1. MANAGEMENT OF WEEDS, PESTS AND DISEASES IN INTERCROPPING SYSTEMS AND USE OF APPROPRIATE EXPERIMENTAL DESIGNS, EVALUATION TECHNIQUES AND ON-FARM RESEARCH APPROACHES

M S Reddy
FAO/UNDP Maize Project
Mount Makulu Research Station
Private Bag 7, Chilanga, Zambia

CONTENTS

INTRODUCTION

Intercropping or growing of two or more crops simultaneously on the same piece of land is an age-old practice in the tropics. The crops are not necessarily sown at exactly the same time and their harvest times may be quite different, but they are usually 'simultaneous' for a significant part of their growing periods. The term intercropping should only refer to situations where the crops are grown in separate rows. Where one or more of the crops are broadcast, the term "mixed cropping" should be used.

Intercropping is most commonly practised among small-scale farmers. The main consideration for mixing crops together is to reduce the risk of failure from drought, pest or disease incidence. The farmers believe that if several crops are grown at the same time, at least one will survive to harvest. There are other reasons too: frequently one can find short-duration and long-duration crops in the mixtures. This helps to spread labour 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 power of the legumes convey to the associated cereal crop or to a subsequent one.

Although research on intercropping may have started to provide an understanding of why the farmers 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, including:

(a) increased efficiency in the utilisation of environmental factors (light, water and nutrients);

(b) more efficient utilisation of labour;

(c) reduction of the adverse effects of weeds, pests and diseases;

(d) insurance against crop failure;

(e) higher gross returns; and

(f) protection of the soil against erosion because of better ground cover.

This paper briefly reviews various approaches to the management of weeds, pests and diseases in intercropping systems, and suggests appropriate experimental designs, evaluation techniques and on-farm research for use in intercropping studies.

WEED MANAGEMENT IN INTERCROPPING SYSTEMS

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 (35). 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 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 (35).

The weed-suppressing ability of intercrops is dependent upon such factors as the component crops selected, the cultivars selected, the plant density used, the proportion of the component crops in the intercrop, their spatial arrangement and the fertility and moisture status of the soil.

Numerous authors (4,5,11,30) have reported that the weight of weeds growing in association with a maize/mungbean intercrop is as low or generally lower than that growing in association with the sole crops. Furoc et al. (23) reported that when soybean was intercropped with maize, the presence of soybean reduced weed growth markedly. Forty days after sowing, 4.0 t/ha weeds were harvested from the sole-crop plots, whereas only 0.5 t/ha were harvested from the intercropped plots.

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 reduction (3). It is assumed in the literature without empirical verification, that growing crops in mixtures results in a saving in labour (38). Norman (38) 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 the weeding of the first, can be combined. In 1968, Norman reported that although, theoretically, labour should be saved by intercropping, the quantitative evidence does not support this statement. According to Harwood (25), 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. Suppression of weeds in 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 maize during weeding about a month after the maize has emerged so that the presence of the cowpea would result in fewer weeds, and fewer weed problems, in subsequent crops. In Colombia (12), in sole and intercropped maize and bean, one weeding was needed to give adequate control compared to the sole-cropped maize.

Methods of weed control

Weed control may be a greater problem in intercropping than when the component crops are grown alone (35). 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 maize or when the row spacings of the component crops are too close to each other. Erbach and Lovely (20) 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 (35). Miller (33) reported that weed control methods utilising mechanical cultivation or herbicides appeared less satisfactory for intercropped maize 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 maize and beans. 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 system (35). The spatial arrangement of different crops makes chemical control of weeds difficult. Young et al (51) stated that technical considerations severely restrict herbicide utilisation in intercropping while Moody (35) 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 is the likelihood of finding herbicides that will effectively control weeds without causing crop damage (34).

Experiments conducted primarily at research stations have identified some herbicides that are suitable for use in simple crop associations. Butachlor applied pre-emergence has been used successfully in maize/mungbean (4,5) and maize/cowpea (39) intercrops to control many weed species. Pamplona and Imlan (39) 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. In a maize/groundnut intercrop, only trifuralin was not toxic to both crops (40). In India, alachlor has been used successfully for weed control in maize/soybean intercrop. The same herbicide at 1 kg/ha gave 85% weed control when sorghum or maize were intercropped with cowpea (16). In Colombia (12), excellent weed control has been obtained in maize/bean intercrop when alachlor and linuron were applied alone or in combination at high rates.

Weed management research in intercropping is still in its infancy. Probably because no systematic and co-ordinated 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 programme. 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:

(a) ecophysiological studies leading to the manipulation of intercropping systems to obtain better management of weeds;

(b) 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. 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 to obtain better weed management.

