with cotton increases the abundance of *H. armigera* because the pest multiplies on maize and migrates to cotton without a check by natural enemies.

The particular growth stage of each crop present at the time of pest invasion usually determines whether or not diversion from the main crop will occur. Thus, the status of maize, intercropped or cropped adjacent to cotton, in decreasing *Heliothis* spp. and *Dysdercus* spp. attack on the latter varies according to its growth stage and amount relative to cotton at the time when cotton is susceptible to attack (Pearson 1958). In Peru, this system, with irrigation, favored the control of *Heliothis* and of other pests by creating a stable and self-contained environment long enough for biological control to be effective (Southwood and Way 1970, Wille 1958).

In Rhodesia and the Sudan, intercropped maize has frequently failed to protect cotton, probably because it was not in an attractive stage when *H. armigera* and *D. suprestitiosus* were most abundant (Bebbington and Allan 1933). In Texas and California, maize and other crops are grown sufficiently early for them to be a major source of *H. zea* attacking cotton (Henry and Adkinsson 1965). Similarly in northern Nigeria, the particular cropping pattern of maize and tomatoes establishes a favorable host plant sequence for *H. armigera* and *Cryptophlebia leucotreta,* leading to severe infestations on cotton (Beeden and Hay ward, quoted in Way 1975). It iscritical, therefore, to selectthe correct plant diversity for a given microclimatic, biotic, and/or intercrop situation; a specific diversity in the same system can be beneficial in one region but harmful in another.

Polyphagous insects are known to be attracted by mixed odors and thrive in a habitat providing two or more essential hosts in close proximity, as with thecoreid *bugs Acanthomica* sp., which appear to be attracted to other legumes in high numbers by interplanted pigeonpea (Kayumbo 1976). Similarly, the increase in an adult male moth population of *H. armigera* in sex-lure traps baited with virgin females was observed in flowering sorghum interplanted with pigeonpea in the vegetative phase compared with sole-crop flowering sorghum at ICRISAT Center.

Entomophagous fungi benefit from high relative humidities beneath denser foliage canopies, and this probably explains the decreased mite abundance on arecanut palm grown with banana (Khader and Anthony 1968).

The ultimate goal of pest management in intercropping systems should be to reduce loss of crop yield and quality rather than merely to reduce pest numbers. The damage due to a given level of pest incidence is likely to vary considerably from one intercropping system to another (ICRISAT 1976), from one cultivar to another, and in different soil environments (ICRISAT 1977d). While pest numbers/plant are much lower in a mixed than in a sole-crop, the physiological stress on plants, such as low-growing annuals intolerant of the shade beneath a taller crop, may cause greater loss of yield in mixed crops (Perrin 1977, ICRISAT 1976, 1977d).

The extent of damage may or may not be related to the intercropping pattern depending upon the crops and/or insect species involved. Less flower damage due to *Maruca testulalis* Geyr. occurred when cowpea was intra-row cropped rather than inter-row with maize in Nigeria (Taylor 1976). However, no differences in egg and larval numbers of *H. armigera* on flowering terminals and final yield loss to intercropped pigeonpea with sorghum were found in a similar situation in India (ICRISAT 1976).

Compensatory ability is often an important attribute of intercropping systems since one crop may benefit from damage or loss of stand, in the other crop, thus maintaining an overall stability of production. This is particularly true in intercropped legumes. In 1977-78, the loss of the first crop of pigeonpea by *H. armigera* resulted in a second flowerfl ush in the intercrop and even a third flush in sole-crop pigeonpea (Bhatnagar and Davies 1978b). In certain intercropping systems, there is good evidence that pest attack is lower on crops grown in mixtures involving maize, cowpea, and pigeonpea and probably other legumes (Caswell and Raheja 1972, Hayward 1975, IRRI 1974).

Intercropping and Pesticides

Even in integrated control programs in cash sole crops where pesticides are used in the most effective way by ecologically guided application methods, there is an ever present danger of some degree of environmental contamination and hazards to natural control agents. Problems will arise in application of pesticides in intercrop situation. For instance, their use will create difficulties of a large number of storage and application points and increasing hazards to the whole family of farmers and particularly the children who often contribute in subsistence cultivation (OECD 1977). Often it is difficult to prevent drift reaching the nontarget crops. Differences in crop height, susceptibility, and maturity and inconveniences to the applicator while spraying or dusting with existing machinery are other problems for pest suppression with pesticides in intercropping and require alternatives.

Given the current economic status of many crops, pest suppression with pesticides is clearly a strategy with limited application in intercropping. However, some insecticide use would seem inevitable, especially as new high-yielding cultivars bred under an insecticide umbrella and with fertilizers at high plant populations are being recommended and introduced. There is considerable scope for use of selective pesticides (to retain a reservoir of beneficial fauna) applied at careful time intervals or as spot treatments. In this context, the use of controlled droplet applicator (CDA) formulations has great potential.

Litsinger and Moody (1975) have given examples of the carry-over of residues from one crop to the next in close succession. Since pesticides are potent biocides, they can adversely affect and alter the crop plant physiology, and also affect parasitoids (ICRISAT 1977d). During 1977-78, a sprayed intercropped pigeonpea (ICP-1) with sorghum (CSH-6) in deep Vertisols was harvested in 160-170 days compared to 260-270 days on unsprayed plots (Bhatnagar and Davies 1978b). Given this situation, the need for methods of control other than use of pesticides is emphasized in intercrop subsistence farming.

Intercrops and Pest-Management Strategies

The exact combination of crops used in intercropped areas is often a function of strictly local conditions and needs. Sole cropping presents a large area for pest multiplication, which often coincides with the period of pest abundance. Novel intercropping systems developed to satisfy the complex socioeconomic objectives of small-scale subsistence farmers are therefore necessary. Some implications of this have been discussed recently by Perrin (1977) and Way (1977).

Prevention of losses caused by pests at all stages of growth in intercrops will initially require a study of the nature and extent of the pest problems in a region followed by identification of the factors responsible for increased losses caused by pests.

Quite clearly, there are levels of pest abundance at which it could be advantageous to modify normal intercropping practices and to select appropriate cultivars more tolerant to pest attack and to utilize escape mechanisms by careful selection of cultivars. In seasons or cycles of low pest incidence, more susceptible high-yielding cultivars can be grown. The challenge is to provide means by which the farmer can attain a more flexible response to pest attack. Unfortunately, the ability to forecastpest incidence is rarely adequate at a sufficiently early stage. The possibility of developing advanced forecasting and warning schemes should be encouraged. Recent efforts in India in this respect may prove useful in generating basic information on seasonal variations in pest species by regular light-trap monitoring (Bhatnagar and Davies 1978a,b, ICRISAT 1977d).

Monitoring pest populations on alternative hosts is meaningful in some situations (ICRISAT 1976, 1977d), while in others the recording of pest numbers in the early-maturing intercrop could provide the basis for a forecast, subject to modification by climatic conditions (Bhatnagar and Davies 1978b).

Where the fully mature pods of intercrop legumes are usually heavily damaged — for example, cowpea pods during the late season in southern Nigeria by *Cydia ptychora* and Lycaenids — a vegetative cultivar harvested at the green pod stage can be grown, provided these are acceptable in the local diet. A similar strategy is now being used in intercropped pigeonpea in some central and southern states of India. Farmers harvestgreen pigeonpea pods (to avoid losses by lepidopteran pod borers) and market them. A limitation of this strategy is availability of markets.

Data are lacking on the extent and factors governing the natural control of key pests in most intercrop situations. A two-pronged approach, with initial surveys of the most severely affected areas by pest management scouts and specialists and use of large-scale trials on the farmers' land, is proving useful. Further involvement of a multidisciplinary approach to intercropping research in the tropics is vital.

The basis of the management of a whole-pest complex in intercrop systems should be a planned manipulation of the various factors which influence the economic injury level, so as to minimize the economic effect of the pests. It is necessary that entomological research in intercropping should be intensified immediately. Principles will have to be established using relatively few crop combinations initially and increased plot size and replication. Large sole-crop plots need to be used to monitor differences in pests, parasitoids, and yield losses, if they exist, and comparisons made with "off-station" situations. Plant type, plant population, various crop and row proportions, planting configuration, crop shading, fertilizer levels, and method of application, and various other local cultural practices in both existing and proposed intercrop systems are majorfactors in insect population dynamics and need investigation.

There is a need for a closer collaboration between the existing international organizations and, more importantly, between scientists within these organizations. A close liaison within various national coordinated research programs in developing countries will further strengthen the pest forecasting system which is currently completely lacking in almost all the countries in the third world. The problems of mixed/intercrop subsistence farming and problems of introducing high-yielding palatable food crop varieties were recently outlined by Lamb (1978), who proposed that a new type of international research institute (to be set up in southeast Asia where the subsistence agricultural population is very large — 710 million people) dealing with small-scale mixed/intercropping is required to provide the basis for improvement in subsistence farming.

It is important that production research in intercrop situations goes hand in hand with pest-management research. There are weaknesses in the existing training, extension, and advisory services which constitute a major constraint to the transfer of existing knowledge. Without serious thought, research and available techniques in intercrop pest management will remain largely unused, and the expertise and money spent on them will be wasted. The provision of training in intercropping entomology to young entomologists from the developing tropical regions should be given consideration. The existing International Agricultural Research Centers can play a major role in both the research and training components in intercrop subsistence farming, and the mandate of these Institutes should clearly include these.

Pest management in intercropping systems should be an important element in the development of cheap and feasible management practices for the intercrop situation; if ignored, the valid techniques will fail. Crop sanitation, optimum seed rate and plant stand, destruction of "overwintering" pests by timely plowing and stubble destruction, observance of fallow and homogeneous planting dates, and choice of pest-tolerant cultivars must be combined. Support for the development of an effective large-scale pest forecasting system, introduction of selective control measures, including possibly mass production and release of parasites/predators and highly selective diseases are among national government measures that must be considered. Subsidized chemical applications for controlling the ravages of the major pests, including migratory locusts, armyworms, birds, and rodents at a regional, national, and international scale must be planned for the benefit of intercrop subsistence farmers.

It is necessary to apply modern knowledge to traditional practices and to modify these as necessary to meet local conditions (OECD 1977). Tillage is an example; various methods of the soil cultivation have long been used for control of pests. Effective tillage requires a thorough knowledge of not only soil management but also the biology and behavior of the relevant pests in intercrop subsistence farms.

The creation of a better infrastructural support for the mixed/intercrop subsistence farmer (including advice on cropping practices, credit facilities, and guaranteed prices for desired intercrops), extension campaigns, demonstration plots at block levels, and pest forecasting schemes will further promote gradual adoption of improved pest-management practices in intercropping systems.

Entomological Studies in Intercropping at ICRISAT Center

A series of experiments have been conducted since late 1974 at ICRISAT Center which are aimed at establishing bases for a realistic approach to a viable pest management/integrated control in mixed/intercropping situations in the semi-arid tropics. It was clear that, given the cereal/legume bias of ICRISAT's mandate, the insect with the greatest overall impact was *Heliothis armigera* (Hubner). Studies on this insect in the intercrop situation were therefore given priority.

Preliminary experimentation in 1974-75 revealed that concentration on a few crop combinations and on larger plots was essential if data of value and relevance was to be obtained. The entomological experimentation in intercropping systems at ICRISAT was circumscribed by the need for large blocks, which act as "ecological units" and provide a more realistic "field" situation. On these plots, real pest shifts, differential parasitism levels (established by insect collections and laboratory incubation), and insect-induced yield losses can be accurately assessed without seriously affecting pest population levels. Sequential sampling procedures are often destructive, again necessitating large plots.

In 1975-76, pigeonpea intercropped with a range of cereals and legumes was studied, but subsequently only pigeonpea with sorghum was studied. In all experiments, plant populations were carefully controlled. Using techniques developed at ICRISAT, pest numbers, pest/parasitoid ratios, and damage caused (yield losses) to intercrops and monocrops were obtained. These data from the research center in both Alfisols and Vertisols have been compared with those obtained by trials on the farmers' land in village sites on an equivalent plot basis and under low-fertility conditions. Farmers' trials were sown using the local implements in flat beds. Data obtained were also compared with frequent off-station surveys.

On sorghum, no differences in levels of shoot fly (*Atherigona soccata* Rond.) attack were recorded in either the mixed or intercropped situation with equal plant stand. However, highly significant differences ($P<0.01$) in levels of shoot fly attack were observed, as early as 23 days after emergence, between locations within a radius of 15 km — with higher incidences at the research center than at the village sites. Grain yield loss measured at harvest also revealed that the losses caused by earhead bugs (*Ca/ocoris angustatus* Leth.) were lower at village sites than at the research center.

Data obtained on the pest/parasitoid relationship to date show that sorghum in mixed/intercropping is an important source of buildup of *Trichogramma confusum* Viggiani, an egg parasite, and *Diadegma* sp., a larval parasitoid of *H. armigera,* but this has no advantage to the immediate intercrop pigeonpea as the parasite complex that builds upon *H. armigera* on sorghum does not transfer to pigeonpea with the pest. A similar trend was noticed in farm surveys.

In general, Dipterans predominate on intercropped pigeonpea but have little real effect on damage levels, as they killed larvae when they were in the prepupal or pupal phase — i.e., after the host larva caused pod damage. Egg parasitism on pigeonpea was almost nil. A more simplified representation of transfer of parasitoids of *H. armigera* in a cereal/pulse intercrop is presented in Figure 1.

Data show that both pest numbers/100 pigeonpea terminals and percentage damage were greater on intercropped pigeonpea than on the sole crop, given the same plant densities and typical low-fertility situations. Since yield from sole-cropped pigeonpea is higher than from the intercrop, the actual weight loss is greatest from the sole crop (Table 1). In certain regions and in particular seasons, migration in *H. armigera* moths occur, which causes disequilibrium with native biotic control agents, leading to a rapid increase in larval populations

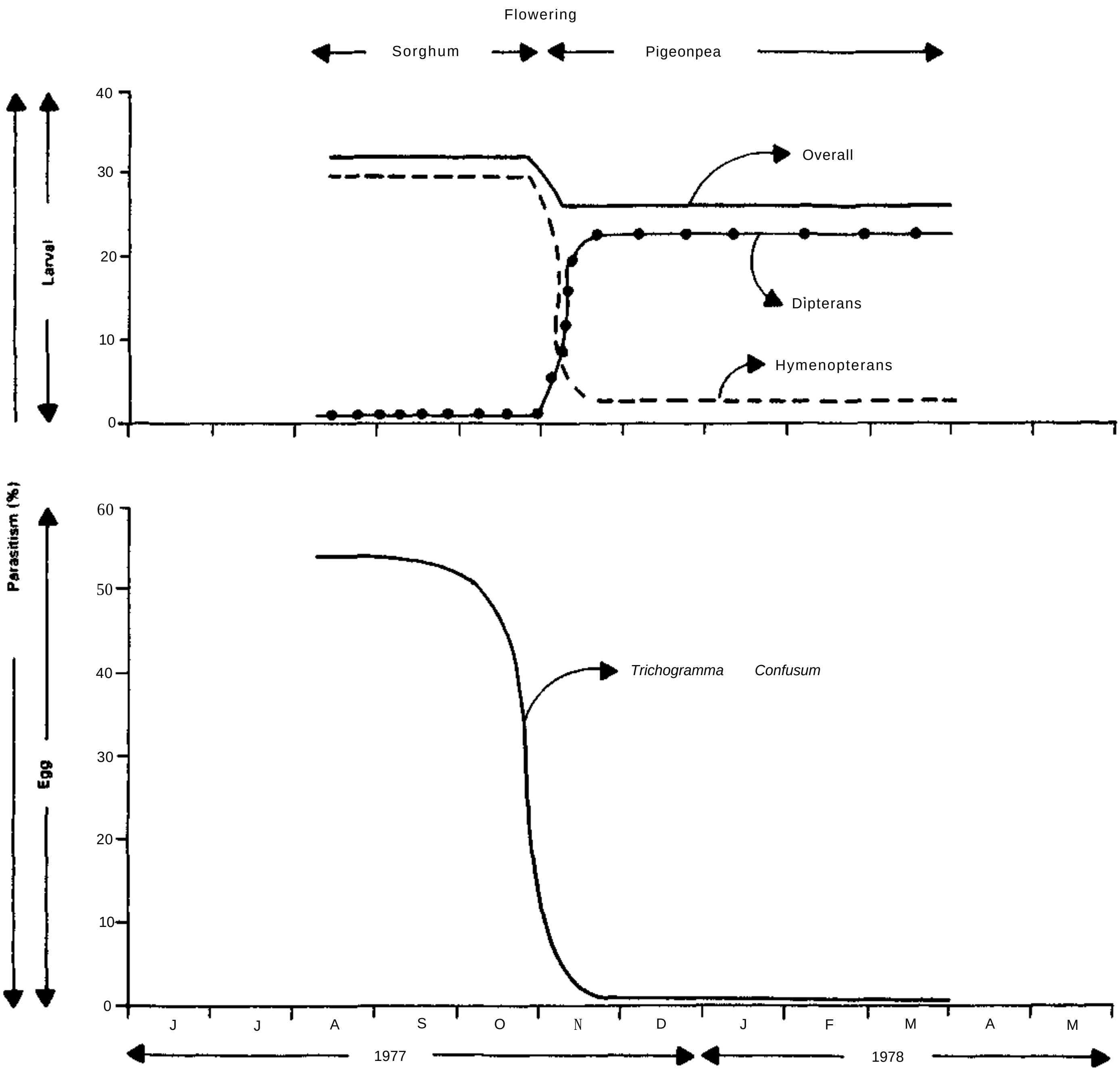

Figure 1. Transfer of parasitoids of* Heliothis armigera *in a cerealpulse intercrop, ICRISAT Center, 1977-78 (simplified).

and subsequent heavy yield loss in intercropped pigeonpea — e.g., in Andhra Pradesh during 1977-78 (Bhatnagar and Davies 1978b). This migration presumably was due to unusual cyclones experienced at the western coastal region of southern India in November-December 1977.

Surveys in districts of Andhra Pradesh, Karnataka, and Maharashtra have confirmed that Dipterans predominated in larvae collected from intercropped pigeonpea, whereas Hymenopterans were the predominant parasites on larvae collected from intercropped sorghum, groundnut, and chickpea. Intercropped chickpea also does not attract parasitoids of *H. armigera.* This is an important contributory factor in the high larval buildup and heavy yield loss on intercropped pigeonpea and chickpea.

Table 1. *Heliothis armigera* numbers, insect-Induced loss, and grain yield in sole and intercropped pigeonpea (Cv ICP-1) at ICRISAT Center, 1977-78.[a]

Pigeonpea grown as:	Pigeonpea population (plants/ha)	Larvae[b]		Loss		Pigeonpea yield (kg/ha)
		No./100 terminals	No./ha	Percent (%)	Actual (kg/ha)	
Sole crop	27 181	37.7	176 855	29.9	152.3	509
Intercrop[c]	26 545	53.7	143 408	50.1	101.3	202

a. *Average* of 8 sites.
b. Peak day: 25 Nov 1977.
c. With CSH-6 sorghum (96 850 plants/ha).

Cropping patterns within large areas had an important effect on distribution and abundance of parasltoids. Parasitism levels by Dipterans were higher in intercropped sorghum and pigeonpea in cotton-growing areas. Levels were higher in mixed/intercropped sorghum than in sole sorghum (20% compared to 13% during 1977-78). However, larvae from sole pigeonpea had more parasitoids than comparable numbers of larvae collected from intercrops (27% as opposed to 18% during 1977-78).

Data so far obtained at ICRISAT Center indicate that the conservation and encouragement of natural enemies has potential as a means of providing more effective management of *H. armigera* populations in mixed/intercropped subsistence farming, where insecticidal control is often uneconomical and beyond the reach of most farmers. In a village-level study during 1977-78 in collaboration with the ICRISAT Economics Program, factors such as low plant populations, high pest numbers due presumably to immigration in *H. armigera* moths, absence of egg parasites, low larval parasitism levels by the Hymenopteran group, and lack of spraying contributed to heavy yield losses on intercropped pigeonpea in villages of Andhra Pradesh and Maharashtra.

Conclusion

The above account of our studies, in intercropping systems reveals that ecological studies, including pest/parasitoid relations, are crucially important in understanding pest problems in intercrop subsistence farming. More attention will be paid to surveys of biotic control agents of key pests in relation to cropping systems of the tropics to explore the possibility of utilizing them in intercrops. Results so far obtained have helped in understanding concepts of pest/parasitoid relationships in intercrop situations. The general statements that diversity of cropping and stability of. yield are related are not always true, and our data reveal thatthese must be examined very critically in each particular situation. We hope to improve our understanding in this complex area in the coming seasons and attain the ability to predict what effects parasitism might have in cereal/legume intercrop systems.

More ecological work and base data are needed. There are no shortcuts. The gaps in knowledge, including pest/parasitoid behavior in specific intercrops, must be filled so that the research and development necessary for improved pest management in intercropping becomes realistic. Entomologists have a vital role to play in furthering the understanding of intercrop systems and enhancing the overall productivity of cereals, legumes, and root crops in the tropics.

Acknowledgments

We are grateful to the staff of Cropping Entomology at ICRISAT for their assistance in the field and survey work.

Discussion

Jana

It is clear from the data presented by Dr. Moody that weeds are less under a cereal situation than under a legume situation. It is also clear that weeds are less in intercropping than in sole cropping. So I think you were confusing us by saying that the data was not at all clear.

Moody

I agree that in almost all cases the suppressive ability of the cereals was greater than the legumes. But I cannot agree with the second statement. In most instances, the intercrop is between the cereal on the one hand and the legume on the other. So this is something we have to be very careful about when comparing weed suppression in intercropping. We have to be careful which of the two component sole crops we are comparing it with.

Rajat De

I think Dr. Moody would agree with me that the incidence of weeds in intercropping will depend on the time frame of the crop, i.e., how slow or how fast crops grow. In contrast to what you have shown for cowpea, there are some cowpeas which will establish very fast and will suppress weeds extremely well.

Moody

I agree wholeheartedly that there are big differences in our cultivars with respect to their ability to suppress weeds. Unfortunately, when we try and pool the different pieces, we cannot find out what is responsible for that suppressive ability. Of course a further problem is that a crop that may be very suppressive may have a low yield potential.

Snaydon

I suggest that you consider only those differences which are significant Also, you separate those experiments which were replacement from those which were additive. In this way you would be able to separate the effects of density from those of intercropping. I am glad that you mentioned yield; just because weed number changes it does not necessarily mean that we are getting yield effects.

Shivashankar

I think proper management of organic matter would be helpful in controlling weeds. For example, an application of straw is very helpful in dispersing weeds.

Moody

Mulching can give you very different effects. In some instances mulching suppresses weeds, in other situations you get no effect at all. And I would say that under most circumstances a mulch may not be particularly advantageous.

Okigbo

I think it is only recently that any effort has been made to manipulatecropping patterns to control weeds. I think workers are only now becoming aware of the potential for manipulating systems to control weeds. I think a lot of Dr. Moody's data is what I would call ad hoc observations. A further point is a lot of us have been using the word "system." I think we ought to be quite sure that we do not mean pattern. Further, we have not tried to identify crops in terms of which ones are better at suppressing weeds. All crops will allow weed growth until they have closed their canopy. If you want to get standardized weed data you have to decide at what time to start your observations. I think we ought to look into ways for standardizing weed measurements. And I subscribe to the view that there is great potential for selecting cultivars with improved weed-suppressing ability.

Wein

In some experiments that were carried out in Ethiopia, the parasitic weed *Striga,* was reduced quite markedly by intercropping with mungbean. *Striga* is an extremely important parasitic weed in Ethiopia and West Africa and intercropping seems to be an important way of achieving some control.

Gilliver

Dr. Bhatnagar said that only about 10% of the farmers in India were using sprays. Are there any plansto carry out simpletrials on farmers' fields, designating areas without sprays and areas with sprays on sole crop situations and/or on intercrop situations?

Bhatnagar

In the Indian situation, spraying crops like pigeonpea is uncommon. Collecting information on entomological problems or the effect of sprays is extremely difficult at the farmers' level. Probably what we will have to do is to begin this kind of simple work at selected villages.

S. P. Singh

There are some systematic studies carried out on pest incidence at the Indian Agricultural Research Institute, New Delhi. If sorghum is intercropped with millet, the pest incidence on sorghum increases. On the other hand, if sorghum is intercropped with mungbean or pigeonpea, the incidence of pests on the sorghum is reduced. Also differing somewhat from Dr. Bhatnagar's results, we have found that when pigeonpea is intercropped with sorghum or millet, the incidence of pod borer in pigeonpea decreases tremendously. In the case of intercropping with millet, pod borer incidence was only 4% of that in sole pigeonpea.

Baker

We had some trials in Nigeria where we were looking at *Cercospora* in mixtures of cereals and groundnut and we also superimposed a benolate spray. It was clearthat a considerably larger response to benolate spray was achieved in the mixture, and the spray significantly reduced the difference between the groundnut yield in the mixture and the sole groundnut yield. In other words, it was clear that *Cercospora* does contribute to the yield decrease of groundnut in intercropping.

Gibbons

Our experience is that once groundnuts are shaded by a tall crop, you are likely to get an increase in leaf diseases.

Okigbo

At IITA we have observed an increased incidence in *Cercospora* in groundnut in intercropping compared with sole cropping. But with rosette we have observed less incidence in intercropping compared with solecropping. I agree with Dr. Bhatnagar's idea that plots have to be very big to assess the insect situation. But I am surprised that more work has not been done in a farming situation instead of in the small plot control system. Surveys at farm level are difficult but they may be very important to establish, for example, whether pest or disease incidence really is lower in intercropping. Surveys would also indicate which systems were likely to be the most rewarding to study further.

S. L Chowdhury

Our discussion seems to suggest that we have some preconceived notions that intercropping ought to bring about some reduction in pests or diseases. This is often popularly supposed, although today there has been some disillusionment on this aspect. It seems to me that when you are putting more than one crop together, one is a favorite of one pest and another a favorite of another pest. Thus when we are bringing these crops together we are bringing a host of different pests or diseases together. So apart from the situation where one crop provides a barrier for another crop, why do we expect a reduction in pests or diseases in intercropping?

Mukiibi

I think it has been suggested that with reference to rosette in groundnut, the vector, the aphid, does not like high humidity. Therefore the higher humidity which occurs in intercropping tends to disfavor the vector.

Okigbo

Even now we seem to be lacking in factual data. I think many of us have observed that where we have only isolated plants of one species in a mixture of many crops, there is seldom any great incidence of pests or diseases on those individual plants. So I don't think we should really doubt that where one has diversity of different plants it can be more difficult for pests or diseases to spread.

S. L. Chowdhury

But I think where we are talking about isolated plants in a mixture, it is often the increased vigor of those isolated plants which appears to reduce disease or pest effects. Often the pest or disease is there but the vigor of the plants reduces the deleterious effects.

Chairman

In this very complex field of weeds, pests, and diseases, it appears that intercropping can sometimes reduce incidence, sometimes increase the incidence, and sometimes have no effect at all. I think we can only conclude that much more work is needed.

Session 4

Evaluation of Intercropping Systems

Chairman: J. G. Ryan

Rapporteur: S. V. R. Shetty

Statistical Considerations in Experiments to Investigate Intercropping

R. Mead and R. D. Stern*

Abstract

Statisticians have contributed little to the design and analysis of experiments specifically to study intercropping problems. A survey is made of the implications of various standard statistical concepts for designing and analyzing intercropping trials. This leads to a variety of possibilities in the design of the experiments, including the greater use of systematic designs and the use of more complex factorial treatment structures. Methods of collecting and analyzing growth data are examined, and suggestions are made of ways in which these could be improved. For the analysis of yield data, it is particularly important to develop computer programs so that the basic analyses can be performed simply. For further analyses, the value and limitations of using a land equivalent ratio as an index of total yield are discussed, and some further possibilities are introduced.

Statisticians have not been much involved in the current upsurge of interest in intercropping. In this paper we shall consider briefly a variety of topics on which we believe a statistician could contribute usefully.

One general point we would like to make initially is concerned with the storage and availability of data from intercropping experiments. The results from many intercropping experiments will be analyzed on a computer, and one consequence of this is that the results could be stored and retained for subsequent further analysis. At the various institutes represented at the Workshop, what arrangements are made for the storage of experimental data? Can you readily recall your previous data for re-analysis? Can you easily make your data available for research workers at other institutes?

The proper organization of the storage of data appears to be particularly important in intercropping since it is often stated that one of the principal advantages of intercropping is "stability." For any investigation of stability, it is clearly necessary to have access to data from many years and experiments.

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The four main sections of this paper are on examples of intercropping experiments, experimental design, the collection of data, and the analysis of data. The section on examples is included to illustrate the points of principles that are discussed in the other sections.

Examples of Experiments

In this section, five experiments are described briefly. They are given approximately in order of increasing complexity. In experiments 1, 2, and 3, only yield data were collected. In experiment 3, one of the treatments was arranged systematically. Bothyield and growth data were collected in experiments 4 and 5. Only two crops were considered in the first four experiments, whereas four crops were used in experiment 5.

Experiment 1: Pigeonpea genotype screening (during 1977 at ICRISAT)

Treatments

There were 17 pigeonpea genotypes. These were sown sole and intercropped with sorghum. Sole sorghum was also included.

Design

There were four replicates of a split-plotdesign. The genotypes were in main plots, and the cropping system (with or without an intercrop) formed the subplots.

Experiment 2: Genotype study, peerl millet/sorghum intercropping (during 1978 at ICRISAT)

Treatments

1. Four sorghum genotypes
2. Four millet genotypes

There were 24 treatments consisting of all combinations of the mixtu res plus the four sole millet and sorghum treatments.

Design

Randomized block design with four replicates.

Experiment 3: Effect of population change of chickpea with safflower (during 1976-77 at ICRISAT)

Treatments

1. Four population levels of chickpea:
   C1—133 000 plants/ha
   C2—267 000 plants/ha.
   C3—400 000 plants/ha.
   C4—533 000 plants/ha.
2. Row proportion:
   R1—Two chickpea rows: One safflower row
   R2—One chickpea row: One safflower row.
3. Fifteen population levels of safflower, S1-S15: (safflower populations increase systematically by 10%):
   S1—44 000 plants/ha.
   S15—169 000 plants/ha.
4. Sole plots:
   Four sole chickpea levels, C1-C4
   Four sole safflower levels, S1, S8, SI2, S15.

Design

Split-plot systematic design. There were a total of 32 plots, which were divided into four replicates. The chickpea treatments formed the main plots; each main plot contained two subplots for the different row proportions. Within each subplot the different safflower levels were arranged systematically. The sole-plot areas were incorporated within each subplot.

Data

Yields of each crop were recorded for each row.

Experiment 4: Growth and resource use study of sorghum/pigeonpea intercropping, ICRISAT, 1978

Treatments

All possible combinations of the levels of the following factors:

1. Sorghum population:
   S1—180 000 plants/ha.
   S2—120 000 plants/ha
2. Pigeonpea population:
   P1—40 000 plants/ha.
   P2—80 000 plants/ha.
   P3—120 000 plants/ha.
3. Row proportion:
   A1—Two sorghum rows: One pigeonpea row
   A2—One sorghum row: One pigeonpea row
4. Sole plots:
   S—Sole sorghum, 180 000 plants/ha.
   P—Sole pigeonpea, 40 000 plants/ha.

Design

Factorial with confounding of second-order interaction and with the two sole crops as additional treatments in each subblock. Each block therefore has eight plots. There are a total of 32 plots — i.e., two replicates. The experimental area is 0.75 ha.

Data

In addition to recording the yields, a number of samples were taken through the season. They included the following.

1. Ten samples of sorghum (weekly) and of pigeonpea (biweekly). A sample consisted of a 1 m x 2.7 m harvest from each appropriate plot.

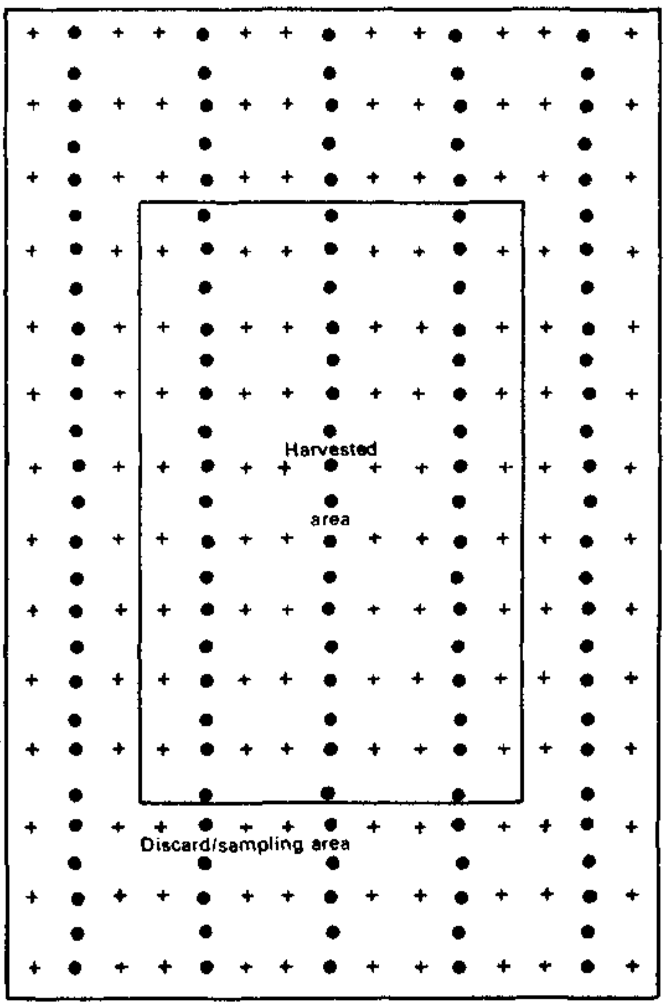
2. Samples from four plots were taken to study rooting pattern.
3. Sixteen solarimeters were used to measure light interception.

Experiment 5: Relay cropping of cereals with cotton and/or cowpea (during 1974 at Samaru)

Treatments

There were two treatment "factors":

1. Cereal:
   - C1—Millet
   - C2 — Maize
   - C3 —None



Cereal Maize or millet on all ridges, 23-cm spacing.
\+ Cowpea, 90-cm spacing.
Cotton, 45-cm spacing.

Figure 1. Diagram of single-plot layout from experiment 5.

2. Relay crop:
   - R1 — Cowpea
   - R2 — 2/3 cowpea, 1/3 cotton
   - R3 — 1/3 cowpea, 2/3 cotton
   - R4 — Cotton
   - R5 — None

The 14 treatments consisted of all combinations of these factors except, of course, C3 x R5.

Design

Randomized block design with six replicates. These were divided into two blocks of three replicates each. The relay crops on one of the blocks were protected against insects by spraying with endosulfan. Unlike the previous experiments, the crops were mixed on the row. A diagram of one of the plots is given in Figure 1. The total area of the experiment was approximately 2 ha.

Data

In addition to recording the yields, weekly samples were taken from the plots of two of the replicates (one sprayed, the other unsprayed) to examine the growth pattern of the cereals and particularly the relay crops. There were a total of 12 sampling dates for the relay crops. A sample consisted of three plants taken at random from the discard area of the appropriate plot.

Experimental Design

General

As yet, there has been very little thought about the problems of designing experiments specifically to investigate intercropping. Most experimenters appear to have used experimental designs similar to those they have previously used for monocrop experiments. This is probably inappropriate for two reasons. First, the development of intercropping is much less advanced at the present time than is monocropping. Second, the statistical understanding of experimental design has advanced greatly since experimentation on monocrops was at a stage comparable to the present state of intercropping.

The particular aspects of intercropping experimentation that require thought are:

1. The need to investigate the effects of many factors and their interactions at an early stage of an experimental program.
2. The need to define the objectives of an experimental program precisely and to attempt to satisfy those objectives through specific experiments.
3. The size of intercropping experiments, which requires efficient use of available space and the careful control of experimental error.
4. The extent to which intercropping experiments should include monocrop plots.

Factorial Treatment Structure

It has become standard to consider interaction effects of different factors in monocrop experiments. Statistical theory suggests that at the early stages of an experimental program, the economic benefits of factorial experiments are particularly strong. Therefore an experimental program should include large factorial experiments either at the outset or after a few preliminary experiments which have investigated single factors. In intercropping there are rather more factors than in monocropping because of the existence of two component crops so that it really is very worrying that so many of the current experiments on intercropping examine only a single factor or include a second factor in a subsidiary role.

There are essentially two advantages of factorial experiments with at least three factors. One is that the experimenter is able to examine the extent to which the response to one factor is affected by differing levels of a second factor (interaction). The other is the greater economy of the factorial experiment through hidden replication. It is important to realize that with a large factorial experiment it is frequently unnecessary to have any replication inthe sense of plots treated identically. Further, it may not even be necessary to have all possible combinations of factor levels included.

Consider, as an example, an intercropping experiment with six replicates of all six combinations of three densities of crop A and four densities of crop B. Comparison of the two densities of crop A is based on 24 plots per density; comparison of any two particular combinations of densities is based on six plots per combination. Suppose we introduce three levels of N and two varieties of crop A and, instead of six replicates, have no explicit replication, giving 72 plots (3 x 4 x 3 x 2), as before. Then we have the same precision of the original comparisons as previously, but also we have comparisons with approximately the same precision between N levels, between varieties, and between combinations of any two of the four factors. Blocking considerations may reduce some of this advantage, but most can be retained through the device of confounding.

The important point is that the usual practice of having three or four replicates is necessary only if the number of treatment combinations is small (< 10). To stick to three or four replicates and to use this as a reason for avoiding large factorials is to misunderstand the purpose of replication.

Use of Monocrops in Intercropping Experiments

In deciding to what extent monocrop plots should be included in an intercropping experiment, it is necessary to be very clear about the aim of the experiment. If the primary aim of the experiment is to assess the benefits of growing mixed crops as compared with sole crops, under a range of conditions, then it may be appropriateto have as many monocrop plots as there are intercrop plots.

However, if the primary aim is to examine how to mix the crops, then the requirement for monocrops is simply to have a good estimate of monocrop yield. This will be used not for a direct comparison with the two crop yields in the mixture, but to express the yield of the crop in the mixture as a proportion of the achievable monocrop yield. It is therefore not necessary to have standard errors to compare monocrops with intercrops, and the monocrops do not need to be grown on plots within the randomized experimental structure. It may be more convenient to grow the monocrop in fewer larger plots around or alongside the experimental intercrop plots and thus obtain a very good estimate of the monocrop mean yield while allowing the blocks, within which the treatments to be compared are grown, to be smaller and therefore more homogeneous.

Blocking

The important ideas of blocking in intercropping are the same as inmonocropping,thatisto recognize sets of plots which are likely to behave homogeneously. Thus the specialized knowledge of the experimenter about his experimental land is vital, and no rules about the size or shape of plots or blocks should be allowed to replace this specialized knowledge. Another possibility that should be kept in mind is that, now that the computational facilities for analyzing experiments are so much more sophisticated than even 20 years ago, there is no longer any requirement that the number of plots per block should equal the number of treatments or even that the number of plots should be the same in each block. The thoughtful identification of groups of plots likely to be homogeneous should be the overriding consideration.

Many existing experiments on intercropping which do include two factors use a split-plot design. We believe that the number of occasions when a split-plot design is appropriate are few. The only good reason for using a split-plot design is that some treatments can only be applied to large plots, whereas a large plot is not necessary or desirable for other treatments. We suspect that frequently split-plot designs are used for simplicity of treatment application, from habit, or from the belief that the design is appropriate when interactions are of interest. More often than not, this last reason is specious because the gain in precision of interaction effects is slight compared with the loss of precision on other effects, and also because the examination of the overall pattern of effects is hindered by the split level of comparisons.

Systematic Designs

Many intercropping experiments require large "general areas" around the harvested portion of each plot. Also many experiments on spatial arrangement of intercrops need to examine a wide range of spatial treatments. In addition, it is often necessary to combine this wide range of spatial treatments with one or more other factors. All these requirements make systematic designs potentially extremely important. Some systematic designs have been used in intercropping (Huxley and Maingu 1978, Wahua and Miller 1978, and at ICRISAT), but these have mainly been simple adaptations of the original ideas of Nelder (1962) and Bleasdale (1967).

We believe that systematic designs or systematic components of designs should be actively searched for, and that there are many new forms of systematic design waiting to be invented A simple form for varying the densities of two component crops independently has yet to be tried (Fig. 2).

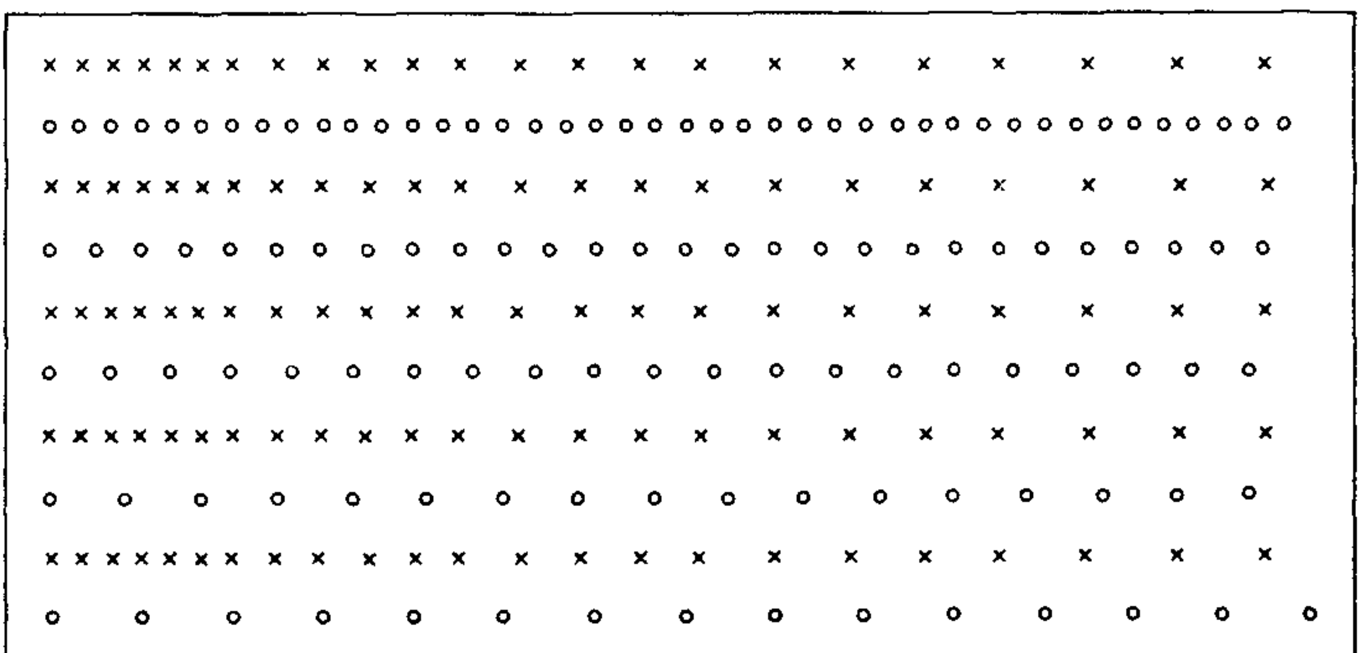


Figure 2. Two-way systematic spacing design for two crops (x and o) with a constant between-row distance.

Experimenters (and statisticians) are sometimes worried about the form of analysis for systematic designs. In general, however, although the analysis of systematic designs is different, it is not more difficult. The use of systematic designs to examine a wide range of spatial arrangements implies an interest in the response of yield to quantitative spacing factors and, therefore, the analysis of systematic designs will usually be through the fitting of response functions by regression for each systematic plot, followed by a comparison of the fitted response functions. When a more conventional analysis seems appropriate, then, provided the principal source of variation is plant variability rather than soil variability, the ordinary analysis of variance will be acceptable as the basis for the summary of the results.

Collection of Growth Data

Present Methods

In many experiments the data consist only of final yields; however, in a few cases, extensive additional effort has been devoted to the collection of growth data. As the collection and analysis of this type of data can be very time consuming, it is clear that considerable thought should be given to the objectives of this aspect of the experiment. It is convenient to distinguish between three types of objectives:

1. To compare the growth of a crop grown sole with its performance within a mixture and to compare the growth within the different mixtures.
2. To merely give a general idea of the growth of the various crops in an experiment.
3. To use information gathered during an experiment in order to make better use of the yield data.

This section will be primarily concerned with the sampling problems for the first objective. The current practice often involves taking 12 to 15 small harvests from all plots. There are a wide variety of ways in which the harvest can be taken. For example, in experiment 4, each sample consists of a 1 m x 2.7 m area selected systematically. In contrast, in experiment 5, each sample consists of three individual plants chosen at random. Variables that are measured usually include the total dry matter, (W), and the leaf area (L). A popular method of analysis involves fitting polynomial curves to log W and log L (Hughes and Freeman 1967). From these, further curves are derived to describe the relative growth rate and the unit leaf rate (net assimilation rate), etc. The present state of the subject is summarized by Hunt (1978).