Some of the areas that need to be researched immediately are:

(a) the weed-suppressive ability of the intercrop system. Does it favour or disfavour weed growth when compared to sole-cropping?

(b) the major weed problems of the system. Does the system encourage the build up of particular weed species?

(c) the physical, biological and cultural factors which increase the weed suppressing ability of the system.

(d) methods of manipulating these physical, biological or cultural factors in order to increase the weed suppressing ability of the system.

(e) the management practices which affect weeds.

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. 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 the representative systems under the farmers' present weeding regimes. This latter approach would also indicate the relative productivity of the system under farmers' present 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.

Weed management studies

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 population (and proportion) 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 favoured 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 the intercrop system be weeded?

(b) do crop mixtures require more labour for weeding? Do crop mixtures help alleviate the labour problem?

(c) can mechanical weeding be practical in intercrops as done 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 weed must be controlled, and which weeds could be left alone?

(e) by continuously practising the same control methods, are we creating favourable conditions that encourage growth and dominance of certain species? What modifications in the present weeding systems are necessary to avoid this? What modifications in cropping systems are necessary? Can we use crop rotations to avoid problem weeds?

(f) can herbicides improve the productivity of the intercropping systems? 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 farmers 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 tools used for weeding or interrow cultivation also need to be determined.

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 basic weed research philosophy in intercropping should be the manipulation of the environment in such a way that it favours a community of "crop" plants and not a community of "weed" plants. The broad research objectives 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.

PEST MANAGEMENT IN INTERCROPPING SYSTEMS

Monocultures, although thought to be often highly productive and efficient, have been criticised for their genetic uniformity and increased pest susceptibility. Unlike monoculture, the regulation of insect pests in multiple crop systems by physical means (protection from wind, hiding, shading, alteration of colour or shape of the stand etc.) and biological interference (production of adverse chemical stimuli, presence of predators/parasitoids, etc) have been emphasised (29,37,44 48). These workers included some examples of the behaviour 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, and one of the reasons for the evolution of these cropping patterns may be reduced incidence of insect pests (1, 3, 10, 15, 21, 46, 47). Factors such as increased parasitoid and predator population, availability of alternate prey, decreased colonisation and reproduction in pests, chemical repellency, masking feeding inhibition by odour from non-host 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. But there is much uncertainty.

Certain pests colonise 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 (31). In Nigeria, unsprayed cowpea is less subject to insect damage when intercropped with sorghum rather than sole cropped (41) and a similar situation prevails in maize/cowpea intercropping in Tanzania (27) and also in South-Western Nigeria (8). Thus the preference of certain polyphagous pests for cereals may enable subsistence farmers to produce an economically viable yield of legumes.

Some pests can attach 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 (22,45). Gavarra and Raros (24) found more predatory spiders in a maize/groundnut system than in sole-cropped maize. This was partly attributed to improved supply of soil micro-fauna 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 (14). 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 semi-wild environment seemingly stimulates "perennial" stability, which ensures that the pests remain a minor problem even in unsprayed conditions. However, in Southern Tanzania, the dry season induces diapause in Heliothis which limits successful biological control (42). In these circumstances, 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.

In a maize/bean intercrop in Colombia (1), adult populations of the most important pests of beans, Empoasca kraemeri, a leaf hopper, and Diabrotica balteata, a polyphagous insect, were reduced by 26% and 45% respectively. Spodoptera frugiperda incidence as cutworms in maize was reduced by 14%. Also intercrops had 23% less infestation of fall army worms as whorl feeders. Planting dates of maize and beans also had an influence on the population dynamics of pests. Advancing planting of maize (30 days) reduced bean pests significantly and advanced planting of beans (30 days) reduced maize pests significantly (1).

Intercropping and pesticides

Given the current economic status of many crops, pest suppression with pesticides is clearly a strategy with limited application in intercropping. Problems will arise in application of pesticides in intercrop situations. Often it is difficult to prevent drift reaching the non-target crops. Differences in crop height, susceptibility and maturity, and inconveniences to the applicator while spraying or dusting with existing machinery are other problems of pest suppression with pesticides in intercropping and require alternatives. Given this situation, the need for methods of control other than use of pesticides is emphasised in intercrop subsistence farming.

Pest management strategies

Prevention of losses caused by pests at all stages in intercrops will initially require a study of the nature 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 utilise escape mechanisms by careful selection of cultivars.

Data are lacking on the extent and factors governing the natural control of key pests in most intercrop situations. The basis of the management of a whole pest complex in an intercrop system should be a planned manipulation of the various factors which influence the economic injury level so as to minimise the economic effect of the pests. It is necessary that entomological research in intercropping should be intensified. Principles will have to be established using relatively few crop combinations initially and increased plot sizes and replication. Large 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, fertiliser levels and methods of application and various other local cultural practices in both existing and proposed intercrop systems are major factors in insect population dynamics and need investigation.

It is important that production research in intercrop situations goes hand-in-hand with pest management research. Pest management in intercropping systems should be an important element in the development of cheap and feasible management practices for the intercrop situation. Crop sanitation, optimum seed rate and plant stand, destruction of "overwintering" pests by timely ploughing and stubble destruction, observance of fallow and homogeneous planting dates, and choice of pest-tolerant cultivars must be combined.

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. 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.

DISEASE MANAGEMENT IN INTERCROPPING SYSTEMS

Cropping systems influence not only the population dynamics of insect pests but also epidemics of plant diseases. With a few exceptions, intercrops suffer less diseases than pure crops with the same overall density (7).

There are several mechanisms whereby disease reductions are achieved in mixed stands. Probably the four most important one are (7):

(a) in a pure stand of plants with uniform susceptibility to a particular pathogen, the replacement of a proportion of these plants by resistant ones reduces the amount of tissue which may become infected and this in turn reduces the amount of inoculum available for subsequent dispersal within the stand;

(b) replacement of susceptible plants by resistant ones results in a decline in the density of the remaining susceptible plants and thus an increase in the average distance that inoculum has to travel between one susceptible plant and another. Increased distance is often associated with factors which reduce the spread of inoculum;

(c) resistant plants may interfere with the passage of inoculum between susceptible plants;

(d) cross protection phenomena may play some part.

Although a few studies have clearly shown a reduction in infection rates in mixed stands, when compared with pure stands (8,9), little attempt has been made to determine the relative contributions which these four factors make towards reducing disease.

The relative importance of the reduced density of susceptible plants (through factors a and b) and the resistant plants which act as barriers to the spread of inoculum (factor c), as regards the reduction of disease rates in intercrops, may be determined by comparing the effect on infection rates when susceptible plants are replaced by resistant ones. This has the effect of simply reducing the density of susceptible pure stands under conditions in which cross-protection cannot occur.

Most times, however, the total plant density of intercrops is higher than that of either sole-crop. This induces a change of micro-climate, especially where low-growing crops are interplanted between tall species (shelter effect). In many cases, the relative humidity is increased, i.e. the micro-climate becomes more favourable for fungal and bacterial diseases. The susceptibility of the crop species, primarily the dominated one, might also increase due to reduced isolation.

Beneficial effects of intercropping on plant diseases are most likely to occur with soil-borne diseases. Intercropping also affects epidemics of air-borne diseases. A significant reduction of cassava bacterial blight by intercropping cassava with maize, melon or other crops is reported from Nigeria (2). This is probably due to the earlier and better soil cover provided by the intercrops which, at least to some extent, prevented the splashing of bacteria from the soil onto cassava leaves. While the apparent infection rate of cassava mildew is increased by interplanting maize, it is reduced by interplanting a low crop such as beans. This is a surprising result, since one would assume that maize acted as a barrier, and reduced the spread of inoculum. At the same time, angular leaf spot infection was reduced on intercropped beans (36).

As for cowpeas, incidence of cowpea mosaic virus and cowpea chlorotic virus was not affected by associating cowpea with maize or cassava. Infection was lowest, however, in intercrops with plantain, due to reduced activity of the vectors. While intercropping has no effect on the frequency or severity of Cercospora leaf spots, intercropping with plantain, cassava and maize significantly reduced the severity of Ascochyta leaf spots.

These examples demonstrate how intercropping influences the frequency and severity of diseases. This potential should be used when developing cropping systems for smallholders. As the influence of cropping systems on epidemics of disease depends on too many variables, it cannot be predicted. Therefore, experiments with different crop associations have to be done and appropriate cropping patterns have to be developed for different ecological zones.