Methods of Sampling within Plots

The assumption that dry matter is to be estimated implies that the sampling method is destructive so that different sample areas must be used for each harvest. This further implies that the growth of dry matter will be investigated on a plot, rather than plant, basis. Thus, the sampling scheme should be expressed in terms of harvesting small areas within a plot rather than in terms of harvesting a number of individual plants.

As the main objective is a comparison of growth curves for different treatments, the comparison will be in terms of comparisons between different plots. Consequently, it is not important to be able to estimate within-plot variance. Hence, areas within a plot may be chosen systematically, and, if it is considered desirable to sample more than one area within a plot, the samples may be bulked before analysis.

In the context of the situation outlined above, the sampling scheme of experiment 5 selecting three plants per plot, seems too small to be useful because of the variability of plants. However, it may be appropriate to take two or three sample areas systematically from each plot to attempt to overcome systematic variation within the plot; each area would then be considerably smaller than the single area in experiment 4.

Number of Harvests

The present method of analysis of growth data often involves fitting a polynomial to the data for the successive harvests. It will rarely be appropriate to fit more than a cubic, and, hence, it is difficult to see why as many as 12 harvests are used. To fit a cubic, the most efficient use of resources is to use only four harvests and to divide the available effort equally. Certainly six harvests are ample to both fit and test a wide variety of growth curves. If the effect of reducing the number of harvests and increasing the sample size at each harvest is to make the harvested material largerthan can conveniently be handled, then the possibility of subsampling for the leaf-area and dry-matter determinations should be considered after initially measuring the fresh weight of the whole sample.

Measurements to Give a General Assessment of Growth

If the aim of collecting the data is merely to give a general idea of the growth of the different crops, the work involved in evaluating the leaf area and dry matter for each harvest may not be justified. Much simpler measurements, such as height of plant and number of branches, may be adequate, particularly if the full data are also collected for a few plants and related to these measurements. The simpler measurements are, in addition, not destructive and, hence, can provide information about the growth of individual plants. As there is usually substantial variation between plants, it is a considerable advantage to be able to take repeated measurements on the same plants, and, even with relatively simple measures, the precision of comparison of growth rates may be better than with destructive harvesting.

Use of Additional Information to Improve Precision

In some mixed-cropping experiments, in which the only objective is to analyze the final yields, the unexplained variation is very large. Related to this is the fact that one or two yields are often considerably out of line with what might be expected and these yields have a considerable impact on the interpretation of the experiment. These effects are sometimes due to waterlogging, insect damage, etc. and are usually only recorded rather generally in the experimental log book. It would be useful to make these records more specific to the extent of giving scores based on eye estimates of the state of the crops during the season. This could either be done at regular intervals or after particularly important events such as heavy rain. These estimates would usually be used informally, but, in some instances, they could be used as a covariate to assess the extent to which aberrant yields have been consistent through the season and to improve the precision of the whole experiment.

Analysis

There are usually a number of different initial analyses that are appropriate for the data from a mixed-cropping experiment. We believe it is important that each research institute should develop a system that allows *all* the initial analyses to be done with little additional effort. If the basic analysis can be achieved in a routine fashion, the research worker will have time to look in detail at the special aspects of interest in the particular experiment.

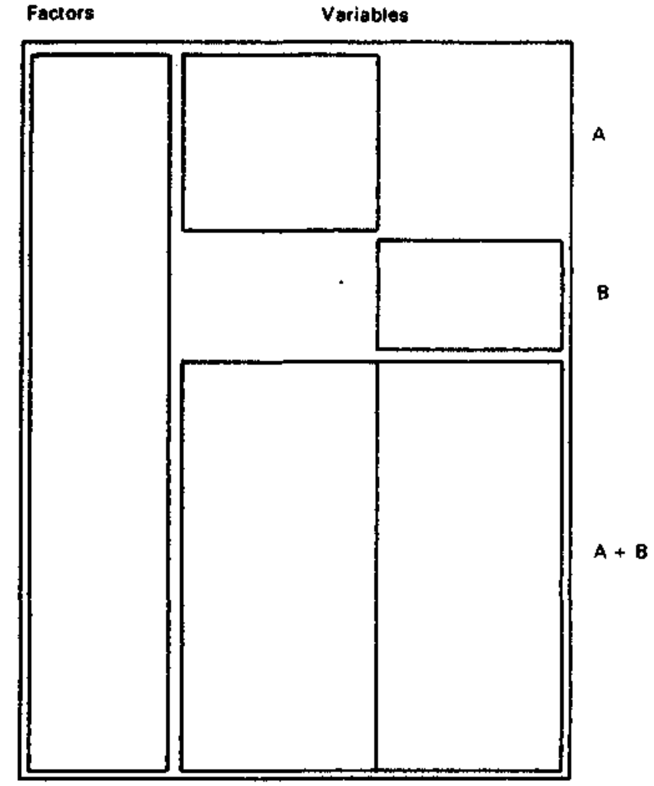
Computing Requirements

The format in which yield data from a simple mixed-cropping experiment can be stored on the computer is shown diagrammatically in Figure 3. The analysis can be considered in three stages.

Analysis of Each Crop Yield Separately

It is sensible to analyze a variety of subsets of the data. For example, for the yield of crop A there could be separate analyses of the sole-crop yields, the yield of A on the mixed plots, and both together. This entails picking out the relevant subsets of the data from the basic matrix given in Figure 3 and can be fairly tedious unless the computer program used allows the user to "SELECT IF...". In this case, each of the analyses uses the full-data matrix and is preceded by a different "SELECT" command.

The treatments for many experiments consist of a full factorial structure for the mixed plots plus the sole-crop treatments. Facilities should be available for the results to be presented in a variety of ways. Thus, in the analysis for all plots on which crop A has been grown, it will usually be sensible to subdivide the treatment effects into components that compare the sole-plot treatments with the mixed, followed by components within the sole treatments and within the mixtures. Few computer programs allow this flexibility; however, it is relatively straightforward to add such a routine to a standard analysis of variance package.



Factors	gives all information about replicates, treatment levels, etc.
Variables	consists of the data collected from each plot (yield, dry matter, etc.).
A	consists of all plots on which A was the sole crop.
B	consists of all plots on which B was the sole crop.
A + B	consists of all plots on which A and B are mixed.

Figure 3. Diagrammatic representation of data from mixed-cropping experiment in a suitable form for computer input.

Analysis of Combined Yields

The calculation of a combined yield in terms of such quantities as total cash or protein returns is relatively straightforward. Most computer programs have a reasonably flexible transformation routine, which allows new variables to be calculated. The appropriate sequence of transformations can therefore be used to derive these combined yields.

The calculation of a land equivalent ratio (LER) is slightly more difficult. This usually involves deriving summary measure(s) of yield from the sole crops and then using these to derive new variables for the plots on which the mixtures are grown. The computing facility that is required is to be able to use the results from an analysis of a subset of the data (sole plots) to compute a new variable on another subset (mixed plots). Few programs have this facility. However, even at its worst this merely implies that the two components of the LER have to be calculated by hand and entered as new variables.

Analysis of Growth Data

If required, the data from each harvest can be entered to the computer in the form given in Figure 3. Additional factors denote the harvest number and possibly the date of harvest. The full data then consists of *k* blocks, one for each harvest. Usually, however, the primary aim of the analysis is to fit growth curves for each crop separately. If combined yields are not required, it is simpler to consider the data for the two crops separately.

The initial analysis of the data will probably involve selecting each harvest in turn and analyzing the corresponding yields as described above in Analysis of Each Crop Yield Separately. The second stage uses a regression program to fit growth curves for each plot. A program for the comparison of regressions is then required if the main aim is to compare the growth curves for the different treatments. This is an area in which considerable development is required. We find it inexplicablethat even many large packages, which emphasize regression, contain no facilities for the straightforward comparison of regressions. The first satisfactory packages seem to be the recent versions of GENSTAT and GLIM.

Difficulties with Fitting Polynomials to Growth Data

In the last few years, there have been a number of studies that have discussed and extended the method of fitting polynomial functions to the growth data as suggested by Hughes and Freeman (1967). In general, the papers have concentrated primarily on discussing the type of function to be fitted — for example, whether polynomials should be used, and, if so, what order of polynomial is satisfactory. The fact that in many cases the data come from a designed experiment with perhaps a randomized block structure (e.g., experiments 4 and 5) is not mentioned. Although it may sound obvious, it is most important to stress that the particular analysis that is appropriate for growth data will depend on the design of the experiment. The result of ignoring this is that many of the methods suggested can give very misleading results if they are applied uncritically. Hunt and Parsons (1974) provide a computer program for the analysis of growth data. If used directly, this essentially fits a polynomial curve to all the data from a given treatment. The residual from the regression could be a mixture of:

1. Between-replicate differences.
2. Within-replicate, between-treatment differences.
3. Within-plot, between-harvest differences.
4. Within-plot, within-harvest, between-sample differences.

The use of such a residual to give standard errors for a regression line is clearly dangerous, and it is extremely unlikely that a simple program like that of Hunt and Parsons will give the correct fitted curve and standard errors.

Indices of Total Yield

The analysis of the yields of the two component crops usually provides only a partial answer because the aim of most mixed cropping systems is to maximize the total production from an area of land. It is important to note, however, that it may not always be necessary to calculate a combined yield, notably when one of the crops is unaffected by the mixing. For example, in experiment 5, the cereals appeared to be unaffected by the presence of cotton orcowpea. The yields of the relay crops were dramatically affected by the presence of the cereal, but there was no evidence that the effect of millet was different from that of maize. Thus, although the experiment involved four crops, the only index of yield that seems appropriate is one involving cotton and cowpea.

To return to the formulation of a combined yield, any total yield index must consist of a sum of standardized yields of the two crops. The three forms of standardization in current use are:

1. In terms of the cash or protein value of each crop:
   e.g., total yield $= £AY_A + £BY_B$
2. In terms of the proportions of the crops sown:
   e.g., total yield $= P_AY_A + P_BY_B$,
   where P_A and ps are the proportions of land occupied by crops A and B.
3. In terms of the land required to grow the harvested yields of the two crops. The usual formulation of this concept is the land equivalent ratio:
   $LER = y_A/S_A + y_B/S_B$
   where S_A and S_B are measures of the yield of the crops grown as sole crops. Thus, an LER of, say, 1.53 implies that an area 1.53 times the size of that used for the mixed crop would be required to be sown with the sole crops to achieve the same yields. The standardizing measures of yield, S_A and S_B, can be obtained in various different ways. For example, in a mixed-genotype trial, it would be possible to standardize the mixed yield for each genotype by the sole-crop yield for that genotype, or to use the best sole-crop yield of all the genotypes in the trial as the standardizing sole crop yield, on the argument that the mixed-crop yield should be compared with the best available sole-crop yield.

   For some experiments it may be sensible to consider both forms of LER calculations, one to evaluate the advantage of growing a particular pair of genotypes together compared with growing them sole, and the other to compare the different mixtures. For an analysis of variance of LERs, the standardization by a single sole-crop yield would seem to be the more appropriate.

The Investigation of a Combined Yield

The advantage of using the land equivalent ratio as a measure of mixed-cropping benefit is that it enables yields to be combined without making assumptions about proportions of land sown with the two crops, or about particular economic values. The LER seeks simply to provide a measure of increased biological efficiency in terms of the yields harvested rather than the seeds sown, and it might therefore be reasonable to hope that the LER would be a more stable measure of mixed-cropping benefit. However, in using the LER, there is an implicit assumption that the harvested proportions of the two crops are exactly those that are required. In actuality, the harvested proportions will be different for the different treatments. Hence, the LER, as a measure of biological efficiency, is in fact measuring a different definition of biological efficiency for each treatment.

For example, in an experiment at ICRISAT on maize and pigeonpea, the results for the two "best" mixtures, in kg/ha, were as follows:

Mixture I		Mixture II	
Maize yield	2234	Maize yield	3130
Pigeonpea yield	896	Pigeonpea yield	571

The optimal sole-crop yields were 3400 and 1035 for maize and pigeonpea, respectively. The calculations for LERs are as follows:

	Mixture I	Mixture II
Standardized maize yield MA	0.66	0.92
Standardized pigeonpea yield MB	0.87	0.55
LER =	1.53	1.47
$\frac{\text{Maize}}{\text{Maize and pigeonpea}}$ proportion =	0.43	0.63

It may be misleading to argue that mixture I is betterthan mixture II because ofthe higher LER. If the desired proportion of maize in the mixture were 0.6, it could well be that mixture II would be preferred. Thus, while it is easy to give an interpretation of any single LER, it is not clear that the comparison of two LERs is a sensible thing to do. With more than two treatments, the difficulty of comparison becomes greater, and Figure 4 shows the LER and harvested proportion of maize for the nine treatments in the experiment which included mixture I and mixture II. What is required is a method of comparing LERs that takes into account the different harvested proportions of the two crops.

We believe that this difficulty of there being implicit assumptions behind any single index of total yield is unavoidable. We would go further and say that no single measure of total yield can be totally satisfactory as a summary of two component crop yields. One possible solution is to use variety of indices of yield, each of which represents a different aspect of the data. An alternative is to accept that, as there are two components of crop yield, it will often be useful to consider a two-dimensional representation of the yields in order to display the yield

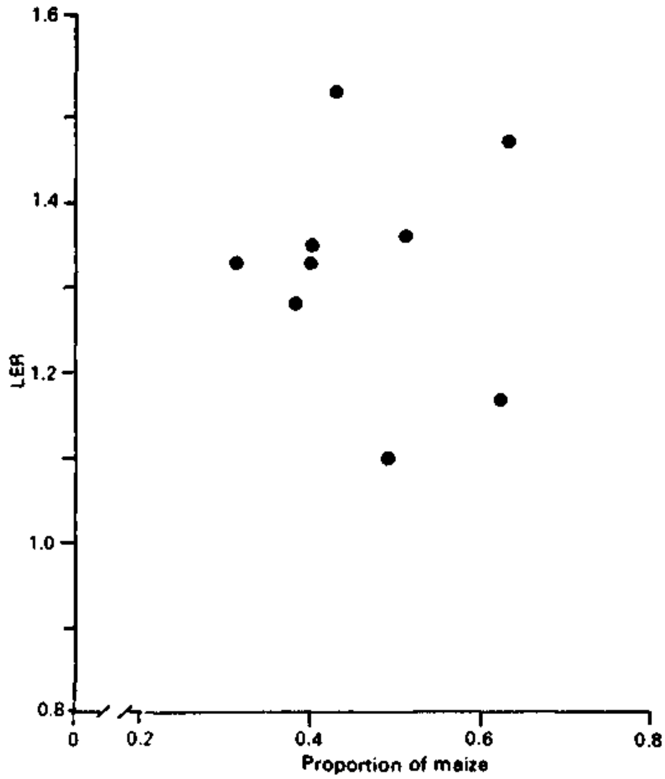


Figure 4. Relationship between LER and harvested proportion of maize for nine treatments, mixtures I and II, ICRISAT.

advantage of the mixture. We shall therefore consider such a representation, which is presented at this present stage as a purely descriptive technique.

An Extension of the LER Concept

Consider again the results for mixtures I and II. Suppose we wish to achieve a maize/(maize + pigeonpea) proportion of 0.63 using mixture I. This could be done by growing the mixture on part of the area and growing sole maize on the remainder. To make the proportion of maize 0.63, we would need to increase the standardized maize yield from 0.66 to 1.48. The sole crop of the maize component of mixture I gives a yield of 3331, which, expressed as a proportion of the optimal sole-crop yield of 3400, is 0.98 (= SA). Hence, to raise the standardized maize yield from 0.66 to 1.48, we would need an area of (1.48-0.66)/0.98 = 0.84 units of sole-crop maize. This would give a total standardized yield of 1.48 + 0.87=2.35 from the total area of 1.84 units and gives a biological advantage, or LER, of 2.35/1.84= 1.28. The calculations are summarized below.

Crop	Area	Yield per area	Yield
Mixture I	1.00	MA =0.66	0.66
		MB = 0.87	0.87
Sole maize	0.84	SA=0.98	0.82
	1.84		2.35

Overall yield per area = 2.35/1.84= 1.28= LER

On this basis, for a required maize proportion of 0.63, mixture I provides a biological efficiency of only 1.28 as compared with the biological efficiency of 1.47 for mixture II.

One can go further and calculate biological efficiencies for any required proportion. As an example, the necessary calculations are given below for a harvested proportion of maize of 0.5. (Note that the component crops of maize and pigeonpea were the same for both mixtures, the sole-crop yields being 3331 for maize and 954 for pigeonpea, giving standardized yields of 0.98 and 0.92.)

Crop	Area	Yield per area	Yield
Mixture I	1.00	MA =0.66	0.66
		MB = 0.87	0.87
Sole maize	0.21	SA = 0.98	0.21
	1.21		1.74

Overall yield per area = 1.74/1.21 = 1.44= LER

Crop	Area	Yield per area	Yield
Mixture II	1.00	MA = 0.92	0.92
		MB = 0.55	0.55
Sole pigeonpea	0.40	SB=0.92	0.37
	1.40		1.84

Overall yield per area= 1.84/1.40 =1.31 = LER

A general method of obtaining the LER for any predetermined crop proportion is given as follows. Suppose that a proportion, *k,* of the area is sown with the intercrop and a proportion (1 - *k*) with sole-crop A. Consider all yields to be standardized by dividing by the maximum-achieved sole-crop yield for each crop, so that all yields are proportions of the best possible sole-crop yield. Let the standardized yields for the mixture be M_A. and M_B and, for the sole crops of thetwo components ofthat mixture, SA and 5B.

Then the total standardized yield is:

K(MA + MB) + (1-K)SA

which, if *k* = *1,* becomes the usual LER.

The proportion of crop A of the total harvest is:

$$\lambda = \frac{kM_A + (1-k)S_A}{k(M_A + M_B) + (1-k)S_A}$$

$$\text{where } \lambda > \frac{M_A}{M_A + M_B}$$

To achieve a required proportion, *X,* We must have the proportion of the sown area intercropped:

$$k = \frac{S_A(1-\lambda)}{\lambda M_B - (1-\lambda)M_A + (1-\lambda)S_A}$$

With this proportion of the area intercropped, the total standardized yield is:

$$LER_\lambda = \frac{M_B S_A}{(S_A - M_A) + (M_A + M_B - S_A)\lambda}$$

Hence, for any desired rates of crop A to the total crop, the biological efficiency of the system can be calculated.

To illustrate the use of this approach, the data for the two mixtures considered previously are given in Figure 5. The peak of yield advantage

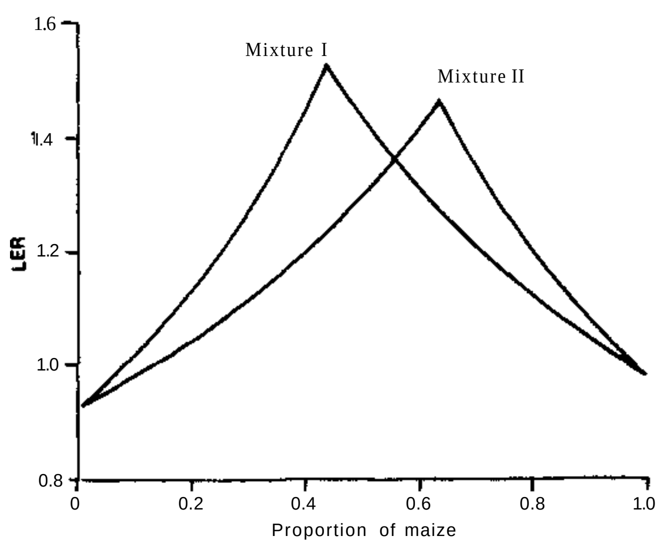


Figure 5. Comparison of yield advantage for two maizelpigeonpea mixtures when different harvested proportions are achieved by growing both a mixture and a sole crop.

for each mixture is obtained by pure intercropping, and the corresponding ratio λ is the ratio of the harvested crops, *MAI(MA+MB).* TO achieve any other ratio, the LER is lower, and, as the ratio tends to 1 or 0, the LER decreases to the values of the standardized sole crops 0.98 or 0.92. It can be seen that mixture I provides a better biological efficiency than mixture II if the desired maize proportion is less than about 0.55.

Figure 6 shows the LER curves for the nine treatments for which LER was plotted against the proportion of maize in Figure 4. It should be noted that the effect of using a single overall sole-crop yield is to give biological efficiencies of less than 1 for some of the sole-crop treatments (λ = 0 or 1). This is because biological efficiency is being measured against the maximum achievable yields under sole cropping.

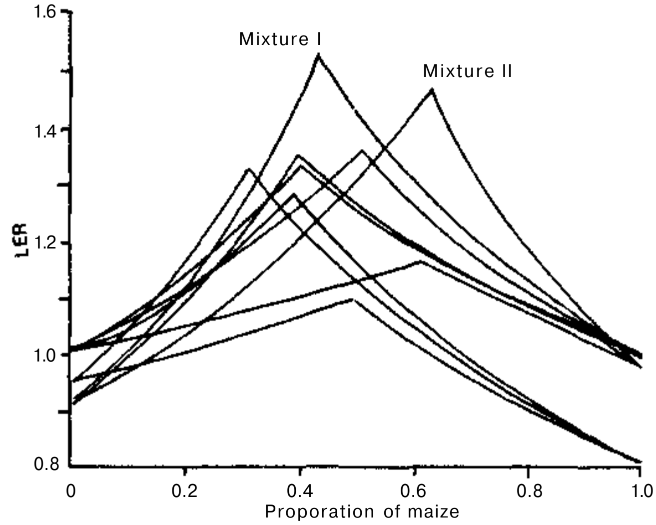


Figure 6. Comparison of yield advantage for all nine maizelpigeonpea mixtures when different harvested proportions are achieved by growing both a mixture and a sole crop.

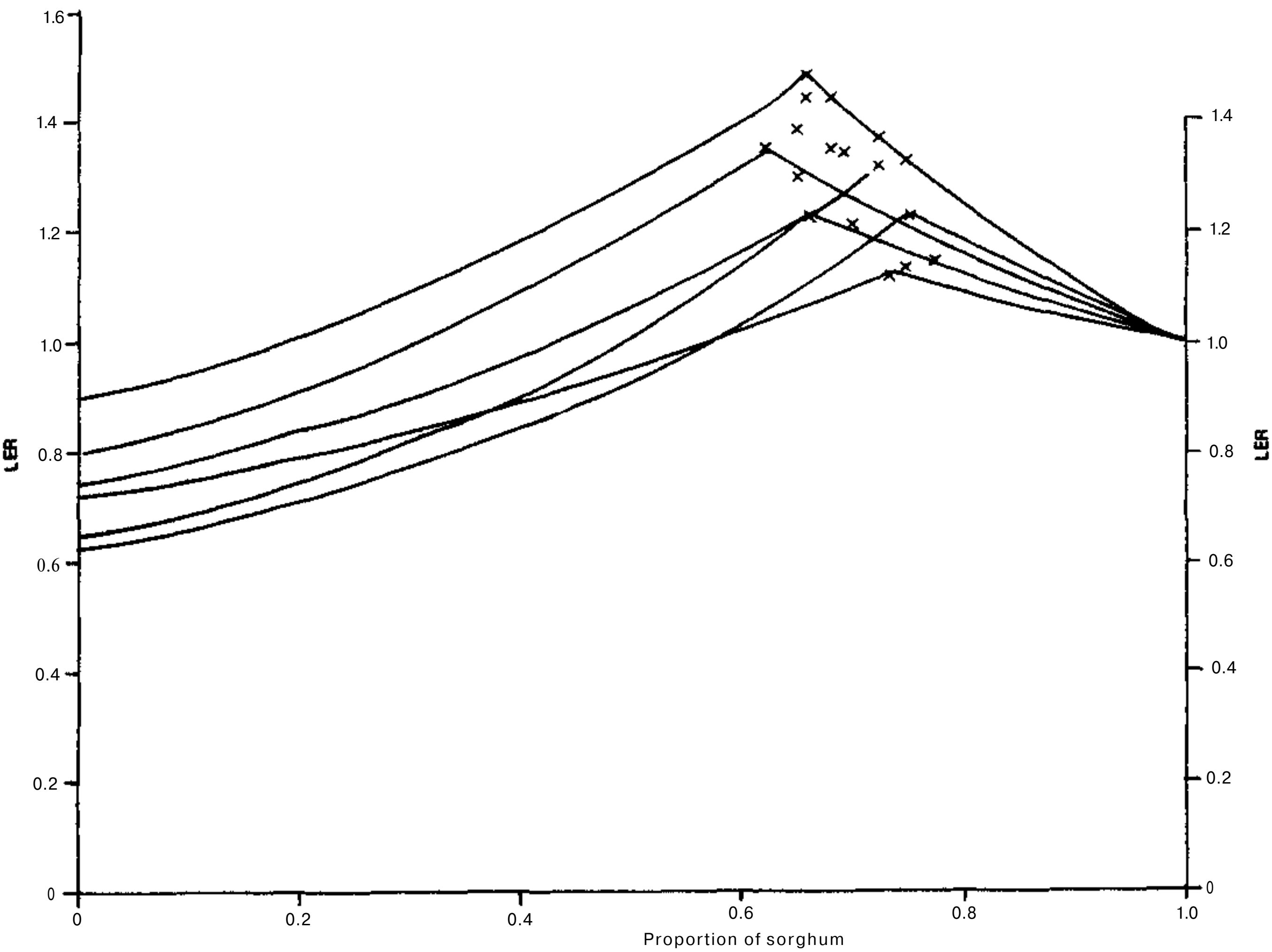


Figure 7. Comparison of yield advantage for mixtures of different pigeonpea genotypes with a standard sorghum genotype when different harvested proportions are achieved by growing both a mixture and some sole crop.

Data from experiments 1 and 2 are displayed in Figures 7 and 8, again using a single overall sole-crop yield. To demonstrate the difference between using a single overall sole-crop yield and using the sole-crop yields for the genotypes of each mixture considered, the data from experiment 2 are shown again in Figure 9 with the sole-crop yields for the genotypes in the mixture used as the standardizing yields. The interpretation is clearly very different.

Conclusions

The design and analysis of good mixed-cropping experiments is an exciting challenge to both experimenters and statisticians. In designing an experiment, a clear statement of the objectives will usually dictate whether sole-plot treatments need to be incorporated within the treatment structure or whether they can be considered separately. The fact that the experiments are often large implies that it is very important to make efficient use of the land. This should lead to the use of more complex factorial designs and also to the increased use of systematic designs.

More care should be given to decisions about sampling within the life of the experiment. The methods and effort devoted to the sampling should clearly be related to the way in which the data are to be used. The recording of simple additional information in quantitative form should be considered as a routine for experiments for which, at present, only yield data are collected.

The development of suitable computing facilities is a high priority. The computer should be used both for data storage, so there can be easy access to the raw data on future occasions, and for data analysis. The programs for data analysis should allow a wide range of analyses to be done simply and easily. An important area, where much more thought needs to be given, is in using measures of combined yield. The approach that is outlined in the sections on Investigation of a Combined Yield and Extension of the LER Concept is given as a purely descriptive technique. If it proves useful, the calculation of standard errors, etc. will become an important priority for statisticians.

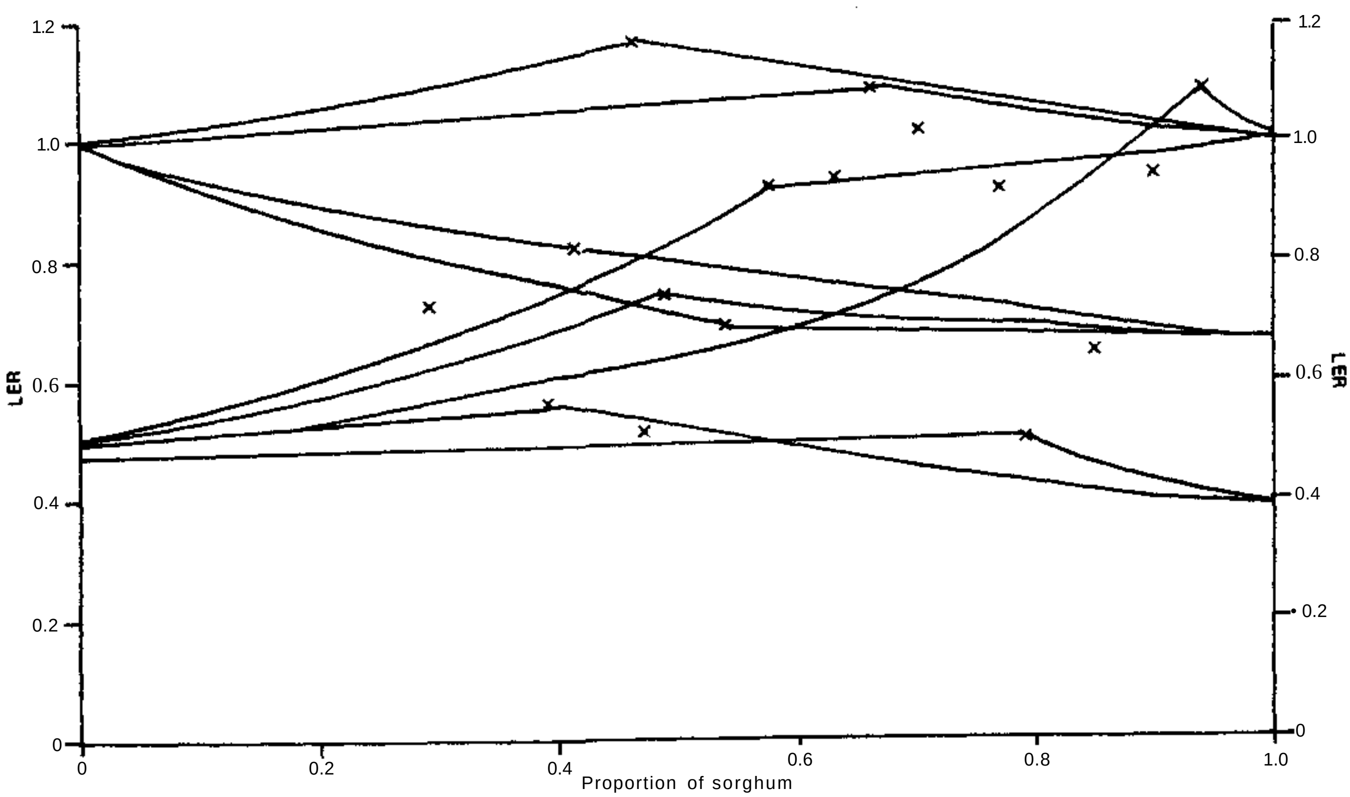


Figure 8. Comparison of yield advantage for sorghumImillet mixtures of different genotypes when different harvested proportions are achieved by growing both a mixture and some sole crop (highest sole crop yield of any genotype taken as LER - 1).

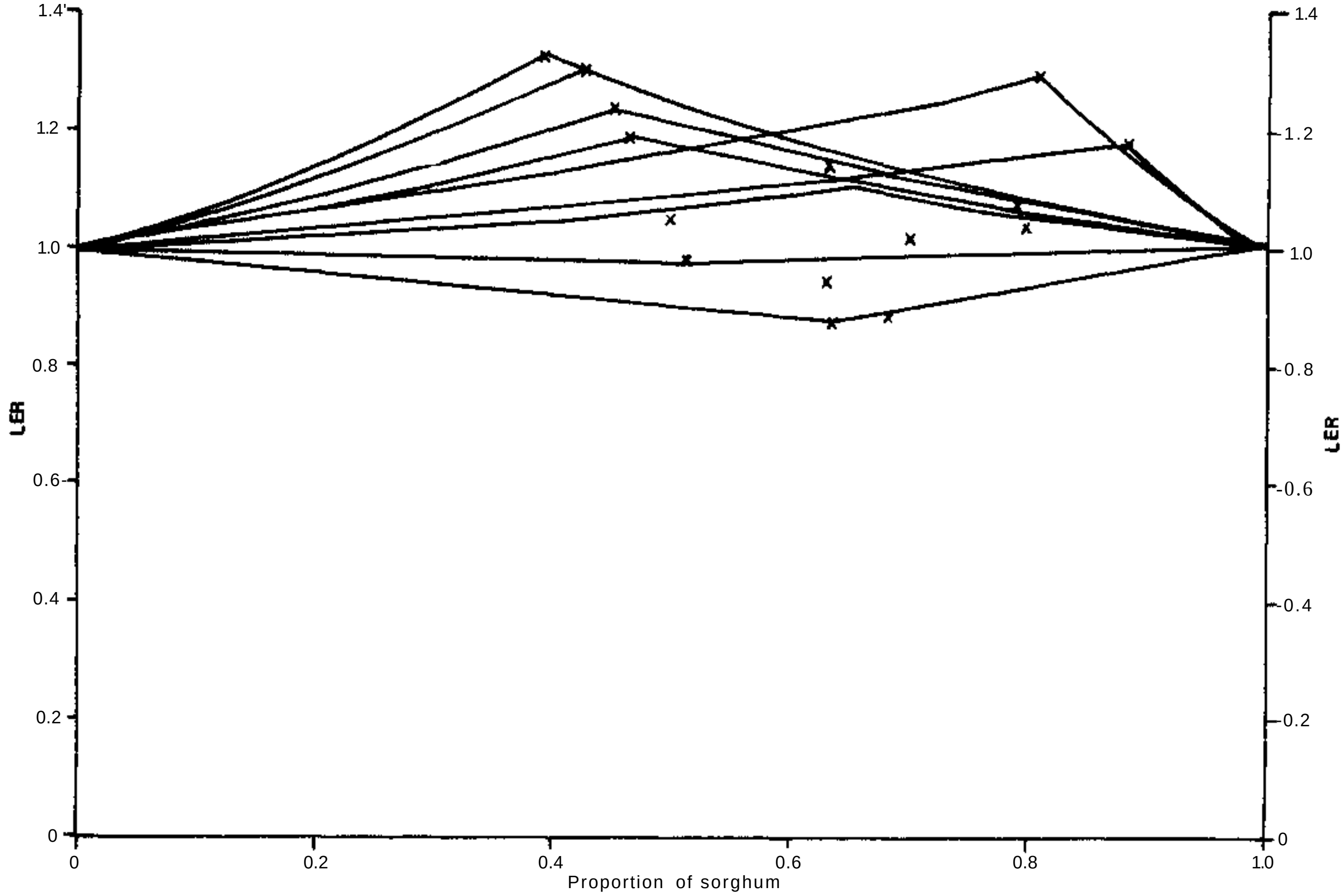


Figure 9. Comparison of yield advantage for sorghumImillet mixtures of different genotypes when the sole crop yield of each genotype is taken as LER = 1.

In general, we feel that the "rules" that experimenters have used in designing and analyzing mixed-cropping experiments have had two major faults. First, they are slightly out of date, largely because many of the excellent standard texts, e.g., Cochran and Cox (1957), were written in essentially precomputer days. Second, the additional complexity of mixed-cropping experiments, compared with experiments on sole crops, has been treated as a problem rather than a challenge and has not yet produced the new designs and techniques of analysis that it deserves. The design and analysis of efficient trials is a most interesting area which warrants a considerable amount of imaginative and collaborative research.

Experimental Designs for Intercropping Systems and Analysis of Data

C. K. Ramanatha Chetty and U. M. Bhaskara Rao*

Abstract

Experiments on intercropping systems are complex and require an innovative approach in design and analysis of data. Choice of experimental design and variate for analysis is related to the objectives of the experimenter. Some designs for major objectives in intercropping research are suggested, and method of analysis of data is indicated. Deficiencies of land equivalent ratio are brought out, and improved indices of efficiency of intercropping are developed.

Experiments on intercropping systems involve testing of more than one crop. As such, the designs need be more complex. It may even require innovative approaches in designing experiments as well as in interpretation of the data. The study of interactions of several factors in an intercropping system is intricate in nature and, therefore, requires flexibility in design and analysis. Some of these aspects are discussed in this paper.

The choice of suitable design is related to the objective of the experiment. Intercropping studies may be designed to:

1. Identify crop combinations so that the yield of the important component crop is not sacrificed;
2. Identify crop combinations so that the total production and/or revenue is maximized;
3. Identify the proper geometry of planting component crops;
4. Evaluate the effect of several factors, such as fertilizers, geometry, plant population, interculture, etc.;
5. Develop intercropping systems involving more than two components.

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Yield of the Important Component Crop

Screening crops and varieties suitable as intercrops with the important crop, henceforth called the "base crop," is simple. Conventional designs may be used and the base-crop yield analyzed. The sole crop of the base crop alone should be the control plot. Depending on the number of varieties and crops and the nature of the experimental field, either a randomized block design or a Latin square design can be used.

Maximal Total Production and Revenue

Analyzing total production is meaningless since the potential of different crops varies. Alternatively, an index of efficiency of the intercropping system may be subjected to analysis of variance. One such index is the relative yield total (RYT) (Trenbath 1974b) or the land equivalent ratio (LER). It may be noted, however, that LER is independent of yield levels and, hence, may not always be meaningful. For instance, let us consider the following two hypothetical cases:

Case I		Case II	
Crop	Yield (q/ha)	Crop	Yield (g/ha)
A (sole)	2	C (sole)	21
B (sole)	3	D (sole)	18
A + B	1.8 + 2.8	C + D	15 + 9
LER	1.8	LER	1.2

System (C + D) is more acceptable in practice despite the fact that the LER of (C + D) is significantly less than the LER of (A + B), as the total production is much more in this system than in the former.

Thus, LER is useful for comparing different systems, provided the same combination of crops is involved in both systems. Further, LER does not specify the spatial arrangement of the component crops and their economics. Considering the above points, the following indices appear to be alternatives to LER:

$$I_1 = \frac{Y_{ij} + Y_{ji}}{P_1 Y_{ii} + P_2 Y_{jj}}$$

where Y_{ij} and Y_{ji} are yields of crops i and j intercropped with j and i; Y_{ii} and Y_{jj} are yields of sole crops, and P_1 and P_2 are proportions.

In the above index, the prices of component crops are not considered. Of course, economic viability of the system would enhance its adaptability. The index considering the prices aspect is based on net revenue:

$$I_2 = \frac{\text{Net revenue from intercropping}}{\text{Highest net revenue from sole cropping}}$$

This index is simple, but the denominator considers only one component and also does not consider the spatial arrangement.

Considering the proportions and prices of component crops, a weighted index is suggested below:

$$I_3 = \frac{RY_{ij} + Y_{ji}}{RP_1 Y_{ii} + P_2 Y_{jj}}$$

where R is the ratio of the price of the ith crop to the price of thejth crop. It may be mentioned here that ratio of prices is subject to much less fluctuation than the fluctuation in prices of individual crops.

Proper Geometry of Planting Component Crops

It is reported that complementary effects in an intercropping system accrue only when the component crops are adjacent to one another. This will happen when the planting system is either 1:1, 2:1, or 2:2 (Shelke and Krishnamoorthy 1978). In orderto maximizethe LER or any intercropping efficiency index, the geometry of planting is important

A coordinated trial was started in AICRPDA in 1971 to compare "uniform" and "paired" row systems of planting for sole and intercrops. A strip-strip-plot design was suggested for this experiment. A typical replication is given in Figure 1. The main feature of the design is provision of dummy controls for sole cropping. This gives better precision for estimating the yield of the sole crop. The layout also serves the purpose of demonstration to farmers. The ANOVA is given in Table 1.

Another common type of experiment tests ratios of crops. The strip-plot design provides flexibility in analysis. A typical replication is given in Figure 2, and the ANOVA is given in Table 2.

In these studies, the pairing distances are generally arbitrary. In order to determine optimum pairing distances in an intercropping system of 2:1 ratio, systematic designs were developed (Shelke and Bhaskara Rao 1976). In this design, the crop that is to be grown in paired rows is planted between the wide rows of the other crop in such a way that the pairing distances change steadily. A typical set is shown in Figure 3-A. Such sets can be repeated to serve as replications. By taking the mirror image, as in Figure 3-B, any slope effects may be eliminated and the number of replications increased. The main advantage of this design is that the space requirement, and so the heterogeneity, is very small and we get continuous variation of component crops with different pairing distances of the base crop. The

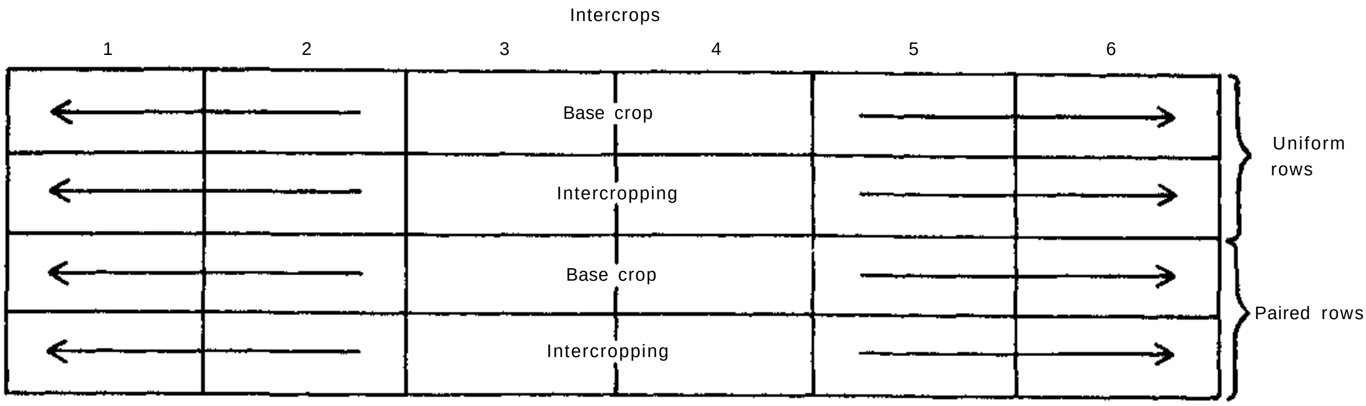

Figure 1. Strip-strip-plot design.

Table 1. ANOVA for the strip-strip-plot design (see Fig. 1).

Source of variation	Degrees of freedom
Between replications *(r)*	$(r - 1)$
Between systems (s)	$(s - 1)$
Error (a)	$(r - 1)(s - 1)$
Type of cropping *(t)*	$(t - 1)$
Error (b)	$(r - 1)(t - 1)$
Type of cropping x system	$(t - 1)(s - 1)$
Error (c)	$(r - 1)(t - 1)(s - 1)$
Between intercrops (k)	$(k - 1)$
Error (d)	$(r - 1)(k - 1)$
Intercrop x system	$(k - 1)(s - 1)$
Error (e)	$(r - 1)(s - 1)(k - 1)$
Absolute (pure) error	$rs(k - 1)$
Total	$rs[t + 2(k - 1)] - 1$

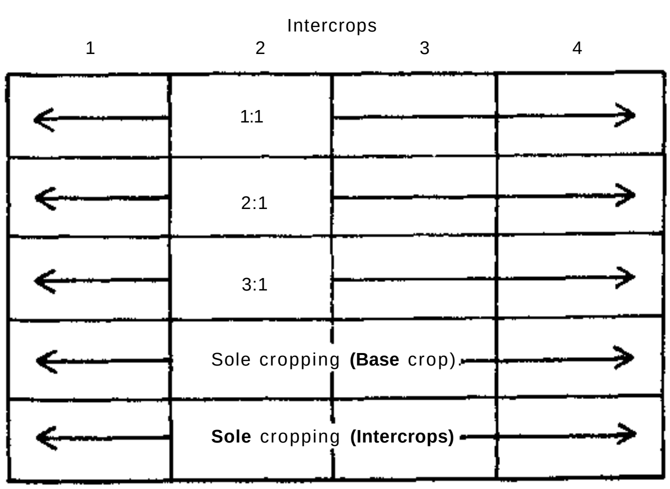

Figure 2. Strip-plot design.

Table 2. ANOVA for the strip-plot design (see Fig. 2).