EXPERIMENTAL DESIGNS AND STATISTICAL ANALYSIS FOR INTERCROPPING SYSTEMS

Experimental designs

Experiments with intercropping systems are more complicated than those with sole-crops. This is true for the experimental design as well as for the final statistical analysis. Probably, this has been a major reason why many researchers have been hesistant to start experiments with such cropping systems. Although substantial experimental programmes of intercropping research have been initiated within the last decade, little thought seems to have been given to the problems of designing experiments specifically to investigate intercropping. Most researchers appear to have used very simple experimental designs similar to those they have previously used for monocrop experiments. The statistical understanding of experimental designs and the availability of computing facilities have, however, greatly improved since monocropping research was at the stage which intercropping research has currently reached and a much wider range of experimental designs is available to the researcher. One reason why the range of experimental designs should be broader is that the involvement of two or more crops in an intercrop means that the set of possible experimental treatments is far larger than for a corresponding monocrop experiment. Among the particular aspects of intercropping experimentation which require thought are:

(a) the need to define the objectives of an experimental programme precisely, and to attempt to satisfy these objectives through a sequence of specific experiments;

(b) the extent to which intercropping experiments should involve monocrop plots;

(c) the need to investigate the effects of many factors and their interactions at an early stage of an experimental programme;

(d) the large size of many intercropping experiments which therefore require efficient use of available space and careful control of experimental error.

As a general guide, the designs should reflect the need to conform to examine objectives efficiently rather than the need to conform to conventional designs which may be easier to layout and analyse. One of the main problems is that although the intercropping treatments themselves often form a balanced factorial arrangement, the control treatments are usually 'additional'. This means that split plot designs are not possible and greater reliance may have to be put on simple randomised blocks.

One simple but very important point is that experiments must include proper 'controls' (i.e. sole-crop treatments). As a general rule, controls should be included for all crops being examined in order that a valid assessment of yield advantages can be made. In many intercropping experiments carried out to date, this has not been done. An exception may be where intercropping aims to achieve a full yield of a 'main' crop with some additional yield of a second crop. In this situation, a control for the second crop could be eliminated on the basis that intercropping is an alternative only to a sole 'main' crop. Without jeopardising the aims of the experiment, controls should be kept to a minimum so that the maximum possible proportion of the experiment is allocated to intercrop treatments. As an example, the simplest possible design of two sole-crops and one intercrop gives only one third of the plots as intercrop treatments. The 'efficiency' of this design could be improved by incorporating more intercropping treatments of the same two crops.

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 programme, the economic benefits of factorial experiments are particularly strong. Therefore, an experimental programme should include large factorial 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.

The important ideas of blocking in intercropping are the same as in monocropping, that is to recognise sets of plots which are likely to behave homogeneously. Many existing experiments on intercropping which do include two factors use a split-plot design. The number of occasions when a split-plot design is appropriate are few. The only good reasons for using a split-plot design is that some treatment can only be applied to large plots, whereas a large plot is not necessary or desirable for other treatments.

Many intercropping experiments require large "general areas" around the harvested portion of each plot. As many experiments on spatial arrangement of intercrops need to examine a wide range of special treatments. All these requirements make systematic designs potentially extremely important.

Statistical analysis

A straight-forward procedure, and one that is usually necessary to some degree, is to analyse the crops separately. This can be done using a 'reduced' design which simply involves ignoring the sole treatments of the crop not being considered. This is particularly useful for examining parameters which are only applicable to one of the crops.

No intercropping situation can be fully analysed without combining the crops in some way, however, and this is where difficulties arise. A straight addition of yields is usually meaningless where they are of very different types. In some instances, yield can be reduced to some common biological denominators such as yield of protein, dry matter, digestible nutrients etc. A more realistic alternative is to assign a monetary value to each crop. But it must be appreciated that a normal analysis of variance then gives a comparison only between actual treatments. This can be useful but where the assessment of an intercropping advantage depends on a comparison with a combined sole-crop yield, the analysis of this comparison is not included. A particularly useful procedure would be a straight analysis of variance of Land Equivalent Ratio (LER) values because the expected combined sole-crop yield is always equal to one. However, the nature of the distribution of LER values seems to be uncertain and thus the statistical validity of this procedure is at present doubtful.

EVALUATION OF INTERCROPPING YIELD ADVANTAGES

As yields of different crops cannot be compared directly with each other, and therefore not simply added together, special methods have been developed in the past, but the discussion here is limited to basic principles and the current methods. One possibility is to compare component yields with their sole-crop yield for every crop in the mixture and add the ratios together. Another possibility is to compare the land area needed to obtain similar component yields in sole and intercrops. Evaluation can be made on the basis of constituents such as calories, fat, crude protein, lysine, methionine (6) or on the basis or net income. All these potential possibilities have their advantages and disadvantages and the method to be used depends on the objectives.

The Land Equivalent Ratio (LER)

Several different concepts have been developed to assess yields of intercrops, such as the relative coefficient (17), the competition index (19), the relative yield total (RYT) (18), the aggressivity (32), and the competitive ratio (50) but the use of the Land Equivalent Ratio (26) has become common practice in intercropping studies because it is a relatively simple concept. The Land Equivalent Ratio may be defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping. It is usually stipulated that the "level of management" must be the same for intercropping and sole-cropping.

An important concept inherent in the use of LER's is that, whatever their type or level of yield, different crops are placed on a relative and directly comparable basis. Although based on land areas, LER also reflects relative yields (the relative yield total is numerical to LER), i.e. the LER can be taken as a measure of relative yield advantage. The ratio is calculated in the following way:

$$LER = LA + LB = \frac{YA}{SA} + \frac{YB}{SB}$$

where LA, LB are the LERs for the individual crops; YA, YB are the individual crop yields in intercropping; and SA, SB are their yields as sole crops. A ratio of > 1 signals no yield advantage, and a ratio of < 1 yield advantage. A LER of 1.2 indicates a yield advantage of the intercrop over the sole crops of 20%, i.e. sole-crops would require 20% more land to achieve the yield obtained by the intercrop.

In this way, LER represents the increased biological efficiency achieved by growing two crops together in the specific environment. The LER term is usually applied to combined intercrop yields but can equally be applied to the intercrop yield of each component crop (LA + LB = LER). The following example should help in better understanding of the concept and use of the Land Equivalent Ratio.

	Maize (kg/ha)	Groundnut (kg/ha)
Treatment 1: sole maize	5225	-
Treatment 2: sole groundnut	-	1221
Treatment 3: maize/groundnut intercrop	4702	513

$$\text{Maize/groundnut} = \frac{\text{Intercrop maize yield}}{\text{Sole maize yield}} + \frac{\text{Intercrop groundnut yield}}{\text{Sole groundnut yield}}$$

$$= \frac{4702}{5225} + \frac{513}{1221} = 0.90 + 0.42$$

$$= 1.32 = 32\% \text{ intercropping benefit or advantage}$$

As the LER is a relative figure, it does not reflect the absolute yields. Large values can be obtained because of high yields in intercropping but also because of small yields in corresponding sole-crops. Therefore, absolute yields have to be given together with the LERs. The LER represents the biological efficiency of an intercropping system and allows a comparison of one, or with sole-cropping. In practice, however, the intercropping combination with the highest LER is not always the best one, as far as the farmers' needs are concerned. In most situations, component crops are not equally acceptable and one crop is needed or preferred more than another one. When assessing the yield advantages of intercrop combinations, farmers' requirements should not be neglected, otherwise the research aimed at improving the intercropping situation is not based on sound objectives.

Criteria for assessing yield advantages

It is not always appreciated that different intercropping situations may have to satisfy rather different requirements if yield advantages are to be achieved. Yet it is important to recognise these different requirements, not just to ensure that advantages are validly assessed, but also to ensure that research aimed at improving the intercropping situation is based on sound objectives. Three different situations can be distinguished (49):

(a) where intercropping must give full yield of a 'main' crop and some yield of a second crop. This situation is largely ignored in literature, yet it is often applicable where the primary requirement is for a full yield of some staple food crop. This has been well recognised in most parts of East and Central Africa where the primary objective of many intercropping combinations is to produce a full yield of a staple cereal and to maximise yield of the second crop without reducing yield of the main crop;

(b) where the combined intercrop yield must exceed the higher sole-crop yield. This is the criterion which has traditionally been used for assessing yield advantages in grassland mixtures. It is based on the assumption that unit yield of each component crop is equally acceptable and therefore the requirement is simply for maximum yield regardless of the crop from which it comes. This criterion also assumes that growing only the higher yielding sole-crop is a valid alternative to growing both;

(c) where the combined intercrop yield must exceed a combined sole-crop yield. This criteria is based on the assumption that a farmer usually needs to grow more that one crop; e.g. to satisfy dietary requirement, to spread labour peaks, to guard against pest and disease incidence risks and market risks, etc. In this situation, a yield advantage occurs if intercropping gives higher yields than growing both the component crops separately. In fact, the combined intercrop yield does not now have to outyield the higher yielding sole-crop since, by definition, growing only the latter is not an acceptable alternative to growing both crops. This is much the commonest situation in practice. Unfortunately, it is also a situation in which the magnitude or even the existence of a yield advantage is not readily apparent. Part of the problem is that component crops which are often very different in type, or level, of yield must be put on some comparable basis. A more difficult aspect is that any assessment of yield advantage involves the comparison of an intercropping situation in which the component crops are competing with each other and a sole-crop situation in which they are not. Such a comparison must take into account the competitive relationship between crops.