Source of variation	Degrees of freedom
Yield of base crop (q/ha)	
Between replications	$r - 1$
Between intercrops	3
Error (a)	$3(r - 1)$
Between treatments[a]	3
Error (b)	$3(r - 1)$
Intercrop x treatments	9
Error (c)	By subtraction
Total	$16(16r - 1)$
Yield of net revenue (Rs/ha)	
Between replications	$r - 1$
Between intercrops	3
Error (a)	$3(r - 1)$
Between treatments[a]	4[b]
Error (b)	$4(r - 1)$
Intercrop x treatments	12
Error (c)	By subtraction
Total	$(20r - 1)$

a. Treatments were as follows:
T_1 = Intercropping (1:1) ratio
T_2 = Intercropping (2:1) ratio
T_3 = Intercropping (3:1) ratio
T_4 = Sole cropping of base crop
T_5 = Sole cropping of Intercrops

b. The 4 df can be split as:

Orthogonal contrast	Degree of freedom
$T_4 - T_5$	1
$T_3 - \dfrac{T_4 + T_5}{2}$	1
$T_1 - T_2$	1
$\dfrac{T_1 + T_2 - T_3}{3} \quad \dfrac{T_4 + T_5}{2}$	1

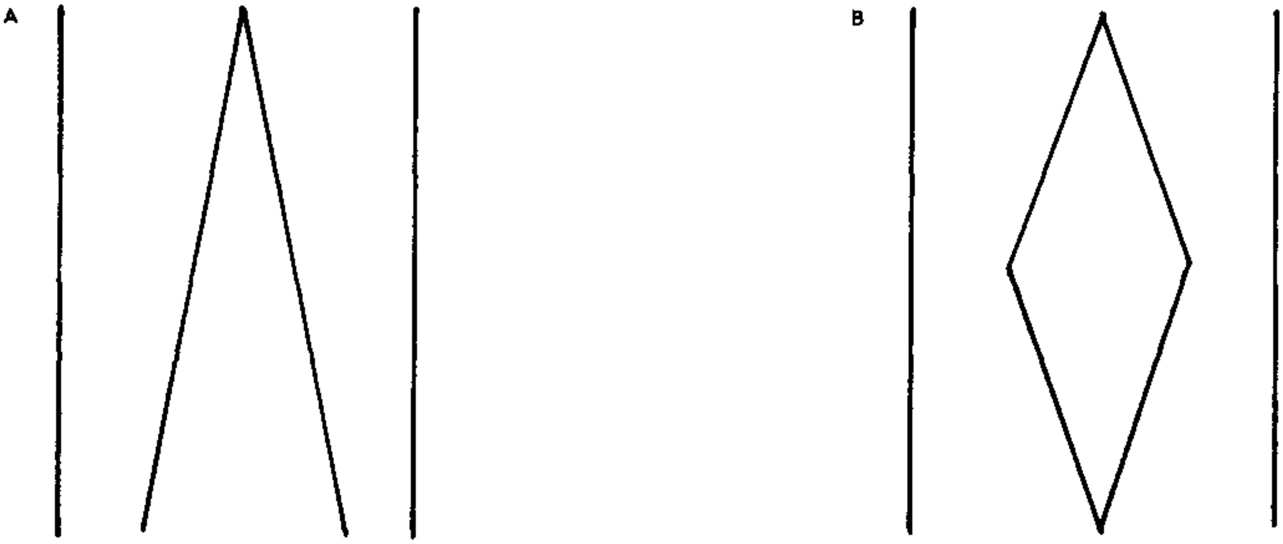

Figure 3. Pairing distances for intercropping systems for statistical evaluation.

yields of these crops can be plotted against the interrow distance, as shown in Figure 4. The point of intersection is to be considered the optimum pairing distance.

Effect of Several Management Factors

In monocrop experiments, the factorial concept can be used profitably. Suitable confounding techniques to increase the precision can be adopted. But in intercropping experiments, the problem is complex. When there are two factors, such as pairing distances of one crop and population of another component crop, the split-plot arrangement will be useful. In each main plot, a sole crop of each of the component crops should be included. This helps in arriving at more precise estimates for sole crops and facilitates computing an intercropping efficiency index within a main plot An example of this design is presented in Figure 5, and the ANOVA is given in Table 3.

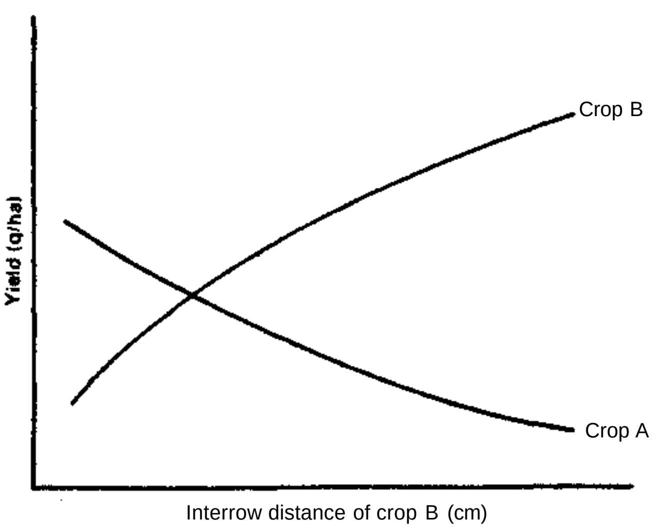

Figure 4. Plotting yields against interrow distance for statistical evaluation of intercropping.

Designs for Intercropping Systems with More than Two Components

When there are three crops, only one arrange-

Table 3. ANOVA for the split-plot design (see **Fig. 5**).

Source of variation	Degrees of freedom
Between replications (r)	$(r-1)$
Pairing	2
Error (a)	$2(r-1)$
Treatments (t)	$(t-1)$
Pairing x treatment	$2(t-1)$[a]
Error (b)	By subtraction
Total	$(3rt-1)$

a. The degrees of freedom will be 4 when considering only one crop, 3 when considering Indices based on both crops, and 5 when considering net revenue.

	Pop 1	Pop 2	Pop 3	Pop 4	Sole crop A	Sole crop B
Pairing I						
Pairing II						
Pairing III						

Figure 5. Split-plot design.

ment is possible. Consider three crops — A, B, and C. By sowing each set of rows continuously as A B C A B C A B C, the information on the effect of each crop when interspersed by different crops can be evaluated. Each set serves as a replicate. When there are four crops, three such arrangements are possible; when there are five crops, six such arrangements are possible. In such cases, all possible arrangements may be taken together with sole crops of each of the component crops. The possible arrangements and sole crops constitute one replication. The individual sets will enable measurement of inherent soil variation.

Acknowledgments

The authors wish to thank Dr. S. L Chowdhury, Project Director, and Dr. J. Venkateswarlu, Project Coordinator (Research) for having gone through the manuscript and suggesting improvements.

Intercropping in Traditional Farming Systems

N. S. Jodha*

Abstract

Though largely neglected by researchers and planners, intercropping is a key element of traditional farming systems. Its superiority over sole cropping has been shown in terms of higher and more dependable gross returns per hectare as well as per unit of peak-period labor use. Its potential for greater employment is also revealed. Studies show that intercropping is largely a system of small and unirrigated farms. A significant implication of this finding is that any breakthrough in intercropping technology will help poor farmers more than the rich. Increased research resource allocation to intercropping will thus serve the equity goals better.

Traditional intercropping is found to be highly complex and diverse because the farmer attempts to achieve his multiple objectives simultaneously through intercropping. Researchers cannot and need not generate equally complex new intercropping systems. Instead, they should concentrate on generating a simple system that satisfies key objectives, such as profitability and stability, without completely ignoring the other objectives that underlie the traditional intercropping system.

Intercropping, or growing crops in mixtures is one of the important features of farming in developing countries. Depending on local agroclimatic variations, 50 to 80% of rainfed crops are planted as intercrops in different parts of the developing countries (Aiyer 1949, Mathur 1963, Norman 1974, Jodha 1977). Viewed from different angles, the practice of intercropping reflects farmers' traditional wisdom or rationality as applied to their cropping decisions (Norman 1974, Jodha 1977). However, notwithstanding its vast coverage and the strong rationale behind it, intercropping has received scant attention from the standpoint of research, policy, and planning. National and international reports of agricultural statistics seldom include details about intercrops; planning documents do not contain programs for intercrops, even at the development block level; agricultural growth models seldom recognize intercropping as one of the variables. Researchers engaged in technology generation for agriculture, for the most part, have shown indifference to intercropping, and, consequently, all high-yielding varieties were developed largely as sole crops. Extension activities for spreading new technology generally place little emphasis on intercrops. One reason is perhaps a general lack of awareness about its spread and potential.

The documented evidence on intercropping at present is limited, but suggests that intercropping gave higher and more dependable per hectare gross returns than did sole crops in the Vidarbha region of India (Mathur 1963) and northern Nigeria (Norman 1974, Norman and Pryor 1978). It gave higher gross returns per unit of labor employed during the labor-scarcity period in northern Nigeria. Intercropping was found to ensure a greater and more even spread of employment of labor in Vidarbha (Mathur 1963), and it was found negatively associated with farm size in three agroclimatic zones of peninsular India (Jodha 1977) as well as the corn-growing areas of Colombia (Colmenares 1975). Traditional intercropping systems were found to be characterized by very high degrees

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of complexity and diversity, as indicated by the numerous crop combinations that may be involved in a single village. Norman and Pryor (1978), for instance, identified as many as 230 different crop mixtures in study villages of northern Nigeria, and Mathur (1963) reported more than 100 crop combinations of mixed crops in the Vidarbha region. Jodha (1977) reported 60 different combinations characterizing intercropping in a single village.

Viewed in relation to the extent of its practice and its enormous complexity, the effort devoted to actual study of intercropping is at best insignificant. No doubt the diversity and complexity make its study extremely difficult. But its understanding alone may meaningfully explain farmers' decisions and crop choice. This, in turn, can generate information directly usable to those engaged in generating and spreading new agricultural technology.

Intercropping in Peninsular India

This paper discusses only a few dimensions of intercropping as practiced in six semiarid-tropic villages — two in each of three agroclimatic zones in peninsular India — where ICRISAT has conducted village-level studies since May 1975. My presentation is based on plotwise details of a cropping pattern of sample farmers for 3 agricultural years (1975-1978).[1] Important characteristics of the villages and the extent of intercropping therein are summarized in Table 1.

As shown in Table 1, the extent of intercropping as a proportion of gross cropped area varied from about 18 to more than 83% in the six villages. This fairly wide variability of intercropping is due to local differences of agroclimatic and related conditions. Conditions varying in vastly different degrees in different villages were the extent of postrainy-season cropping, extent of irrigation, and extent of high-yielding varieties (HYVs) as well as extent of certain crops (which are rarely grown as mixed crops), such as paddy, castor bean, etc., all of which, for one reason or another, discourage intercropping. Tables 2 and 3 clearly illustrate that the above factors lead to greater emphasis on sole cropping.

Reducing the weather-induced instability of farming through irrigation reduces the need for intercropping as a crop-diversification strategy against risk. Unlike rainy season (kharif) cropping, postrainy season (rabi) planting begins with a known state of soil moisture, and hence, the need for intercropping to adjust to eventual fluctuations in moisture becomes less important. The HYVs that require higher input costs do not fit well to the farmers' intercropping systems, and the farmer does not want to divert costly inputs meant for HYVs by interplanting non-HYV crops with HYVs.[2] Moreover, until recently, very little research was done on different aspects of intercropping involving HYVs. The phenomenon of unwillingness to divert costly inputs to unwanted crops also prevents mixing other crops with high water requiring, high payoff crops, such as paddy and sugarcane. In addition, the lack of technical complementarity of crops like paddy, castor, and sugarcane with other crops discourages intercropping, and the villages with a high proportion of these crops (Table 4) correspondingly had a lower extent of intercropping. On the other hand, the villages with higher extent of crops such as pigeonpea, groundnut, cotton, and rainy season sorghum (largely grown as intercrops, Tables 3, 4), had a higher extent of intercropping.

Intercropping and Farm Size

An important phenomenon related to the risk-minimizing potential of intercropping is the popularity of this system with small farmers who (unlike large farmers) have neither enough capacity to take risk nor enough land to diversify cropping by putting different sole crops on several plots. Table 5 further confirms the results reported by Jodha (1977), which indicate the decline in intercropping with an increase of farm size. This was the case in all villages except

1. For the methodology and other details of ICRISAT village-level studies, see Jodha et al. (1977).
2. The difficulty of incorporating HYVs into an intercropping system could be one of the factors responsible for limited spread of HYVs in the areas as well as farming groups (i.e., small farmers) where intercropping gets higher priority (see Table 5).

Table 1. Extent of intercropping and related details in six villages in SAT India.[a]

Village	Rainfall: Annual average (mm)	Rainfall: Variability (CV) (%)	Soil type	Situation on sample farms (3-yr. average)[b]: Gross cropped area (ha)	Proportion (%) of gross cropped area having: Inter-cropping	Irrigation	HYVs[c]	Specific crops[d]	Net sown area (%) planted in: Postrainy season	Rainy season
Kanzara (Akola Dist. Maharashtra)	820	27	Medium-deep Vertisols	6.5	72.7	4.9	15.6	1.5	1.7	94.7
Kinkheda (Akola Dist. Maharashtra)	820	27	Medium-deep Vertisols	6.6	83.1	3.8	6.6	1.8	3.1	91.2
Kalman (Sholapur Dist. Maharashtra)	690	29	Deep and medium-deep Vertisols	9.0	47.4	10.4	1.0	3.49	60.8	31.5
Shirapur (Sholapur Dist. Maharashtra)	690	29	Deep Vertisols	6.7	17.6	13.3	0.2	6.65	67.5	21.2
Aurepalle (Mahbubnagar Dist. Andhra Pradesh)	710	28	Shallow and medium-deep Alfisols	4.5	34.9	21.0	11.7	53.49	5.2	80.7
Dokur (Mahbubnagar Dist. Andhra Pradesh)	710	28	Shallow and medium-deep Alfisols	3.2	20.9	60.1	43.9	49.75	18.11	69.2

a. Based on details from sample farms in six villages. Village-level studies have been conducted in these villages since May 1975 (Jodha et al. 1977).
b. Number of sample farms selected in May 1975 was 30 in each village.
c. High-yielding varieties of crops include mainly hybrid sorghum and cotton in Akola villages and HYV paddy in Mahbubnagar villages.
d. Includes crops like sugarcane, paddy, and castorbean which are seldom grown as mixed crops. See Table 3.

Table 2. Proportions of postrainy season not sown area (NCA), gross irrigated area, and high-yielding varieties (HYV) area devoted to sole cropping in six SAT villages in India during 1975-76 to 1977-78.[a]

	Proportion of sole cropping (%) in the total of:		
Village	Postrainy season NCA	Gross irrigated area	HYV area
Kanzara	98.9	100.0	76.70
Kinkheda	100.0	73.7	73.26
Kalman	64.7	83.4	61.35
Shirapur	78.9	90.13	100.0
Aurepalle	100.0	93.8	100.0
Dokur	98.7	99.6	100.0

a. Based on details from sample farms in six villages. Village-level studies have been conducted in these villages since May 1975 (Jodha et al. 1977).

in Dokur and Shirapur, where small farmers were better endowed than large farmers in terms of the factors (proportion of area irrigated, postrainy season, net cropped area) that discouraged intercropping. The proportion of intercropping was consistently higher on small farms during all 3 years.

Another reason for the higher proportion of intercropping on small farms is the fact that the small farmer has to satisfy all his profit-oriented as well as his subsistence-oriented requirements from the same small piece of land. Intercropping serves this purpose well.

A significant implication of this result is that any breakthrough in intercropping technology will benefit less-endowed farmers more than the relatively better-endowed farmers. This offers a unique opportunity of explicitly incorporating equity considerations into agricultural research strategies by means of allocating greater resources to intercropping research.

Traditional Intercropping Systems

As mentioned earlier, complexity and diversity are other important features of a traditional intercropping system. Table 6 provides an illustration. The number of sole crops grown in six villages ranged from 17 (in Dokur) to 44 (in Shirapur), butthe number of crop combinations used for intercropping exceeded the number of sole crops in most of the villages. Within intercrops, two-crop mixtures were popular in most villages, but mixtures involving five to eight crops were not uncommon. The proportion of gross cropped area occupied by two-crop mixtures ranged from more than 5 to about 26% of gross cropped area in these villages. The corresponding proportions of three- and four-crop mixtures ranged from 2 to 41% and 2 to 19%, respectively. Of course, viewed from their share in gross cropped area, the most important mixtures (identified by number and not type of crops involved) were different in different villages. Furthermore, in terms of seed rates and distribution of rows of different crops in the mixtures, no uniform pattern was found to prevail in all the villages. However, intercropping by mixing seeds (as against putting different rows of different crops) was not very common except in the case of minor components of the mixtures.

The inter-village differences (Table 6) could be further elaborated with the help of details in Tables 3 and 4, providing additional information on cropping patterns in the six villages. Cotton-dominated mixtures followed by sorghum-dominated mixtures were prominent in the villages of Akola district (Table 4).[3] In the remaining villages (except Dokur), sorghum-led mixtures were most important. In Dokur, groundnut-led mixtures were dominant. As shown in Table 3, pigeonpea, pearl millet, mung bean, and safflowerwere grown as mixed crops in most of the villages, but, since they were subsidiary crops of the mixtures, they do not figure explicitly in most villages as shown in Table 4.

The complexity of traditional intercropping, as discussed above, is partly an outcome of farmers' informal experimentation with crops that satisfy their requirements and also fit the agricultural environment of the region. In developing countries, the farmer is engaged in

3. Mathur (1963) also reported similar phenomena for that region.

Table 3. Proportion off Individual crop areas devoted to Intarcropping in aix SAT villages in India during 1975-76 to 1977-78.[a]

	Proportion (%) of individual crop's area devoted to intercrops in village[b]					
Crop	Kanzara	Kinkheda	Kalman	Shirapur	Aurepalle	Dokur
Sorghum (HW)	46.7	33.6	15.0	–	0.0	0.0
Sorghum (Local-K)[c]	96.4	99.4	-	-	88.4	41.4
Sorghum (Local-R)[d]	-	-	35.4	21.6	-	-
Pearl millet (Local)	100.0	-	100.0	—	99.3	-
Wheat (HYV)	0.0	3.7	0.0	0.0	0.0	-
Wheat (Local)	0.0	11.2	72.6	49.5	40.0	0.0
Paddy (HYV)	-	-	-	-	0.0	0.0
Paddy (Local)	62.2[a]	63.2[a]	35.3[a]	4.1	0.0	0.0
Maize (HYV)	-	-	26.1	-	-	-
Maize (Local)	-	-	59.2	32.1	-	-
Cotton (HYV)	44.6	84.4[a]	—	–	–	—
Cotton (Local)	91.1	94.6	-	-	-	-
Sugarcane	0.0	-	6.6	9.0	-	-
Pigeonpea	100.0	98.7	94.6	23.2	100.0	100.0
Mung bean	93.2	94.2	97.2	85.4	-	-
Chickpea	29.2	5.3	68.2	26.9	—	0.0
Groundnut	81.8	61.8	41.0	8.8	13.3[a]	41.4
Safflower	0.0	0.0	100.0	85.7	18.3	—
Castorbean	-	-	-	-	9.9	-

a. Bated on details from sample farms in six villages. Village-level studies have been conducted Inthese villages since May 1975 (Jodha et al. 1977).

b. For calculating proportions, the area of the concerned crop grown as sole as well as all mixtures containing the concerned crop Irrespective of Its actual share in the mixture was considered.

c. Local-K - Local variety of (kharif) rainy-season crop.

d. Local-R = Local variety of (Rabi) postrainy-season crop.

a. Actual area under these crops was too insignificant to warrant meaningful comparison.

agriculture with multiple objectives. Since a single crop or a group of similar crops (because of their physiological, economic, and other characteristics) have comparative advantage in satisfying specific objectives, and in densely populated countries the farm size is not large enough to permit growing of sole crops to meet all these objectives, the farmer resorts to intercropping in order to satisfy his multiple objectives simultaneously.

For instance, his profitability objective can be satisfied best with high-value cash crops, such as cotton and groundnuts, while his subsistence requirements are best served by sorghum, pigeonpea, etc. While the maintenance of soil fertility is best achieved by leguminous crops, fodder requirements of farmers' animals are served better by crops such as sorghum and pearl millet, which have enough crop by-products. Similarly, while trying to achieve the highest output from his crop enterprises, a farmer has to guard against possible mid-season droughts. Crops such as pigeonpea, with greater drought resistance, and sorghum, with higher salvage value (i.e., in the event of crop failure, at least fodder is available), better satisfy his security requirements. Similarly, despite the broad regional suitability of soils for particular crops, each part of a land parcel operated by a farmer is not uniformly suited to the same crop. Patches of plots characterized by salinity, depressions having accumulation of

Table 4. Proportion off important crops/crop mixtures in gross cropped area (GCA) in six SAT villages In India during 1975-76 to 1977-78.[a]

Crop/Crop mixture[b]	Proportion (%) of crops/crop mixtures in GCA in villages:					
	Kanzara	Kinkheda	Kalman	Shirapur	Aurepalle	Dokur
Sorghum[c]	9.0	2.3	38.1	42.7	4.0	6.3
Sorghum mixtures[c]	18.4	35.6	20.3	11.8	30.0	7.6
Wheat	2.7	3.4	1.4	2.4	0.1	0.4
Paddy	1.1	1.0	2.5	1.7	16.6	48.1
Other cereals	0.1	-	1.6	2.1	0.3	4.4
Pigeonpea	-	0.8	1.2	6.8	–	—
Pigeonpea mixtures	-	-	19.4	0.5	—	-
Chickpea	2.0	4.9	2.3	4.6	—	1.2
Other pulses	1.0	1.4	1.5	8.7	1.1	1.6
Groundnut	2.1	1.5	1.6	2.1	0.7	17.0
Groundnut mixtures	9.1	2.1	0.8	0.2	0.1	12.0
Castorbean/cotton[d]	7.7	2.3	—	—	33.2	-
Castorbean/cotton mixtures[d]	45.9	43.6	-	-	3.7	-
Other crops	0.8	0.6	2.4	10.3	8.1	0.6
Other mixtures	0.1	0.5	6.9	6.1	2.1	0.8

a. Based on details from sample farms In six villages. Village-level studies have been conducted In these vllages since May 1975 (Jodha at al. 1977).
b. The crop mixtures have been named after the prominent crop of the mixtures.
c. Sorghum crop and its mixture in Kalman and Shirapur villages are postralny-season crops.
d. Castorbean and castorbean mixtures were In Aurepalle village; cotton and cotton mixtures were in Kanzara and Kinkheda villages.

fine silt or potential for seasonal stagnation of water, and gravelly infertile soil are not uncommon. In order to adjust to these specific features, the farmer undertakes "patch cultivation," raising different crops on different patches within a small plot. "Patch cultivation" also takes place through "midseason" corrections in the cropping pattern when part of the crop in a small plot fails because of insect attack or excess or lack of timely postsowing rainfall. Despite overall excess availability of manpower in agriculture in countries like India, labor (because of time-specific crop operations) does prove a bottleneck especially at the harvest season. Raising of crops with distinctly different maturity periods (e.g., sorghum vs pigeonpea) helps in a more even spread of the labor requirement. Thus, both the objectives of having maximum cropped acreage without subsequent labor bottlenecks and yet providing maximum gainful employment for family workers are achieved through intercropping of crops with different growth cycles.

To the extent that different crops can complement each other in satisfying farmers' multiple requirements, the intercropping of these crops serves as most rational cropping strategy on the part of the farmer.[4]

To illustrate the points mentioned above, crop mixtures in the study villages were classified into six categories on the basis of crops (having specific characteristics) included in each crop combination of intercrops. Their brief description is as follows:

4. This paper does not refer to technical complementarities of crops when grown as intercrops. For a detailed review, see Willey (1979).

Table 5. Extant of intercropping and related details on small and large farms in six SAT villages in India during 1975-76 to 1977-78.[a]

		Proportion (%) of gross cropped area devoted to intercropping				3-yr average (%)	
Village	Size[b]	1975-76[c]	1976-77	1977-78	Average	Irrigated area[d]	Postrainy season cropping[e]
Kanzara	Small	83.1	85.6	92.6	87.3	6.1	1.8
	Large	68.6	65.6	75.2	69.7	5.4	1.6
Kinkheda	Small	92.0	79.2	100.0	90.7	4.4	2.1
	Large	79.6	78.3	87.0	81.8	4.6	2.7
Kalman	Small	65.6	44.1	67.1	59.5	7.1	65.8
	Large	34.5	41.0	46.5	41.1	10.7	58.6
Shirapur	Small	3.1	14.1	15.7	11.2	21.9	77.1
	Large	16.7	20.7	19.0	19.0	10.4	70.5
Aurepalle	Small	49.3	27.4	57.2	44.4	4.5	5.4
	Large	44.1	25.4	26.2	33.7	25.2	6.6
Dokur	Small	12.3	0.0	0.0	5.1	74.0	7.9
	Large	20.2	21.4	22.1	21.2	59.0	18.8

a. Based *on* details from sample farms in six villages. Village-level studies have been conducted in these villages since May 1975 (Jodha et al. 1977).

b. Farmers having operational area between the following ranges have been considered as small and large in the respective villages (area in ha):

Village	Small	Large
Kanzara	0.21-2.25	>5.60
Kinkheda	0.21-3.00	>5.60
Kalman	0.21-6.00	> 10.75
Shirapur	0.21-2.50	>6.00
Aurepalle	0.21-2.50	>5.25
Dokur	0.21-1.00	>3.00

c. The figures indicating proportion of intercropping on smalland largefarms differ slightly from those indicated by preliminary analysis (Jodha 1977) due to recategorization of farm size groups. See Ghodake and Asokan (1978).

d. Gross irrigated areas as proportion of gross cropped area.

e. Net area sown during postralny season as proportion of total net sown area.

Category A: Mixtures or crop combinations involving crops planted in order to use patches of problem soils (saline soils, depressions, etc.) within the plot. Combining paddy with sorghum or pigeonpea is one illustration of such a mixture. This category of crop mixture is intended to satisfy the objective of adjusting crops to features of the land-resource base.

Category B: Mixtures involving crops such as seasonal vegetables, tobacco, fiber crops, and (in some cases) minor millets, pulses, and oilseeds, raised mostly for self-provision of the family. Their insignificance is indicated by very low seeding rate when compared with the seeding rate of other component crops of the mixture in a plot. Most of these crops — especially vegetables — are seldom harvested systematically. Leaves and fruits are picked up if and when the need arises and time permits. These crops are different from other subsistence crops (e.g., sorghum, pigeonpea, etc.) which are raised as a major component of mixtures and which,depending upon their production, are marketed.

Category C: Mixtures involving crops with different growth periods facilitating spread of peak-period (harvest) labor requirements.

Table 6. Number of sole crops, crop combinations in crop mixtures, and their share in gross cropped area in six SAT villages in India during 1975-76 to 1977-78.[a]

			Intercrops with mixture of									
	Sole crop		2 crops		3 crops		4 crops		5-8 crops		Total	
Village	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Kanzara	22	27.5	17	25.8	13	23.8	11	18.8	4	4.1	67	100.0
Kinkheda	19	16.9	15	23.8	14	41.2	11	17.3	1	0.8	60	100.0
Kalman	34	52.7	40	24.6	28	14.7	13	6.3	3	1.7	118	100.0
Shirapur	44	82.4	23	15.2	3	1.6	1	0.8	—	—	71	100.0
Aurepalle	21	64.3	4	5.5	2	9.8	-	1.5	11	18.9	38	100.0
Ookur	17	79.3	4	5.3	3	2.1	2	6.8	1	6.5	27	100.0

a. Based on detalls from sample farms in six villages. Village-level studies have been conducted in these villages since May 1975 (Jodha et al. 1977).

The combination of sorghum or pearl millet and pigeonpea is an example.

Category D: Mixtures involving drought-resistant and drought-sensitive or less drought-resistant crops, such as pearl millet and groundnut or pigeonpea and cotton, to at least partially guard against drought risk.

Category E: Mixtures involving crops conventionally described as cash crops and food-grain crops. Groundnut and pearl millet, or cotton and sorghum, or castorbean and pigeonpea are examples of this mixture designed to satisfy both profitability and subsistence requirements.

Category F: Mixtures involving legume and nonlegume crops to maintain soil fertility without sacrificing nonlegumecrops and also fulfill crop-rotation requirements.

It may be noted that the above categories of crop mixtures are not mutually exclusive.

The proportions of mixtures qualifying for the above categories in different villages are presented in Table 7.

Accordingly, the extent of intercropping (Category A) induced by need for adjustment to features of the land-resource base through patch cultivation was important only in Kalman and Shirapur villages. These villages belong to the region having the highest extent of heterogeneity of resou rce base created by types of soils, bunding, and very erratic rainfall in two phases. Intercropping induced by need for self-provision (Category B), which is different from requirements for subsistence, ranged from 9 to 36% of the total area under intercrops.[5] Crop mixtures under Category C, involving crops with different peak labor-requirement periods accounted for 32 to 83% of the acreage under intercrops in different villages. However, in predominantly postrainy season cropping villages, the proportion of crop mixture of Category C was relatively low, as the cropping season did not offer enough scope for crops with vastly different maturity periods. Lack of mixtures of Category C in postrainy-season crops influenced the overall proportion of these mixtures in both Kalman and Shirapur.

The lower extent of mixture Category D (involving drought-resistant and less drought-resistant crops) in the above two villages was

5. The highest extent of intercropping of Category B in Aurepalle and Dokur was partly due to the tradition that every farmer should plant nine crops in at least one of his plots. This ritual practice known as *Nava Dhanyam* (nine grains) is guided by a belief that it is the duty of every farmer to preserve the germplasm, which nature has provided. This practice — prevalent in several parts of the country—is now fast disappearing due to more and more specialized farming.

also partly due to the impact of postrainy-season intercrops. Crops in this season are grown on the basis of moisture stored in deep Vertisols, and one does not have to plan crop mixtures that will guard against the impact of likely drought. Mixing of drought-resistant crops only also reduced the extent of mixture Category D in Kalman and Aurepalle villages.

Intercropping induced by need for combining cash and subsistence crops as well as combining legume and nonlegume crops was also very substantial in most of the villages, as revealed by crop-mixture Categories E and F (Table 7).

The analysis of data to quantify the extent to which farmers could actually achieve their goals through the six categories of crop mixtures is still in progress.[6] The above picture convincingly demonstrates that the traditional intercropping system is complex and varied because it embodies a conscious and rational attempt of the farmer to adjust his cropping pattern according to his needs and resource base.

However, a closer look at traditional intercropping raises an important question. Can one generate new intercropping technology which can satisfy multiple goals of the farmer? The honest answer is "no." In the first place, it is not possible for researchers to clearly perceive the diverse and multiple objectives of the farmer in raising intercrops. Secondly, even if the objectives are clearly understood, their incorporation into research strategy is more difficult, notwithstanding the availability of multilocation- and multiseason-trial facilities.

Indeed, it could be argued that it is not necessary that scientists generate an intercropping system as complicated and diversified as witnessed in traditional agriculture. The best strategy lies in evolving only a few simple intercropping systems, which can satisfy at least the key objectives of profitability and stability (i.e., risk reduction). However, the dominance of crop-mixture Categories C, D, E, and F (Table 7) indicates that fertility maintenance and labor-peak problems also need to be incorporated. Hence, while profitability and

6. The biggest problem faced in such analysis is that of decomposing the mixture and judging the contribution of each component of the mixture in fulfilling different objectives.

Table 7. Proportions of different categories of crop mixtures in the total area of intercropping in six villages in SAT India (average of 1975–76 to 1977–78).[a]

Crop-mixture categories[b]	Example	Proportion (%) of different categories of crop mixtures in total area of intercropping in Kanzara	Kinkheda	Kalman	Shirapur	Aurepalle	Dokur
A — Problem soils	Paddy + sorghum or pigeonpea	2.1	3.4	15.4	12.2	2.6	1.8
B — Self-provision	Seasonal vegetables, such as cucumber, tobacco, millets, pulses, linseed, oilseed	9.4	11.2	18.4	14.1	35.9	28.7
C — Labor requirements	Sorghum or pearl millet + pigeonpea	58.1	83.9	46.1	32.4	71.1	79.0
D — Drought resistance	Pearl millet + groundnut, pigeonpea + cotton	71.9	80.6	17.7[c]	24.6	12.5[c]	40.5
E — Cash + food-grain	Groundnut + pearl millet, cotton + sorghum, castorbean + pigeonpea	72.7	59.2	44.2	60.6	53.2	50.3
F — Legume + nonlegume	Sorghum, pigeonpea, green gram	87.5	77.2	58.5	39.8[d]	84.4	37.7[d]

a. Based on details from sample farms in six villages. Village-level studies have been conducted in these villages since May 1975 (Jodha et al. 1977).
b. The crop-mixture categories are not mutually exclusive. See text for fuller descriptions.
c. Bulk of the other mixtures consisted of only drought-resistant crops. d. Bulk of the other mixtures consisted of only legumes.

stability should perhaps get the main focus, labor use and soil fertility also need to be kept in view while developing intercropping technology. This itself may not be very difficult because a particular mixture may fall in perhaps all the categories. To make itself superior to the traditional one, the new intercropping system should incorporate new agrobiological components, such as HYVs, and new knowledge about land and water management. If the new, simple intercropping options prove viable, the farmer would be induced to adopt them. If he finds it more useful to incorporate new elements to them, he — through informal experimentation— can very well make them more complex to serve his multiple objectives, as has been the case in the past.

Conclusions

Though neglected by both researchers and agricultural planners, intercropping is an important feature of traditional farming systems. It embodies traditional wisdom of the farmer as it relates to his crop decisions. The available documented evidence shows the superiority of intercropping over sole cropping in terms of gross returns per hectare, as well as per man-day used during the labor-scarcity period of the crop season. Intercropping ensures a greater and more even distribution of employment of labor.

The present paper has highlighted two important features of traditional intercropping system having significant research and policy implications. Firstly, intercropping is less important on large farms and irrigated farms than on small farms and rainfed farms, respectively. Thus, any breakthrough in intercropping technology will help the poorly endowed farmers more than the well-endowed farmers. This suggests a unique opportunity to incorporate equity-bias in research resource allocation by way of increased allocation to intercropping research.

Secondly, the traditional intercropping system is highly complex and diverse, as indicated by a multiplicity of combinations in crop mixtures. The farmer uses crop mixtures in order to satisfy his multiple objectives simultaneously. The researchers cannot and need not try to generate equally complex new intercropping systems. They should concentrate on generating simple intercropping systems that satisfy at least a few key objectives, such as profitability and stability, without completely ignoring the other objectives that underline the traditional intercropping system.

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Stability, Productivity, and Profitability of Some Intercropping Systems in Dryland Agriculture

N. G. P. Rao, B. S. Rana, and P. P. Tarhalkar*

Abstract

Keeping in view the emerging dry/and farming systems for semi-arid tropics, an attempt has been made to design and develop appropriate intercropping systems that reflect transgressive yielding, stability, and profitability.

Studies on competition between species enabled characterization of complementary, aggressive, and relatively neutral species. Under competition stress sorghum was the most stable species followed by pigeonpea, while groundnut has been found to be most sensitive.

At the varietal level, it has been demonstrated that suitable varieties of pigeonpea, like Hy-3a with no basal branches, are more stable at an appropriate population level in intercropping systems. Sowbhagya castor and CSH-6 sorghum are similar examples.

Studies on alternate planting patterns established that generally the interaction between intercropping systems and planting patterns was highly significant, but in certain specific systems based on pigeonpea and sorghum the interaction was not significant.

While the yields of intercropping systems generally tend to fall between the yield levels of component crops, transgressive yielding of the system is not ruled out. Apart from yield, prevailing prices also become an important factor in the choice of component crops. In seven of the most profitable intercropping systems identified, sorghum was a constant component, it is inferred that in-depth studies on factors involving transgressive yielding ability could further enhance stability, productivity, and profitability of intercropping systems.

Mixed cropping, an established system of traditional dryland subsistence agriculture in semi-arid tropics, needs different orientation in the context of the emerging productive dryland farming systems. Cultivar improvement involving genotypic alterations resulting in a reduction of total dry matter but a more efficient distribution between stalk and ear, shortening of duration to match the duration of rainy season, exploitation of advantages of hybrid vigor, increased input use, practice of improved cultural practices etc., result in minimizing climatic vulnerability and confer higher levels of productivity and stability (Rao 1977). In such a context, intercropping systems have to be viewed not only from the point of view of further risk cover but also transgressive yielding, stability, and profitability.

Keeping these objectives in view, a series of intercropping experiments were conducted at the IARI-Regional Station during 1971-78 to obtain information on (1) choice of crops and varieties, based on inter- and intra-species competition, (2) genotype x density interactions, and (3) alternate planting patterns. Sorghum, pigeonpea, groundnut, castor, and soybean were included as principal and/or companion crops. The results of some of the experiments have been reported earlier (Tarhalkar and Rao 1975; 1978). Based on some of these intercropping studies, an attempt is made to project various aspects pertaining to stability, productivity, and profitability of intercropping systems.

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Competition between Species and Stability of Performance

Studies during 1971-1973 (Tarhalkar and Rao 1975) indicated that soybean, pigeonpea, and groundnut as companion crops did not significantly reduce grain yields of the principal crop of sorghum; soybean and pigeonpea as companion crops were least competitive to groundnut, and pigeonpea and groundnut to the main crop of castor.

An examination of the competitive effects of principal (sorghum) and companion crops reveal that soybean performed well as a companion crop, mung bean was suppressed by sorghum, while pigeonpea and castor occupy intermediate positions (Fig. 1).

Further studies during 1973 and 1974 involving all possible intercropping systems based on four crops (Table 1) revealed that sorghum-based intercropping systems are the most productive followed by pigeonpea, castor, and groundnut. The interaction between principal crops and companion crops was highly significant (Table 2).

Analysis of the stability of the species under competition stress using regression approaches (Breese and Hill 1973) again points to sorghum as the most stable followed by pigeonpea, castor, and groundnut; groundnut was most sensitive to competition (Fig. 2).

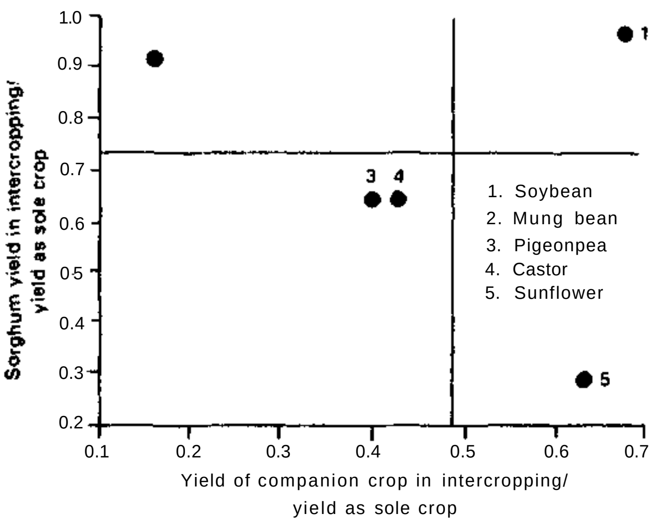

Figure 1. Species competition in sorghum-based intercropping systems, rainy season 1971.

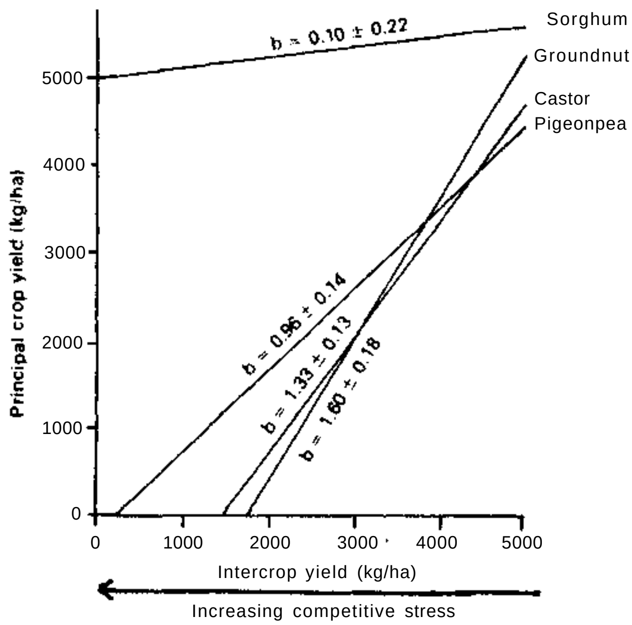

Figure 2. Regression of principal crop yield on intercrop yield over five planting patterns.

Table 1. Total yield (kg/ha) of Intercropping systems averaged over five planting patterns, rainy seasons 1973 and 1974.

	Companion crop					Stability parameters		
Principal crop	Sorghum	Pigeonpea	Castor	Groundnut	Soybean	Mean	$\hat{b}_i$	δ^2_{ij}
Sorghum	5285	5684	5216	5053	5553	5358	0.10 ± .22	81 788
Pigeonpea	3766	2654	2076	2380	2675	2710	0.96** ± .14	31 753
Castor	3624	2165	1405	1652	1872	2144	1.33** ± .13	29 593
Groundnut	3877	2315	1654	1132	1743	2144	1.60** ± .18	54 360
Mean	4138	3205	2588	2554	2961	3089		
Evn. Index	1048.8	115.8	-501.2	-535.2	-128.2			

** Significant at the 1% level.

Further analysis of competition among species based on diallel approaches (Table 3) indicates that both general and specific competitive abilities are highly significant. Reciprocal competitive effects are also highly significant indicating that it will not be possible just to interchange species in intercropping systems.

Table 2. Pooled ANOVA for total yield in intercropping systems.

Source	DF	MSS
Combinations	19	23 578 782**
Principal crops (P)	3	11 798 645**
Intercrops (1)	4	16 673 984**
P x I	12	28 825 416**
Average error	15	159 690

** Significant at the 1% level.

Competition within Species

Varietal differences within a species also account for differences in growth rhythms, canopy display, branching habit, and various morphological and physiological attributes. It is possible to manipulate one or more of these attributes which in turn influence competition.

As an example, two varieties of pigeonpea Hy-2 with basal branches and Hy-3A with no basal branches differ in their competitive abilities when grown with sorghum as the principal crop. Yield data involving two population levels for each variety in an intercropping system with sorghum are presented in Table 4 and analysis of variance in Table 5. It is interesting to note that the intercropping systems x planting patterns interaction is not significant. Stability analysis (Fig.3) reveals that Hy-3a at half population is least sensitive or more stable in yield. On the other hand, Hy-2 is

Table 3. ANOVA for competitive ability of species in five planting patterns.

		Total Yield				
		Planting pattern				
Source	DF	1	2	3	4	5
Replications	1	5 571 120**	2 633 510*	277 880	291 080**	304 780**
Combinations	15	12 143 806**	6 061 549**	3 411 929**	3 422 497**	3 091 693**
General competitive ability	3	45 362 600**	24 492 106**	14 190 286**	14 180 493**	12 468 533**
Specific competitive ability	6	1 491 053*	501 990	1 172 813**	1 019 923**	1 139 603**
Reciprocal competitive ability	6	6 187 179**	2 405 830**	261 866	446 070**	355 356**
Error	15	458 702	442 907	110 089	24 787	1 488

* Significant at the 5% level; ** Significant at the 1% level.

Table 4. Performance of sorghum/pigeonpea intercropping systems.

	Yield (kg/ha)			
Intercropping system	Sorghum	Pigeonpea	Sorghum + Pigeonpea	Monetary returns (Rs/ha)
Sorghum (pure)	6257		6257	6257
Sorghum + pigeonpea Hy-3[a] (H)[a]	5618	1182	6800	8926
Sorghum + pigeonpea Hy-3[a] (F)[b]	5291	1279	6570	8874
Sorghum + pigeonpea Hy-2 (H)	5337	1017	6354	8183
Sorghum + pigeonpea Hy-2 (F)	5108	1133	6241	8281

a. H = Half population — 27 500 plants/ha.
b. F = Full population — 55 000 plants/ha.

Table 5. ANOVA for yield (kg/ha) in sorghum/pigeonpea intercropping system.

Source	DF	Sorghum	DF	Pigeonpea	DF	Sorghum + Pigeonpea
Combinations	24	503 286**	19	77 383**	24	481 502**
Intercropping systems (IS)	4	2 018 986**	3	119331**	4	834 836**
Planting patterns (PP)	4	906 654**	4	224 505**	4	1 293 474**
IS x PP	16	23 519*	12	17 855**	16	190 175
Pooled error	20	8 412	15	459	20	100 198

* Significant at the 5% level; ** Significant at the 1% level.