Net income of intercropping systems

The net income has served for a long time as the basis for comparing different cropping systems. It has the advantage that it compares not only the biological efficiency of cropping systems but also takes into account the fact that inputs, mainly labour in this context, are limited and have to be used in different amounts for different cropping systems. There are several disadvantages to this method and it is therefore being replaced more and more by the LER. The calculation of net income assumes that the farmer is producing for the market and can change his cropping pattern with changing price relations. But this is not always correct because the multiple production goal of the majority of smallholders is not maximisation of cash income, i.e. they do not produce mainly for the market but, at first, they have to meet the subsistence needs of their families. Except for genuine cash crops, only surpluses are marketed. Another disadvantage is that market prices change with time and from region to region. Therefore, the use of net income criteria allows the comparison of cropping systems only with limited areas and over limited periods.

Yield stability

When discussing yield advantages and explaining the concept of the LER, the impression may be given that the only advantages of intercropping are higher yields or higher net incomes, and that research on intercropping is only concerned with increasing yields. Apart from ecological and socio-economic aspects, a major advantage of mixed cropping is yield stability, i.e. reliable food production over the years.

When improving cropping systems, especially in areas with climate and pest or disease epidemic hazards, it is not the maximum yields under favourable conditions but acceptable yields over a number of years which are of interest. In fact, intercropping systems give more stable yields than sole-cropping systems. This is one of the main reasons why farmers still prefer this system.

There are several reasons why intercrops give more stable yields than sole-crops. One basic principle of intercropping is compensation. When one component crop suffers from drought, pests or diseases, and does not develop properly, the loss of this crop is compensated at least partially by the other component crop(s), since there is now less competition for resources. No compensation could be obtained, on the contrary, if a farmer has planted sole-crops only. He would obtain no yield or only a small yield from one field, while the yields of the other crops would remain unchanged.

ON-FARM EXPERIMENTATION OF INTERCROPPING SYSTEMS

Research on intercropping, if it is to serve the small-scale farmers, has to be organised along lines different from the approach used in the past. Besides investigating basic questions, more importance must be attached to adaptive research. Promising cropping systems have to be adapted to the specific agro-ecological zones and economic and socio-cultural conditions. This cannot be done entirely on research stations but requires on-farm experimentation. The farmer should participate actively at the stage of planning of experiments. Only continuous contact with the farmer will ensure that the methods developed are accepted by the majority of the farmers in the end. On-farm experimentation passes through different phases with an increasing participation of the farmer, from research managed, researcher executed, through research managed-farmer executed, to farmer managed-farmer executed trials. On-farm experimentation must be much simpler than station experiments, i.e. with a reduced number of treatments and replications to enable the farmer to realise differences between treatments. Farmer-managed trials should be nearly of field size, as only this will force farmers to take real decisions as regards the timing and quantity of inputs (mainly labour).

CONCLUSIONS

To improve intercropping system, not only a higher productivity but also a reduction of crop losses due to pests, diseases, and weeds must be aimed at. Higher plant populations and early ground cover by one of the component crops can contribute directly to weed control. The reduction of pests and disease, however, depends much more on the species and varieties in the association, crop ratios, relative planting time and also on agro-ecological conditions. Not enough is known yet to make full use of the potential of intercrops in this respect. There is no doubt that the reduction of yield losses will only be small and not comparable to those achieved by means of chemical crop protection.

In spite of these limitations, the potential of intercrops for reducing yield losses must be regarded as one of the main advantages of these cropping systems, in particular because chemical crop protection is no real alternative in smallholder food production.

LITERATURE CITED

1. Altieri, M. A., Francis, C. A., Van Schoonhoven, A., and Doll J. D. (1978) A review of insect prevalance in maize and bean polycultural systems. Food Crops Research 1 33-49.

2. Arene, O. B. (1976) Influence of shade and intercropping on the incidence of cassava bacterial blight. In: Perseley, G., Terry E. R., McIntire, R. (Eds) 1977 Workshop on Cassava Bacterial Blight. Ibadan, Nigeria, IDRC, Ottawa, Canada.

3. Baker, E. F. I., and Norman, D W (1975). Cropping systems in northern Nigeria. In Procd. of the Cropping Systems Workshop, IRRI, Los Banos, Philippines, 334-361.

4. Bantilan, R. T., and Harwood, R. R. (1973) Weed management in intensive cropping systems. Saturday Seminar Paper, 28 July 1973, IRRI, Los Banos, Philippines.