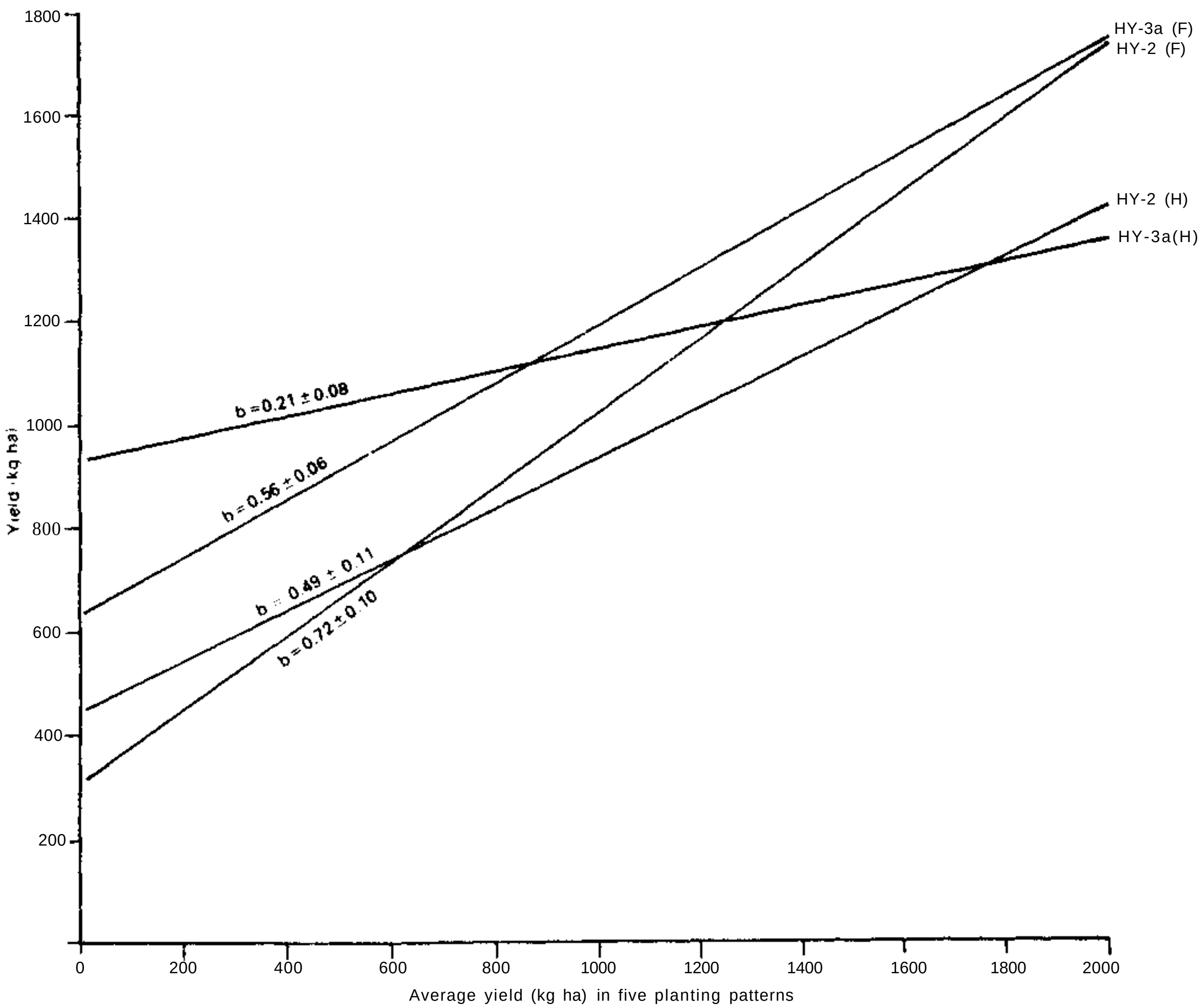

Figure 3. Stability of pigeon pea genotypes in sorghumlpigeonpea intercropping systems at two population levels: full (F) = 55 000 and half (H) = 27 500 plants/ha.

more sensitive and yield declines more rapidly under competitive stress. This illustrates the role of genotypic manipulations at varietal level to suit intercropping systems.

Sowbhagya, a variety of castor developed at our Station (Ankineedu et al. 1975) —a dwarf and compact plant type with shorter petioles — is suitable for intercropping while the traditional tall castors are decidedly not suitable for intercropping systems. Compared to the traditional tall and late sorghums, hybrid sorghums like CSH-6 with medium dwarf height and less foliage are favorable for Intercropping. The competitive advantages of such genotypes need to be quantified.

Population Density, Planting Patterns, and Stability

It has been fairly well established that at optimal population levels for any crop, there is considerable scope for manipulating planting patterns involving between- and within-row spacings. Adequate data on this aspect has been presented in progress reports of the All India Coordinated Sorghum Improvement Project and also by Tarhalkar and Rao (1975).

Table 6 presents analysis of variance for various intercropping systems based on sorghum, pigeonpea, castor, and groundnut. While the intercropping systems and planting patterns show significant differences, the interaction between them is not significant in pigeonpea-based systems and significant only at 5% for sorghum-based systems, indicating their greater stability.

Analysis of stability parameters for various intercrop combinations (Table 7) reveals that sorghum-based systems are the most productive and stable with high mean values and regression coefficients close to 1.0. This is followed by pigeonpea-based systems.

Productivity and Profitability

We have pointed out earlier (Rao et al. 1975) that unless improvements in dryland agriculture reflect a quantum jump and have the capacity to

Table 6. ANOVA for total yield (kg/ha) in different Intercropping systems, rainy seasons 1973 and 1974.

		Mean square for intercropping systems based on				
Source	DF	Sorghum	DF	Pigeonpea	Castor	Groundnut
Combinations	24	1 509 521**	19	1 488 050**	1 594 120**	2 494 950**
Intercropping systems (IS)	4	796 680**	3	807 764**	7 908 090**	10 628 800**
Planting patterns (PP)	4	790 431**	4	834 248**	1424 715**	2 429 419**
IS x PP	16	89 032*	12	58 588	72 099**	43 334**
Pooled error	20	38 363	15	67 567	18 150	9 653

* Significant at the 5% level; ** Significant at the 1% level.

Table 7. Stability parameters for total yield (kg/ha) in intercropping systems.

Principal crop															
	Sorghum				Pigeonpea				Castor				Groundnut		
IS	M	bi	δ^2ij	IS	M	bi	δ^2ij	IS	M	bi	δ^2ij	IS	M	bi	δ^2ij
S + P	5685	0.92	NS	P + S	4043	0.81	NS	C + B	3625	0.92	NS	G + S	3877	2.11**	**
s + c	3957	1.00	NS	P + C	1950	0.95	NS	C + P	2165	1.14	»»	G + P	2315	0.89	NS
S + G	5053	0.99	NS	P + G	2422	0.78	NS	C + G	1652	0.65*	NS	G + C	1654	0.51**	*
S + SB	5553	1.03	NS	P + SB	2675	1.46	NS	C + SB	1872	1.28*	NS	G + SB	1734	0.49**	**
Mean	5358				2273				2328				2395		
S.E.	61.9	NS			42.6	NS			95.3	0.09			31.1	0.11	

* Significant at tha 5% level; ** Significant at the 1% level; NS - Not significant.
S = Sorghum, P - Pigeonpea, C = Castor, G = Groundnut, SB = Soybean.
IS - Intercropping system.

Table 8. Yields and monetary returns of some intercropping systems over five planting patterns, rainy season 1973 and 1974.

Intercropping system	Yield (kg/ha)			Proportion (%) of principal crop in the system	Monetary returns (Rs/ha)[d]
	P1[a]	P2[b]	M 1.2[c]		
Sorghum + groundnut	5285	1132	5053	92.2	5378
Sorghum + pigeonpea	5285	2654	5684	88.3	7442
Sorghum + castor	5285	1405	5216	79.7	5364
Groundnut + sorghum	1132	5285	3877	53.2	4711
Groundnut + pigeonpea	1132	2654	2315	85.7	5948
Groundnut + castor	1132	1405	1654	74.3	3494
Pigeonpea + sorghum	2654	5285	3766	61.4	6979
Pigeonpea + groundnut	2654	1132	1380	72.0	6501
Pigeonpea + castor	2654	1405	2076	54.4	5071
Castor + sorghum	1405	5285	3624	71.3	4631
Castor + groundnut	1405	1132	1652	87.0	3411
Castor + pigeonpea	1405	2654	2165	78.1	5182

a. P1 = Principal crop yield as pure crop.
b. P2 = Companion crop yield as pure crop.
c. M = Total yield of intercropping system.
d. Rates/100 kg: Sorghum, Rs. 100; groundnut Rs. 225; pigeonpea Rs. 280; castor Rs. 200.

Table 9. Performance of most productive intercropping systems.

Intercropping systems	Yield (kg/ha)			Monetary returns (Rs/ha)	Stability over planting patterns
	P1[a]	P2[b]	M1.2[c]		
Sorghum + pigeonpea	4464	1221	5685	7022	Stable
Sorghum + Soybean	4949	604	5553	5971	Stable
Sorghum + groundnut	4726	327	5053	5400	Stable
Sorghum + castor	4105	712	4817	5392	Lowest yielding in sorghum-based systems
Pigeonpea + sorghum	1631	2412	4043	6443	Stable
Groundnut + sorghum	602	3275	3877	4630	Unstable
Castor + sorghum	1002	2623	3625	4626	Stable

a. P1 = Principal crop yield as pure crop.
b. P2 = Companion crop yield as pure crop.
c. M = Total yield of intercropping system.

break the environmental barrier, yield improvement may not be perceptible.

Yield data from 1973 and 1974 *kharif* (rainy) seasons involving all possible intercropping combinations among the four crops are presented in Table 8. The yields of various intercropping systems, by and large, tended to be between the yield levels of component crops. Several such situations have been listed by Trenbath (1974b). However, there are three cases wherethe yields of the systems exceeded yields of the component crops; in all these cases, one of the components was a legume. These increases may or may not be genuine cases of transgressive deviations.

Seven of the intercrop combinations were more profitable compared to their components grown as sole crops (Table 8). Apart from the competitive effects, prevailing prices become an additional and important factor in choosing components of intercropping systems. The value of the sorghum-based systems will be further enhanced if the value of the stover is also taken into account.

Based on data obtained during 1973 and 1974, further studies were undertaken in subsequent years to identify the most profitable intercropping systems based on sorghum, pigeonpea, groundnut, and castor. A summary of the more profitable systems observed is presented in Table 9. Out of the seven profitable systems, four are sorghum-based and the rest are based on pigeonpea, groundnut, and castor, but even in these cases sorghum formed the intercrop component.

The studies thus bring out the important role of sorghum in intercropping. As pointed out by Trenbath (1974b), systematic studies of such systems to capitalize on complementary use of environmental resources in time and space, nutritional complementation, favorable canopy configurations, enhanced water-use efficiency, and possible allelopathic effects could lead to development of stable, productive, transgressive yielding, and profitable intercropping systems.

Recent Studies in Intercropping Systems on the Drylands of India—Some Thoughts, Some Results

S. L. Chowdhury*

Abstract

Some doubts are expressed regarding the adequacy of documentation on the benefits often claimed to accrue from intercropping systems of the "replacement series" type. The doubts are illustrated by the results presented and obtained in trials conducted at Cooperating Centers of the All-India Coordinated Research Project for Dryland Agriculture during 1971-72 to 1977-78. The land equivalent ratio measure is found inadequate to measure total productivity or incomes. Expected money value is recommended as a better measure for trials on intercropping systems involving optimal populations of both components to establish conclusions in this area of research.

How Beneficial Are Intercropping Systems?

In discussions of intercropping systems, or crop mixtures, an observation is often made that they are unique features of traditional subsistence farming in the tropical and subtropical regions — implying, perhaps, that monocropping (sole cropping) is a preserve of the temperate regions. Why this system is considered more productive in unfavorable environments than in favorable environments is left unanswered. In the Indian context, mixed cropping, intercropping, and monocropping are age-old practices. Area statistics for the three classes are not available, but monocrops occupy the largest area.

In these discussions, similarly, many benefits are claimed to accrue from crop mixtures/intercrops:

- Risk distribution. Risk due to vagaries of weather or incidence of pests and diseases. Research evidence for acceptably long periods (5 to 10 years) to conclude the higher or lower susceptibility of one system or the other is not adequately documented.
- Better utilization of labor resources and natural endowments. This makes good sense, but the efficiencies should be reflected in achievements (higher productivity), moreover, in the semi-arid regions, one crop a year is the rule, and the claim is more relevant to irrigation farming.
- Better quality product. This is evidently true if production is for domestic food only. In the present world, however, production is market oriented. Prices are still not determined by the protein/lysine contents of the produce.
- Higher productivity/income. Recommendations of this sort are framed assuming that growers have perfect knowledge of weather and prices. Both are unpredictable.

Components — Their Critical Roles

Components

Usually cereals, grain legumes, and oilseeds

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are used as components in intercropping systems in India. Common cereals are wheat and barley (winter season) and sorghum, pearl millet, finger millet, maize, and upland rice (rainy season). Pigeonpea, green gram, black gram, cowpea, and dolichos (rainy season) and chickpea, field pea, and lentils (winter season) comprise the grain legume group. Groundnut, castorbean, soybean, and sesamum (rainy season) and mustard, rapeseed, linseed, safflower and, *Eruka sativa* (winter season) form the oilseed group. A binary system (i.e., two component crops) is common for intercrops.

Stability of Production

Cereals are relatively shallow-rooted; they suffer more from moisture stress. New cultivars are of short duration — 80 to 120 days. Grain legumes have deep root systems; they suffer less from moisture stress. Some are short duration — 75 to 100 days; some (pigeonpea) are long duration — 150 to 180 days. Oilseed crops have medium (groundnut) to deep (castorbean) root systems; damage due to drought is intermediate. They have a medium to long growth period.

The damage crops suffer from variable moisture stress (drought) is considerably influenced by the crop stage at which it occurs, the soil properties, and the saturated or otherwise condition of the profile at different depths within the root zone.

Despite popular belief, reduction in the yield of cereals as components of intercrops is relatively less than the loss in yield of grain legumes and oilseeds — the average partial land equivalent ratios are 0.70 and 0.52, respectively. This is no index of suitability/stability in favor of grain legumes/oilseeds.

Productivity, Prices, and Income

For well-known reasons of energy requirements, the productivity of cereals, in physical terms, is higher than that of grain legumes/oilseeds. Another common cause of low yields of the latter (the legumes, at any rate) is the casual way resources (including land) are applied to raise these crops. Even so, the comparative loss in production is more than compensated by the two to three times higher prices these crops fetch. Hence, even a small reduction (25% or more) in the yield of the "high-value" component considerably lowers the total income from an intercropping system compared with the total income from either of the two sole crops.

Land Equivalent Ratio (LER)

This is a good measure for evaluating land productivity, in physical terms, under sole crops vs intercrops. It is of no value when monetary gains from the two systems are assessed, since it has no relationship with income expectations due to changing prices or variable falls in production of the components involved. The total LER of an intercrop system could be unity, or greater than unity, and yet the expected income from the enterprise could be substantially less when compared to the expected income from the "high-value" sole crop.

Some Results from Intercropping Studies

The results presented in Table 1 and Table 2 are from the trials conducted from 1971-72 to 1977-78 by the author's colleagues (to whom all gratitude is due) at the Cooperating Research Centers of the All India Coordinated Research Project for Dryland Agriculture. The intercrop systems were binary in composition, planted in alternate rows, using common rates of seeding, and close to replacement series rather than optimal population levels of both components (current concept). In all, results of 46 trials in the *rabi* (postrainy) season and 112 trials in the *kharif* (rainy) season were available. Agronomically typical results only were selected for reporting.

Rabi Crops (Winter/Postrainy Season)

These crops are raised mainly on limited soil moisture conserved from the preceding monsoon rains. On the Deccan plateau, they receive little or no rain (Bijapur), but some winter rains are received in the north and central parts of the country (Ranchi, Jhansi, Samba, and Agra). Past and present experience has shown no superiority of crop mixtures/intercrops over sole crops. The results are presented in Table 1.

Table 1. Performance of typical intercropping systems: rabi (postrainy-season) cropa grown mainly on limited, conaarvad soll moisture. (Figures within paranthaaaa denote partial LERs.)

Station	Year	Cropping system	Yield (kg/ha) As sole crop	Yield (kg/ha) As inter-crop	LER		EMV[a] (Rs./ha)
Bijapur	1971-72	Sole sorghum	2160				2160
		Sole safflower	1640				3280
		Sorghum +		1070	(0.49)		
		Safflower		760	(0.47)	0.96	2590
	1973-74	Sole sorghum	2040				2040
		Sole safflower	1810				3620
		Sorghum +		930	(0.46)		
		Safflower		810	(0.45)	0.91	2550
Ranchi	1974-75	Sole wheat	640				640
		Sole linseed	670				1675
		Wheat +		200	(0.31)		
		Linseed		570	(0.81)	1.16	1625
	1975-76	Sole wheat	610				610
		Sole linseed	840				2100
		Wheat +		280	(0.46)		
		Linseed		490	(0.57)	1.03	1505
Jhansi	1971-72	Sole wheat	690				690
		Sole chickpea	470				940
		Wheat +		700	(1.08)		
		Chickpea		180	(0.38)	1.46	1060
	1976-77	Sole barley	2080				2080
		Sole chickpea	1100				2200
		Barley +		1710	(0.82)		
		Chickpea		380	(0.35)	1.17	2470
Samba	1971-72	Sole wheat	4990				4990
		Sole chickpea	1240				2480
		Wheat +		3910	(0.78)		
		Chickpea		160	(0.13)	0.91	4230
	1976-77	Sole wheat	1920				1920
		Sole chickpea	620				1240
		Wheat +		1430	(0.75)		
		Chickpea		240	(0.39)	1.14	1910
Agra	1975-76	Sole barley	1450				1450
		Sole chickpea	620				1240
		Barley +		1490	(1.03)		
		Mustard		670	(0.39)	1.42	2830
	1976-77	Sole barley	14P0				1400
		Sole mustard	1990				3980
		Barley +		1030	(0.73)		
		Mustard		690	(0.34)	1.07	2410

a. EMV is expected monetary value calculated on the basis of assumed prices approximating farm harvest prices during 1974-75.

- At stations reporting good to high crop yields (Bijapur, Samba, and Agra), no gain in income from intercropping over sole cropping was noted.
- Sole crops yielded the highest incomes — oilseeds at Bijapur and Agra

and wheat at Samba.

- At Ranchi, poor yields were reported for both years of the trial. Here, too, the pure crop of linseed yielded higher incomes over intercropping.
- At Jhansi only, some monetary gains were made from intercropping over pure crops (both when yields were poor or average).
- At Jhansi only, the average gain from intercrops was Rs. 195/ha. At other stations, an average loss of Rs. 674/ha was sustained due to intercropping compared to sole crops.
- The LERs exhibited no trends with incomes. Incomes were high when the LER was less than unity (Bijapur and Samba), and incomes were low when the LER was substantially higher than unity (Jhansi and Ranchi).
- The total physical output of the intercrops was also often less than the output of either component as a sole crop.

Kharif Crops (Rainy Season)

These crops often suffer damage from spells of moisture stress (droughts) at some stage of growth. The stress is nonspecific in time, length, and periodicity.

Moisture stress tolerance (droughttolerance) of crops is the overriding consideration for increased and stable production in this season. Because of the stress's nonspecificity, the effects are unpredictable. For instance, in 1972 there was a prolonged drought from early July to early September in the Hyderabad region when pearl millet (considered drought sensitive) yielded 16 q/ha compared with pigeonpea (considered drought tolerant) which yielded only 6 q/ha. The results of 28 trials are presented in Table 2.

- In 10 of 28trials, gains (in monetary terms) from intercropping were indicated ranging from very low to very high (range: Rs. 10/ha to Rs. 1810/ha). The average gain came to Rs. 831/ha.
- In the remaining 18 trials, income losses were indicated. These ranged from Rs. 10/ha to Rs. 2450/ha, averaging Rs. 566/ha.
- Of the 11 regions reporting, only Ranchi region reported consistent gains from intercrops over sole crops. The LERs at this station were high, ranging from 1.40 to 1.96, indicating only small reduction in the yield of components when intercropped.
- In 10 of 28 trials, the total physical output (not necessarily income) of intercrops was higher than the yield of either component as sole crop.

Points for Discussion

1. There is an extensive body of evidence to conclude that the "replacement series" type of intercropping system or crop mixture so far evaluated lead to neither higher physical productivity, nor greater stability, nor better incomes. Should these investigations continue?
2. Recent trials based on the concept of "optimum (full) population levels of both components" in intercrops hold promise. Theoretically, there are flaws here too. Some of these could be favorably modified by pairing of rows. These trials should be conducted extensively in different agroclimatic regions and should continue for a minimum period of 5 years. These trials are in progress in the Project from the current season.
3. In the new trials, only the most-adapted genotypes of good genetic potential should be used. Sole crops and intercrops should be raised with the best agronomic practices. This alone will provide answers enabling growers to make choices for sole crops or intercrops.
4. Serious efforts should be devoted to elevate the current base-level productivity (both agronomically and genetically) of grain legumes and oilseeds as these are high-value components of intercrops and also considered relatively stable during adverse weather conditions. This could be done as part of the intercropping systems where these crops are also grown as pure crops.
5. The LER does not appear to be a valid measure of evaluating the revenue-yielding worth of intercrops. The average partial LER of the base crops in 112 kharif trials reviewed (all not reported) was found to be 0.70 with an SD of 0.248 and a

Table 2. Performance of typical intercropping systems: kharif (rainy-season) crops. (Figures within parentheses denote partial LERs.)

Station	Year	Cropping system	Yield (kg/ha) As sole crops	Yield (kg/ha) As inter-crops	LER		EMV[a] (Rs./ha)
Bijapur	1971-72	Sole pearl millet	970				970
		Sole pigeonpea	1670				4175
		Pearl millet +		840	(0.87)		
		Pigeonpea		1010	(0.61)	1.48	3365
	1973-74	Sole pearl millet	1410				1410
		Sole pigeonpea	1700				4250
		Pearl millet +		1160	(0.81)		
		Pigeonpea		800	(0.47)	1.28	3160
Bangalore	1971-72	Sole finger millet	2690				2690
		Sole *Dolichos lablab*	1310				2620
		Finger millet +		1950	(0.72)		
		Dolichos lablab		460	(0.35)	1.07	2870
	1972-73	Sole finger millet	2360				2360
		Sole *Dolichos lablab*	940				1880
		Finger millet +		1710	(0.72)		
		Dolichos lablab		190	(0.20)	0.92	2090
	1974-75	Sole finger millet	3830				3830
		Sole green chilies	320				320
		Finger millet +		1180	(0.31)		
		Green chilies		200	(0.62)	0.93	1380
	1975-76	Sole finger millet	2380				2380
		Sole green chilies	1110				1110
		Finger millet +		830	(0.35)		
		Green chilies		700	(0.63)	0.98	1530
Kovilpatti	1975-76	Sole sorghum	1350				1350
		Sole pigeonpea	140				350
		Sorghum +		710	(0.52)		
		Pigeonpea		70	(0.48)	1.00	885
	1975-76	Sole sorghum	1350				1350
		Sole castorbean	170				340
		Sorghum +		260	(0.19)		
		Castorbean		140	(0.82)	1.01	540
Ranchi	1973-74	Sole rice	3140				3140
		Sole pigeonpea	430				1075
		Rice +		2100	(0.67)		
		Pigeonpea		420	(0.97)	1.64	3150
	1974-75	Sole rice	1640				1640
		Sole pigeonpea	1370				3425
		Rice +		1370	(0.84)		
		Pigeonpea		1100	(0.80)	1.64	4120
Ranchi	1975-76	Sole rice	2290				2290
		Sole pigeonpea	680				1300
		Rice +		990	(0.43)		
		Pigeonpea		670	(0.98)	1.41	2640
	1973-74	Sole maize	2860				2860
		Sole pigeonpea	620				1550
		Maize +		2820	(0.99)		
		Pigeonpea		600	(0.97)	1.96	4320

Continued

Table 2. *Continued*

Station	Year	Cropping system	Yield (kg/ha) As sole crops	Yield (kg/ha) As inter-crops	LER		EMV (Rs./ha)
	1974-75	Sole maize	2280				2280
		Sole pigeonpea	1190				2975
		Maize +		2490	(1.09)		
		Pigeonpea		530	(0.44)	1.53	3815
	1975-76	Sole maize	4050				4050
		Sole pigeonpea	1200				3000
		Maize +		3370	(0.83)		
		Pigeonpea		680	(0.57)	1.40	5070
Akola	1975-76	Sole sorghum	3350				3350
		Sole green gram	1640				3280
		Sorghum +		3000	(0.88)		
		Green gram		730	(0.45)	1.33	4460
	1975-76	Sole sorghum	3350				3350
		Sole black gram	1800				3600
		Sorghum +		2670	(0.89)		
		Black gram		440	(0.25)	1.14	3550
	1977-78	Sole sorghum	5270				5270
		Sole pigeonpea	2670				6675
		Sorghum +		4800	(0.91)		
		Pigeonpea		610	(0.23)	1.14	6325
Sholapur	1974-75	Sole pearl millet	1670				1670
		Sole pigeonpea	2380				5950
		Pearl millet +		1650	(0.99)		
		Pigeonpea		1500	(0.63)	1.62	5400
	1975-76	Sole pearl millet	1930				1930
		Sole pigeonpea	1970				4925
		Pearl millet +		2010	(1.04)		
		Pigeonpea		1890	(0.96)	2.00	6735
Hyderabad	1973-74	Sole sorghum	1950				1950
		Sole pigeonpea	1330				3325
		Sorghum +		1200	(0.62)		
		Pigeonpea		730	(0.55)	1.17	3025
Rajkot	1971-72	Sole pearl millet	770				770
		Sole green gram	540				1080
		Pearl millet +		690	(0.89)		
		Green gram		060	(0.11)	1.00	810
	1972-73	Sole pearl millet	890				890
		Sole green gram	570				1140
		Pearl millet +		600	(0.68)		
		Green gram		120	(0.21)	0.89	840
Samba	1976-77	Sole maize	2370				2330
		Sole cowpea	440				880
		Maize +		1550	(0.66)		
		Cowpea		200	(0.45)	1.11	1950
	1977-78	Sole maize	1020				1020
		Sole Cowpea	830				1660
		Maize +		790	(0.77)		
		Cowpea		430	(0.52)	1.29	1650
Rewa	1973-74	Sole sorghum	2540				2540
		Sole pigeonpea	1030				2575

Continued

Table 2. *Continued*

Station	Year	Cropping system	Yield (kg/ha)		LER		EMV (Rs./ha)
			As sole crops	As intercrops			
		Sorghum +		2230	(0.88)		
		Pigeonpea		470	(0.46)	1.34	3405
	1975-76	Sole sorghum	590				950
		Sole pigeonpea	680				1700
		Sorghum +		590	(0.62)		
		Pigeonpea		240	(0.35)	0.97	1190
Indore	1977-78	Sole maize	3170				3170
		Sole soybean	2240				4480
		Maize +		2440	(0.77)		
		Soybean		790	(0.35)	1.12	4020
	1977-78	Sole maize	3170				3170
		Sole groundnut	1850				3700
		Maize +		2370	(0.75)		
		Groundnut		530	(0.29)	1.04	3430

a. EMV is expected monetary value calculated on the basis of assumed prices approximating farm harvest prices during 1974-75.

CV of 35.49%. Values for the companion crop were 0.52, 0.262, and 50.38%. The total LER for the intercrops was 1.22, with an SD of 0.255 and a CV of 20.93%. Similarly, for the 46 trials (all not reported) in the rabi season, the total average LER of the intercrops was found to be 1.07 with an SD of 0.221 and a CV of 20.66%. Obviously, the standard deviation and the coefficient of variation values are too high for much reliance.

For purposes of assessing the superiority of a system, it is suggested the EMV (expected money value) may be considered, which will directly indicate the profitability or otherwise of a system, which the LERs do not.

Stability of Performance of a Pigeonpea/ Sorghum Intercrop System

M. R. Rao and R. W. Willey*

Abstract

Results of 89 experiments available on sorghum/pigeonpea intercrops have been pooled, and some basis for understanding the stability of performance is presented. On an average, the intercrop system provides the equivalent of 90% of the sole-sorghum yield and about 52% of the sole-pigeonpea yield. Row arrangements, either 1 sorghum: 1 pigeonpea or 2 sorghum: 1 pigeonpea do not make much difference to sorghum yields or the overall advantage (42%); however, the probability of obtaining more sorghum seems slightly higher in 2:1. Stability is evaluated by the (1) coefficient of variation in yields, (2) relative advantage of the intercrop with changes in fertility and water use, (3) regression of yields, and (4) returns from soles and intercrops against the environmental index based on location mean performance. Coefficient of variation of intercrop yields was less than the yields of sole crops, but this method does not suggest substantially higher stability for intercrops. The relative advantage of intercropping remained more or less similar at different levels of fertility. There was no relationship between relative advantage and the amount of water used. Regression analysis showed that the intercrop system is superior to sole crops at all levels of yields and is more widely adoptable. The failure of intercropping to obtain a specified income level, with either constant prices or randomly varied prices, was less frequent than for sole cropping.

That crop mixtures provide insurance against risks and give stable returns even under aberrant weather has often been said to be the outweighing consideration why small farmers show preference for them over sole crops. The major way intercropping can achieve greater stability is from the compensation of one component when the other fails or grows poorly because of drought, pests, etc.; when the two species are growing separately as soles, there is no possibility of this compensation. Anderson and Williams (1954) quote maize/sorghum as an example where if rains are poor, sorghum is higher yielding, and, in years of high rainfall, maize is higher yielding but still with reasonable yields from sorghum. Fisher (1976) reported substantial compensation when the maize in a maize/bean mixture suffered considerable damage due to both hail and disease. Similar effects are suggested for millet/sorghum and sorghum/pigeonpea — i.e., if early rains fail, the later-maturing crop can compensate; if later rains fail, there is still the yield from the early crop. However, Harwood and Price (1975) have questioned this compensation effect. They reported from their experiments that crop failure often occurred after considerable intercrop competition had already taken place, and they considered sole cropping to be more stable.

Another way intercropping could achieve greater stability is if it gives higher yield advantages under stress — in other words, this would ensure less yield fluctuation than from sole cropping even under unfavorable conditions (Ogunfowara and Norman 1974). Mixtures might also stabilize returns over seasons, as they provide more than one commodity and can act as a buffer against frequent price changes in any one component (although this effect occurs, of course, whether the crops are mixed or grown separately). Prices fluctuate quite often in countries such as India, where more than

* Agronomists, ICRISAT.

40% of food items come from rainfed agriculture.

Growing two or more crops together on the same land in various spatial arrangements has been a centuries-old practice in India. "Intercropping" is more frequently used to refer to the arrangement where each species in the mixture is in distinct rows. This system of cropping is more prevalent in low- and erratic-rainfall regions where agriculture is more risky (Aiyer 1949). Intercropping with a late-maturing crop is particularly important on lighter soils where double cropping by sequence or relay is a rare possibility to extend cropping more than a single crop. Pigeonpea/sorghum is one of the most widely grown and typical of the intercrop systems where an early-maturing cereal is combined with a late-maturing legume. Of the little intercropping research so far conducted, pigeonpea/sorghum has received relatively more attention than others. This combination is found throughout the country (Aiyer 1949, Kaushik 1951), but sorghum as a food crop is more important in the central and south central (Deccan plateau) semi-arid areas. Subsistence farmers expect a "full" yield of sorghum from intercropping and consider pigeonpea as a "bonus" or "extra" crop (Shelke 1977, Krishnamurthy et al. 1978).

The evidence for higher yields of sorghum/pigeonpea intercropping is fairly well established, but how stable this intercrop is over sole cropping is not known. This paper examines the stability of yields and returns of pigeonpea/sorghum intercrop based on a large amount of experimental data.

Source of Data

Results of experiments on sorghum/pigeonpea, or those containing this combination, from the All India Coordinated Sorghum Improvement Project (AICSIP), All India Coordinated Research Project for Dryland Agriculture (AICRPDA), ICRISAT, All India Coordinated Model Agronomic Experiment Scheme (AICMES), and a few others, were collected and used for the present study (see Appendix I). Of the 89 experiments thatcould befound, 15did not have a sole crop of pigeonpea, whereas 12 did not have sole sorghum, thus making only 62 experiments useful for the purpose of calculating land equivalent ratios. Along with yields, information on soil type, sowing and harvest time, fertilizer used, row proportions, populations adopted, weekly rainfall, and evaporation at the experimental site was also gathered.

Stability of Sorghum-Proportional Yields in the Intercrop

The traditional intercropping system consists of a high proportion of sorghum (i.e., one to six rows of sorghum alternating with one or two rows of pigeonpea) in order to ensure the "full" yield of sorghum, which the farmer prefers. This is unfavorable to pigeonpea as it occupies too little area of the ground after sorghum harvest to be able to use late-season resources efficiently; as a result the overall advantage is not high. Based on AICRPDA results, Krishnamurthy etal (1978) summarized that the productivity is high with the arrangements of 1 sorghum:1 pigeonpea, 2:2 and 2:1—all three being equally good—2 sorghum: 1 pigeonpea could be recommended because of ease in planting with the local drills. Intercropped pigeonpea is very much reduced in growth, and late in the season may provide relatively little leaf cover even in 2:1 (Willey and Natarajan 1978). It has often been suggested that alternate rows provide more uniform distribution of pigeonpea plants and the scope for improved performance is higher. However, since these systems have to meet the specific requirements of the farmer, it is important to examine how far the objective of "full" yield of sorghum is met for different spatial arrangements. It is particularly important in alternate rows, since the sorghum-proportional area is reduced. Results from Shelke's trials (Shelke 1977) and some of the ICRISAT studies indicate that "full" yield of sorghum can be obtained from 2 sorghum: 1 pigeonpea, provided the full population of the sole crop is maintained in intercropping.

The consistency of sorghum-proportional yields in these two arrangements (2S: 1P and 1S:1P) has been examined from the experiments that have used constant optimum population in sole and intercrop (Table 1). It can be seen that complete yield of sole sorghum could

Table 1. Effect of 1:1 and 2:1 row planting methods in sorghum/pigeonpea intercropping on land equivalent ratios.

	Sorghum[a]		Pigeonpea		Total	
	1S:1PP	2S:1PP	1S:1PP[b]	2S:1PP[c]	1S:1PP	2S:1PP
	0.876	0.899	0.543	0.521	1.40	1.42
SE±	0.012	0.013	0.022	0.021	0.027	0.024
T test	(0.05) NS		NS		NS	

a. Average of 57 observations.
b. Average of 40 observations.
c. Average of 53 observations.

not always be achieved from intercropping, and the two row arrangements did not differ significantly. The 2:1 arrangement has given a slightly higher proportion of sorghum — i.e., 90%, compared to the 1:1, which gave 88% of the sole crop. The frequency distribution of sorghum land equivalents (Fig. 1) also shows that the probability of obtaining high proportional yields is somewhat higher in the 2:1 than in the 1:1. For example, the proportion of observations which gives a sorghum land equivalent of 0.9 or more is 50% in the 2:1 compared to 35% in the 1:1. The pigeonpea yields in the intercrop were 52-54% of the sole crop. Alternate rows showed only a slight advantage to pigeonpea, and there was no significant difference between the two arrangements. The overall advantage worked out to just over 40%.

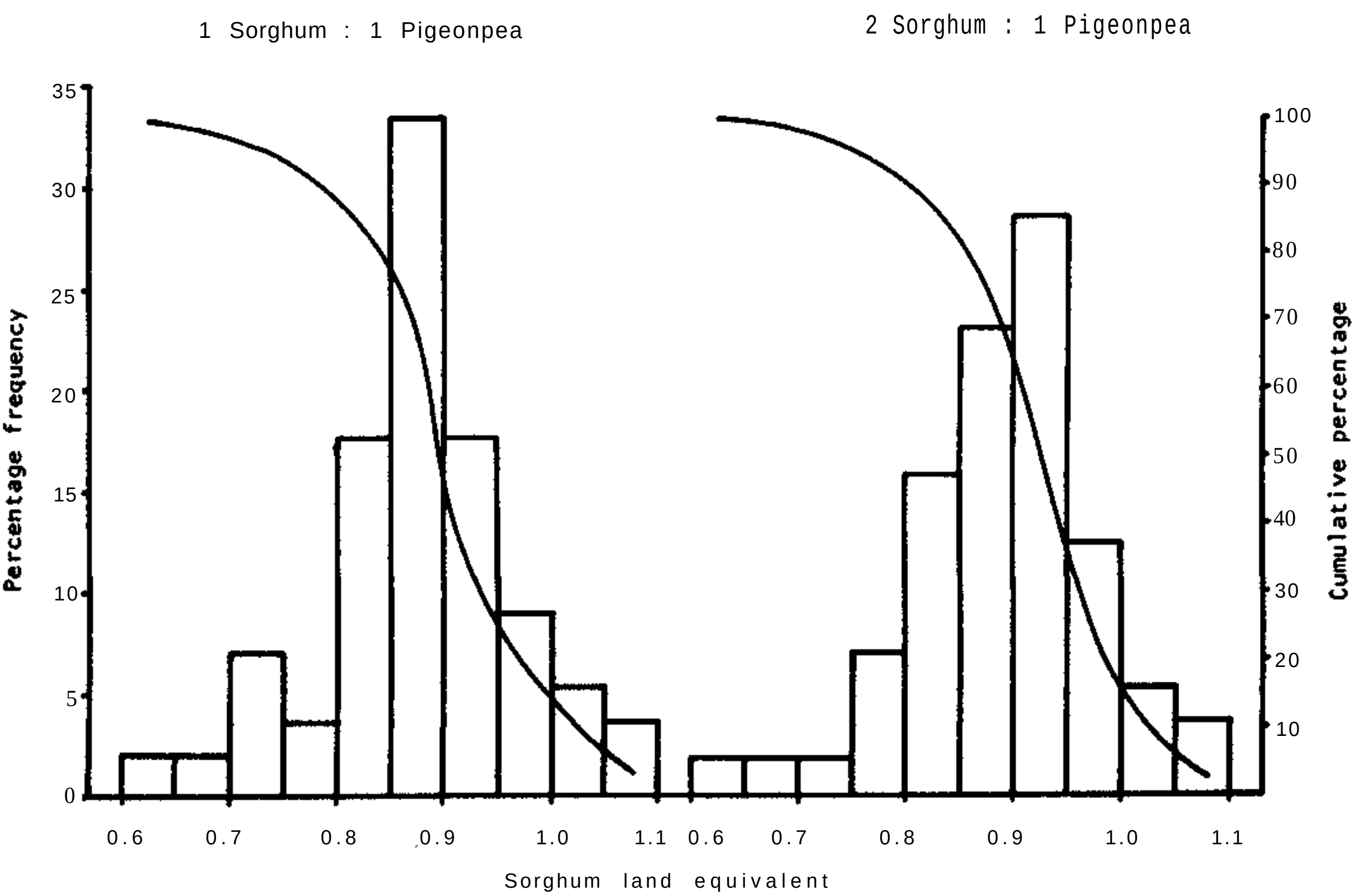

Figure 1. Distribution of sorghum relative yields in two row arrangements of sorghumlpigeonpea intercropping with sorghum population the same as in sole crop (57 observations).

Stability of Intercrop Advantage

The behavior of the relative intercrop advantage expressed as a land equivalent ratio is due tothe stress of two major resources, fertility and water.

Not many experiments have studied the effect of different levels of N in intercropping. The data collected was from different experiments conducted atdifferent levels of fertility. Figure 2 shows the relative advantage for different levels of applied N, averaged over a number of experiments. These data have the limitation that they do not take into account inherent soil-fertility differences and P levels between experiments, but these differences may have less influence on yields than the added N, especially in dryland conditions. All the trials received one application of P within moderate limits. In spite of this, it is clear that the level of N stress did not affect the relative advantage. A slight decreasing trend from 0 to 80 kg N/ha still only showed a decrease in LER from 1.57 to 1.44, and the differences were not statistically significant. One of the ICRISAT experiments in 1977, which examined 0, 40, 80, and 120 kg N/ha, gave LER values of 1.46,1.52,1.38, and 1.46, respectively, which gives support to the trend observed in Figure 2 (Rao and Willey 1978). It should be noted, however, that the monetary value of the relative advantage would be high at high levels of fertility because of higher yields. Palada and Harwood (1974) also observed similar results in a maize/soybean intercrop.

In dryland conditions, rainfall variability from season to season is high, and it might show a greater influence on yields than fertility; the farmer's interest in stability may be more related to the effect of moisture stress than nutrients. This aspect has not been studied at any length. Fisher (1977a) reported advantages for a maize/bean intercrop in good rainfall seasons and no advantage in a drought year. However, in contrast, an ICRISAT experiment in the postmonsoon season of 1977 on sorghum/groundnut and sorghum/millet showed LER advantages of 1.2 and 1.23, respectively, under stress conditions, but0.95 and 1.08 under no stress. The effect might have been because the combined root systems were able to make better use of moisture, which would only have been beneficial under conditions of moisture stress. However, it was observed that the dominant crop became even more dominant under no stress, which may have resulted

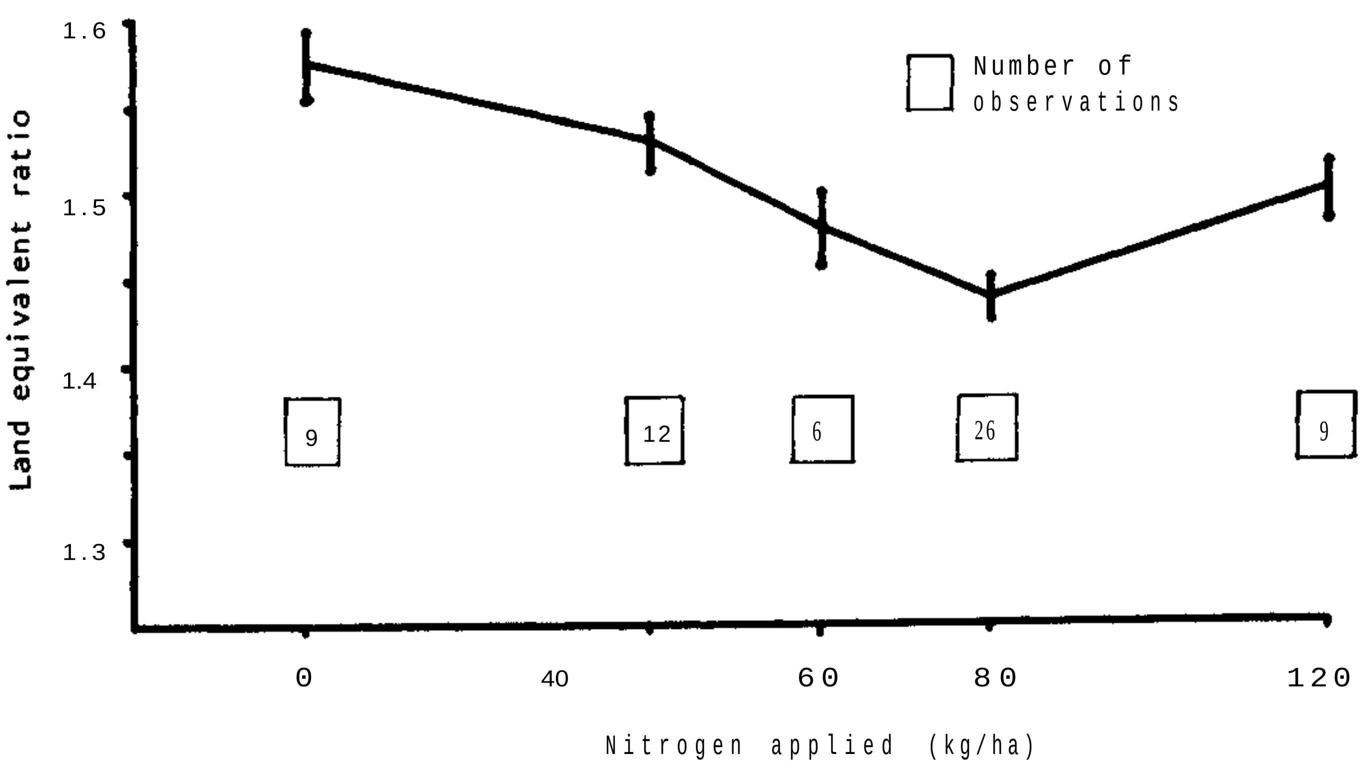

Figure 2. Effect of nitrogen on the relative advantage of sorghumlpigeonpea intercropping (Source: see Appendix I).

in an adverse effect of competition (Rao and Willey 1978). Moisture effects in the case of sorghum/pigeonpea were examined by calculating the relationship between relative advantage and moisture availability from 32 experiments (Fig. 3). This is the estimated evapotranspiration during the growing period based on a soil/water balance model which takes into account rainfall, evaporation, and soil characters (Reddy 1977). The results do not show any observable relationship between yield advantage and water availability. The intercrop performance is more or less independent of water availability within the range of 190-750 mm water used.

Evidence for Greater Stability of the Intercrop

For stability analysis, results of 40 experiments conducted during 1972-77 were used. These contained constant optimum populations of both the components in sole and intercrop, and the pigeonpea genotype was in the medium maturity group of 150-180 days. As a first approximation of stability, CV in yields were calculated (Table 2). The variation in yields of either sorghum or pigeonpea in the intercrop, although they experienced competition with each other, was of the same magnitude as that from sole crops. But the combined yields of the

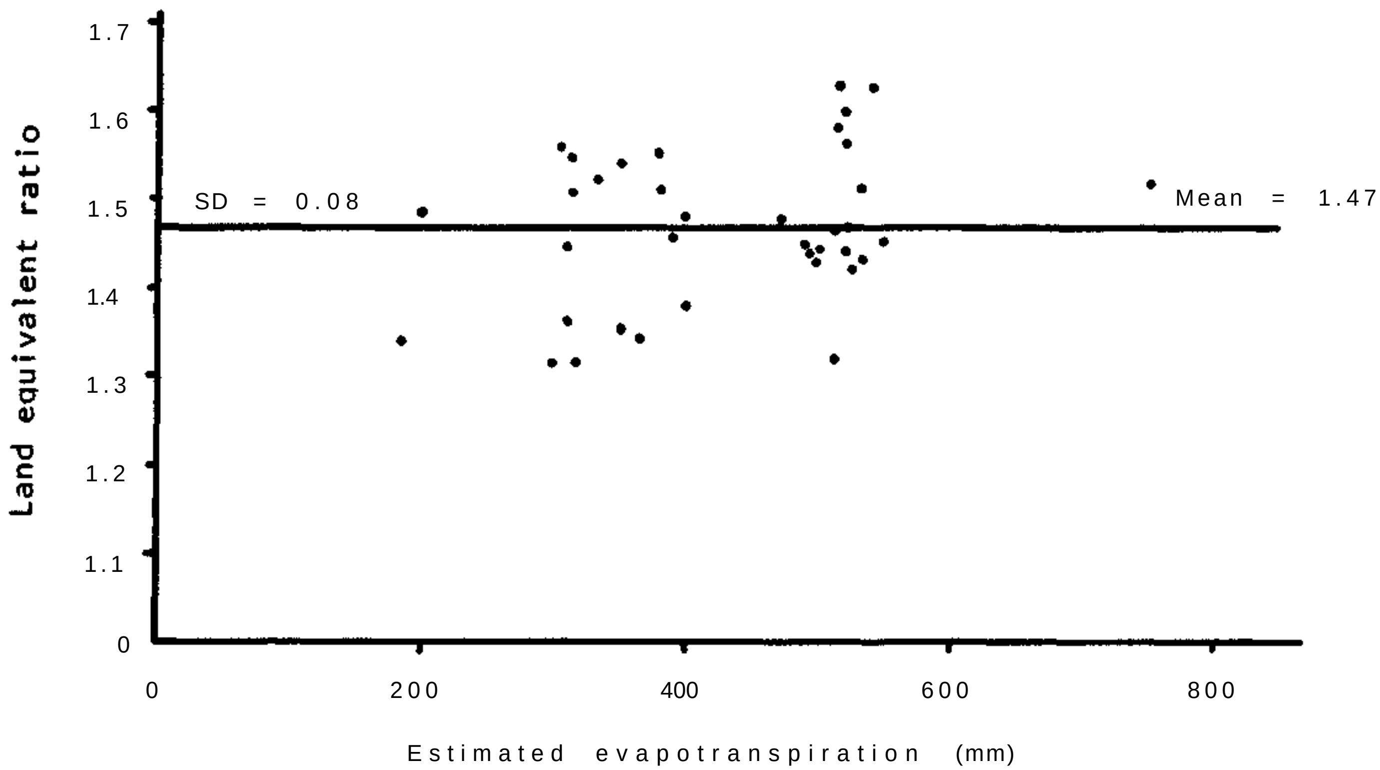

Figure 3. Effect of moisture availability on the relative advantage of sorghumlpigeonpea intercropping.

Table 2. Variability in yields (kg/ha) of sorghum and pigeonpea as sole crops and in intercrop. (Mean of 49 observations from 40 experiments.)

	Sole crop		Intercropped			
	Sorghum	Pigeonpea	Sorghum	Pigeonpea	Total	LER
	3278	1450	2893	815	3708	1.46
SE ±	2.23	0.93	1.94	0.50	2.04	0.02
CV<%)	47.73	45.15	46.90	43.55	38.53	9.60

intercrop showed a noticeably lower CV, which should indicate a likelihood of less fluctuation over different seasons. However, this reduction in variability indicated by this particular method seemed to be rather small.

The stability of a genotype or a system across environments could be more easily studied if an index integrating the various factors affecting growth were available. Eberhart and Russell (1963) suggested an environmental index based on yield itself as an integrator of these factors. The standard techniquethat has been in use for finding the stability of genotypes in sole crops is to fit a linear regression of yield of any given genotype against the environmental index for each location. This index is calculated by subtracting the mean *of* all the locations from the treatment mean of any given location; a positive value signifies that location is better than average, a negative index, poorer than average. The performance of any gentoype is then given by the mean yield (x), the slope of the regression *(b),* and the squared deviations of the residual (S^2di). The genotype which has high mean, a slope of 1, and minimum residual is considered more "stable." Such a "stable" system responds well proportionately to the environment. This may seem to be in contrastto what "stable" commonly denotes—i.e., a similar performance in various environments as indicated by/) equal to zero. But this means that a stable system does not respond to a good environment. In many respects, a system that shows this lack of fluctuation over seasons is important for small farmers, but in practice this may be more likely to happen with crops that have potentially very low yields. And part of the objective of any cropping-systems research program should presumably be to develop systems that use available resources efficiently and yield well in a favorable environment but, at thesame time, provide reasonable returns even under unfavorable situations. However, for the systems having the same mean, the one with a lower *b* value would be more stable.

Figure 4 shows the stability of sole crops vs intercrops measured in absolute yields, but in Figure 5 yields were calculated relative to the yields of the sole crops meaned over all the locations; the latter method allows yields of both crops to be put on the same scale. The analyses of variance for these characters illustrating the model are presented in Table 3. The fitted regressions have shown high goodness of fit for sorghum sole and intercrop (Table 4). The slopes higher than 1 for these situations suggests that these are more responsive to a favorable environment than is pigeonpea,

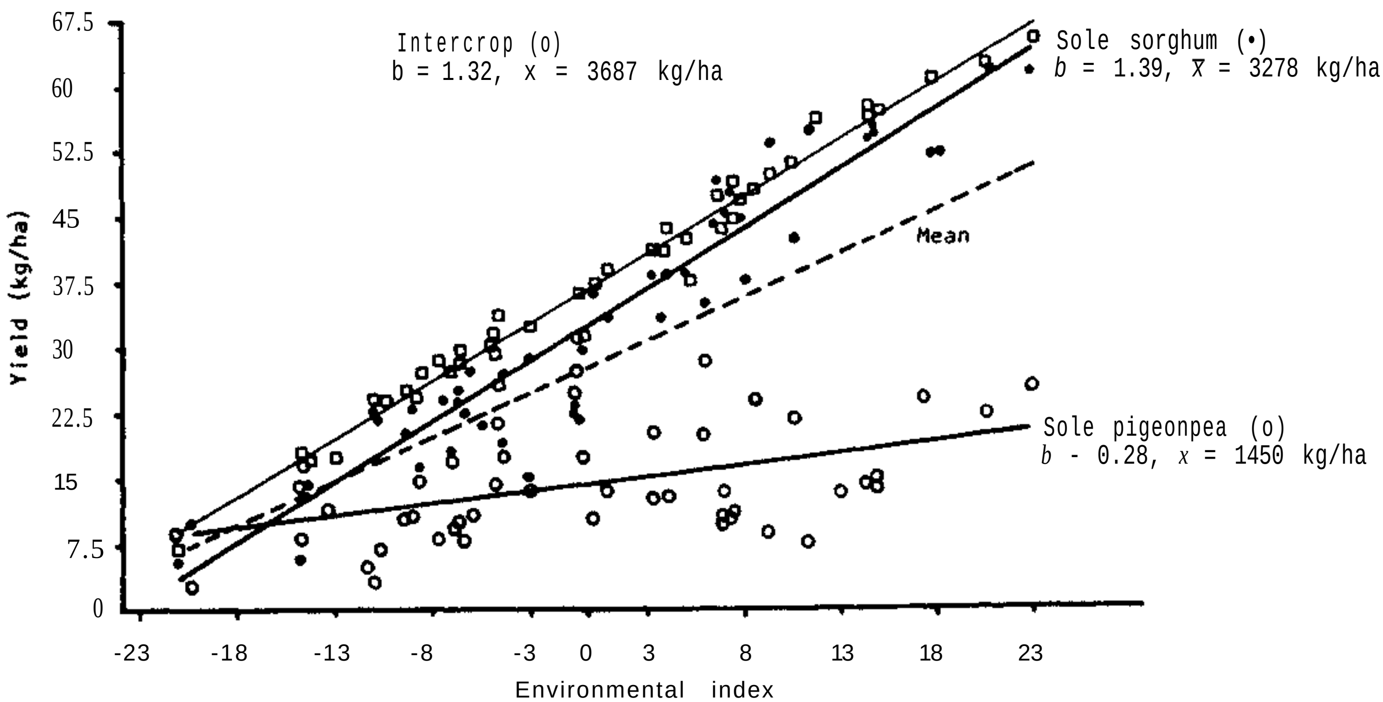

Figure 4. Performance of sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index.

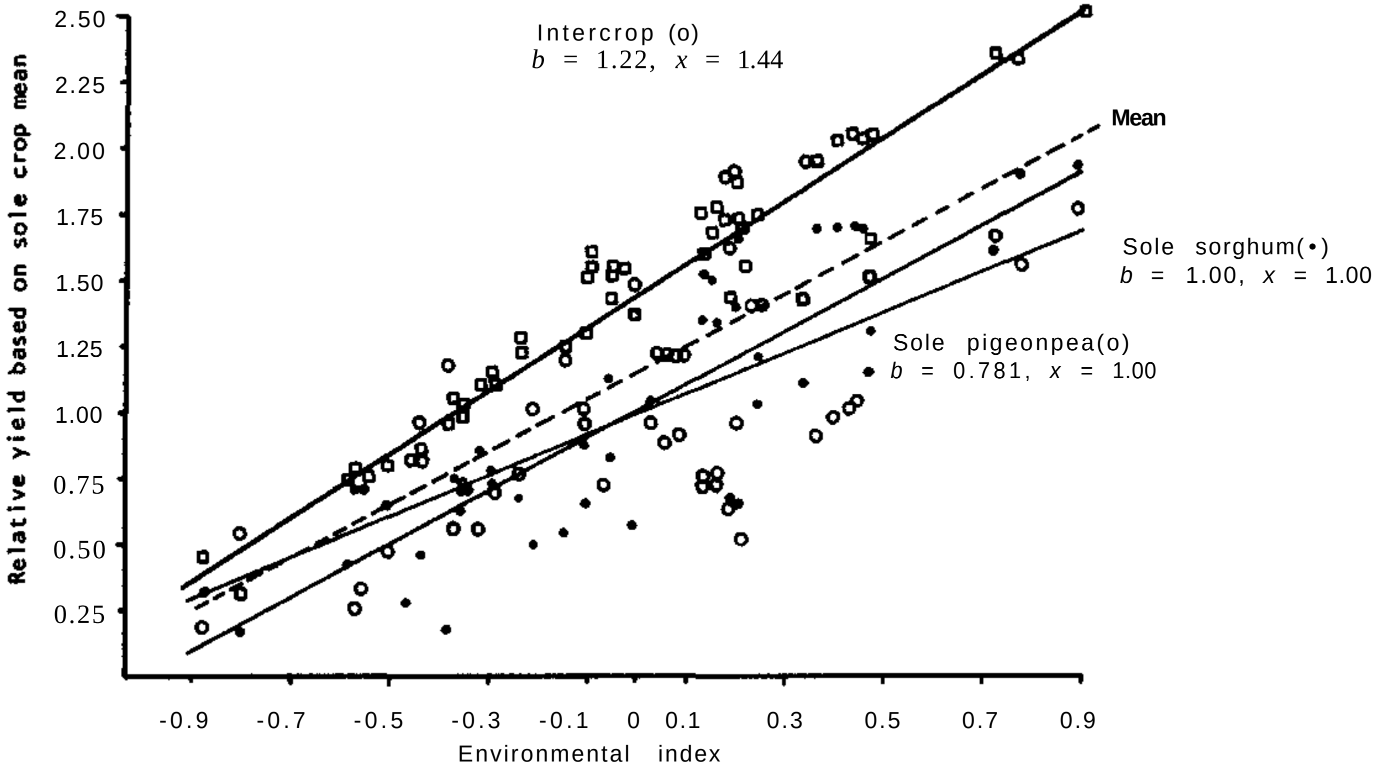

Figure 5. Performance of sorghum and pigeonpea in sole and intercrop systems (sole crop mean yield =1.0) in different environments as indicated by the environmental index.

Table 3. Analysis of variance whan stability parameters are computed.

	Yield (1 000 kg/ha)			Relative yield	
	df	SS	MSS	SS	MSS
Total	146	37 592.14		39.1970	
System (s)	2	13 980.76	6 990.38*	6.442	3.2211*
Environment *(L)*	1	16 517.47	16 517.47*	22.9644	22.9644*
Systems x environment (L)	2	4 244.72	2 122.36*	0.7877	0.39385*
Pooled deviations	141	2 849.39	20.21	0.0027	0.0639

* - Significant at the 5% level.

Table 4. Stability parameters of fitted regressions on yields and relative yields based on sole crop mean.

	Yield (kg/ha)				Relative yield			
System	$\bar{x}$	b	S^2_{di}	r^2	$\bar{x}$	b	S^2_{di}	r^2
Sole sorghum	3278	1.39*	22.0616	0.91	1.00	1.00	0.07043	0.63
Sole pigeonpea	1450	0.28*	24.3580	0.18	0.00	0.78	0.10915	0.45
Intercrop	3687	1.32*	4.5879	0.98	1.44	1.22*	0.01197	0.95
Mean	2805	1.00*			1.15	1.00		
SE ±	64.2				0.04			
LSD (0.05)	178				0.10			

* These b values are significantly different from 1.0.

which shows little response to the environment. In fact, it is evident from Figure 5 that under an unfavorable environment pigeonpea performs better than sorghum. The intercrop showed a higher mean (x = 1.44) and maintained its superiority over both the soles in the entire range of yield levels. In fact, better performance of the intercrop is much more evident in a better environment than in poorer ones. From the three parameters of regression, the intercrop can be regarded as more widely adaptable than any of the sole crops. It has combined the advantages of sorghum, which yields well and has average stability (x = 1.0, *b* = 1.0), as well as of pigeonpea, which is relatively unresponsive to changes in environment but yields well in poorer areas (x = 1.0, *b* = 0.78). However, the intercrop assumed the characteristics of sorghum rather more because this is the dominant crop. This illustrates particularly clearly that intercropping can be responsive to better conditions and that, for this combination at least, an improved level of resources should not necessarily be associated with a need for sole cropping.

One limitation in the above analysis could be that characterization of the location is based on the mean yield of all three systems. Unlike genotypes of the same species, which mature more or less at the same time, sorghum and pigeonpea are separated in time markedly and mature at different times of the year. Thus, a season unfavorable to one crop may not be unfavorable to the other. As a result mean yields of the three systems may not give an accurate idea of the environment. However, correlations worked out between the relative advantage and the absolute yields of sole sorghum (r= -0.07) or sole pigeonpea (r= -0.08) have not shown any discernible relationship.

Stability of Income

Figures 6, 7, and 8 show the comparison of intercrop and sole crops for stability of returns

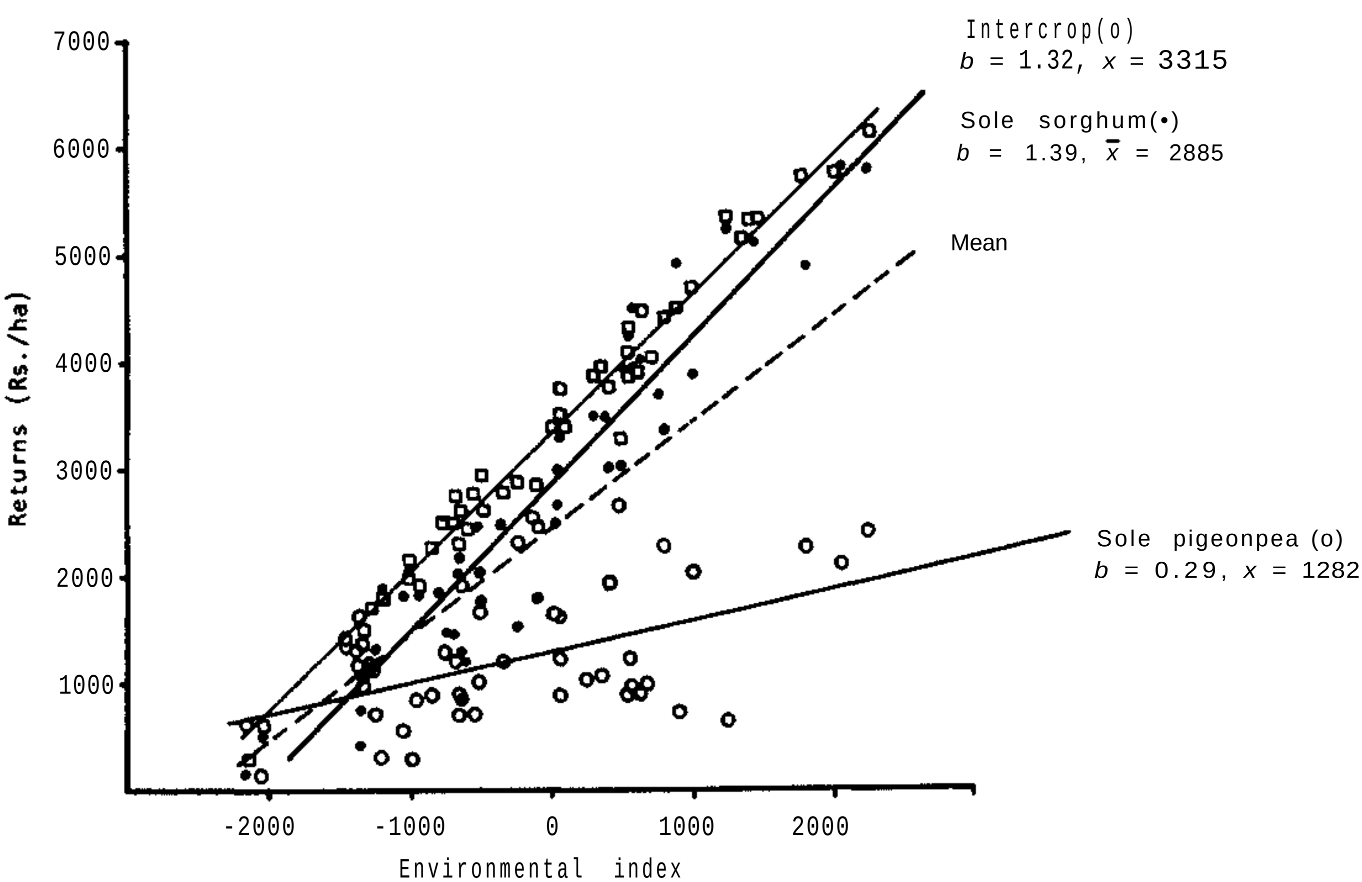

Figure 6. Returns from sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index (market price: sorghum Rs. 100/100 kg and pigeonpea Rs. 100|100 kg).

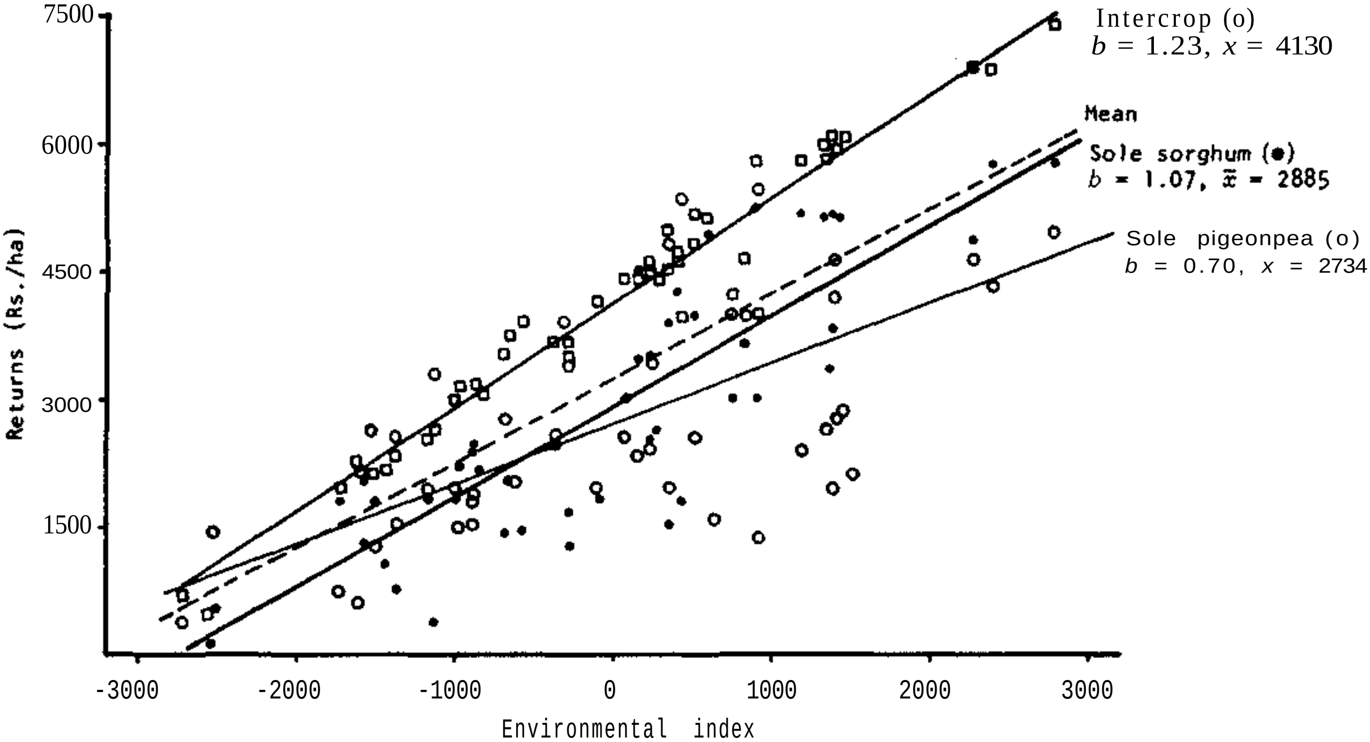

Figure 7. Returns from sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index (market price: sorghum Rs. 1001100 kg and pigeonpea Rs. 200|100 kg).

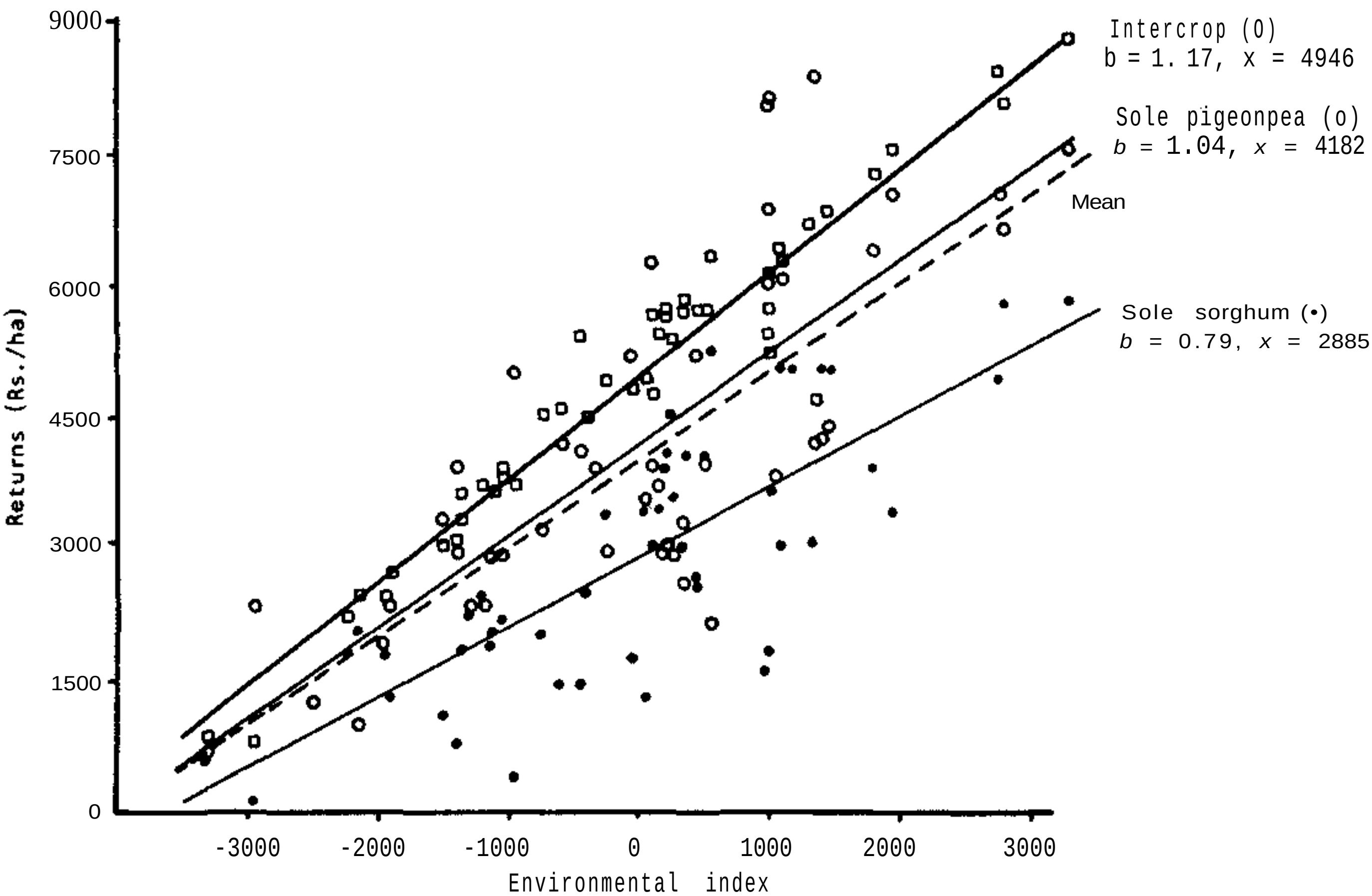

Figure 8. Returns from sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index (market price: sorghum Rs. 1001100 kg and pigeonpea Rs. 300/100 kg).

calculated at three different price ratios. The parameters of the regressions are in Table 5. Returns were computed deducting the costs.of the fertilizer. These show more or less the same trend as in the case of yields; however, as the price ratio increased in favor of pigeonpea, the slope of its regression line increased, whereas that for sorghum decreased. Except at the narrow ratio, where the returns from sole pigeonpea were greater than those from sole sorghum and the intercrop at very low environments, the intercrop showed superiority at all levels of return; a greater increase occurred in good environments than in poorer environments.

The variability in returns from the soles and intercrop and the expected risks associated with these systems for obtaining any specified level of income are given in Table 6. Returns from "shared crops" were also computed. "Shared crops" represent a situation where sorghum and pigeonpea as sole crops share 1 ha of land. Returns of shared sole were calculated from the respective soles on the yield-proportional basis as sorghum and pigeonpea in intercropping (0.61 ha S: 0.39 ha PP). Shared sole compared to intercrop provides an objective comparison, because both involve the two components in the same proportion, but in the latter situation the crops are intercropped. The results show that, although the intercrop as such has not shown marked difference from the shared crop, intercrop returns showed substantially less variability than either of the sole crops at all three price ratios. With an increase in the price of pigeonpea, returns from sole pigeonpea, shared and intercropped, revealed much less variability because of the same cost of fertilizer deducted at all prices. However, the probability (by normal deviate test) of returns falling below any specified disaster level shows the superiority of the intercrop over any of the sole crops. For example, at a market price of Rs. 100/100 kg of sorghum and 200/100 kg of pigeonpea, the probability of returns falling below Rs. 1000, is once in 9 years from sorghum sole, once in 11 years from pigeonpea sole, once in 20 years from shared crop, but only once in 50 years from the intercrop. In the above, returns were based on constant prices for components, which is rather unlikely to prevail over several years. Figure 9 shows the risk from these systems when the price ratios between sorghum and pigeonpea vary randomly between ratios of 1:1, 1:2, and 1:3. At lower disaster levels (i.e., lower required income), the inter-

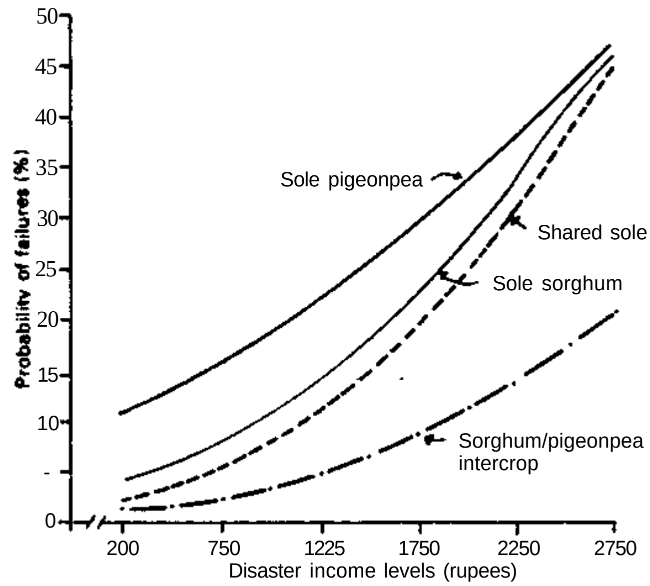

Figure 9. Probability of returns from sole sorghum and pigeonpea and from sorghum/ pigeonpea intercrop falling below specified disaster levels.

Table 8. Stability parameters for fitted regressions on monetary basis.

	Sorghum — Rs. 100/100 kg Pigeonpea — Rs. 100/100 kg				Sorghum — Rs. 100/100 kg Pigeonpea — Rs. 200/100 kg				Sorghum — Rs. 100/100 kg Pigeonpea — Rs. 300/100 kg			
	$\bar{X}$	b	S^2di	r^2	$\bar{X}$	b	S^2di	r^2	$\bar{X}$	b	S^2di	r^2
Sole sorghum	2885	1.39	222229	0.90	2885	1.07	641803	0.72	2885	0.79	1027050	0.55
Sole pigeonpea	1282	0.29	337082	0.18	2732	0.79	990869	0.40	4182	1.04	1597650	0.57
Intercrop	3315	1.32	39721	0.98	4130	1.23	105602	0.95	4946	1.17	199441	0.93
SE ±	99				117				142			
LSD (0.05)	275				325				393			

Table 6. Risk associated with sorghum and pigeonpea in sola and intarcrop systems at spaciflad levels of returns.

System	Mean income (Rs./ha)	SD	CV%	Probability of income falling below disaster levels (Rs./ha)		
				500	1000	1500
Sorghum 100 : Pigeonpea 100						
Sole sorghum	2885	1528	52.95	0.06	0.11	0.18
Sole pigeonpea	1282	650	50.64	0.11	0.33	0.63
Shared sole[a]	2261	1009	44.63	0.04	0.10	0.23
Intercrop	3315	1394	42.06	0.02	0.05	0.09
Sorghum 100 : Pigeonpea 200				Disaster levels		
				1000	1500	2000
Sole sorghum	2885	1528	52.95	0.11	0.18	0.28
Sole pigeonpea	2734	1304	47.70	0.09	0.17	0.29
Shared sole	2826	1140	40.33	0.05	0.12	0.23
Intercrop	4130	1543	37.36	0.02	0.04	0.08
Sorghum 100 : Pigeonpea 300				Disaster levels		
				1000	1500	2000
Sole sorghum	2885	1528	52.95	0.11	0.18	0.28
Sole pigeonpea	4182	1958	46.80	0.05	0.08	0.13
Shared sole	3392	1308	38.56	0.03	0.07	0.14
Intercrop	4946	1753	35.44	0.01	0.02	0.04

a. Shared sole is 0.61 ha sorghum and 0.39 ha pigeonpea — i.e., the same as the mean proportions of sorghum and pigeonpea in intercropping.

crops did not show marked superiority in stability over the shared crops, but at higher levels, failures due to intercropping are much less frequent than with any of the sole crops. Higher risk from shared sole compared to the intercrop, although it has the benefits of having both crops, is presumably because of the lack of compensation that could occur in intercropping.

Appendix I. Source of Data

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Intercropping on an Operational Scale in an Improved Farming System

B. A. Krantz*

Abstract

Mixed cropping, or intercropping, evolved in traditional agriculture where it has been practiced at a low level of technology largely for risk reduction. Recent research has shown substantial benefits from intercropping at medium to high levels of technology; however, due to several factors, including the lack of operational-scale research, sole-cropping technology is being promoted by national programs, and the potential benefits of improved intercropping are not being achieved. Therefore, scientists should take the next step of conducting research on an operational scale to uncover and solve possible problems and constraints. Since the farmer in the semi-arid tropics has limited capital and land, scientists should provide him with the necessary information to capitalize on the intercropping benefits and the synergistic effects of nonmonetary-improved management to use in combination with his costly monetary inputs.

Intercropping[1] and mixed cropping[2] evolved in traditional agriculture of tropical and subtropical countries and have been practiced for centuries. In traditional agriculture, mixed cropping has usually predominated, particularly in the early stages, and has been practiced at a low level of technology, largely for risk reduction (Norman 1975). Even though mixed cropping is centuries old, the modern concepts of intercropping are relatively new, and very little research has been conducted in intercropping until recently.

There are many reasons for the neglect of intercropping research including the following:

1. With the advent of mechanical harvesting, especially in developed countries, the practice of intercropping was abandoned.
2. Since intercropping is generally associated with traditional agriculture and subsistence farming at low inputs, breeders concentrated on developing genotypes for sole crops and not for intercropping.
3. There was a general belief that intercropping advantages were manifested only at low levels of inputs and technology. However, recent research has shown that there are substantial yield advantages of intercropping at medium to high levels of technology (Krantz et al. 1976; ICRISAT 1977e).

Even where experiment stations have conducted research showing substantial yield advantages of intercropping at medium to high levels of technology with high-yielding varieties, the extension programs for high-yielding varieties have usually been launched using sole-cropping systems. Thus, farmers who normally intercrop with their local varieties have been strongly encouraged to abandon this practice and sow the high-yielding varieties as sole crops. Unfortunately, then, sole cropping has become identified with improved technology. There are various possible reasons for this situation.

1. The extension of sole-crop technology is simpler and easier than that of intercropping technology.

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1. In intercropping, two or more crops are grown simultaneously on the same land in different, but proximate, rows.
2. In mixed cropping, two or more crops are grown simultaneously in the same area with no row arrangement.

2. Intercropping research at experiment stations is almost always carried out in small plots under carefully controlled hand operations. Due to the lack of research on an operational scale, the more complex intercropping technology may need further adaptation before it is ready for farmer adoption.

Research in small plots under controlled experiment station conditions may show alternate row arrangement of intercrops, such as a cereal and pigeonpea, to give the greatest yield advantage. However, the alternate-row pattern presents many problems on an operational scale under farm conditions, such as (1) inefficiency of applying needed N or plant protection chemicals to one row of cereal and not to pigeonpea, (2) the problem of hand harvesting the cereal at physiological maturity without damaging the pigeonpea, which has spread out and is in the flowering stage, and (3) the problem of handling regrowth of sorghum, which competes with the pigeonpea for residual moisture in the soil at the critical reproductive stage of growth.

Since many farmers in developing countries are acquainted with intercropping at low levels of technology, and research has shown that substantial yield advantages persist at high levels of technology, it behooves us as scientists to go one step further and work out principles of the best production practices which can be used by farmers on an operational scale.

Operational-scale Research at ICRISAT

The aim of intercropping research is to optimize the use of natural resources including light, water, and nutrients (Donald 1963). However, if intercropping is to be fitted into improved farming systems, other factors must be considdered. These factors include the human, capital, and power resources available to the farmer. Thus, we must ask some questions: Is the specific intercropping system operationally feasible with the farmers' present resources? If not, what additional resources or inputs will be needed? Will the weed and insect problems be greater or less than with sole crops? Do the crops fit his needs, and is there a market for his surplus? Does intercropping fit in with other facets of his farming system?

In the Farming Systems Research Program at ICRISAT, operational-scale research was started a few years ago and is being carried on as a complement to small-plot research. The operational-scale research is being carried out in watersheds (catchments) that were established to study the effect of different soil-, water-, and crop-management systems upon water balance and soil and water conservation. Thus the operational-scale research is conducted under many different land-management systems, such as the traditional field or the contour-bunded system with traditional implements, flat cultivation with improved implements, and the bed-and-furrow system at varying slopes created by adjusting furrow direction within the watershed. This provides an opportunity to investigate and solve many operational problems under a wide range of soil- and water-management systems and cropping systems using animal-drawn implements.

In the early years, a wide range of crops was investigated in inter-, relay, and sequential cropping systems. These included (1) pigeonpea intercropped with sorghum, pearl millet, and setaria and (2) sorghum, pearl millet, sunflower, and maize followed by relay and sequential crops of chickpea, safflower, sunflower, and sorghum. In this operational-scale research, many problems that did not show up in small-plot experiments were discovered, and, as a result, certain crops and cropping systems were eliminated. Some examples of these are as follows:

1. Relay cropping was eliminated in the 75-cm beds because of damage to the standing cereal or sunflower crop and the problems of cultivation and planting with present equipment.
2. *Kharif* (rainy season) pearl millet was eliminated in the deep Vertisol watersheds due to the difficulties in harvesting during the rainy period in these montmorillonite clay soils. Kharif sorghum was reduced to a minimum forsimilarreasons. Analysis of the rainfall data indicated that the possibility of having the required 3 consecutive days for harvesting these crops was very small (Table 1). This highlighted the need for mold and weathering resistance in sorghum and pearl millet genotypes.
3. Although setaria appeared to be compatible and mutually noncompetitive with the

Table 1. Field workday probabilities at maturity of sorghum and millet crops in two soil types at Hyderabad.

Crop	Maturity (no. of days)	Number of 3 consecutive work day probabilities in: Alfisols	Vertisols
Millet	65-70	50	4
Sorghum	90-100	77	29
Sorghum	130-150	93	83

pigeonpea intercrop, it was eliminated because of low yield, low price, and limited market. Sunflower was eliminated because of parrot damage and harvesting and drying problems.

4. Tractor use was eliminated and bullock power only was used in order to develop feasible farming systems using the same power source as that available to the farmers of the SAT.
5. The 75-cm beds and furrows were replaced with 150-cm bed-and-furrow system. (Reasons for this change are given in a later section.)

Soil and Water Management and Cropping Systems

Vertisols

After several years of operational-scale research on a field-scale, the following guidelines for soil-, water-, and crop-management systems have been developed and found successful on the deep Vertisol watersheds.

a. Establish a 150-cm bed-and-furrow system at about 0.6% slope after minor smoothing to erase the microrelief. (These beds can be established on a semipermanent basis and maintained by minimum tillage.)
b. Till beds using toolbar with left- and right-hand plows immediately after the harvest of the last crop of the growing season to kill weeds and stubble and cover the soil cracks with a cloddy mulch, thus conserving residual moisture in the soil profile.
c. After premonsoon rain has moistened the clods and the soil has redried sufficiently to avoid compaction, harrow if necessary to kill weed seedlings and use a ridger-cum-bed former to reshape the beds. This completes the seed bed preparation during the dry season well ahead of planting time with minimal tillage and soil compaction. Premonsoon land preparation also reduces peak power and labor demands during the early monsoon,
d. About 7 to 10 days before the expected onset of the rainy season, fertilize and plant "dry" any crop which can be planted 5-7 cm deep (Fig. 1). This includes crops such as sorghum, pigeonpea, maize, and cowpea. In the past 6 years, planting such crops in dry soil has been successful. Dry planting is much faster and less hazardous than attempting to plant after the rains start on these montmorillinitic clay Vertisols, which become very sticky when wet. (In cases where planting was necessary after the onset of the monsoon, the time required for planting was greater and poorer stands were obtained.) Because of the high water-holding capacity of these soils and the relatively deep planting required, no germination will take place after small showers of 5-10 mm. When there is sufficient rainfall to germinate the seed at the 5-7 cm depth, there is sufficient soil moisture to keep the plant alive at least 10-15 days with no further rains.

In most of the Vertisol watershed units, two cropping systems (inter- and sequential cropping) were used with two replicates. The positions of the two systems were rotated each year.

The intercrop system consisted of medium-duration pigeonpea (180-190 day) and a short-duration maize (85-95 day) intercrop. At physiological maturity, the tops of the maize plants were cut just above the ear level and the green fodder was used for feed. This removed the major shade competition from the pigeonpea and allowed it to spread and approach full vegetative growth. Beets (1975) reported similar practices in Indonesia to facilitate early relay planting. The maize cobs were allowed to dry in the field on the stalk and were harvested whenever convenient. Immediately after the removal of the maize cobs, the beds were tilled using the left- and right-hand plows on the high-clearance, wheeled tool bar to kill weeds and partially incorporate the maize

Figure 1. A pigeonpealmaize intercrop being planted on beds in dry Vertisols just before the rainy season.

stalks. Since this was done before the pigeonpe a flowering time, itdid notdamagethe pigeonpea plant.

The sequential crop system involved sole maize (105-110 day duration), which was harvested by removing the ears from the standing stalk and drying them in cribs. The fodder was then removed for feed. The land was then cultivated by bullocks and hand weeded, where necessary, to remove large weeds, in preparation for planting of the relay crop of sorghum, chickpea, or safflower.

Alfisols

a. Establish the bed-and-furrow system on a semipermanent basis after land smoothing as in the Vertisols (Fig. 2).
b. In a single-crop system, till the beds with left- and right-hand plows immediately after crop harvest to kill weeds and form a rough cloddy surface, which is receptive to premonsoon showers and resists possible wind erosion.
c. In sorghum/pigeonpea intercrop, till immediately after sorghum harvest with left- and right-hand plows to kill weeds and uproot sorghum stubble on each side of the pigeonpea intercrop.
d. Where Alfisols are double cropped and are very dry and hard after the second crop, the primary plowing may have to be delayed until after the first early monsoon rain.
e. Since Alfisols have a low water-holding capacity, delay planting until after the rains have moistened the soil to a depth of 15-20 cm.

Procedures Used on Both Soils

a. Cultivate and hand weed early, as soon after crop emergence as weather permits. In high-rainfall areas, where early weeding

Figure 2. Ridger-cum-bed former reshaping beds for the third yean

is difficult use a minimal application of preemergence herbicide for early weed control in deep Vertisols.

b. In intercropped systems involving a medium-duration cereal, harvest the cereal as soon as possible after physiological maturity to remove light and moisture competition from the long-duration crop.

c. Where ratoon cropping of sorghum is planned, harvest the heads and cut the stalks just above ground level soon after physiological maturity.

d. Where double cropping is practiced, remove the monsoon crop as early as feasible and cultivate and plant between the standing stubble. This technique has worked successfully and greatly reduces the power demand and time required for land preparation. Saving energy is an important factor when all cultural operations are carried out by the use of bullock power; saving time increases the length of the growing season for the second crop and conserves soil moisture for germination of the postmonsoon crop.

Relay and Sequential Cropping

Some crops, such as *rabi* (postmonsoon) sorghum and pigeonpea, are benefited by early planting as relay crops before the normal harvest time of the rainy-season crop, such as maize. However, operationally it is very difficult to relay plant in between standing crops. The planting arrangement used in the broadbed-and-furrow systems offers an opportunity for developing operationally feasible relay planting systems.

An experiment was initiated in which the two maize rows in every second bed were harvested for green cobs and green fodder, thus providing an opportunity for relay planting with the wheeled tool bar in a 235-cm space between the standing maize plants. In all systems, chickpea was planted after maize grain harvest at physiological maturity in the remaining 65-cm space. Thus, chickpea occupied 22% of the space of the post harvest season while the pigeonpea, safflower, or sorghum occupied 78% of the space. Since all yields are recorded on the hectare basis, it is possible to add the monetary values together to get the total monetary value. The aim of this experiment was to explore various aspects of the problems involved on an operational scale to determine production opportunities and operational constraints. After 50% of the maize was harvested for greencob and green fodder, the 235-cm area between the standing maize plants was cultivated and planted with the wheeled tool bar and no operational difficulties were encountered.

In the treatment in which 50% of the maize was harvested for greencob and the rest for grain, the total monetary value was Rs. 7510, which was 60% greater than the monetary value of the plots harvested for grain only, due largely to the higher monetary value of the maize greencob (Tabel 2). Likewise, the relay-planted pigeonpea produced 180 kg/ha more than the sequentially planted pigeonpea. However, the companion chickpea crop produced 140 kg/ha less with the relay pigeonpea compared to the sequential pigeonpea. Thus, there was only a slight net advantage for relay planting. It is recognized that there is a limited market for maize greencobs. However, where a market is available, the system appears to be promising and the experiment is being repeated in 1978.