5. Bantilan, R. T., Palada, M. C., and Harwood, R. R. (1974) Integrated weed management 1. Key factors affecting crop-weed balance. Philippine Weed Science Bulletin 1 14-36.

6. Beets, W. C. (1977) Multiple cropping of maize and soybeans under a high level of crop management. Neth. J. Agric. Sci. 25 95-102.

7. Burdon, J. C. (1978) Mechanisms of disease control in heterogenous plant populations - an ecologist's view. In: Scott, P. R., Brainbridge, A. Plant Disease Epidemiology, Blackwell Scientific Publications, Oxford, 193-200.

8. Burdon, J. J. and Chilvers, G. A. (1975) Epidemiology of damping-off disease in relation to density of Lepidum sativum seedlings. Ann. Appl. Biol. 81 135-143.

9. Burdon, J. J. Chilvers, G. A. (1976) Epidemiology of induced damping-off in mixed species seedling stands. Ann. Appl. Biol. 82 233-240.

10. Burleigh, J. H. (1973). Strip cropping effect on beneficial insects and spiders associated with cotton in Oklahoma. Environmental Entomology 2 281-285.

11. Castin, E. M., San Antonio, S., and Moody, K. (1976). The effect of different weed control practices on crop yield and weed weight in sole cropped and intercropped corn and mungbeans. Paper presented at the 7th Annual Conference of Pest Control Council, Philippines, 5 - 7 May 1976, Cagayan de Oro City, Philippines.

12. C.I.A.T. (Centro Internacional de Agricultura Tropical) (1974) Annual Report for 1973. Cali, Colombia.

13. C.I.A.T. (Centro Internactional de Agricultura Tropical) (1976) Annual Report for 1975. Cali, Colombia.

14. Coaker, T. H. (1960) Investigations on Heliothis armigera in Uganda. Research Memoir No. 36, London. Empire Cotton Growing Corporation.

15. Crookston, R. K., and Kent, R. (1976) Intercropping - a new version of an old idea. Crops and Soils 28 7-9.

16. Damodaran, A., and Sankaran, S. (1974) A note on evaluation of herbicides in cereal-legume mixtures. Madras Agricultural Journal 61 924-925.

17. De Wit, C. T. (1960) On competition. Versl. Landbouwk Onderz 66 8.

18. De Wit, C. T. Van Den Bergh, J P (1965) Competition between herbage Plants. Netherlands Journal of Agricultural Science 13 212-221.

19. Donald, C. M. (1963) Competition among crop and pasture plants. Advances in Agronomy 15 1-118.

20. Erbach, D. C., and Lovely, W. G. (1976) Machinery adaptions for multiple cropping. In: Multiple Cropping Eds. R. I. Papendick, P. A. Sanchez and G. B. Triplett. Madison, Wisconsin: American Society of Agronomy Special Publication No. 27, 337-346.

21. Francis, C. A., Flor, C. A., and Temple, S. R. (1976) Adapting varieties for intecropped systems in the tropics. In: Multiple Cropping. Eds. R. I. Papendick, P. A. Sanchez and G.B. Triplett. Madison Wisconsin: American Society of Agronomy Special Publication No.27, 235-254.

22. Fye, R. E. (1972) The interchange of insect parasites and predators between crops. Pest Articles and News Summaries 18 143-146.

23. Furoc, R. C., Magbantay, D. Z. and Javier, E. Q. (1977). Intercropping of fodder soybean with green corn. Paper presented at the 8th Annual Meeting of the Crop Science Society of the Philippines, 5 - 7 May 1977, La Trinidad, Banguet, Philippines.

24. Gavarra, M. R., and Raros, R. S. (1975) Studies on the biology of the predatory wolf spider, Lycosa pseudoannulata. Philippines Entomology 2 427-444.

25. Harwood, R R (1974) The application of science and technology to long range solutions: multiple cropping potentials. Paper presented at the International Conference on Nutrition and Agricultural and Economic Development in the Tropics, 2 - 6 December 1974. INCAP Guatemala, 13 pp.

26. IRRI (International Rice Research Institute) (1974) Multiple cropping. Pages In: Annual Report for 1973. IRRI, Los Banos. Philippines, 16-34.

27. Kayumbo, H. Y. (1975) Ecological background to pest control in mixed-crop ecosystem in East Africa. Paper presented at AAAS/Ford Foundation Workshop on Cropping Systems in Africa, Morogoro, Tanzania.

28. Leonard, K. J. (1969) Factors affecting rates of stem rust increase in mixed plantings of susceptible and resistant oat varieties. Phytopathology 59 1845-1850.