Investigations on Bed-and-Furrow Systems

Systems involving graded (150-cm) beds separated by furrows that drain into grassed waterways appear to fulfill most of the requirements of soil and water conservation and management (Krantz et al. 1978). The improved surface drainage function of beds and furrows over that of flat cultivation has been shown by Chowdhury and Bhatia (1971) and Krantz and Kampen (1973). An example of the type of system envisaged is illustrated in a schematic drawing (Fig. 3).

During the 1975 season, a wide (150-cm), graded (0.4% slope) bed-and-furrow system was compared to a 75-cm system on the Alfisols. In these soils, the 75-cm beds were unstable, and cross flow and erosion were encountered during high-intensity storms, especially in slight depressional areas. This problem was overcome by the use of a 150-cm bed-and-furrow system. In order to evaluate the effect of different land-management treatments on deep Vertisols, an experiment was established in watershed no. BW5A using relatively large plots (0.3 to 0.4 ha) to study relevant

Table 2. Effect of time of maize harvest and relay and sequential planting upon gross yields and monetary value on a deep Vertisol, 1977-78 (average of four replications).

	Maize			Pigeon pea[a]				
Treatment	Grain	Green cob	Chickpea	Relay	Seq.	Safflower	Sorghum	Total
Grain yield (kg/ha)								
1	1735	29 360[b]	205	863	-	-	-	
2	1650	28 320	213	-	-	316	-	
3	3310	-	345	-	683	-	-	
4	3310	-	302	-	-	-	660	
Monetary values (Rs/ha)								
1	1579	3 524	461	1942	-	-	-	7510
2	1502	3 399	479	-	-	758	-	6140
3	3012	-	776	-	1537	-	-	5330
4	3012	-	680	-	-	-	561	4250

a. Relay plantings of pigeonpea and sorghum were made on 8 Sept (sorghum was severely damaged by cutworms and was replanted to safflowar). Sequential plantings were made on 22 Sept.

b. Green cob yield given as number/ha.

Table 4. Mean monetary values (Rs/ha) of flat and semipermanent bed-and-furrow systems on Vertisol watersheds using Improvad tachnology in 1976 and 1977.

Water-shed No.	Land management system	Year	Intercrop			Sequential crop			Means	
			Maize	Pigeonpea	Total	Maize	Chickpea	Total	Both systems	Both years
Deep Vertisols										
1,2,3A	Beds	1976	2840	2080	4920	2730	950	3680	4300	
1,2,3A	Beds	1977	2270	2770	5040	2880	2400	5280	5160	
Means										4730
3B,4B	Flat	1976	2530	1680	4210	2300	570	2870	3540	
3B,4B	Flat	1977	2450	1810	4260	2790	2200	4980	4620	
Means										4080
LSD (0.05)										280
CV(%)										9.2
Shallow to Medium-deep Vertisols										
7B,C,D	Beds	1976	2020	1570	3590	1970	560	2530	3060	
7B,C,D	Beds	1977	2460	1630	4090	2410	1550	3960	4030	
Means										3550
6C,6D	Flat	1976	1960	1490	3450	1570	560	2130	2790	
6C,6D	Flat	1977	2310	1880	4190	2290	1390	3680	3940	
Means										3370
LSD (0.05)										NS
CV(%)										15.6

vated watersheds (BW3B and BW4B). The average monetary values for both the inter- and sequential cropping systems under the flat and the bed-and-furrow systems for 1976 and 1977 are given in Table 4. In the deep Vertisols, the average monetary value of each of the four crops was consistently better with graded beds and furrows than with the flat system. The mean monetary value of all combinations for the bed-and-furrow system was Rs. 650/ha greater than for the flat system. This difference was highly significant. The monetary trends were less consistent in the shallow to medium-deep Vertisols than in the deep Vertisols and the increase of bed-and-furrows over the flat systems was not significant. (Table 4).

The beds function as "mini bunds" at a grade which is normally less than the maximum slope of the land. Preliminary data at ICRISAT Center indicate that the optimum slope for a bed-and-furrow system is 0.3 to 0.6% in Alfisols and 0.4 to 0.8% in Vertisols. When runoff occurs, the velocity is reduced and infiltration opportunity time in the furrows increases. Thus, the semipermanent bed-and-furrow system provides water control for in situ soil and water conservation throughout the year. The conservation and utilization of water can give an immediate impact on crop yields. Thus, it is important to develop cropping systems, including intercropping, relay cropping, and sequential cropping, that will capitalize on the improved resource for improved crop production. With improved water-resource development and utilization in the semi-arid tropics, it is often possible to grow two good crops in place of the one mediocre crop that is commonly grown in traditional agriculture. This requires integration of a number of cropping and management systems into a complete farming system.

This increased intensity of cropping will require more total labor and animal power than the traditional systems but not necessarily any higher peak demands. Operational-scale research carried out at ICRISAT has developed procedures for land development and preparation during the hot dry premonsoon season when no crops are grown. In this manner, the power and labor demand is spread out and high peaks are avoided.

Integration of Various Facets of Improved Technology

To achieve full benefits of improved cropping systems and resource development and management, all facets of farming systems must be considered. In the development and implementation of improved technology there are many steps involved. If one attempts to research each of the individual factors, the total number of combinations becomes unmanageably large. The many facets were grouped into the following four phases: variety, fertilization, soil and crop management, and supplemental irrigation.

In 1976, an experiment, was conducted with sorghum, involving a comparison of "traditional" and "improved" technology in Alfisols. During the rainy season,the rainfall distribution was fairly adequate and uniform and no supplemental irrigation was used. Thus, only the first three phases were considered. There was a significant response to improved fertilization. Improved variety and improved management as single factors showed an upward trend but were not significant; however, treatments involving two or three steps in combination were highly significant The yield increase from the three steps (variety, fertilization, and soil and crop management) applied in combination was double that of the sum of the increases due to the same three steps applied singly, thus illustrating the large synergistic effect when all three steps were applied together in a system (Fig 5). It was also noted that there was a slight synergistic effect when any two factors were combined; however, the magnitude of this effect was far less than that of the three-factor combination.

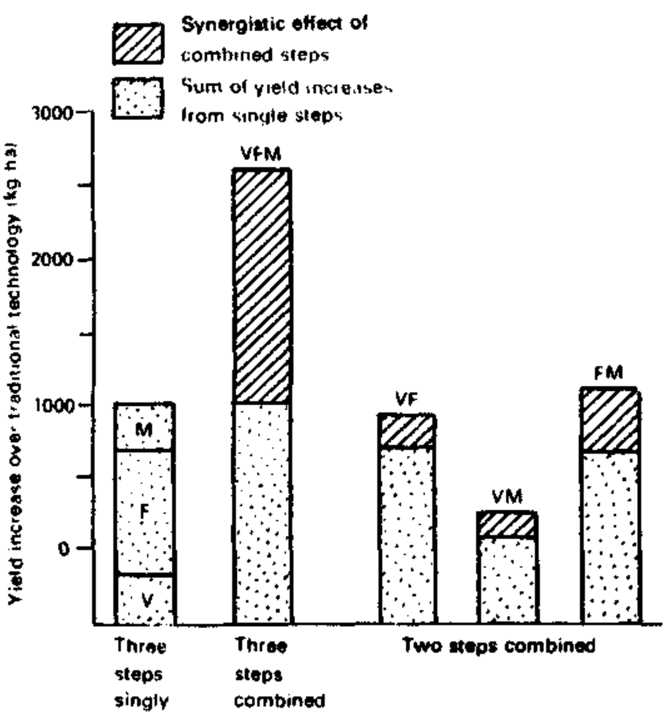

Figure 5. Sorghum grain yield increases from improved variety (V), fertilization (F), and soil and crop management (Mi singly and in combination over traditional technology, 1976.

Similar results were obtained on a Vertisol with maize in 1976 and sorghum in 1977 (Table 5). Synergistic effects were observed in maize yields in North Carolina (Krantz and Chandler 1954) and in wheat yields in India (Krantz et al. 1975) when all major factors were combined in a production system. From the data in Table 5 it is apparent that the greatest treatment effects upon yield are found with cereals in which the improved varieties have had a far greater breeding effort than in the grain legumes. This is reflected in the greater responsiveness of the cereals to improved fertilization and management. The sum of the increase for improved variety, fertilization and management applied singly is Rs. 2660/ha, and the value for these three factors combined is Rs. 3870/ha, which reflects a strong synergistic effect for combining the three factors. The largest proportion of the synergistic effect is due tot he increase from improved management over traditional management at improved levels of variety and fertilization (treatments 7 and 8).

Five cm of water applied to the pigeonpea in 1976 and to chickpea in 1977 resulted in an average increase of Rs. 550/ha or Rs. 11 000/ha meter of water.

Broadened Research Approach Needed

There is an urgency to increase and stabilize food production in the semi-arid tropics where there is undependable rainfall, the recent population explosion, repeated food crises, and the rapid expansion of cultivated land into more erodible areas causing degradation of the soil-resource base.

Table 5. Effects of traditional[a] and improved[b] levels of four steps in improved technology upon maize/pigeonpea intercrop in 1976-77, sorghum/chickpea sequential crop grain yield (kg/ha) in 1977-78, and mean gross annual value (Rs/ha) for the 2 years on a medium-deep Vertisol.

Treat-ment no.	Variety	Fertility	Soil and crop management	Supple-mental water	1976-77 intercrop		1977-78 seq. crop		2-year[c]
					Maize	Pigeonpea	Sorghum	Chickpea	Mean value
1	Trad	Trad	Trad	0	450	320	1110	169	1020
2	Trad	Trad	Imp	0	660	614	1370	185	1490
3	Trad	Imp	Trad	0	1900	452	1670	129	1890
4	Trad	Imp	Imp	0	2610	572	2090	291	2620
5	Imp	Trad	Trad	0	630	499	2950	479	2340
6	Imp	Trad	Imp	0	960	639	3570	596	2970
7	Imp	Imp	Trad	0	2220	540	4800	557	3770
8	Imp	Imp	Imp	0	3470	604	5840	708	4890
9	Trad	Imp	Imp	5[d]	2610	728	2090	660	3180
10	Imp	Imp	Imp	5[d]	3470	837	5840	987	5440
LSD	(0.05)					470	218	440	179

a. Trad = Traditional system: Varieties—maize, short duration local; pigeonpea, local; sorghum, PJ8K; chickpea, local. Fertilization—10 tons/ha farmyard manure in 1976 and none in 1977. Soil and crop management simulates the present traditional farmer practice with bullocks and desi implements; fertilizer broadcast and seed sown with 3-row desi drill (called Tippon) 30 cm between rows; 3 rows of maize to 1 row of plgeonpea; one insecticide application on pulses only.

b. Imp = Improved technology. Varieties—maize SB23; pigeonpea, ICRISAT-1; sorghum, CSH-6; chickpea, local. Fertilization—75 kg/ha 18-46-0 plus 67 kg/ha N topdressed. Soil and crop management—all tillage, planting, and cultivation with improved animal-drawn implements. Fertilizers banded and seed sown with one row of plgeonpea In center of ridge and one row of maize 45 cms to each side on broad (150-cm) beds, sorghum three rows and chickpeas four rows/150-cm bed. One Insecticide application on pulses only.

c. Market price (per 100 kg): Maize—traditional, Rs. 85; SB23, Rs. 83; Pigeonpea—traditional, Rs. 190; ICRISAT-1, Rs. 210; sorghum, local Rs. 61; CSH-6, Rs. 68; chickpea—both local, Rs. 225; value of fodder not Included.

d. No water applied to maize Intercrop, plgeonpea main crop, or sorghum crop; 5 cms of supplemental water was applied at harvest of pigeonpea for the ratoon crop in 1976 and at flowering time on chickpeas in 1977.

Therefore any improved variety, cropping system, or new management innovation should be tested in combination with other parts of the farming system on an operational scale to uncover problems and constraints and find opportunities for solution of these problems. Often in experimental stations researchers have shown yield advantages of 20,40, or even 60% from intercropping, but, due to operational problems and unresearched constraints, this information is ignored, and sole cropping is practiced because of a lack of operational research and extension effort. This emphasizes the importance of working out the operational problems for various intercropping or sequential cropping systems before making recommendations to the extension service agents and to farmers.

With the possibilities of increased yield of cereal food grains such as sorghum and millet, the farmer will need to devote less of his land to grow food grain for himself and the community. This would release the land from food-grain production to provide opportunities for more cash crops and livestock feed. This possibility for diversification should increase stability and profitability for farmers. However, farmer adoption can be made more feasible if the associated land-management and cropping systems possibilities are researched on an operational scale to develop alternative, economically viable farming systems.

Seeding and Interculture Mechanization Requirements Related to Intercropping in India

D. T. Anderson*

Abstract

Intercropping imposes a new set of requirements for seeding and for interculture. Trends for mechanization of bullock operations in India presently favor sole crop production. Guidelines for intercropping must be set out. Field research indicates the need for mechanical seed metering and for development of the unit planter concept. Furrow opener requirements on drills and planters will favor semideep or deep furrow seeding for rabi *(postrainy season) crops but considerable latitude exists for* kharif *(rainy season) crops. Interculture tools are needed which utilize sweeps instead of the blade harrow. The development of multipurpose tool bars or tool heads on bullock equipment should be encouraged.*

Intercropping offers the opportunity to increase productivity per unit area of land compared with sole cropping. It does this by utilizing crops that differ in growth habits so that peak demands for moisture, nutrients, and light occur at different stages in the crop season. The fact that two physically different crops are planted together imposes a new set of demands on tools and techniques used by the farmer for seeding, for interculture, and for other husbandry practices.

Intercropping has had its greatest research attention in areas where agricultural mechanization is least. However, in the semi-arid tropics, there presently exists a strong drive to develop suitable tools to bring the benefits of mechanization to food production. The question of degree of mechanization has been debated at length. In India it is estimated that there are 35 million pairs of bullocks, over 65 million operational holdings, and about 130 million agricultural workers. Pathak (1978) estimates that added power is needed to make 30 million farmers and about 100 million workers more productive. One of the solutions to the problem is to develop a low-cost mechanization technology for small-size land holdings. Rao (1978) indicates that the experience of the last decade in India clearly shows the need for mechanization, particularly for land preparation, for input application, and for output appropriation. He indicates that while the addition of more energy through a machine may disturb the employment level in a particular activity, studies so far indicate that the overall level of employment in the total agricultural system does not decrease. This is because the use of better equipment and energy sources in the appropriate operations leads to the creation of additional on-farm and off-the-farm opportunities.

Baig (1977) in a review of the tractor industry in India indicated that there was an acute shortage of labor during the sowing period (except on the very small farms). The farmer who walks 80 km to prepare 1 ha for seeding cannot take advantage of the benefits of timely operation; he must adopt some form of mechanization. The pace of tractorization has slowed, but not stopped, in India. Baig (1978)

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estimates that it will take 4.1 million tractors to raise India to the target of 1 horsepower available energy per ha. He indicates that 80% of the tractors in India are used for hire-services, and, thus, their benefits do reach the small and marginal farmers. It is of interest that 10% of the tractors in India are owned by small farmers who use them as a major source of income.

It is beyond the scope of this paper to do more than point out that two trends in development are apparent: the trend to tractorization continues, and a trend to mechanize the small farmer and make bullocks a more efficient source of mobile power is also evident. Those interested in developing the concepts of intercropping must be prepared to guide the mechanization process so that the capability of the farmer to carry out the technology is not lost in the process.

This paper reviews machine developments and field-research studies, and indicates some potential concepts that, hopefully, will facilitate the adoption of intercropping practices by farmers.

Constraints

Land Holdings

Size of operational holdings varies considerably within India. Size has a strong impact on the overall economics of the farm operation. Equally important to this discussion is the impact of farm size on the time required to carry out field operations such as seed bed preparation, seeding, and interculture work. Maximizing the size of machines to efficiently utilize a pair of bullocks helps to gain the advantages of timeliness in field operations.

Size of holdings and area operated are presented in Table 1, on a percentage basis for selected states to give an overview of the variation that exists. In all states except Rajasthan, between 50 and 80% of the households operate less than 2 ha of land. However, in five of these states, the land area involved is less than 10% of the total cultivated area of the state; in two, less than 20%; and in the remaining two, less than 50%. Rao (1978) has suggested that mechanization of agricultural operations has meaning only for those farmers whose holdings are large enough to sustain high levels of investment. Small farmers (less than 2 ha) may gain little from selective mechanization, unless, of course, they do not own bullocks and can utilize the benefits of hire services.

It is argued that all mechanization is meant to displace labor, gain time, and perform operations more efficiently (Rao 1978). Agriculturists must realize that mechanization (whether by bullocks or tractors) may have a function of input application divorced from purely economic considerations. For example, a seed drill that provides more agronomically sound seed and fertilizer placement than do indige-

Table 1. Percentage households and percentage area operated for different farm sizes in selected States in India.

	No. of households				Area operated			
Farm size (ha)	0-2	3-4	5-8	9-12	0-2	3-4	5-8	9-12
Rajasthan	43.5	21.6	18.1	7.2	6.2	12.3	20.8	14.5
Gujarat	58.7	16.1	14.6	5.5	7.3	15.1	26.5	18.3
Madhya Pradesh	55.0	20.3	10.3	10.8	10.0	18.5	16.2	29.1
Karnataka	57.2	21.3	12.6	7.6	8.8	21.2	24.2	16.1
Punjab	65.1	14.8	13.7	3.9	7.6	18.3	33.2	17.3
Maharashtra	61.0	14.1	27.3	10.0	8.2	12.8	24.0	38.4
Andhra Pradesh	77.1	11.2	6.9	1.6	16.1	17.8	22.2	12.0
Uttar Pradesh	77.5	14.7	6.1	1.1	32.2	29.2	24.0	8.4
Tamil Nadu	88.0	8.4	2.9	0.5	40.8	29.2	18.9	6.6

Source: This table adapted from Ryan and Associates (1974).

nous methods will be a justifiable form of mechanization even though labor displacement and timeliness are not strong factors in an economic analysis. On this basis, selective mechanization must be considered even for 2-ha farmers.

It is pertinent to point out that, on an area basis, in 5 out of the nine selected states, the less-than-2-ha farmers operate less than 10% of the cultivated lands; in two states, they operate less than 20%; and in all lands, they operate less than 50% (Table 1). If the concepts of intercropping and selective mechanization are to be utilized to increase the livelihood of farmers, the impact can be considerable over large land areas.

Seeding Rates

Seed size and rate of seeding vary considerably among crops of the semi-arid tropics. Fine-seeded crops, such as finger millet and pearl millet are sown at 10 kg/ha, while cowpea, pigeonpea, and maize usually range between 15 and 20 kg/ha. Close-seeded crops, such as wheat and rice, are sown at about 100 kg/ha, as is groundnut. The latter is one of the boldest of seeds and most sensitive to mechanical damage.

Crop combinations such as sorghum/groundnut, pigeonpea/setaria millet, maize/cowpea or cowpea/setaria millet obviously require distinctly different settings on the mechanical feed mechanism.

Hand dibbling or hand feeding into "pora" tubes is practiced with success on medium-seeded crops, such as sorghum, maize, and pigeonpea. Hand metering becomes very inaccurate on fine-seeded crops. With bold seeds, such as groundnuts, storage capacity of the hand becomes a limiting factor.

The above considerations suggest that, for intercropping, mechanized metering is desirable and thatthe unit planter concept should be considered.

Row Spacings

Row spacings vary with the different crop combinations used in intercropping studies. Final spacings usually vary from 18 to 60 cm. Sorghum/pigeonpea combinations in either 1:1 or 2:1 ratios are usually at 45 cm. Cowpeas are often seeded at the 30-cm row width using 2 or more rows of cowpeas or one row of cowpeas with one row of the main crop (e.g., sorghum or maize). Similarly, the combination of 5 or 6 rows of groundnut sown at 20- or 30-cm widths to one of sorghum or maize has been used in many studies. The close-seeded crops, such as upland rice or setaria, have been seeded at 18- to 25-cm spacings in intercrop studies.

Space for traffic during interculture and harvesting is a consideration. Crop damage from interculture toolsand transplanting by laborers, animals, or tractor wheels must be avoided. Tractors and animals require row widths of 45 cm or more for satisfactory movement at early plant-growth stages. Humans can move more easily through 20- to 45-cm rows. Simple animal-drawn interculture tools (blade harrow, desi plow) lack stability; hence, considerable side clearance (6.8 cm each side) is required to avoid damage. Hand tools can be used with considerable precision in narrow rows (e.g., 18-20 cm).

It must be recalled that on any onefarm, some sole cropping will exist. Therefore, the capability to interculture sole crops in row widths up to 75 or 90 cm must also be considered.

Time and Labor

Considerable data has been collected in India on labor and energy requirements of different crops. The data given here (Table 2) have been adapted from reports of the Coordinated Research Scheme for Energy Requirements in Intensive Agricultural Production 1977 to provide a basis of discussion. The time requirements for indigenous methods using the desi plow and hand tools show up in strong disfavor with techniques using improved tools. The advantages in labor costs are obvious. Equally important, but difficult to document, are advantages gained from doing timely operations. Moisture is lost rapidly from the seed beds on light soils. The farmer who insists on spending 200 hours per ha plowing the land after good showers are received is strictly at the mercy of the weather. On the other hand, the use of the bullock and a three-row seed drill gives a reasonable chance of obtaining a good crop stand with less dependence on postseeding rainfall.

Table 2. Approximate labor and machlna hours par hectare required for selected dryland operations.

Operation	Labor	Bullocks (2)	Machine (1)
Seedbed preparation			
Mold board plow (20 cm)	16.4	16.4	16.4
Disc harrow (twice at 0.8-cm depth)	8.6	8.6	8.6
Planting (2 m) twice	4.2	4.2	4.2
Bukhar (90 cm) once	3.7	3.7	3.7
Oesi plow four times	200	200	200
Seeding			
Three-row drill (18 cm), mechanical	7.4	7.4	7.4
Three-row drill (45 cm), handfed 2 crop + fertilizer	15.0	3.0	3.0
Interculture once over			
Khurpi	173	—	—
Wheel hoe	34	—	—
Bukhar in 30-cm rows	11.2	11.2	11.2
Bukhar in 45-cm rows	7.4	7.4	7.4
Bukhar in 75-cm rows	4.5	4.5	4.5

Source: Annual Report of the Coordinated Research Scheme for Energy Requirements in Intensive Agricultural Production (1976-77).

Results of Seeding Trials

Within the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), most centers have evaluated seeding techniques to determine potential needsfortheirareas. Some typical results extracted from annual reports of various centers (AICRPDA 1977-78) are given in Table 3. At Dehra Dun, drills established good stands, and results did not vary greatly between them. Direct seeding of upland rice proved superior to transplanting in these trials. The drills at Varanasi provided adequate stands, and results were superior to those of the country plow where inferior stands lacked uniformity.

Results of *kharif*(rainy season) seeding trials on soils subject to rapid drying (red sandy soils of Hyderabad and Anantapur) indicate that drills are generally superior to indigenous techniques. In Table 4, plant counts are clearly superior for drills or planters that mechanically meter seed, place seed at uniform depth, and provide some soil firming over the seed (Swastik drill and the planter). The pora method provides fairly precise seed placement, and, if laborers are skilled in hand metering, this method usually competes with drills in establishing stands.

Table 3. Results of seeding trials at Dehra Dun and Varanasi for upland rice, kharif 1975-76.

Seeding device	Yields (100 kg/ha) Dehra Dun	Varanasi
Double disc wheel drill	36.3	24.6
Double disc press drill	38.3	Not used
Hoe press drill (semideep furrow)	44.6	20.3
Three-row hoe drill	44.0	Not used
Country plow	40.6	17.6
Transplanting	23.3	Not used
CD. (0.05)	2.0	3.2

Source: AICRPDA (1977-78).

Table 4. Plant emergence counts (g/ha)[a] of sorghum and plgaonpaa, Hyderabad, kharif 1977.

Seeding device	Plant emergence counts (angular transformation values)	
	Sorghum[b] (%)	Pigeonpea (%)
Country plow (kera)	40.6	41.6
Country plow (pora)	45.9	37.5
Two-row cultiseeder	37.5	37.0
Reyala *Gorra*	37.1	27.8
Swastik seed drill	42.6	46.2
Single-row double disc planter	48.8	46.6
CD. (0.05)	5.2	5.6

a. Emergence figures are based on percent of seeds placed In soil that emerged as seedlings.
b. Sorghum emergence counts are averaged across three dates.

Table 6. Seeding trials for Pearl Millet, Anantapur, kharif 1975-76.

Seeding device	Yield (q/ha)
Country drill	4.7
Swasrik drill	8.0
Indo-French drill	6.1
Maharashtra Token Yantra	2.8
CD. (0.05)	0.57

Table 6. Seading trials for rabi wheat, 1974-78.

Seeding device*	Yields (kg/ha)	
	Dehra Dun	Ranchi
Three row hoe drill (bd)	3610	600
Hoe press drill (semideep furrow) (td)	4060	950
Double disc drill (td)	3610	730
Country plow (bd)	3330	550
CD. (0.05)	410	160

a. bd - bullock-drawn; td = tractor-drawn.

Results at Anantapur (Table 5) again confirm the utility of seed drills for crops grown under droughty conditions. The Swastik and Indo-French drills are mechanically metered and have an element of semideep furrow seeding in the design of their furrow openers. The other two units use tyne openers, and one uses hand metering. Stand establishment plays a key role in successful production on droughty soils even during kharif.

Under drought conditions in Ranchi (Table 6), the semideep furrow drill provided a significant advantage arising from greater uniformity of stand and earlier, more uniform emergence. Stand establishment can be a problem in Dehra Dun for *rabi* (postrainy season) crops. In the 1974-75 trials (Table 6), relatively good stands were obtained by drills. Other factors account for differences within the drills, but again lack of uniformity in country plow plots partly explains yield difference compared to drills. These and other trials indicate that some preference should be given to the furrow-seeding principle for stand establishment in rabi crop areas where receding moisture conditions exist.

In rabi areas, stand establishment can be obtained equally by a variety of techniques in some years (Table 7, Hissar 1975-76), and equal yields result. However, when surface soil has dried, some techniques fail, and either the semideep furrow technique (Table 7, Ranchi, 1975-76, item 1), or under extreme conditions the deep listing technique (Table 7, Hissar, 1974-75, item 4). At Hissar, the bullock-drawn ridger seeder (an experimental development) lacked the precision of depth control required for the seedbed conditions encountered. Normal drilling could not reach soil moisture without burying seed too deeply for emergence.

Many seeding trials have been conducted using yields as the formal evaluation criterion. Where plant emergence counts have been used for evaluating seeding methods, results confirm the desirability for using either moderate or severe lister seeding techniques (Table 8)—i.e., the semideep furrow drill or the ridger seeder. In trials at Hissar, on farm fields, several instances were encountered where adequate stands were obtained in the postrainy season using the ridger seeder, but the country plow (kera) system failed. The country plow (pora) system (especially if the rope-trailed pora tube is used) is an indigenous form of lister seeding.

Table 7. Studies with ridger seeder for rabi crops.

Seeding device[a]	Yields (kg/ha) Ranchi, 1975-76 wheat	Hissar, 1975-76	Raya 1974-75
Hoe press drill (td)	1140	1270	F[b]
Double disc drill (td)	800	1720	F
Three-row Hoe opener drill (bd)	480	1440	F
Ridger seeder (td)	Nu	1650	570
Ridger seeder (bd)	760	Nu	60
Country plow (pora)	660	1430	430
Ranchi, two-row prototype	670	Nu	Nu
C.D. (0.05)	290	NS	Not reported

a. bd - bullock-drawn; td = tractor-drawn.
b. F = Failed to establish stand; Nu = Not used; NS = Not significant.

Table 8. Rabi seeding mathods and plant emergence.

Seeding device*	Number of plants per meter of row: Ranchi, 1977, wheat	Hissar, 1975-1976 mustard at days after seeding: 10	17
Hoe press (semideep furrow) (td)	26		
Three-row hoe drill (bd)	32		
Ranchi, two-row prototype (bd)	35		
Lister seeder (td)	Not used	19	21
Country plow (kera)	18		
Country plow (pora)	Not used	8	12
C.D. (0.05)	7	—	—

a. bd = bullock-drawn; td = tractor-drawn.

It is frequently comparable in performance to the semideep furrow drill; occasionally to the ridger seeder. Because it is hand metered, crop stands can be variable.

Wright (1971) in a review of drought stress on plants has highlighted studies on stress on seedling growth. Two environmental factors play a role. These are moisture and temperature. High soil and air temperatures and water stress following imbibition of moisture by seed can seriously reduce seedling vigor and hamper growth.

Detailed measurements of seedbed environmental conditions have yet to be made for rabi and kharif seeding conditions in India. It is reasonable to assume that the success of lister seeding for rabi crops is attributable to better seedbed environment, leading to uniform stands with good seedling vigor. In kharif cropping, seeding usually occurs during periods of high rainfall probabilities. A wide variety of techniques can be successfully used for either sole or intercrop plantings. Where relay cropping is advantageous, early in-crop planting may provide good seedbed moisture conditions for shallow seeding techniques. However, under rapidly receding surface moisture conditions, lister seeding may be needed to establish stands of the relay crop within a rapidly maturing kharif crop where soil moisture is being rapidly depleted.

Results of Interculture Trials

It is no secret that weeds rob crops of moisture and nutrients and may compete for light. Weed control costs money and time. Quantitative evaluation of effects is crop and area specific. In intercropping studies, adequate and timely weed control is an essential component for high yields. In India, where dryland crops may be in competition with irrigated crops for labor, timing of weeding operations can be a critical management decision and a critical agronomic decision. Selected results of weed control studies are presented.

Data are given in Table 9 for three AICRPDA Centers and Table 10 for ICRISAT. All crops are sensitive to weed infestations at the seedling stage. Cotton (Table 9) and groundnut (Table 10) may be more sensitive.

Data have been presented earlier to indicate

Table 9. Timing of interculture at three AICRPDA centers.

Weed Control at:	Yields (kg/ha) Sholapur, 1973, pearl millet, HB3, weed infested	Ranchi, 1974, upland rice Weed infested	Weed-free	Akola, 1975, cotton weed-free
First 10 days	1420	2540	1430	80
20 days	1380	2750	2400	-
30 days	540	2270	2790	410
40 days	570	1760	2960	-
50 days	230	1530	2760	730
Till maturity	130	97	2720	-
CD. (0.05)	363	6.8		216

Table 10. Effects of different weed-free periods following kharif planting for aavaral crops on rod soil, ICRISAT.

Crop	Yield (kg/ha) at weed-free weeks: 0	4	6	8	10
Sorghum	800	1500	1700	1800	1800
Pearl millet	500	1200	1500	1700	1700
Sorghum intercrop	1800	2200	2400	2600	2600
Groundnut	600	1300	1800	1900	1900

Source : Adapted from Figure 40, page 177, Annual Report ICRISAT(1976).

Table 11. Weed control using various hand tools, Varanasi.

Tool	Yield (kg/ha) Paddy, Kharif, 1976	Wheat, Rabi, 1977-78
Three-tyned hand hoe	1550	2550
Three-tyned wheel hoe	1680	2840
Sweep hand hoe	2020	3020
Paddy weeder	1230	Nu
Dryland weeder (blade wheel hoe)	Nu	3150
Control (weedy check)	1160	2330
CD. (0.05)	340	410

Table 12. Weed control in pearl millet, Agra, Kharif 1977.

Treatment	Yield (kg/ha)
Hand weeding	1200
Atrazine	1120
Dryland weeder 20 days after sowing	950
Dryland weeder 30 days after sowing	940
Dryland weeder 30 days after sowing + intrarow hand weeding	1160
Country plowing	820
Control (weedy check)	770
CD. (0.05)	170

the labor requirements for some operations including manual and machine operations. Hand tools play an important role in increasing labor efficiency. Studies have been carried out at several centers to evaluate the usefulness of improved hand tools. Data for three centers are presented in Table 11.

At Varanasi (Table 11), most hand tools increased weed control efficiency over the check in both kharif and rabi. Sweep or blade-type wheel hoes or hand hoes appeared to be more efficient than tyned tools or the paddy weeder.

At Agra (Table 12), the blade-type wheel hoe has proven effective in weed control, and the necessity for intrarow weeding is apparent. The ineffectiveness of the country plow as an interculture tool is also apparent.

Data from Hyderabad (Table 13) clearly illustrate that, despite variations in planting patterns, which might facilitate effective blade harrow operations, the need for within-row weed control exists. Where utilization of labor is a consideration, hand weeding using an efficient hand tool is agronomically an effective

Table 13. Intrarow hand weeding for castor-bean, Hyderabad, kharif 1976.

Planting pattern	Blade harrow interculture	Intrarow hand weeding	Yield (kg/ha)
90 x 22.5 cm	2 operations	nil	1210
	2 operations	twice	1500
135 x 15 cm	2 operations	nil	1070
	2 operations	twice	1420
90 x 40 cm	2 operations	nil	920
	2 operations	twice	1430
135 x 27 cm	2 operations	nil	950
	2 operations	twice	1520
45 x 45 cm	2 operations both ways		1200
60 x 60 cm	2 operations both ways		1130
CD. (0.05)			380

substitute for in-the-row chemical treatment. Intercropping systems involve different plant types. Cultivating close to plants may be difficult for multirow tools. Effective hand tools will play a role in the system until such time as an improved interculture mechanization technology is developed. At present, Indian farmers have a limited choice of tools for interculture work.

Machinery Development

Seeding Machines

In India today there is considerable activity aimed at developing improved farm implements and hand tools. Most of this activity at various institutions is guided by Indian Council of Agricultural Research (ICAR) f arm machinery development scheme. Sridharan (1977) has summarized developments in seeding mechanisms. The devices described (a total of 61 now in use or under development) range from one- to nine-row drills with one- to three-row models predominating. About half are seed-cum-fertilizer drills. The fluted rooler, the plate, and the internal run metering mechanisms predominate. Shovel, boot and knife-type furrow openers are common, but for seeding under dry conditions the lister or ridger opener is now in use. It is importantto notethat, in the review, none are listed as planters for common row crops, although one or two of the machines could be classified as planters. Several of the seeding machines described by Sridharan (1977) have been discussed in other technical reports (AICRPDA 1978, Panigrahi et al. 1976, Sandge 1977, Srivastava 1975, Verma et at. 1977, and Yadav and Wagh 1977).

Among the machines in use or under development in India, only a few are easily adaptable for use in intercropping. These include the machines equipped with both a large and a fine-seed box plus the fertilizer box at Sholapur and Hissar (AICRPDA 1978) and the single-row bukhar-cum-ferti seed drill at Jodhpur (Yadav and Wagh 1977). The latter is bullock-drawn and is capable of adaptation to tool-bar mounting for use as a unit planter.

Intercropping imposes additional requirements on seeding techniques. Generally unit planters, i.e., one unit per row capable of adaptation for either kharif or rabi seeding, are most useful for multicrop seeding.

Interculture

Recently there has been considerable activity within SAT countries to develop multipurpose animal-drawn tool bars. These units utilize a tool bar, or bars, as a base for mounting a wide range of tools for tillage, for interculture, and for seeding. In some cases, the cart can also be used as a transport vehicle. Descriptions of several of these follow.

The "Vorsatool" is a two-row, tool bar carrier, which is usable for a complete range of tillage and seeding operations. This tool was developed in Botswana and has been described by Gibbon (1974).

The "Kenmore" toolbar is a development imported from England. It is under test at the College of Agriculture, Indore (AICRPDA 1978). The wheel-mounted unit carries a full range of cultivator tools and seeding and fertilizing attachments.

The "Tropiculteur" is an animal-drawn cart tool bar, produced commercially in France. The machine is under indigenization in Hyderabad and improvement at ICRISAT (ICRISAT 1976, 1977). A complete range of tools is being developed for the cart.

The "Snail" is an attempt to increase the efficiency of the single-axle tractor for traction work. It utilizes a walk-behind tool bar frame pulled by a winching arrangement on the tractor. Development reports have been summarized (Muckle et al. 1976).

The tool bar concept is in use in India. Blade harrows (bukhar harrows) have been modified for carriage of tools, and a selection of blade widths are available, on modified head pieces, for interculture work. The blade, the hand wheel hoe, and the khurpi are the present farmer standby tools for interculture work in an intercropping system. The blade plugs easily when stubbles and stemmy weeds are in the field. Attempts are being made (AICRPDA 1978) to adapt the sweep on simple tool bars to improve field efficiency and work quality and also to improve the hand tools (Muckle et al. 1976).

Prospects for Mechanization

There is active interest in India in mechanization technology for small farms. Field experience is accumulating on the agronomic and other guidelines required for machinery development. With the continued growth in India of agroservice centers, now numbering about 3000 (Baig 1977) and of a large network of dealers and interested government agencies, the infrastructure required for animal- and tractor-powered mechanization exists. Infrastructural growth must continue. The natural trend for mechanization is toward sole-crop husbandry. Given early guidance on equipment needs for farmer-acceptable intercropping systems, the industries supportive to agriculture will fill the need.

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Discussion

Statistics

Rana

When we consider the LER, this is not related to the total productivity or the total returns of a system. Thus LER has very limited use and I think we ought to use it cautiously. Also LER is a ratio, so should not some transformations be done? If LER is not very satisfactory, can Mr. Mead suggest some multivariate analysis which might be appropriate? Further, is a single sole plot of each crop enough, or should there be more sole plots, e.g., for every level of fertilizer, each population, etc?

Mead

I think your question about having different levels of yield for any given LER was quite satisfactorily taken care of in my suggested standardizing procedure. I agree that a given LER is only appropriate for a particular intercropping treatment. But if you are comparing different treatments and using the same standardizing yield, then LERs between those treatments are comparable.

Willey

I think the problems that we are suggesting for LER are not inherent in the LER itself but in the terrible things that we try to do with it. I tried to define LER in my opening talk. I said it was the relative physiological efficiency, and, being a relative term, we must give some indication of the absolute yield level that we are talking about. I agree, as has just been pointed out, that a high LER value at a very low yield level may not mean very much to the farmer. However, one of the first things we are looking for in any intercropping situation is any evidence of improved physiological efficiency. If there is such evidence, then that situation may be worth exploring further. If there is no improvement in physiological efficiency, then there is nothing we will ever get out of that situation.

Mead

As an example of what Dr. Willey has just said, let us consider the millet/sorghum data I had referred to. Taking the actual millet and sorghum genotype yields for each combination, we can get an indication of the physiological efficiency and we then know which particular combinations can give advantages in terms of their own sole crop yields. On the other hand, taking a single common sole sorghum yield and a single common sole millet yield, gives the yield comparisons. Between both of these it seems to me that you answer both the questions about biological efficiency and about yield comparisons.

I would like to also comment on the use of split plots because in our paper we argued against this particular design. The problem with split-plot designs is that you divide your information. You get better information on some comparisons — i.e., those that are in the subplots. But you get poorer information on those that are in main plots, and this is not just for the main plot treatments but it is for the main plot comparisons between particular subplot treatments. And we have seen several split-plot designs used in this conference where only one standard error is given, and this must be wrong. The split-plot design leads to a multiplicity of different standard errors and what you lose on those comparisons of poorer precision is a lot more than what you gain on those comparisons of better precision. So you have to think very carefully about your split-plot designs and be absolutely sure that you do not want any information on those main plot treatments.

Jodha

What kind of problems do you think we run into when we use systematic designs?

Mead

We run into problems when the area over which those systematic changes occur is markedly heterogeneous. But one of the advantages of using a systematic design is to get down to a small block size and hopefully in some situations the block will be more homogeneous. You will then get much more precise comparisons.

Snaydon

We have been talking about systematic designs as if we had only one block. But perhaps what we really need to be doing is to be comparing densities or different ratios or whatever over a range of different conditions. So you have a series of blocks at, say, different nitrogen levels, phosphate levels, etc., and we then have replicated the systematic part of the design. We would then be able to use an analysis of variance on that systematic part.

Mead

In such a systematic arrangement, one would probably fit a regression relationship over the systematic range of factors, and then observe how our relationship varied with the other factors. In effect, one would carry out an analysis of responses. One would not be analyzing a given crop yield, but a response to a wide range of densities. This can be quite easily done.

Shetty

In our weed science experiments we usually have a weedy check plot where we have often 200 to 300 g/m^2 of weed and this may be compared with a weed-free situation where we do not have weeds at all. Yet when we try to use an LSD we still do not get significance. Can Mr. Mead comment on this please?

Mead

If you have a weedy check plot I think to some extent you are only putting that in to see how much weed you would have got and you do not necessarily have to include that in the analysis. Also I would be very surprised if in your weed experiment the variability of yield over particular treatments stayed the same overall treatments. In other words you need a transformation. You almost certainly have multiplicative effects, and therefore you could use a log transformation, or a square root transformation, for your weed counts. In this way you would avoid most of the difficulties.

Willey

How much difference does this bivariate analysis make compared with the very common practice of simply plotting the yield of one species against the yield of the other species on a straightforward 90° angle?

Gilliver

It depends on the size of the angle that you get. If the angle is in fact 90°, then there is no correlation between the two crops. So there is no advantage of doing it this way.

Willey

We appreciate that, but what I am really asking is how often in practice do we get an angle that is sufficiently different from 90° to make an observable difference to the analysis?

Gilliver

In some of the experiments that we have analyzed we have got angles up to 110 or 115°, and that is a quite considerable effect, of course.

Mead

I like the idea of plotting the two yields on angled axis, but is it not true that you make the assumption that this angle is the same for all treatments. Do you in fact have evidence that this is correct?

Gilliver

This is one of the criticisms that is leveled against this method. You are in fact making the assumption that you have a constant correlation between the two crops in all your mixture treatments. In fact we know that in most instances this will not be true. But I think it is better than assuming it is zero, which is what you do if you plot on a 90° axis.

Yield Stability and Economics

Chairman

I think Dr. Jodha deserves our congratulations for drawing our attention to something which has so far been very much lacking in our intercropping considerations, and that is the inputs as opposed to the outputs. We have previously concentrated very heavily on the outputs, measuring them in all sorts of ways, but this is one of the first occasions when we have considered inputs, both labor and financial.

Lira

I have heard no one yet talk about cattle in the system. Is there not a need in many situations to grow an intercrop to produce some forage for cattle? I am worried that we may be oversimplifying the system.

Jodha

I think I mentioned that one of the objectives for the farmer is to have sufficient fodder for his animals. So, I agree producing fodder is one of his objectives. We have not analyzed this yet, but I think we may show that a farmer with more animals will probably produce more forage amongst his intercrops.

D. Sharma

Dr. Jodha has said that high-yielding varieties do not appear to be used in intercropping, and he has said that more use of high-yielding varieties would lead to sole cropping. The example he gave was hybrid cotton. I feel that because hybrid cotton is a very sophisticated crop with high level of crop management and requiring a whole lot of inputs, the farmer grows it only in a very assured environmental situation. In contrast, we find that the area of high-yielding varieties of sorghum in Maharashtra has increased considerably. And this is widely used in intercropping with pigeonpea. So I think your statement depends entirely on the cropping situation and the crops you are handling.

Jodha

In general I agree that many of these effects will be crop specific but in my data for Akola, 90% or more of the cotton crop was intercropped. But this was not a hybrid crop. Once you have hybrid cotton the proportion of intercropping goes down.

Ryan

One reason why the introduction of high-yielding cereal varieties tends to lead to sole cropping, is that almost exclusively they have been shorter-duration varieties. This factor leads to a substitution of more double cropping. Thus with the short-duration, high-yielding varieties farmers try to get them off the ground quickly, which they cannot do with the traditional intercrops containing one long-season crop, and then they try and follow with another crop in a sequential double crop system. We have observed some of this in our Village-Level Studies. It is also because of this type of system that I would question the LER because in a short crop/long crop intercropping system, the LER calculation tends to favor the intercrop system because it ignores the possibility of growing a further sole crop after the short-season crop, if it was sole.

M. R. Rao

In discussing the sorghum/groundnut system Dr. N. G. P. Rao said in his paper that in the predominantly sorghum system it was more stable than a predominantly groundnut system. Can you comment please?

N. G. P. Rao

Yes. There were reciprocal effects. In the sorghum/groundnut system the groundnut yield went down and the sorghum yield was maintained. On the other hand, groundnut as the main crop showed that the groundnut/sorghum system was not stable. This was obvious from the data.

Gilliver

When you are using total yields over all your crops, and comparing these within the system, I wonder if your analysis of variance assumptions are relevant. When we try to do this with our combinations at IITA, we have anything but an additive model. Have you tried to do this?

N. G. P. Rao

We have probably come near this in some of our plant breeding techniques, for example, the line tester mating systems. Here you put the female on one side and the males on the other and you have all possible combinations. You can thus get out the female effects and the male effect. I believe this kind of analysis is more advantageous than simply growing the mixtures and studying competition. In this way you could get both intercrop effects and main crop effects possibly averaged over several systems or several densities. I would not comment on the statistical aspects but this I believe has been done by many competent workers. For example, Breeze and Hill in the U.K. have adapted a regression technique for analyzing competition.