29. Listinger, J. A., and Moody, K. (1975) Integrated pest management in multiple cropping. In: Multiple Cropping Eds. R.. J. Papendick, P. A. Sanchez, and G. B. Triplett, Madison, Wisconsin: American Society of Agronomy Special Publication No.27.

30. Mahyuddin, S., Azirin, A. and Ponidi, S. (1976). Land Equivalent Ratio of corn and mungbean intercropped under varying weed management practices. Paper presented at The 2nd Workshop on Cropping Systems 23 - 24 August 1976. Central Research Institute for Agirculture, Bogor, Indonesia, 10 pp.

31. McBeth, C. W. and Taylor, A. L. (1944) Immune and resistant cover crops valuable in bootknot infested peach orchards. In: Procd. American Society of Horticultural Science 45 158-166.

32. McGilchrist, C. A. (1965) Analysis of competition experiments. Biometrics 21 975-985.

33. Miller, P. C. (1976). Weed control systems for representative farms in developing countries. Technical Report, International Plant Protection Centre. Corvallis, Oregon: Oregon State Univesity 118 pp.

34. Moody, K. (1973) Weed control in tropical grain legumes. In: Procd. First IITA. Grain Legume Improvement Workshop, Ibadan, Nigeria, 162-183.

35. Moody, K. (1973) Weed control in intercropping in tropical Asia, Paper Presented at the International Weed Science Conference, 3 - 7 July 1978. IRRI, Los Banos, Laguna, Philippines.

36. Moreno, R. A. (1979) Crop protection implications of cassava intercropping. In: F. Weber, B. Nestel and M. Campbell (Eds). Intercropping with Cassava. Procd. International Workshop, 27 November - 1 December 1978, Trivandrum, India, 17-24.

37. Nickel, J. L. (1973) Pest situation in changing agricultural systems. A review. Bulletin of Entomology Society of America.

38. Norman, D. W. (1973) Crop mixtures under indigenous conditions in northern part of Nigeria. In: Factors of Agricultural Growth in West Africa, Ed. I. M. Ofori, Institute of Social Economic Research, University of Ghana, 130-144.

39. Pamplona, P. P. Imlan, J. S. (1976) Prospects and problems of intercropping corn with legumes in Southern Mindano, Philippines. M I T Research Journal 6 1-9.

40. Punzalan, F. L. (1972) Field screening of herbicides for weed control in corn intercropped with peanut. In: Weed Science Report 1971-72. Laguna, Philippines, Department of Agricultural Botany, University of Philippines, 87-90.

41. Raheja, A. K. (1977) Pest and disease relationship within various crop mixtures, Research Program 1977-78. Cropping Systems, Samaru, Nigeria: Institute of Agricultural Research.

42. Reed, W. (1965) Heliothis armigera (Hb) in Western Tanganyika, II. Ecology and natural and chemical control. Bulletin of Entomoloical Research 66 127-140.

43. Shetty, S. V. R. and Rao, M. R. (1977) Weed management studies in pigeon pea based intercropping. Presented at the 6th Asian Pacific Weed Science Society Conference, 11-17 July, 1977. Jakarta, Indonesia.

44. Southwood, T. R. E. and Way, W. J. (1979) Ecological background to pest management. In: L. R. Rabb. and E. E. Cuthrie, (Eds). Concept of Pest Management. Procd. of a Conf. held at North Carolina State University, 25-27 March 1970, Raleigh, North Carolina, U.S.A.

45. Stern, V. M.(1969) Interplanting alfalfa in cotton to control Lugus bugs and other insect pests. In: Procd. Tall Timber Conferences on Ecology. Animal Control by Habitat Management, 55-59.

46. Tahvanainen, J. O. and Root, R. B. (1972) The influence of vegetational diversity on the population ecology of a specialised herbivore, Phillotreta cruciferae. Oecologia 10 321-346.

47. Taylor, T. A. (1977) Mixed cropping as an input in the management of crop pests in tropical Africa. African Environment 2/3 111-126.

48. Van Emden, H. F. and William, G. F. (1974) Insect diversity and stability in agro-ecosystems. Annual Review of Entomology 19 455-475.

49. Willey, B. W. (1979) Intercropping. Its importance and research needs. I. Competition and yield advantages. II. Agronomy and Research Approaches. Field Crop Abstracts 32 1-10 and 73-85.

50. Willey, B. W. and Rao, M. R. (1980) A competitive ratio for quantifying competition between intercrops. Expt. Agric. 16 117-125.

51. Young, D., Miller, S., Fisher, H. and Shenk, M. (1978) Selecting appropriate weed control systems for developing countries. Weed Science 26 209-212.