Mead

I think that these regression techniques were probably taken up for use with quite large numbers of different environments. Here you are dealing with a very small number of crops. In one instance you are regressing the yield of one crop on the average of that crop with three others. And I wonder if this gives you much value in terms of looking at small differences between regression coefficients.

N. G. P. Rao

But such data is very often replicated over different locations or different seasons.

Chairman

I was also a little worried about those regressions. I was concerned about what proportion of the variability was accounted for by the regression.

Rana

The calculations showed that the proportion of variability accounted for by the linear regression varied between 40 and 70%.

Chairman

I felt that Dr. Chowdhury's data needed examining a little bit further. For example, I found that of his eight nonlegume mixtures none gave higher expected monetary value. In the case of chickpea and other legumes in only 20% of the cases was there a larger expected monetary value. But in the case of pigeonpea, 50% of the cases gave a higher monetary value than the sole crop. I think these situations are probably worth noting.

Baker

Dr. Chowdhury's emphasis on cash returns does imply that the farmer is cash oriented and that he is therefore not a subsistence farmer. So to use a 50 : 50 situation to argue that a mixture is more or less remunerative is probably incorrect. I would like to ask Dr. Chowdhury what value he places on the cereal food supply in the subsistence situation and when the farmer must ensure himself of that food supply.

S. L. Chowdhury

I would not agree with Mr. Baker because, whether the farmer is a subsistence farmer or more progressive, ultimately he will be concerned about what he is spending on crops and what he is getting in return.

Ryan

I think the answer to that question is that even subsistence farmers in the interior who may not go to markets can tell you the prevailing sale prices for the produce. If this is so, even though they do not actually enter the cash market, by opportunity cost principles the fact that they know the prices means that it does enter into their decisions about proportions of crops which they grow.

Sivakumar

I think it would be a lot more meaningful if you were able to group the data into different agroclimatic zones, for example, on the basis of moisture available in the soil profile, and then to compare within these agroclimatic zones.

D. Sharma

Of all the combinations referred to there seems little doubt that sorghum/pigeonpea is one of the best systems. But when we talk about the stability of these two crops in an intercropping system I think we are talking in a very ill-defined way. If you suggest that 3:1 or 2:1 systems are the best and the most stable, why do we see such a high range of different systems and combinations as we go from one area of India to the other? I think insect pests are probably one of the more important aspects in determining stability. I am sure that the big differences in the proportion of pigeonpeas which the farmer grows is to guard against losses by borers and other pests. My feeling is that if we are going to talk about stability we must define the environment not only in physiological or soil terms but in totality by including such factors as pest incidence.

N. G. P. Rao

There are two aspects of intercropping. One is the principles involved and the other is the practice of it in particular regions. In relation to the principles, I think we are attempting to understand these and they can be examined in relation to a few known parameters. But I think it would be extremely difficult to define the whole gamut of things to make up the environment, e.g., the pest incidence, or disease incidence.

M. S. Chowdhury

I am a little confused about the economic returns from the sorghum/pigeonpea system. The earlier paper we had from Dr. S. L. Chowdhury showed that in all except one case, the sole pigeonpea was giving greatest returns. Yet in Dr. M. R. Rao's paper, the returns were always less from pigeonpea than sorghum or the intercrop. I find this puzzling.

M. R. Rao

Dr. S. L Chowdhury considered only a few experiments and locations. My data considered a very wide range of different experiments and locations, over a period of 5 years.

Chairman

With reference to Figure 7 in your paper, although the regression lines are more or less equal, perhaps the important point to notice is the great variation that occurs round about the line for sole sorghum, and the relative stability along the line for intercropping. So I think we should be careful not to use just the regression constant itself.

M. R. Rao

The regression lines for the intercropping and the sole sorghum gave a very good fit, anything above 90%, whereas the pigeonpea fit was only between 40 and 80%.

Rana

Your stability analysis is based on the mean of three treatments: sole sorghum, sole pigeonpea, and intercropping. One will always find that pigeonpea, being inherently lowyielding, is atthe bottom and the intercrop and the sorghum are increasing. This is a very inadequate way of defining the environment.

M. R. Rao

I did mention that we considered it and that the mean yield of these three systems is a poor means of characterizing the environment, compared with the mean yield of many genotypes of the same species which mature at the same time.

Ryan

Considering the method of comparing sole and intercrop, it seems that most of the comparisons of profitability and stability are between the total intercrop and the individual sole crops. I wonder if it would be more valid to compare sorghum and pigeonpea grown either as intercrop or as sole crop. By bulking the sorghum and pigeonpea yields together in intercropping, are we not biasing the comparison in favor of the intercrop. This also applies to your regressions against the environmental index where you are only comparing sole crops and not combined sole crops.

Willey

We did make this comparison. For example, the last graph, which I believe is the key to this paper, shows the probability of failure for the individual sole crops, the intercrop, and the "shared sole" crop, this last being the situation where the farmer grows both sorghum and pigeonpea separately.

I would like to add one brief comment here about the principle of comparing the value of the intercrop with the valueof thehigher value sole crop. In practice this does make the assumption that growing only that higher value sole crop is a valid practical alternative to the farmer. And for a host of reasons which are not necessarily related to intercropping, the farmer may often want to grow more than just that one crop. He may want to grow two or three crops. And this is why I think the comparison of intercropping must often be with growing some of each of the sole crops.

Mead

As long as we try to find any one index of yield which is the best one, we are doomed to failure. We should recognize that all the indices that we are talking about have several faults. The problems of LERs have been pointed out; monetary values have faults because if we carry this to one extreme we end up by growing nothing else but pigeonpea. We need to do the kind of thing that Dr. M. R. Rao has done and consider a range of indices, although I am not sure that Dr. Rao has considered a wide enough range.

Laxman Singh

In a rainfed and low fertility situation, one of the factors in intercropping is that the farmer is able to increase his cropping intensity by growing both the kharif and rabi season crops together. The farmer also often uses broadcast or scatter planting. I would like to see some of our competition studies including this broadcast or scatter planting system.

S. L Chowdhury

I would doubt the value of such studies because of the many advantages that we recognize for crops grown in rows.

N. G. P. Rao

On the question of various environmental parameters including pests and diseases, I think we should go back to Finlay and Wilkinson's paper where they first used the term "environmental index." I think they made it clear that since measurement of the individual parameters is very difficult, the sum total of the effects of the individual parameters would be indicated by the ultimate mean yield. So that is probably still the best way of measuring the sum total of all the parameters.

Gilliver

But this environmental index was designed to compare a number of genotypes over a number of sites. And as Or. N. G. P. Rao said, we use the environmental index as a measure of the environment at the individual sites. But if we look at the paper which Dr. M. R. Rao has presented, when you are using total returns and just using two crops in combination, it is obvious that the crop that yields less is going to giveyou the smaller slope. So I do notthink that is a very good measure of stability. I think we probably need to look at these different sites and try to identify some of the characters such as rainfall, altitude, and so on and see if we can account for some of the variability in the data due to these factors.

Chairman

I must agree with Dr. Gilliver on this. I am particularly unhappy about the use of an environmental index to try and simplify what is essentially a very complicated thing. And if any of you have not read Knight (1971) on his criticism of environmental index I would suggest you do so. He certainly pulls the concept of environmental index to pieces.

Rajat De

Mechanization for intercropping may be relevant where line sowing is practiced. But we have been given many examples from Africa and from Brazil where the crops are not sown in rows. In such situations, what is the relevance of mechanization?

Anderson

I think this question presupposes that there is not going to be any change in the planting pattern. But I can think of areas within our scheme in India, for example the Bangalore region, where for centuries finger millet has been broadcast. Due to operational-scale research by the University of Agricultural Sciences, Bangalore, in the last few years, most farmers have now converted to line sowing. Further, a 150 rupee drill (US$ 20) has been devised and already 500 units have been sold this season and a 500 more are being made. So the farmers are converting to line sowing. And the same thing is happening at Ranchi in Bihar state. Once this happens, then mechanization can take off.

Krantz

I feel that there are definite advantages here with mechanization, and of course it is likely that some day labor will not be as cheap as at present. When this happens, we will automatically move to better technology which will include some type of mechanization. But of course that does not necessarily mean a combustion engine; we may well be talking about animal power.

Operational Management

Mead

I would like to query whether Dr. Krantz's interpretation of synergistic effects between "improved" factors in the "steps-in-technology" experiment is in fact the simplest one. It seems to me that each of your three steps in improvement produces a very consistent proportional effect. And the results of imposing the three together is to simply multiply the three proportional effects. And I would have thought this is what one would expect biologically.

Krantz

Well, perhaps synergistic is not a good word, but I like to illustrate it by saying that 2 + 2 + 2 gives 8.

Baker

In areas of the semi-arid tropics in Northern Nigeria, the major components of intercropping systems are almost all line sown. It is the apparently random sowing of the minor crops which are filled in which gives the apparent mixed pattern.

Plenary Session

Chairman: R. C. McGinnis **Rapporteur: G. D. Bengtson**

The Chairman opened the session with the remark that the session chairmen will first present brief summaries of the highlights of the individual sessions. Session 1 was divided into three subsessions — (a) India, (b) Brazil and West Africa, and (c) East Africa and Genotypes. Following these reports, there was a general discussion of the major points brought out during the Workshop.

Summary of Session 1 (a) India

D. J. Andrews — Chairman

Five papers were presented in this session. Dr. Rajat De reviewed a number of typical traditional intercrop combinations in India and some more recent ones developed with irrigation. Increased water-use efficiency and reduced pest and weed incidence could be noted. Research has shown that a number of management factors can enhance production from intercrops, e.g., (1) choice of crops, (2) use of new, shorter-duration varieties, (3) staggering the time of planting, and (4) adjusting planting geometry.

In his first paper, Dr. S. P. Singh showed that sorghum yields were not reduced when rows were paired 30/60 cm compared with rows at a uniform row-width of 45 cm. This arrangement permits a range of intercrops to be grown, both in irrigated and rainfed conditions, such as cowpea, soybean, green gram, black gram, pigeonpea, castor, cluster bean, *Dolechos,* and groundnut. In some experiments increased yields of sorghum were noted with some legume intercrops.

In his second paper, Dr. Singh et al. showed that, in the case of millet and legumes, the intercrop effect can be increased by transplanting the millet into the previously sown stand of the legume. Millet is still able to realize its full potential and legume yields are increased due to the delayed competition. However, the effect could be lost by delayed planting, or delay in transplanting beyond 14 days.

Dr. Venkateswarlu reported on the sorghum/pigeonpea intercropping work in dryland conditions in Andhra Pradesh. Improvements over traditional ways of growing this intercrop were found by using earlier-maturing, higher-yielding sorghum hybrids, crop protection measures, increased plant populations, and different row arrangements.

Dr. Tarhalkar again used sorghum as a base crop investigating the best way of intercropping with several legumes and castor, but principally with pigeonpea. High returns were recorded with hybrid sorghum and new pigeonpea genotypes; sorghum appeared slightly better with a late, erect type of pigeonpea, HY-3a, than with an early bushy type, HY-2.

The principal point of the discussion that followed was the possible exchange of nitrogen from legumes to the cereal. There appeared to be a lack of conclusive evidence on this point, which might be worthy of definitive experimentation.

It was pointed out that some of the proposed manipulations, such as staggering of planting, would not work in dryland farming when there were other more compelling reasons for timely operations. There was some discussion on whether density effects with changing geometries were being confused with intercrop effects. It was generally accepted that increased densities were often necessary to get maximum yields from intercrop mixtures.

Most of the work reported in this session dealt with two-crop mixtures, but more complex mixtures are often used by farmers. The degree of importance of intercropping in the overall production of a state or a country was not quantified nor was the value of Intercrops in erosion control. It was shown that new genotypes and management practices could be profitably used in existing intercrops in India although the pest and disease aspects could not be overlooked. Significantly, all the new genotypes involved had been developed under sole-crop conditions. The time is ripe to consider designing experiments for prediction purposes, rather than for solving individual problems; this would obviate the need to try out every variety combination.

Some thought should also be given to expanding research on mixtures other than those where the base crop is required to give an yield close to the sole crop (Baker's superimposed type of mixture). In India the base crops are all cash crops, or of high-energy value. The other type of mixtures (the replacement type of Baker) offers better chances of higher total productivity.

Summary of Session 1 (b) Brazil and West Africa

Rajat De — Chairman

Or. Lira discussed his study of intercropping corn and sorghum with cowpea and beans in two ecological zones of Brazil. He showed that sorghum, because of its higher stability, could replace corn in a corn/legume system.

In his analysis of population, time, and crop mixtures of Nigeria, Mr. Baker concluded that the effect of plant population change within the crop mixtures depended upon the type of mixture, whether "replacement" or "superimposed." Plant size and length of the season were the two determining factors. He felt that the genotypes for replacement mixtures should be plastic in behavior.

After describing the soil and climatic features of the West African semi-arid tropics, Dr. Stoop discussed the implications of these parameters on the stability of the traditional cereal/legume cropping systems. He advocated the development of productive cereal/cowpea cropping systems with improved sorghum, millet, and cowpea varieties.

Or. Yayock described the state of agriculture in Kaduna State of Nigeria. He also suggested improved cultivars and management for increasing the productivity of intercrop systems.

A lively discussion followed. One of the points raised was the role of mechanization in the African SAT. It was suggested that there is scope for the introduction of improved animal-drawn implements. Another point was the need to develop suitable intercropping systems for particular soil and climatic conditions including the need for breeding legume genotypes suitable for such situations.

Complementarity in legume/nonlegume associations was also discussed. Several speakers noted the positive aspect of this association.

Summary of Session 1 (c) East Africa and Genotypes

N. G. P. Rao — Chairman

On cereal/cowpea mixtures, Dr. Wein and Dr. Smithson outlined a sequence of six steps for the selection of genotypes for intercropping. While endorsing the strategy, the Chairman suggested that some priorities be set up within that general framework. The components of an intercropping system should first reflect reasonably good yield and stability of performance under monocropping in the area concerned. The second step is genotype selection in terms of growth habit, canopy display, rooting pattern, and so on. Selected genotypes may first be put in genotype/density studies, preferably in systematic design because these occupy less space. It is at the third stage that one can go to actual selection of genotypes in the intercropping situation.

The next paper, by Dr. Willey and Dr. Rao, discussed three intercropping systems studied at ICRISAT. The first involved a single sorghum genotype, with 17 pigeonpea genotypes; they recommended a compact growth pigeonpea in the early stages with a spreading habit later. The second study was based on three millets and four groundnut genotypes; they felt that the advantage was derived by the groundnut genotypes. The third study reported was on the millet/sorghum combinations.

The Chairman commented that it is desirable to have a pigeonpea genotype of an appropriate duration because otherwise, even if the plant type is right, it may not be useful. Studies by the Indian national programs have shown that groundnut is highly sensitive. Improving groundnut for yield is difficult, and to improve it for intercropping is particularly difficult. Therefore, it would be preferable that to begin with the best groundnut genotype available be used and then select the other component, say a millet which is less leafy, has a single stalk to give less competition, and is a short-duration type. The emphasis should be on the other crop rather than on the groundnut.

In East Africa, there are various conditions starting from the monsoon-type situation of India, the high altitude/high rainfall situations of bimodal distribution, and moderate rainfall areas of unimodal distribution. In many of the moderate and high rainfall situations, there is no great pressure on land, certainly not equivalent to the land pressures of Southeast Asia. Under such circumstances, if a scientific intercropping system is to be introduced, the entire farming system has to be changed. Unless substantial advantages of new cropping systems are demonstrated, it would be rather difficult to change the farming system. It may be specially necessary to show sufficient monetary advantage of an improved cropping system.

The second point is that, especially in the bimodal rainfall situations, the system should be a short-season crop combined with a long-season crop. Research in India has shown that in these situations two consecutive sole crops are more profitable. As an alternative, it is suggested that in the first season the components of intercropping should be of single duration so that the land is clearforthe possibility of growing a second crop. Thus, the merits of a two-crop system versus intercrop or single-crop system should be established.

With regard to target areas and target crops, we have to identify the target areas, then the target crop, and from that point proceed to develop an appropriate intercropping system. To find the intercropping system first and then try to find the target areas is likely to be difficult. It is obvious that in East Africa the scope for intercropping in the high potential areas is rather limited. In the marginal areas, efforts are being made to settle farmers and to replace mai2e with sorghum.

Regarding the criteria for selection of component crops, particularly in the subsistence farming situation in Africa, if at least one of the crops is resistant to the birds, then this is one component which should receive emphasis in the intercropping system. The other important factor is the capacity of the crop to suppress weeds, e.g., a crop that grows quickly and thus provides canopy cover. In India there is evidence that when certain crops are grown, they do stimulate *Striga* to germinate but do not provide host crops. This applies to *Striga asiatica* and it is not known if this is so for *Striga hermonthica.* These problems could be resolved if they became a part of the criteria for selection of component crops.

Dr. Nadar seemed to be doing an excellent job trying to quantify the environment and develop the various systems. The emphasis thus far has been on maize, and if Dr. Nadar and others take care of the changing situation in the marginal areas and then develop models to decide the most suitable system, they will have a wide applicability.

Summary of Session 2 Physiological Aspects

J. S. Kanwar — Chairman

Dr. Trenbath gave a very clear theoretical analysis of light use by plants in intercropping and suggested several characteristics that may be desirable in intercropping. He emphasized the necessity for field experimentation to test the validity of these considerations. If the theory is borne out by such experimentation, then we will need to develop simple methodologies that can be used to identify crop varieties and species that are suitable for intercropping.

Dr. Okigbo discussed intercropping in the humid tropics. He underlined the problems of a large number of intercropping systems that are relevant to these environments. Growth analysis for complex intercropping systems was found useful in the study of plant-crop competition and in the development of a strategy in cropping systems research.

From a study of sorghum and pigeonpea intercropping on the Vertisols, Dr. Natarajan and Dr. Willey showed that in a 2 row sorghum: 1 row pigeonpea system the yield of sorghum was similar to the sole sorghum, while the yield of pigeonpea was 70% of its sole crop yield. Light interception by the intercropped pigeonpea was very low immediately after the harvest of sorghum, and it was suggested that this was a factor that needs improvement.

Dr. Snaydon and Dr. Harris emphasized that in the SAT it is not light but water and nutrients that are the limiting factors. They suggested that research should be directed to the manipulation and improvement of efficiency of these factors. The experimental evidence showed that plant interactions below ground can be more intensive than those above ground, though the particular limiting resources and the mechanisms involved have rarely been studied in detail.

Dr. Reddy and Dr. Willey reviewed a pearl millet/groundnut intercropping system that gave an yield advantage of 26% in seed yield, mainly by improving the efficiency of light conversion. There was no evidence that the intercrop root system was any more efficient than the root system of the sole crops.

Dr. Rego, from a study of the effects of variation in nitrogen and plant population on a sorghum/pigeonpea intercropping system, reported that intercropped sorghum responded to the application of nitrogen similar to sole sorghum. Pigeonpea did not seem to contribute any nitrogen to its companion sorghum, although at a high level of nitrogen application, there was a marginal benefit to the pigeonpea along with a substantial benefitto the sorghum.

Dr. M. S. Chowdhury discussed his sorghum/chickpea intercropping experiments in Tanzania. There was not much evidence of N contribution from chickpea to sorghum.

A few recommendations emerged from the discussion that followed. Realizing that moisture and nutrients are the major limiting factors in SAT crop production, and that intercropping is a means to achieve stability in production under subsistence-farming situations, highest priority should be given to research on improving the efficiency of the soil moisture and nutrients through intercropping. The conceptual and theoretical evidence regarding the interception and utilization of light needs to be tested in well-planned field experiments. In the area of nitrogen fixation, the question of contribution of the legumes to the companion crop in the intercropping situation in the field remains unanswered. Critical experimentation using reliable methodology for measurement of the benefits is needed.

Summary of Session 3 Plant Protection Aspects

B. R. Trenbath — Chairman

In the paper by Dr. Moody and Dr. Shetty, the authors found no clear-cut advantage with respect to weed incidence in intercrops as compared to sole crops. A wide survey of literature showed variable results in which weed levels were lower in the two-component intercrop than in both corresponding sole crops, were lower than in one of the sole crops, or showed no difference. The Chairman said that the result would have been expected to depend on the type of intercrop considered. In a substitutive intercrop, if the two components differed in their aggressiveness, fewer weeds might be expected in the intercrop than in one sole crop. If, on the other hand, the components had similar aggressiveness, then no difference would be expected between intercrop and sole crops. However, in an additive intercrop, fewer weeds would be expected than in either sole crop. When the data have been analyzed according to type of intercrop involved, it seems possible that some of the apparent variability in the results may disappear.

Concerning the suppressive ability of crops, the authors considered comparisons among crop species and cultivars. As is common in the weed literature, differences in suppressive ability were usually ascribed to canopy characteristics since virtually nothing is known about their root structure and function. It is possible that dense crop canopies may exert effects not only through competition for light but also by reducing the temperature fluctuations in the surface soil; such fluctuations can trigger the germination of weed seeds.

Of the possible control methods, the Chairman suggested rotation of intercrops to control weeds. To plant the same intercrop year after year seems to be inviting trouble. If crop rotation is not feasible, perhaps at least control methods can be rotated between seasons.

In the second paper on weeds, Dr. Shetty and Dr. Rao raised the idea of using a smother crop. Used appropriately, smother crops hold considerable promise. Again, it will probably be preferable to rotate smother species between seasons.

Among comments and questions, it was pointed out that all too few experiments had been carried out to study long-term effects of cropping practices on the same area.

In their excellent review of pests and their management in intercropping systems, Dr.

Bhatnagar and Dr. Davies established that host-specific insect pests may indeed sometimes be controlled by planting intercrops. However, the condition for this is that the right sort of diversity must be present. The really difficult pests to control seem to be those without strong dietary preference. The revelation that "polyphagous insects are known to be attracted by mixed odors" seems to have really serious implications.

The difficulty of spraying individual components in intercrops is understandable; however, it is not necessary that all hopes of insecticidal crop spraying by subsistence farmers be abandoned on that score. It was suggested to be out of reach of most such farmers. The possibilities of devising cheap knapsack sprayers or other forms of application should be fully explored. It is worth investigating the occurrence of natural insecticidal compounds in the local flora as a basis for a local extraction industry. The screening studies by the International Centre for Insect Physiology and Ecology in East Africa could serve as a model. In the discussion, Dr. Bhatnagar emphasized that for pest studies in crops, very large plots are needed to produce valid results.

Since so many noxious species are involved, there are clearly questions about whether we need to be concerned about all the weeds, pests, and diseases that threaten our crops. There is an urgent need to identify the truly serious ones and, for these, to estimate the damage functions (i.e., the curves of yield loss vs population of noxious species) so that protection strategies could be planned rationally. Many farmers are looking forward to the delivery of the various pest- and disease-resistant cultivars that are in the pipeline. Nevertheless, we do not yet have enough knowledge to use them intelligently. Unless we plan their use in integrated programs, their resistance may prove short-lived. As one extra measure to protect resistant varieties, we should consider a more complete mixing of species within fields, and more species per field. As attempts to intensify farming bear fruit, and plants grow more densely on soil of higher fertility, the pest and disease menace can only increase. How to direct the increased production into the right mouths seems to be a problem to challenge the ingenuity of the guardians of our crops for many years to come.

Summary of Session 4 Evaluation of Intercropping Systems

J. G. Ryan — Chairman

The eight papers presented in this session generated a lively discussion pointing to the need for more extensive research and, indeed, interaction between agronomists, breeders, statisticians, and economists on the design, analysis, and evaluation of intercropping studies. In the papers on statistical evaluation, there was considerable emphasis on statistical design and analysis, such as the use of factorials; also, on measuring quantitatively the environmental differences that are expressed over different treatments or different experiments, and incorporating them explicitly in multivariate analysis so the stability factors can be separated from the data. Dr. Mead referred to what we might call parametric methods of extracting maximum information from a given set of intercropping data. This was a very useful illustration.

As in the earlier sessions of this Workshop, there was considerable discussion about the value of land equivalent ratio (LER) as a means of evaluating intercrop systems. It seems to indicate that we must not look only at LER; such factors as absolute yield differences, monetary values, and other means (such as bivariate transformations) may be desirable in order to make evaluation of the superiority, or inferiority, of different systems. There was a strong plea not to search for a single index because no one index is likely to be ideal for all situations.

The papers on yield stability and economics stressed the complexity of existing farming systems and the need for simple experiments to examine the profitability and stability of cropping systems. A further factor that was emphasized was that most of the beneficiaries of intercropping technology and improvement may well be the less well endowed farmers. There was a dilemma about the fact that the introduction of high-yielding varieties in India tends to lead to sole cropping. This led to a further discussion of the value of LERs, especially when this index ignored double crop potential after a short-duration high-yielding variety. It was stressed that intercropping systems be developed to absorb the emerging high-yielding technology rather than to suit low-input and low-management situations; to quote Dr. N. G. P. Rao, "we must plan for quantum jumps."

Innovative analyses of various techniques were presented that were patterned on the breeder's analysis to examine stability over different environments. There is a clear need for examination of the evidence in a multidisciplinary fashion that properly integrates available data. This is necessary if we are to come to firm conclusions that stand up to scientific scrutiny. And in future design of intercropping experiments, there is a need for a wider range of treatment variability. Questions were raised in the various papers on the economic yield, thus highlighting the need for more multidisciplinary work on this subject. Various comparisons of the measures of intercropping stability were also discussed, and much more work in this general area is required; and, of course, measures of stability are not only of interest to statisticians but also to agronomists and economists. Each discipline tends to have its own measures, but perhaps another key element is some decision on what farmers' stability means.

In the operational research area, more research is essential. It was suggested that national programs should do more promotion of intercrops than sole crops. Improved machinery and implements should be used selectively in intercropping situations; while sometimes they greatly improve productivity, as was demonstrated, hand-oriented methods can be better. More research is needed on improved machinery and implements under intercrop conditions; this again points to the need for operational-scale research.

In conclusion, the Chairman suggested that one question, which has not been explicitly discussed in this Workshop, be taken up in the plenary session discussion. The question arises in the context of the methods of evaluation of intercrop systems compared with other systems, and the responsibilities of national and international programs in designing more robust measures of evaluation of the performance of the different cropping systems. And here perhaps we are particularly concerned at an international center such as ICRISAT in looking at measures of evaluation which the national research programs are not in such a good position to look at.

General Discussion

Chairman

We now come to the final part of our program. We are running a little late as you can see but at the same time I feel we must give everyone the opportunity of bringing up any point that has not been fully covered.

Okigbo

I think the report of this Workshop will be much more useful than the proceedings of the conference held at Morogoro in 1976, due to the explosion of research in this area since then, and that this will be regarded as a reference by many people involved in cropping systems work. But I would suggest there may be a need to add a section on terminology so that subsequent to this meeting there will be an adoption of some standard terminology.

The other point I wanted to make was with respect to Dr. Ryan's remark on the problem of evaluation. The review of farming systems which was held last year did point out that one of the major roles of the international agricultural institutes was to sharpen the techniques and methodology and help support the national programs to develop their own abilities in this area. I think there is a need within the International Agricultural Research Centers (IARC) to decide on how this can be done. Some of the experiences and points developed here may well be developed for use of the national programs. It is also necessary to point out that the problem that has arisen with respect to methodology relates to the fact that although we have had discussions on statistics, there is a need to determine whether these statistical designs apply equally to other aspects, e.g. physiology, crop management, economic evaluation, weeding, and screening. Lastly, I would tike to suggest that as a follow-up to this meeting, cooperative research be organized among the major disciplines that were discussed in this meeting.

This could result in the development of standardized techniques. Another aspect may be the need for future workshops so that we can meet the challenges of the explosion of research in this particular area.

Chairman

You have brought up some very good points that certainly we in this Institute would want to consider further.

Kanwar

Mr. Chairman, I endorse what Dr. Okigbo has said particularly his two recommendations. Both these are mandatory for all the IARCs. One is the development of the methodology which should be applicable to other situations, particularly those that can be transferred to national programs. Second is the development of a glossary of terms. This is something of a mandatory requirement because it has in fact been requested by our Governing Board a number of times. As yet it has not made headway. Now our Governing Board has indicated that they would like to see it at their next meeting.

Baker

I would like to mention two points which I feel have not been covered in this conference because they are areas in which we are doing something at Samaru. One is the fertilization and nutrition of mixtures — to which crops should we apply the fertilizer, and what is the interaction between the crop which is fertilized and the other components in the mixture? Secondly, the very important area of developing mixed cropping rotations and looking at the long-term residual effects of mixed cropping.

Bhatnagar

I think we would all agree that there are weaknesses in the present training, advisory, and extension services that are likely to become constraints to the transfer of existing technology in intercropping.

Krantz

I certainly agree with Dr. Bhatnagar here that extension and training aspects are important, and I think that this has to start at the experiment stations. I think we are each doing our own little thing — the engineers are developing their machinery, the physiologists are working somewhere else, and so on. However, until we can put these things together on an operational-scale on our experiment stations, it is futile to expect an extension man to go out and tell the farmer how to do it.

The Chairman concluded the session by thanking all those who had helped in organizing the Workshop and participated in its presentations and discussions.

Appendix I

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Appendix II

French Translations of Abstracts

Resumes des Communications

Seance d'Ouverture

Une approche scientifique de la recherche sur les associations de cultures

R. W. Willey

Une approche scientifique deia recherche sur les associations de cultures est ebauchee en reference au programme ICRISAT. Pour les besoins du colloque, une association de cultures est definie comme tout systeme de culture mettant en jeu un niveau significatif de concurrence entre les cultures. Les avantages possibles de rendement d'une association de cultures sont, par comparaison avec la monoculture, (i) des rendements superieurs pour une saison donn6e, et (ii) une plus grande stabilite de rendement au cours des differentes saisons. L'objectif de rendements superieurs pour une saison donnee correspond a trois situations distinctes: (i) le rendement combine des cultures associees est superieur a celui de la culture pure ayant le meilleur rendement; (ii) l'association de cultures donne le plein rendement d'une culture principale, plus le rendement supplemental d'une deuxieme culture; (iii) le rendement combine des cultures associees est superieur au rendement combine des cultures pures. L'evaluation de l'avantage en rendement dans chacune des trois situations est discutee. En ce qui concerne, plus particulierement, letroisiemecas, quelques avantages et inconvenients du rapport equivalent terre (Land Equivalent Ratio, LER) sont exposes. D'autres fonctions de concurrence sont egalement brievement decrites.

Les grands champs d'investigation de la recherche sur les associations de cultures sont definis. Il est suggere, en physiologie vegetate, de developper l'etude des modeles de croissance et de l'utilisation des ressources. Le travail presente en agronomie sur le peuplement vegetal illustre l'approche scientifique, detainee, que peut adopter le chercheur sur les associations de cultures. On souligne la necessited'etudier davantage la stabilitedes rendements, le roledes legumineuses, des mauvaises herbes, des parasites et des maladies des cultures.

Seance n° 1 — Agronomie

Pratiques de gestion de systemes de culture intercalaire

Rajat De et S. P. Singh

La culture intercalate est l'une des pratiques les plus anciennes parmi les systemes traditionnels d'agriculture appliques dans les pays en developpement. Une bonne exploitation des systemes de culture intercalaire pourrait permettre de rendre ceux-ci beaucoup plus productifs. A cet egard, le choix des cultures qui devront etre plantees en association joue un rdle primordial. Les cultures qui poussent de maniere dissymetrique, de sorte que les periodes de maturation ne coincident pas, peuvent assurer une productivite optimum des deux cultures associees. Pour les cultures a maturation tardive, dont le rythme de croissance est lent, telles le mil a chandelle, le niebe et le haricot mungo, decaler le temps de plantation 6limine les risques de concurrence. Changer la geometrie des plantations peut permettre d'eviter que les plantes ne se fassent mutuellement de l'ombre. Maintenir constante la population des plantes, et modifier l'orientation des rangees pour les plantations en rangees doubles ou triples, permet d'offrir plus d'espace pour le developpement des cultures associees. Des precisions sont egalement donnees sur une meilleure efficacite des systemes de culture intercalaire, en ce qui concerne l'utilisation de l'eau sur terre seche comme sur terre irriguee. Par ailleurs, l'apparition de mauvaises herbes et de parasites est considerablement reduite dans une culture en association.

Etudes sur la culture intercalaire de sorgho

S. P. Singh

Cette etude presents des experiences visant a ddcrire la geometric des plantations de sorgho, la compatibilite des differentes cultures associees et l'effet benefique potentiel d'une culture intercalaire de legumineuses sur une base de cultures non legumineuses. Trois series d'experiences sont expliquees:

- serie I: le sorgho a ete compare, sur des rangees uniformes (45 cm) et jumeiees (30/60 cm) avec differentes cultures associees;
- serie II: le sorgho a ete compare, sur des rangees uniformes de 60 cm et deux systemes de rangees jumeiees de 30/60 cm et 30/90 cm egalement avec differentes cultures associees;
- serie III: le sorgho a ete cultive, a un certain nombre d'emplacements, sur des rangees uniformes de 60 cms, avec une rangee de legumineuses; en 1976, a I'IARI, on a egalement fait une comparaison alimentation en pluie/irrigation.

Par comparaisonaux rangees uniformes de 45 cm, le rendement du sorgho en rangees jumeiees de30/60 cm n'a pas diminue, et I'espace Iiberepar les schemas de rangees jumeiees a fait augmenter le rendement de la culture associee de legumineuses. Une liste de cultures associees compatibles est donnee. Quelques effets benefiques sur le rendement de la culture de legumineuses associee au sorgho sont egalement expliques.

Introduction d'une periode de non-concurrence a regard de la plante associee: un nouveau concept

S. P. Singh, R. C. Gautam et V. R. Anjaneyulu

Plusieurs experiences conduites a l'lndian Agricultural Research Institute sur des associations de cultures incluant le mil a chandelle sont decrites. En 1974, le semis tardif du mil, le 11 aout, a eu pour consequence un rendement en mil inferieur a celui obtenu avec un semis plus pr6coce, les 12 et 27 juillet, maisle rendement en poisd'Angole, culture associee, s'est accru. Les recherches conduites les trois ann6es suivantes ontpermis d'etablir que le diminution du rendement en mil due au semis tardif etait moins grande lorsque la plante etait repiquee au lieu d'etre semee directement. Une telle pratique donnait encore un rendement accru de la legumineuse associee (dans ce cas, le haricot dore). L'augmentation de rendement de la culture associee a ete attribuee a la p6riode de non-concurrence introduite par la mise en place tardive du mil. La duree optimale s6parant l'etablissement des deux cultures a ete 6valu6e a 3-4 semaines lors des deux premieres annees d'exp6rience, puis a 2 semaines les deux annees suivantes.

Au cours des quatre ans de recherche deux modes d'agencement des cultures ont ete compares, deux rangs de mil 6loign6s de 30 cm alternant avec (a) un double rang de culture associee (distance

de70 cm entre deux paires de rangs demil), ou(b) un triple rang de culture associee(distancede 90 cm entre deux paires de rangs de mil). Ce dernier arrangement a donne des rendements nettement superieurs de la culture associee, avec peu ou pas de diminution des rendements en mil. Quelques effets des traitements mentionnes sur le nombre de nodules de la legumineuse associee sont egalement decrits.

Maximisation de la production dans un systems de culture intercalaire sorgho/pois d'Angole, applique dans les zones tropicales semi-arides

J. Venkateswarlu, N. K. Sanghi, U. M. Bhaskara Rao et Ch. Hanumantha Rao

Dans la r6gion tropicale semi-aride de Hyderabad, dont le sol a une faible capacite de stockage de l'eau, et ou la periode de vegetation est de 150 jours, seul peut etre applique, pour augmenter l'intensite des cultures, un systeme de culture intercalaire. Les cultures associees ideates pour la region sont le sorgho et le pois d'Angole.

Le systeme trad itionnel de culture intercalaire est inefficace. Des tests d'experimentation et de verification effectues sur les champs des exploitants agricoles ont demontre que I'on pourrait arriver a un plein rendement en sorgho et a un rendement de 60% en pois d'Angole: (a) en passant a des hybrides de sorgho a haut rendement (CSH-5/CSH-6) et a des varietes de pois d'Angole a 150 jours (HY-2); (b) en utilisant 40-30-0 kg de N, P_2O_5 et lOO/ha; (c) en adoptant des mesures adequates de protection des plantes; (d) en ayant recours a un systeme de plantation 2/1 avec une population de sorgho de 120 000 plants/ha et une population de pois d'Angole de 40 000 plants/ha, a 45 cm.

Des tentatives de parvenir a un plein rendement en pois d'Angole sont en cours.

Considerations sur le genotype et la densite de peuplement pour l'elaboration d'un systeme efficient de culture intercalaire base sur le sorgho

P. P. Tarhalkar et N. G. P. Rao

Des recherches sur diverses combinaisons de cultures prenant comme cultu re de base le sorgho ont ete menees de 1971 a 1974 dans le but d'identifier un systeme efficient de culture intercalaire et d'evaluer sa productivite et ses avantages economiques. Des etudes ont ete entreprises en 1975-76 pour l'elaboration d'un systeme optimum d'association sorgho-pois d'Angole; des plantes au genotype approprie ont ete cultivees suivant diff6rents modes d'agencement du sorgho dans l'espace, le pois d'Angole etant cultive a deux niveaux de densite de peuplement, pour evaluerla productivite totale du systeme et sa rentabilite economique.

Les rendements en sorgho obtenus selon les divers modes d'arrangement des plants dans I'espace ont atteint 97% du rendement de la culture pure. Associe au pois d'Angole, la cultivar de sorgho Hy-2a subi une reduction de rendement plus forte (12%) que le cultivar erige, a long cycle, Hy-3a (8%). Les rendements et revenus nets les plus eleves ont ete obtenus lorsque le sorgho etait cultive en rangs appariees, intercales avec une culture de pois d'Angole de moindre densita de peuplement (27 000 plants/ha). L'agencementdu sorgho en rangs largespermetcependant une meilleure expression du rendement en pois d'Angole, meme en forte densite.

L'association optimale sorgho-pois d'Angole reunit done le sorgho cultive en rangs appari6s (60-30 cm) et le pois d'Angole en densite 27 000 plants/ha, ou le sorgho cultive en rangs larges (60 cm) et le pois d'Angole en forte densite (55 000 plants/ha). Dans chacune de ces associations, la densite du sorgho restait egale a 148 000 plants/ha. La disposition du sorgho en rangs larges est souhaitable pour la gestion de la culture.

Etude sur la population des plantes et l'arrangement spatial d'une culture Intercalate de mais et haricots (*Phaseolus vulgaris* L.) au nord-est du Bresil

A. F. Lima et L. H. O. Lopes

Au nord-est du Bresil, les paysans cultivent habituellement leurs plantes en association, et la culture intercalate de mais et de haricots *(Phaseolus vulgaris* L.) est tres frequente.

Afin d'examiner la population des plantes et l'arrangement spatial de cultures associees de mais et de haricots, une experience a ete conduite a Filadelfia, au Bresil, emplacement situe a 10°45' sud et 40°07' ovest et a 550 m d'altitude. La pluviosite annuelle moyenne dans la region est de 811 mm.

Le schema statistique etait un bloc compact pris au hasard avec un arrangement divise en parcelles, r6pete quatre fois. Quatre niveaux de population de maTs (25 000, 50 000, 75 000 et 100 000 plants/ha) et de haricots (150 000, 200 000, 250 000 et 300 000 plants/ha)constituaient les principales parcelles. Les sous-parcelles etaient composees de cinq arrangements spatiaux (culture pure de mais (M) et culture pure de haricots (beans-B), 1M:2B, 1M:3B, 1M:4B).

On a conclu deces experiences que le meilleur arrangement etait 1:3, comportant 12 500 plants/ha de ma'i's et 150 000 plants/ha de haricots.

Etudes sur la culture intercalaire de sorgho et de mais avec des haricots communs *(Phaseolus vulgaris)* et du niebe (*Vigna ungulculata)*

R. C. Mafra, M. de A. Lira, A. S. S. Arcoverde, G. Roberio et M. A. Faris

Une etude sur la culture intercalaire de mais et de sorgho avec du niebe *(Vigna unguiculata)* et des haricots communs (*Phaseolus vulgaris)* a 6te men6e dans "I'Agreste" et le "Sertao", deux zones ecologiques differentes de l'Etat du Pernambuco, au Bresil. Le nombre des unites de plantes etait le meme dans les deux systemes de culture intercalaire et de culture pure, une rangee de mais ou de sorgho ayant ete remplacee par une rangee de niebe ou deux rangees de haricots. Les resultats indiquent clairement que le mais peut etre remplace par le sorgho dans des systemes de culture intercalaire maVs/legumine, sans porter prejudice au rendement des Iegumineuses. Le fait de proceder a une telle mutation des cultures devrait entrainer une meilleure stabilite du rendement, car le sorgho est moins sensible aux conditions climatiques que le mais.

Population, temps et melanges de cultures

E. F. I. Baker

Les effets du changement de population des plantes dans le cadre de melanges de cultures sont rapidement evoques, en particulier en ce qui concerne les melange de cereales. L'augmentation du rendement dans de tels melanges est expliqu6e par ('augmentation du rendement par plante; l'indice de recolte n'a pas change.

Il apparaltque les melanges de remplacement sont generalement constitute de cultures du meme groupe phenologique, et que I'augmentation du rendement dans de tels melanges resulte simplement de la reponse des populations de plantes "reduites" a cause d'une complementarite dans l'espace et/ou dans letemps. Il est d6montre que le rendement peut encore etre ameliore si I'on augmente la population des piantes par une quantite proportionnelle a la difference dans la taille des piantes et dans la longueur de la saison.

La situation est tres differente en ce qui concerne les melanges surimposes qui, generalement, sont constitues de cultures de differents groupes phenologiques. Dans de tels melanges, le rendement d'une composante determinee (presque toujours une c6r6ale) ne d iff ere pas de celui d'une culture pure, tandis que le rendement de la composante determined depend du taux de reprise lors de la phase de reproduction, une fois que la cereale a 6t6 retiree. L'indice de recolte de la composante indeterminee a beaucoup augmente, et la plante a diminue en taille, en raison de la concurrence lors de la phase de vegetation.

Dans les melanges surimposes, la population de la composante determinee devrait rester la meme que celle de la culture pure, tandis que celle de la culture indeterminee pourrait devoir etre augmentee, pour devenir superieure a celle de la culture pure, d'une quantite dependant de la couverture de voute restant apres que la cereaie ait ete recoltee.

Ainsi, les genotypes des melanges de remplacement devraient repondre de maniere tres souple au changement de population, tandis que la composante indeterminee des melanges surimposes devrait faire preuve d'une reprise rapide, par compensation, apres le stade de concurrence dans la phase vegetative, et durant la phase reproductive de la croissance.

Systemes de cultures intercalaires bases sur des cereales dans la zone tropicale semi-aride d'Afrique occidentals, en partlculier la Haute-Volta

W. A. Stoop

La zone tropicale semi-aride d'Afrique occidentale est caracterisee par une saison des pluies de 3 a 6 mois, avec des chutes de pluies souvent tres irregulieres et a tres forte intensite. Ces conditions, s'ajoutant a des sols sableux, fragiles, a faible fertilite et sensibles a l'acidification par les engrais acides et a l'erosion par le vent et par l'eau, creent un milieu tres difficile pour l'amelioration de l'agriculture.

Les systemes de cultures traditionnels cereales/legumineuses, fondes sur des varietes photosensibles de grandes piantes de sorgho et de mil a talles associes a des niebes rampants photosensibles, sont tres adaptes a la plantation precoce et fournissent ainsi une bonne couverture du sol des le debut de la saison. En outre, a l'aide des diverses combinaisons de culture, t elles que mil/niebe ou sorgho/ni6b6, on utilise pleinement la saison, dans toute sa longueur, tant sur sols pauvres et peu profonds que sur sols riches et profonds.

Avec ('introduction de varietes ameliorees de sorgho, de mil et de niebe, ayant souvent des types de piantes et des cycles de maturation tres differents des materiaux locaux, il est possible de mettre au point des systemes de culture cereales/niebe plus productifs. Cependant, il est important que de tels systemes de culture ameliores aient la meme stabilite que le systeme traditionnel. Cela necessite done, entre autres, un adaptation aux principaux types de sols (sols profonds et peu profonds), a une couverture du sol efficace, et a une stabilite du rendement, meme pour des populations de piantes assez faibles.

Modes de cultures dans la region de la savane du Nigeria: la situation au Kaduna

J. Y. Yayock

La situation de l'agriculture dans l'Etat du Kaduna est brievement decrite, car il semble qu'elle soit typique de la situation prevalant dans la zone soudanaise du Nigeria. Certains problemes importants lies a la production de cultures sur champ sont identifies et des suggestions sont avancees en vue d'y apporter des ameliorations.

Il n'existe pas, dans aucune des zones 6cologiques de l'Etat, de modes de culture clairement definis, ou rigides. Cependant, sans qu'on lui donne le nom de culture intercalaire, la plantation de plus d'une culture sur le meme champ, et en meme temps, est pratiquee dans tout l'Etat, davantage au nord qu'au sud. Le "gicci", un systeme de culture intercalaire caracteristique de la zone soudanaise, relativement seche, est a l'heure actuelle la seule approche rationnelle de ce type de culture qui puisse etre decrite comme modele. Dans la plupart des cas, le choix et le nombre de cultures dans un melange est une decision arbitraire, de sorte qu'en partique on ne fait pas facilement appel a la rotation.

La monoculture, autre systeme de culture, est beaucoup moins largement pratiquee, et diminue encore d'importance lorsque l'on remonte du sud vers le nord. Certains modes definis de culture peuvent parfois etre reconnus, mais, dans la plupart des cas, la rotation des cultures n'est ni rationnelle ni largement partiquee.

Parmi les facteurs agronomiques qui sont la cause des bas rendements des cultures dans tout l'Etat, se trouvent ('utilisation de varietes non-ameiiorees, l'absence de planification quant aux periodes de plantations, l'impossibilite de maintenir une population totale ou elevee de plants, l'inadequation de l'amendement du sol et les faiblesses de la lutte contre les mauvaises herbes, les parasites et les maladies.

Population des plantes et arrangement des cultures dans des melanges de sorgho/pois d'Angole et millet digitaire/arachide

D. S. O. Osiru et G. R. Kibira

Des melanges de sorgho/pois d'Angole et millet digitaire/arachide ont ete etudies dans des arrangements en rangees alternees, et dans une meme rangee. Une technique de "series de remplacement" a ete utilisee; tous les traitements ont ete 6tudi6s a quatre niveaux de populations. Les rendements des melanges ont ete importants en comparaison avec les standards de culture pure. Dans le melange sorgho/pois d'Angole, les rendements ont augmente de 29%, tandis que, dans le melange millet digitaire/arachide, ils ont augmentede 44%. De meme que lorsd'experiences anterieures, il apparait que les rendements les plus eleves interviennent dans les melanges, car les cultures les composant sont capables de mieux utiliser les capacites du milieu que dans les standards de culture pure.

Culture de relais et association de cultures: une approche pour maximiser le rendement en mais dans les zones de pluviometrie marginale du Kenya

H. M. Nadar et G. E. Rodewald

Une experience conduite pour mesurer la reponse du rendement en maYs a deux methodes de plantation, deux ecartements des rangs et deux systemes de cultures, dans une zone de pluviometrie marginale du Kenya caracterisee par une repartition bimodale des pluies, est commentee. Les resultats de cette experience, ainsi que l'etude economique des systemes de culture utilises par les exploitants agricoles dans la zone d'etude, ont montre que les rendements en mais obtenus en periode de pluies tongues peuvent etre sensiblement ameliores par des modifications mineures apportees aux techniques actuellement utilisees par les exploitants. L'un des facteurs les plus decisifs determinant le rendement en mais en periode de pluies longues est la date de semis. Le retard de celle-ci au-dela de la premiere semaine de mars s'est traduit par des diminutions substantielles de rendement. La culture de relais peut permettre une mise en place precoce du ma'ts durant les longues pluies.

Dans l'association de cultures mais-haricot, le rendement en haricots est reste quasiment inchange lorsque l'espacement des rangs de mais etait de 60,75 ou 90 cm, tandis que le rendement en mais s'est trouve sensiblement reduit dans l'espacement 75 cm. Les essais de determination de l'effet de l'introduction d'une nouvelle technologie sur le revenu agricole net par l'emploi de trois mode les de programmation lineaire ont ete commentes.

Les etudes sur les associations de cultures au Swaziland: situation actuelle et perspectives d'avenlr

G. T. Magagula, I. Haque, W. Godfrey-Sam-Aggrey, I. Fendru et G. T. Masina

Cette communication eclaire la place qu'occupentactuellement les systemes de culture intercalaire dans l'agriculture du Swaziland et envisage leurs perspectives de developpement dans l'avenir. Il y a au Swaziland deux regimes d'acquisition et de propriete du sol, caracteristiques d'une structure agraire moderne et d'une structure traditionnelle. La zone de structure agraire traditionnelle est appelee Swazi Nation Land et couvre 56% des terres agricoles. Les pratiques culturales y sont essentieliement celles d'une agriculture de subsistance. On estime que 42, 8% des champs de la Swazi Nation Land sont exploites au moyen de systemes de culture intercalaire. Le mais est normalement la culture dominante et il est cultive en association avec d'autres cereales, des legumineuses, des courges et d'autres plantes. On a propose la creation d'un projet de recherche et de vulgarisation sur les associations de cultures dont l'objectif general est l'accroissement de productivite des principaux systemes de culture intercalaire utilises par les petits exploitants du Swaziland pratiquant une agriculture de subsistance. La composition de l'equipe de recherche et les activites du projet propose font l'objet d'une discussion detaillee.

L'evaluation de genotypes pour la culture intercalaire

H. C. Wien et J. B. Smlthson

Bien que la selection de genotypes pour des conditions de culture intercalaire soit pratiquee par les paysans des tropiques depuis des siecles, jusqu'a une epoque recente peu de tentatives avait ete deployees d'utiliser des moyens scientifiques pour evaluer l'adaptation des plantes aux cultures en association. Nous estimons qu'une strategie de selection pour la culture intercalaire, pour etre couronnee de succes, doit comporter une serie d'etapes visant a etablir les methodes etcritferes de selection. Ces etapes sont les suivantes:

1. Definition des systemes de culture intercalaire pour lesquels les genotypes doivent etre seiectionnes, determines par des etudes sur les pratiques utilisees dans la region ou l'on doit appliquer le systeme de culture intercalaire, ainsi que sur les facteurs climatiques, des considerations economiques, et les resultats d'experiences agronomiques.

2. Manipulation de l'epoque de plantation, de l'espacement, et des niveaux des elements nutritifs du sol pour produire un niveau moyen de contraintes, de sorte que les lignees reellement adaptees aux cultures intercalaires definies puissent etre selectionnees.
3. Criblage, sous des conditions definies de culture intercalaire, d'un grand nombre de lignees pures, pour identifier I'importance de leur adaptation a la culture intercalaire.
4. Determination de I'etendue jusqu'a laquelle les memes caracteres sont exprimes sous des conditions de monoculture, afin de permettre la selection de cultures pures pour la culture intercalaire.
5. Criblage preiiminaire negatif pour l'adaptation a la culture intercalaire, utilisant des conditions de monoculture; par exemple: rejet des plantes susceptibles aux maladies et aux insectes, ou de celles qui ont des habitudes de croissance non adaptees.
6. Criblage positif des genotypes du N°5 ci-dessus, pour leur adaptation au systeme de culture intercalaire selectionne.

Cette progression est illustree, pour le niebe, d'exemples tires d'experiences de culture intercalaire cereales/niebe menees a trois emplacements en Afrique occidentale.

Etudes sur des genotypes a l'ICRISAT

R. W. Willey et M. R. Rao

Cette etude pr6sente des experiences faites au Centre ICRISAT entre 1976 et 1978 sur des genotypes. En 1977, dans une experience sur une association sorgho/pois d'Angole, on a etudie 17 genotypes de pois d'Angole avec un genotype standard de sorgho. Le sorgho a eu des rendements allant de 82 a 99% du rendement en culture pure, mais aucune difference n'a ete vraiment sensible. Les genotypes de pois d'Angole ont eu des rendements allant jusqu'a 1,66. Bien que les rendements absolus du pois d'Angole en culture intercalaire dependent, de maniere 6vidente et jusqu'a une certaine limite, des rendements en pois d'Angole, cette dependance n'a compte que pour 40% de la variabilite dans les rendements obtenus en culture intercalaire. II est apparu que le type de plante de pois d'Angole le plus adapte avait une croissance compacte raisonnable, dans les premiers stades, pour eviter une concurrence avec le sorgho, mais avait I'habitude de s'etaler ulterieurement pour utiliser les ressources apres la recolte du sorgho.

Dans deux experiences, trois genotypes de mil ont ete examines dans toutes les combinaisons comprenant quatre genotypes d'arachide. La premiere experience etait un schema de parcelles divisees, avec des genotypes de mil dans les principales parcelles; la seconde etait un schema de parcelles en bandes. On a obtenu une augmentation du rendement allant de 25 a 30%.

On a conclu de cette experience que l'importance de l'augmentation du rendement etait principalement determinee par le genotype d'arachide, tandis que la proportion entre le rendement en arachide et le rendement en mil etait principalement determinee par le genotype de mil.

Trois experiences sur des genotypes de sorgho/mil sont decrites. La premiere etait une experience non repetee dans laquelle 48 genotypes de mil a chandelle etaient cultives avec un genotype standard de sorgho. Les correlations entre l'augmentation du rendement et plusieurs caracteres de la plante de mil n'ont pas beaucoup aide a identifier les caracteres les plus souhaitables en culture intercalaire. Deux experiences ulterieures ont porte sur quatre genotypes de sorgho en association avec quatre genotypes de mil. Les augmentations de rendement ont depasse 30%. Ces augmentations ont ete considerees comme tres importantes pour ces deux cultures similaires; on en a conclu que cette association etait particulidrement interessante, et qu'elle m6rite d'etre etudiee de maniere plus approfondie.

Seance n°2 — Aspects physiologiques

Eff icacitd de ('utilisation de la lumiere par les plantes et potentlel d'amelioration grace a la culture intercalaire

B. R. Trenbath

L'interception de la lumiere par les cultures pures varie selon les positions des sources de lumiere, l'indice de superficie de la feuille, l'inclinaison et la distribution des feuilles. Des modeles mathematiques peuvent gen6ralement prendre en compte avec succes ces differents effets.

Les especes varient grandement dans la maniere dont la photosynthese nette de leurs feuilles (Pn) repond a un niveau de lumiere. Tandis que les reponses Pn des feuilles au niveau du flux de lumiere interceptee sont hyperboliques, les r6ponses Pn de toute la voute (et aussi de la croissance) a li tendent a se montrer strictement proportionnelles. La constante de proportionalite dans le modele resultant- "reponse proportionnelle" - est l'efficacite de la voute quant a la conversion de la lumiere (Pn/li). Les simulations de la *Pn* quotidienne dans une culture mixte de voutes similaires ne different essentiellement qu'en hauteur, elles laissent a penser que le modele "reponse proportionnelle" peut egalement s'appliquer aux composantes individuelles dans le cadre des cultures intercalates.

L'efficacit6 photosynth6tique d'utilisation de la lumiere (light-useefficiency - LUE) de la voute est le produit de deux composantes: la proportion entre la lumiere incidente qui est interceptee ($I/_o$) et la voute Pn/li. Les contributions possibles de la culture relais et de la culture intercalaire a ('augmentation de li/lo sont examinees, et une attention speciale est accordee a l'adaptation de l'ombre par les plantes de petite taille dans les systemes mixtes. En vue d'augmenter Pn/li des etudes analytiques et experimentales effectuees sur les cultures pures et des calculs de la Pn dans des systemes mixtes donnent a penser que les cultures intercalairesdevraientconsisteren: (a) une voute superieure de feuilles petites et inclinees avec des taux maximum de photosynthese des feuilles; (b) une voute inf6rieure de feuilles plus horizontales, arranges si possible en mosaiques, avec des taux minimum de photosynthese des feuilles. Une methode de choix des composantes d'une culture intercalaire, pr6sentant les caracteres des feuilles et des voutes les mieux adapters, est decrite. Une approche plus adequate consisterait a utiliser un modele dynamique plutdt que statique.

L'evaluation des interactions entre plantes et de la productivite dans les associations complexes de cultures comma base d'elaboratlon de systemes de culture ameliores

Bade N. Okigbo

L'association de plus de deux cultures, telle qu'elle est pratiquee dans les systemes de culture traditionnels d'Afrique tropicale, entratne la formation d'un agro-ecosysteme complexe mettant en jeu des interactions complexes entre les plants d'espece, de varidtd et d'age identiques. Si les plantes peuvent entrer en concurrence pour diffdrents facteurs, elles manifestent egalement des adaptations en reponse a la concurrence pour la lumiere, l'espace, les elements nutritifs, etc... L'analyse de la croissance dans les systemes complexes de cultures associees joue un role important dans l'6tude de la concurrence entre plantes et la mise au point d'une strategic de recherche sur les systemes de culture. II est possible, en s'appuyant sur des observations et analyses detainees de (1) seiectionner des cultures compatibles, en association, avec des changements minimum du niveau de peuplement de la culture pure et des modes d'arrangement spatial des plants permettant un comportement optimal des cuitu res, (2) determiner quels facteurs doivent etre factoriell ement appliques aux combinaisonsde cultures s6lectionnees pour identifier avec uneplus grande precision les modes de gestion des cultures favorisant l'efficience des system es d'association et (3) prevoir dans quelle mesure la culture de relais, l'arrangement spatial des plants et ('introduction de cultures au couvert vegetal particulier ou remarquables par quelque autre caracteristique, peuvent ameiiorer la production des associations. Bien que piusieurs indices soient utilises a present pour evaluer la productivite des associations de cultures, on peut s'appuyer sur des indices comme le LER, le coefficient de concurrence, les rendements relatifs, l'equivalent-calorie et le revenu brut pour seiectionner des combinaisons efficientes de plantes cultivees en relais ou simultan6ment Dans une experience d'association complexe de cultures incluant I'igname, le mats, le melon et le niebe, les rendements caloriques et les revenus les plus eleves ont 6te atteints par les melanges contenant I'igname et le mats. Lorsque ces cultures ne sont pas incluses dans ('association, il peut sembler preferable de cultiver les plantes s6par6ment. Les rendements les plus stables ont ete obtenus pour les com binaisons des quatre cultures. L'etude de la concurrence entre plantes cultiv6es et mauvaises herbes permet d'envisager des changements possibles de strategie dans la lutte contre les mauvaises herbes; des combinaisons de cultures peuvent etre specialement 6labor6es pour minimiser I'infestation des adventices et les pertes qui en decoulent.

Les resultats preiiminaires des recherches menees sur les associations complexes de cultures montrent que la strategie adoptee a I'HTA — mise au point de combinaisons et de successions culturales centr6es sur quelques-unes des principales cultures de base, comme le manioc, I'igname, le ma'is, le riz et le plantain — est bien fondee, eu 6gard aux milliers de combinaisons possibles associant les nombreuses cultures, principales comme secondares, susceptibles d'etre cultivees dans les zones tropicales humides.

Etudes sur la croissance dans une culture intercalaire de sorgho et de pois d'Angole, portant plus particulierement sur le developpement de la voute et l'interception de la lumiere

M. Natarajan et R. W. Willey

Au cours des annees 1977 et 1978, deux experiences ont ete menees au Centre ICRISAT sur un Vertisol profond moyen, en vue d'etudier en detail la croissance et I'utilisation des ressources de cultures pures et intercalaires de sorgho et de pois d'Angole. Dans la premiere experience, la croissance et le rendement du sorgho dans un systeme de culture intercalaire de 2 rangees de sorgho pour 1 rangee de pois d'Angole, ont ete les mernes que ceux d'une culture pure de sorgho. Le pois d'Angole cultive en association s'est ressenti de maniere importante de la concurrence avec le sorgho, mais aprfes la recolte de sorgho, la croissance initialement lente du pois d'Angole a ete compensee par un rendement en graines equivalent a 70% de celui de la culture pure. L'utilisation de la lumiere par la voute en culture intercalaire a ete efficace, excepte pendant une periode de tr6s faible interception, situ6e immediatement apres la recolte de sorgho. Dans la seconde experience (qui est toujours en cours), on a tente d'ameiiorer I'interception de lumiere durant cette periode en changeant I'arrangement des rangees pour passer a un systeme 1/1, et en augmentant la population du pots d'Angole. Les donn6es disponibles jusqu'a present indiquent que ces deux changements ont permis d'ameiiorer I'interception de lumiere; en general, ils ont produit une reponse de la matiere seche, mais les derniers rendements en graines ne sont pas encore connus.

Interactions du sol et utilisation des elements nutritifs et de l'eau

R. W. Snaydon et P. ML Harris

Nous avons etabli une classification entre les diff6rents mecanismes de culture intercalaire susceptibles de permettre une utilisation plus ou molns efficace des ressources limitantes, et ainsi d'augmenter le rendement. Les cas ou des especes de plantes cultivees en association sont en totale concurrence ont 6t6 d'abord separes de ceux ou la concurrence n'est que partielle; de nouvelles subdivisions ont alors ete faites.

Les conditions necessaires pour que tous ces mecanismes fonctionnent sont habituellement trouvees dans le sol. En particulier, les ressources du sol (eau et elements nutritifs) sont plus communement les facteurs limitants dans la production agricole; il existe donc une possibilite de parvenir a une meilleure utilisation de ces ressources.

Les r6sultats des experiences montrent que les interactions du sol sont normalement plus intenses que celles en surface, bien que les ressources particulierement limitantes et les mecanismes en jeu aient ete rarement Studies en detail.

Les resultats tant directs qu'indirects montrent que les interactions du sol entrament souvent de meilleurs rendements en culture intercalaire. Les rendements les meilleurs apparaissent habituellement lorsque des I6gumineuses et des non-iegumineuses sont cultivees en association principalement parce que I'on utilise les differentes ressources (N2 et NO3), dont une seule {NO3) est limitante, bien que d'autres mecanismes puissent egalement etre parfois importants. Dans les melanges de non-l6gumineuses, la repartition des systemes radiculaires peut entratner une utilisation plus efficace des elements nutritifs ou de I'eau, ainsi qu'un meilleur systeme de culture intercalaire.

II n'existe pour l'instant que trop peu d'elements pour que l'on puisse definir clairement les conditions d'environnement et les attributs des plantes qui sont susceptibles d'etre plus profitables dans la culture intercalaire. En general, les benefices semblent etre meilleurs lorsque les elements nutritifs sont deficients, et lorsque les especes different dans leur utilisation temporelle ou spatiale des ressources du sol.

Differentes techniques experimental sont examinees, qui pourraient ameiiorer notre comprehension des interactions du sous-sol et de leurs effets sur la culture intercalaire. La plupart de celles-ci necessitent d'etre etudiees de maniere plus intensive que cela a ete fait par le passe, et devraient faire l'objet d'un effort collectif d6ploy6 par des agronomes, des physiologistes des plantes, des pedologues et des statisticiens.

Une etude sur une culture intercalaire de mil a chandelle et d'arachide, particulierement axee sur l'efficacite de la voute foliaire et du systeme radiculaire

M. S. Reddy at R. W. WIlley

Une etude detainee a ete menee au Centre ICRISAT durant la saison des pluies de 1978 sur une culture intercalaire de mil a chandelle et d'arachide. Les cultures pures ont 6t6 cultivees sur des rang6es de 30 cm et un traitement de culture intercalaire isoiee a ete examine dans un arrangement de rangees: 1 rang6e de mil/3 rangees d'arachide, avec les memes espacements dans les rangees que ceux des cultures pures.

La culture intercalaire a produit une amelioration du rendement de 28% en total de matere seche (LER - 1,28) et de 26% en graines et gousses (LER = 1,26). Les valeurs de LER ont 6t6 egalement calculees pour l'indice de superficie des feuilles et la densite d'enracinement, qui ont montr6 respectivement une augmentation de 30 et 18%. II n'est pas apparu de maniere 6vidente que le systeme radiculaire dans la culture intercalaire etait beaucoup plus efficace que ceux des cultures pures. Cependant, si Ion considere la voute foliaire, on peut conclure que I'augmentation du rendement en matiere seche dans la culture intercalaire a 6te obtenue grace a I'amdlioration de I'efficacite de conversion de la lumiere, et non grace a I'interception de davantage de lumiere.

Etudas sur la reponse a I'azote d'una culture intarcalaira da sorgho at da pois d'Angole

T. J. Rego

En vue d'etudier la r6ponse a I'azote (N) d'une culture intercalaire de sorgho et de pois d'Angole, trois experiences ont ete men6es sur des Vertisols, entre 1976 et 1977, au Centre ICRISAT, a Hyderabad, en Inde. Dans I'exp6rience I, une culture pure de sorgho (180 000 plants/ha), une culture pure de pois d'Angole (40 000 plants/ha) et trois traitements de populations en association (40:40,80:80 et 120:120% de la culture pure optimum) ont 6t6 sem6s sur des parcelles principales, avec quatre niveaux de N (0,40, 80 et 120 kg/ha) appliques seulement pour le sorgho dispose dans des sous-parcelles. Dans I'experience II, une culture pure de sorgho avec une population de plantes optimum (180 000 plants/ha), et une culture intercalaire de sorgho avec une population a 33, 67 et 100% de la population optimum associ6e a une population constante de pois d'Angole (40 000 plants/ha), et les memes niveaux de N que dans I'exp6rience I, ainsi qu'une culture pure de pois d'Angole (40 000 plants/ha) ont 6te cultiv6es au hasard dans un systeme en bloc. Dans I'exp6rience III, des populations constantes de sorgho (150 000 plants/ha) et de pois d'Angole (40 000 plants/ha) ont ete plantees en monoculture a 45 et 90 cm, et en association de maniere altern6e dans des rang6es s6par6es de 45 cm avec trois niveaux de N (0, 60 et 120 kg/ha) appliques seulement pour le sorgho, et au hasard, dans un systeme en bloc. Dans chacune des trois experiences, on a fait pousser la variee CSH-6 de sorgho et la variete ICRISAT-I de pois d'Angole.

En se fondant sur les resultats de ces experiences, on peut conclure que le sorgho en association ou en monoculture a r#pondu de maniere similaire a I'azote applique. De meme, les differentes populations de sorgho en culture intercalaire ont eu des reponses similaires. Le pois d'Angole n'a pas sembie etre contributif, a cet egard, envers le sorgho. Le sorgho aux niveaux de N les plus eleves a eu un effet trds important surle rendement en pois d'Angole. Le sorgho et le pois d'Angole se sont tous deux bien comportes a 45 et a 90 cm lorsqu'ils ont ete cultives en monoculture.

Essais d'una culture intarcalaira da sorgho at de pois chicha a Morogoro, an Tanzania

M. S. Chowdhury et R. N. Misangu

Le sorgho a ete cultive en association avec du pois chiche inocuie ou non-inocule a differents niveaux de fertilite du sol dans une experience utilisant un schema en bloc au hasard. Le pois chiche a 6te inocuie avec I'inoculant Nitrogerme - Pois chiche sous trois niveaux defertilite du sol: (a) aucun engrais (contrdle); (b) 20 kg de N/ha comme sulfate d'ammonium; (c) 20 kg de N/ha plus 100 kg de P/ha respectivement comme sulfate d'ammonium et triple superphosphate. La nodulation, la matiere seche et la teneur en N du pois chiche ont ete examinees a differents stades de croissance. Les resultats ont indique une absence de bacteries des nodosites pour le pois chiche. L'inoculation a fait sensiblement augmenter la teneur en matiere seche et en N du pois chiche, mais n'a pas pu entramer une augmentation sensible du rendement en graines. La culture intercalaire a fait beaucoup diminuer la teneur en matiere seche et le rendement en graines du pois chiche, mais n'a eu aucun effet sur le rendement du sorgho. La variation des niveaux de fertilite du sol n'a eu aucun effet sur la nodulation, la matiere seche, la teneur en N ou le rendement en graines du pois chiche, mais a fait diminuer sensiblement le rendement en.graines du sorgho.

Seance n°3 - Aspects de la protection des plantes

Lutte contre les mauvaises herbes dans les systemes de culture intercalaire

K. Moody et S. V. R. Shetty

La recherche sur la lutte contre les mauvaises herbes dans la culture intercalaire est limitee. Un grand nombre d'auteurs affirment que l'une des raisons, en ce qui concerne la culture intercalaire, en est la suppression des mauvaises herbes, mais il existe tres peu de preuves resultant d'experiences pour appuyer cette conception. Les quelques experiences qui ont ete menees sur un systeme de culture intercalaire portant sur la lutte contre les cultures composantes sp6cifiques indiquentqu'un grand nombre defacteurs, parmi lesquels les cultures composantes specifiques, les cultivars des plantes, la population des plantes, l'arrangement spatial et la fertilite du sol, determinent la capacite de concurrence avec des mauvaises herbes dans les cultures associees.

Les principales methodes de lutte contre les mauvaises herbes dans les cultures intercalaires sont manuelles ou mecaniques. Selon les auteurs evoques ci-dessus, les combinaisons de cultures en association ne necessitent pas que la lutte contre les mauvaises herbes soit tres intense, mais les elements quantitatifs obtenus n'appuient pas cette declaration. La lutte mecanique contre les mauvaises herbes peut s'averer difficile, et meme impossible, dans certains arrangements spatiaux. II a ete difficile de trouver des herbicides adequats a grande 6chelle, car les herbicides n'attaquent souvent qu'une categorie de plantes. Plus le systeme est complexe, plus il semble improbable de trouver des herbicides appropries. Un reexamen des anciennes experiences sur la lutte contre les mauvaises herbes dans des systemes de culture intercalaire indique qu'il est necessaire d'adopter des methodes d'approche concertees et coordonnees pour determiner les implications de la culture intercalaire sur les mauvaises herbes et pour mettre au point des methodes efficaces et economiques de lutte contre les mauvaises herbes. Les auteurs du present rapport suggerent que soient intensifiees les etudes eco-physiologiques visant a observer la rGponse des mauvaises herbes, ainsi que les etudes cherchant a evaluer ce qui devrait etre fait pour trouver les moyens de les faire disparattre.

Etudes sur la lutte contre les mauvaises herbes dans des systemes de cultures intercalaires de sorgho/pois d'Angole et de mil a chandelle/arachide — Quelques observations

S. V. R. Shetty et A. N. Rao

Des etudes ont ete entamees au Centre ICRISAT pour examiner la concurrence entre les mauvaises herbes et les systemes de cultures intercalaires, et ('augmentation de la suppression des mauvaises herbes par l'addition d'autres cultures. Dans ce rapport, quelques observations preliminaires sur des systemes de cultures intercalaires de sorgho *(Sorghum bicolor* L)/pois d'Angole *(Cajanus cajan* L), et de mil a chandelle *{Pennisetum typhoides* L)/arachide *(Arachis hypogaea* L) sont mises en evidence, en insistant particulierement sur la croissance des mauvaises herbes, dans la mesure ou elle peut etre affectee par quelques facteurs bio-physiques seiectionnes. Avec I'augmentation de densite d'un systeme sorgho/pois d'Angole, est apparue une rapide diminution dans le poids a sec des mauvaises herbes. L'inclusion de cultures additionnelles "plus douces", telles que le niebe (*Vigna unguiculata* L.) et le haricot mungo (*Vigna radiata* L.), a minimise I'infestation des mauvaises herbes. Ces cultures pourraient remplacer un sarclage a la main sans affecter les rendements des principales cultures. Plus tard dans la saison, le niebe s'est av6r6 plus efficace que le mungo dans sa capacite de suppression des mauvaises herbes. Le systeme mil a chandelle/arachide avec un arrangement de: un mil a chandelle pour trois arachide, a entrame une suppression optimum des mauvaises herbes et une amelioration maximum de la culture intercalaire. Avec I'augmentation dans les rangees d'arachide, il y a eu une rapide augmentation des poids totaux en matiere seche de mauvaises herbes. *Digitaria* et *Celosia* ont augments de densite et de biomasse au fur et a mesure que les rangees d'arachide augmentaient. La composition relative *de Cyperus* a cependant tendu a diminuer dans les systemes avec I'arachide.

Dans ce rapport, quelques-unes des tendances initiates dans la croissance des mauvaises herbes, telles qu'affectees par differents facteurs intervenant dans les melanges complexes de cultures, sont examinees dans une perspective plus large de recherche sur les mauvaises herbes en culture intercalaire en general.

La lutte contra las mauvaises herbes dans la culture da subsistence an association

V. S. Bhatnagar et J. C. Davies

Les informations de base sur I'entomologie des systemes de cultures intercalaires dans les regions tropicales, en particulier en ce qui concerne la situation des petits exploitants, sont rares. II faut en trouver la raison dans l'interet porte autrefois a I'entomologie des cultures pures, et dans le fait que la recherche mettait surtout I'accent sur les cultures commerciales, de sorte que, tres souvent, les ressources et le personnel etaient detournes de la recherche sur les insecticides. II est d'une necessite vitale de rassembler des donnees de base obtenues a partir d'essais correctement repetes et representatifs de la situation telle que contrdlee prevalant tant dans la station de recherche que dans les champs des exploitants. Au depart, les travaux devront etre concentres sur un nombre relativement petit de situations typiques de cultures intercalaires, en utilisant de grandes parcelles et en faisant des repetitions en divers emplacements. Lesresultats obtenus a ce jour montrent que le niveau de parasites au centre de recherche est tres different de celuiqui existe dans les champs des exploitants.

Les donnees obtenues jusqu'a present a I'ICRISAT indiquent que la situation concernant les pertes de rendement dans un systeme de culture intercalaire, causees par les insectes parasites, et la relation ravageur/predateur/parasite, est tres complexe. II apparait, et on peut le demontrer, qu'il existe des differences dans la relation ravageur/parasite, differences basees non seulement sur les combinaisons decultures, mais egalement surdes facteurs tels que le type de cultivar, la saison, et le type de sol. Ces micro-effets peuvent etre serieusement affectes par des problemes climatiques qui resultent en une immigration a grande echelle des principales especes de ravageurs. Dans ce rapport, est presente un exemple de migration de *VHeliothis armigera* (Hubner) en Inde, qui cause un desequilibre avec les agents de lutte biotiques conduisanta une augmentation rapidedu nombre de larves et provoquant des pertes importantes de rendement en culture intercalaire de sorgho et de pois d'Angole. Des etudes menees dans de petites exploitations *ont* demande un travail experimental important et detailie.

Des suggestions sont apportees au sujet des prochaines actions a entreprendre afin de mettre au point des strategies realistes de luttecontre les parasites et d'ameliorer la situation de la culture en association de plantes de subsistance. Les entomologistes ont un rdle vital a jouer pour que l'on parvienne a une meilleure comprehension des cultures intercalaires dans les tropiques, et a l'am6lioration de leur productivite en suivant la methode que ce rapport tente de resumer.

Seance n°4 - Evaluation du systeme de la culture intercalai re

Considerations statistiques a l'occasion d'experiences menees sur des cultures intercalaires

R. Mead et R. D. Stern

Les statisticians ont quelque peu contribue a la conception et a l'analyse d'exp6riences mises au point specialement pour etudier les problemes propres a la culture intercalaire. Une etude a etefaite sur les incidences de differents concepts statistiques standards sur la conception et l'analyse d'essais portant sur la culture intercalaire. Cette etude a permis de decouvrir diverses possibilites dans la conception des experiences, notamment l'usage plus large de conceptions systematiques et ('utilisation de structures factorielles de traitement plus complexes. Des methodes de collecte et d'analyse des donnees sur la croissance sont etudiees et des suggestions sont faites sur les moyens de les ameliorer. En ce qui concerne l'analyse des donnees sur le rendement, il est particulierement important de mettre au point des programmes informatiques pour que les analyses de base puissent s'effectuer de maniere simple. Au sujet des analyses utterieures, la valeur et les limitations dans l'utilisation d'un rapport equivalent terre (land equivalent ratio- LER) en tant qu'indice du rendement total sont discutees, et quelques nouvelles possibilites sont presentees.

Concepts experimentaux pour des systemes de culture intercalaire et analyse de donnees

C. K. Ramanatha Chetty et U. M. Bhaskara Rao

Les experiences sur les systemes de culture intercalaire sont complexes et necessitent l'adoption d'une methode d'approche innovatrice pour la conception et l'analyse des donn6es. Le choix du concept experimental et des variables pour l'analyse depend des objectifs du chercheur. Quelques conceptions sont proposees pour les principaux objectifs dans la recherche sur la culture intercalaire et la methode d'analyse des donnees est indiquee. Les deficiences en rapport equivalent terre (land equivalent ratio - LER) sont mises en evidence, et des indices ameliores d'efficacite de la culture intercalaire sont mis au point.

La culture intercalaire dans les systemes d'exploitation traditionnels

N. S. Jodha

Bien qu'ellesoitpresquetoujours ignorde des chercheurs et des planificateurs, la culture intercalaire est un element cle des systemes d'exploitation traditionnels. Sa superiorite sur la monoculture a et6 demontree en termes de rendements bruts par hectare plus eleves et plus sure, ainsi que par unite d'utilisation de la main-d'oeuvre pendant les pleines campagnes. Son potentiel pour un emploi plus important est egalement demontre. Les etudes montrent que la culture intercalaire est un systeme particulierement adapte aux exploitations de petite taille non-irriguees. Une incidence importante de cette decouverte est que n'importe quelle percee technologique dans la culture en association beneficiera davantage aux exploitants pauvres qu'aux exploitants riches, L'augmentation des ressources allouees a la recherche sur la culture intercalaire servira done davantage des objectifs d'equite.

Il apparalt que ia culture intercalaire est extremement complexe et diverse, en raison des tentatives deployees par l'agriculteur en vue de realiser simultanement ses objectifs multiples au moyen de ce systeme de culture. Les chercheurs ne peuvent pas mettre au point de nouveaux systemes de culture en association aussi complexes, et cela ne s'avere vraiment pas necessaire. Au contraire, ils devraient concentrer leurs efforts a l'elaboration d'un systeme simple qui satisfasse les objectifs cles tels que la rentabilite et la stabilite, sans ignorer totalement les autres objectifs sous-jacents a un systeme de culture intercalaire.

Stabilite, productivite et rentabilite de quelques systemes de culture intercalaire dans l'agriculture en terre seche

N. G. P. Rao, B. S. Rana et P. P. Tarhalkar

Si I'on observe les systemes d'expioitation productifs en terre seche, pour les zones tropicales semi-arides, qui ont pris naissance recemment, on s'apergoit qu'une tentative a ete faite de concevoir et de mettre au point des systemes de culture intercalaire appropries,qui permettent un rendement, une stabilite et une rentabilite nettement meilleurs.

Des etudes sur la concurrence entre les especes ont permis de caracteriser des especes complementaires, agressives et relativement neutres. Sous des contraintes de concurrence, le sorgho, suivi par le pois d'Angole, s'est avere etre l'espece la plus stable tandis que l'arachide s'est revelee etre la plus sensible.

Au niveau varietal, il a ete demontre que des varietes appropriees de pois d'Angole telle que Hy-3A avec des branches non basilaires a un niveau de population adapte sont plus stables dans des systemes de culture intercalaire. *Swobhagya* dans le cas du ricin, et CSH-6 dans le cas du sorgho sont des exemples similaires.

Des etudes sur les modes de plantation altemes ont revele que ('interaction entre les systemes de culture intercalaire et les modes de plantation etait tres importante, mais certains systemes specifiques, bases sur le pois d'Angole et le sorgho, n'ont pas 6te significatifs. Les sorghos ont montre qu'ils etaient les plus stables.

Tandis que les rendements des systemes de culture intercalaire tendent generalement a tomber entre les niveaux de rendement des cultures les composant, le rendement transgressif du systeme ne tombe pas. Hormis le rendement, les prix appliques deviennent egalement un facteur important dans le choix des cultures composantes. Dans sept des systemes de culture intercalaire les plus rentables identifies, le sorgho a ete une composante constante. Il semble que des etudes en profondeur sur des facteurs tels que la capacite d'ameliorer le rendement pourraient, par voie de consequence, faire augmenter la stabilite; ia productivite et la rentabilite des systemes de culture intercalaire.

Quelques etudes recentes sur les systemes de culture intercaiaire en terre seche en Inde - quelques reflexions, quelques resultats

S. L. Chowdhury

Quelques doutes sont exprim6s a propos du caractere adequat de la documentation sur les avantages et benefices qui decouleraient, comme on le dit souvent, de systemes de culture intercaiaire du type "s6rie de remplacement". Ces doutes sont illustr6s par les resultats presentes et obtenus a la suite d'essais conduits dans les centres de cooperation du All-India Coordinated Research Project for Dryland Agriculture (Indian Council of Agricultural Research) au cours des annees 1971-1972 a 1977-1978. La mesure du rapport equivalent terre (land equivalent ratio - LER) s'est avere inadaptee a evaluer la productivite totale ou les revenus. La valeur en capital attendu (expected money value - EMV) est recommandee en tant que mesure plus adaptee a des essais sur des systemes de culture intercaiaire dans lesquels des populations des deux composantes sont a leur maximum, pour etablir des conclusions dans ce domaine de la recherche.

Stabilite du rendement dans un systeme de culture intercaiaire pois d'Angole/ sorgho

M. R. Rao et R. W. Willey

Les resultats disponibles obtenus a la suite de 89 experiences menees sur une culture intercaiaire de sorgho/pois d'Angole ont 6t6 rassembies, et quelques bases sont presentees pour permettre d'appr6cier la stabilite du rendement. En moyenne, un systeme de culture intercaiaire produit l'equivalent de 90% du rendement en culture pure du sorgho et d'environ 52% du rendement en monoculture du pois d'Angole. Les arrangements des rang6es, qu'ils soient de 1 rang6e de sorgho pour 1 rangee de pois d'Angole, ou de 2 rang6es de sorgho pour 1 rang6e de pois d'Angole, n'ont pas beaucoup change les rendements du sorgho ni le rendement global (42%); cependant, la probabilite d'augmentation du rendement en sorgho semble legerement plus elevee dans le systeme 2/1. La stabilite est evaluee au moyen du coefficient de variation dans les rendements, du benefice relatif de la culture intercaiaire avec des changements dans l'utilisation de l'engrais et du sol, des baisses de rendement, et des rendements des cultures pures ou intercalaires vis-a-vis de l'indice d'environnement base sur le rendement en un emplacement donne. Le coefficient de variation des rendements en culture intercaiaire a ete moindre que celui des rendements en culture pure, mais cette methode n'a pas entraine une stabilite reellement sup6rieure pour la culture intercaiaire. La superiorite relative de la culture intercaiaire est restee au moins similaire a differents niveaux d'engrais. Il n'est pas apparu de lien entre le benefice relatif et la quantite d'eau utilisee. L'analyse des baisses de rendement a montre que le systeme de culture intercaiaire etait superieur a celui de la monoculture a tous les niveaux de rendement, et qu'il peut etre adopte de mani6re plus large. L'impossibilite d'obtenir un niveau de revenu donne, avec soit des prix constants, soit des prix variables pris au hasard, s'est averee moins fr6quente dans un systeme de culture intercaiaire qu'en monoculture.

Culture intercalaire a un niveau operationnel dans un systems d'exploitation ameliore

B. A. Krantz

La culture mixte ou intercalaire a fait son apparition dans l'agriculture traditionnelle, ou elle a ete pratiquee a un bas niveau de technologie en grande partie pour reduire les risques. La recherche effectuee recemment a montre une amelioration sensible des resuitats de la culture intercalaire a des niveaux moyens ou eleves de technologie; cependant, en raison de plusieurs facteurs, notammentdes lacunes dans la recherche au niveau operationnel, la technologie de la monoculture a ete promue au moyen des programmes nationaux, et l'on n'a pas pu obtenir de benefices potentiels dans la culture intercalaire amelioree.

La recherche a donne de bons resuitats avec la technologie de la culture intercalaire amelioree, et ces importants effects synergiques resultent de plusieurs pratiques de production ameliorees et associees. Les chercheurs devraient done, dans une prochaine etape, mener des recherches au niveau operationnel pour decouvrir et reoudre les problemes et contraintes possibles. Puisque l'exploitant agricole dans les zones tropicales semi-arides a un capital et des terres limites, les chercheurs devraient lui fournir les informations necessaires pour qu'il puisse realiser des benefices au moyen de la culture intercalaire et des effets synergiques de la gestion amelioree non-financiere, et pour qu'il utilise ces benefices de maniere associee avec les couts tres onereux.

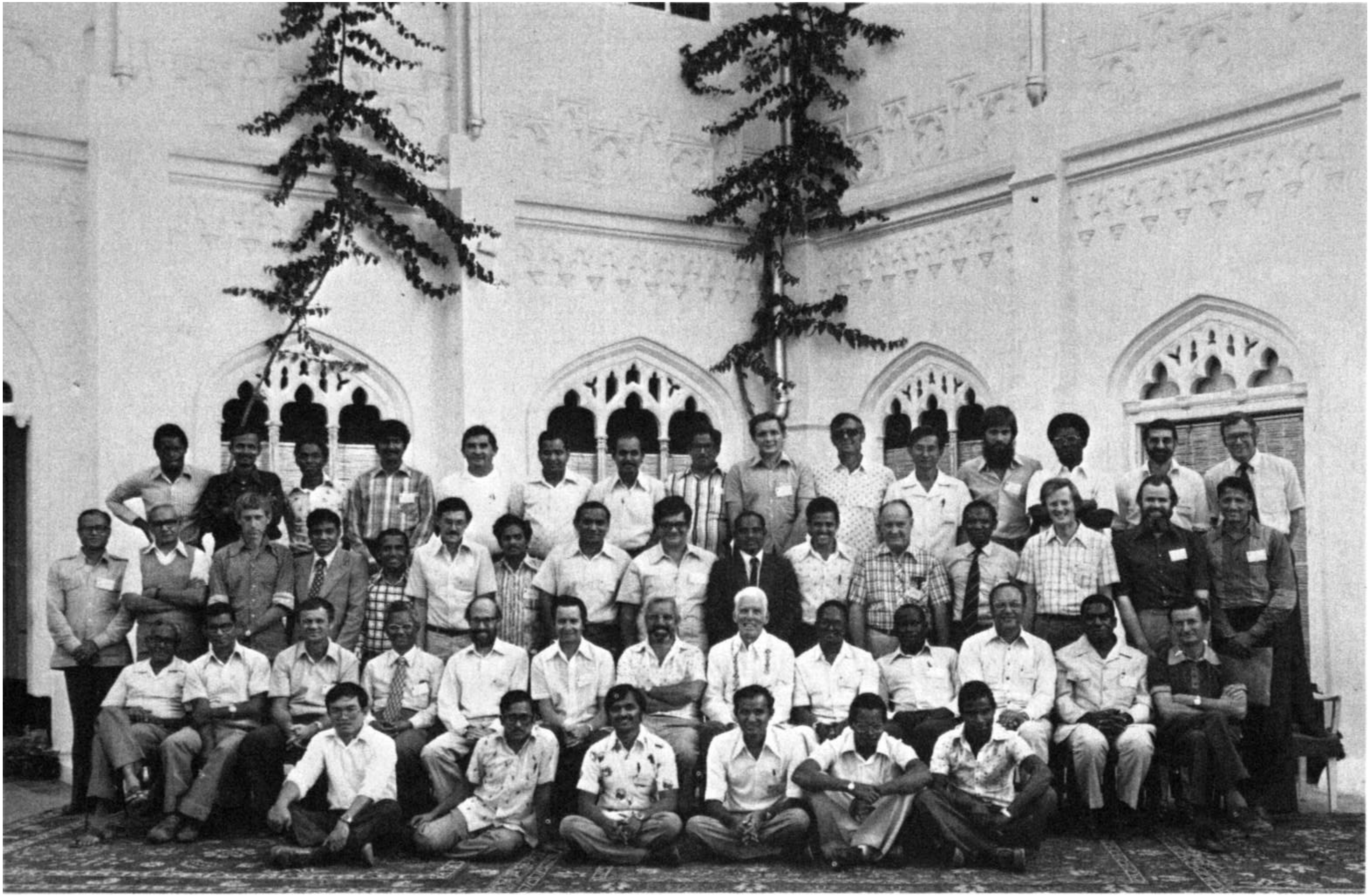
Besoins de mecanisation du semis et des operations culturales inter-lignes suscites par la culture intercalaire en Inde

D. T. Anderson

La culture intercalaire suscite un nouvel ensemble de besoins quant au semis et aux operations culturales inter-lignes. En Inde, la tendance a la mecanisation des travaux realises avec les bovins favorise actuellement la production de cultures pures. Des lignes directrices doivent etre definies pour la culture intercalaire. La recherche de terrain indique le besoin d'elaboration d'un procede mecanique de distribution dosee des semences ainsi que du developpement du concept d'element semeur. La necessite de corps rayonneurs sur les semoirs et planteuses f avorisera le semis en sillon semi-profond ou profond des cultures rabi, mais un large eventail de possibilit6s existe pour les cultures kharif. Des outils destines aux operations culturales inter-lignes et equipes de socs a ailes ouvertes, au lieu de la herse-cultivateur, sont necessaires. La mise au point de barres ou de tetes porte-outils a usages multiples, sur l'equipement des bovins, est encourag6e.

Appendix III

Participants



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