SOME CONCEPTS AND EXPERIMENTAL METHODS IN INTERCROPPING RESEARCH

M. R. Rao
Cropping Systems Specialist
IICA/EMBRAPA

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Centro de Pesquisa Agropecuária do Trópico Semi-Árido - Petrolina-Pernambuco.

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SUMMARY

Experimental methods and analytic procedures in intercropping research are not as much developed as in sole crop research, although some of the techniques of sole cropping can be extended to intercropping. The research strategy for yield improvement in intercropping should be same as for sole crops, requiring studies in crop physiology as well as on various agronomic factors. The intercrops can be evaluated by scale neutral indices such as land equivalent ratio, area-time equivalent ratio or combining yields by monetrary value, protein, calories etc. Evaluation of yield stability is of utmost importance for subsistence farmers, and in this context multilocation tests are emphasised. Some aspects related to selection of treatments, particularly of sole crops, factorial arrangements for estimating independent and interaction effects, plot size, minimum data sets to be recorded and standardisation and analysis of results are discussed briefly.

INTRODUCTION

Intercropping is a widely practised traditional cropping system in developing countries of the tropics. While this practice is more common with annual food crops in arid and semi-arid conditions, it is seen in humid tropics with perennial and plantation crops also. Intercropping is known to offer a number of advantages and to mention a few are: (i) the diverse crops growing together will make efficient use of the limited resources (ii) it will help meet the subsistence needs of the farmer (iii) reduce risk due to abberrant weather as well as due to market fluctuations, (iv) can reduce costs an weeding and other pests (v) spread labour peaks to different times of the season, and (vi) possibly help economise nitrogen use where legumes are involved. The major disadvantages seem to be difficulties in mechanising certain operations and use of herbicides.

Generally intercropping is more common amogst small to medium farmers who operate at low levels of inputs. This has been one of the reasons why intercropping has not received the necessary attention of researchers and many even tempted to think that it will give way to sole crops with the introduction of high input technology. But in many developing countries neither the practice has changed nor the contention that sole crops are superior to intercropping at high inputs has been proved. In fact a good deal of current evidence suggests that still higher yields and higher intercropping advantages can be obtained by the use of improved technologies. The view that intercropping is difficult to mechanise is only partly correct because research at ICRISAT, some African countries and in Brazil has shown that improved animal drawn equipment such as tropicultor and other types of wheeled tool carriers can be used for most of the operations in intercrop systems also.

With the realization of the above and also due to a change in the political will of the countries in recent years to improve the living standards of small farmers, intercropping research has been receiving a good deal of attention in the past ten years. However, it is still a young field in which much remains to be done. This paper summarises briefly some of the concepts and methods that are emerging from recent research. For detailed information one can refer to the review of Willey (1979) and proceedings of intercropping symposia held in Tanzania and at ICRISAT for agronomic information and the review of Mead and Reily (1981) for statistical aspects.

CLASSIFICATION OF INTERCROPPING SYSTEMS

Four types of intercrop systems can be identified on the basis of the objectives with which they are grown. Such a distinction helps in deciding the appropriate criteria for evaluating them.

(i) A base crop intercropped with a subsidiary crop:

Systems in which one of the crops is more important than the other. The farmer does not expect any yield loss to occur in this crop due to intercropping and considers the other as a bonus. The base crop can be a staple food crop (eg. sorgum/pigeonpea), a high value cash crop (eg. groundnut/pigeonpea) or a long duration and widely spaced crop which simply permits intercropping without being affected (eg. castor/cowpea). The criteria for evaluation of these combinations would be how closely the system produces the 'full' yield of the base crop and how much additional yield of the other crop. The same criteria is applicable for perennial crop based systems also.

(ii) Crops with similar products:

Systems in which both the components produce similar products with equal acceptability such as mixtures of grasses for forage purpose, cereals for food purpose (eg. sorghum/millet, sorghum/maize) or oil seed crops (castor/ groundnut). Here total yield is more important than the contribution of individual components. For the intercrop to be advantageous, its combined yield must exceed the highest yielding sole crop.

(iii) Crops for different purposes:

Often small farmer's systems involve crops that cater to his different requirements such as a cereal and a legume (eg. maize/beans), a food and a cash crop (eg. sorghum/groundnut) or a food and a feed crop (eg. palma/ maize/cowpea). In such cases the intercrop is advantageous if the combined intercrop yield exceeds sum of the yields of the components grown seperately. This is the most common situation and also makes the intercrop vs sole crop comparison difficult because of the need to combine yields of different species and the competition between species alters the yield proportion from that of the sown proportion.

(iv) Combinations with 'modifier' crops:

These are mostly the systems in which one of the component is intended to improve the fertility status (eg. sugarcane/green manure crops for incorporation), decrease pests and diseases on the principal crop (eg. crotalaria with banana to reduce nematode problems) or to modify the microclimate for better growth of the other (eg. intercropping of coffee, tea or cacao with shade giving trees). Such systems to be more productive the 'modifier' components, apart from acheiving the specific objective, should be non-competitive and preferably of economic value.

RESEARCH STRATEGY

In the farming practice we come across numerous combinations with crops ranging from two to four, or even more in number. It is difficult to work on all such combinations and in fact one does not know how advantageous they are over simple systems, say with 2 or 3 crops. The logical approach would be to work on a few systems that have definite yield advantage, at least 15 to 20%. Generally the complementary effects are closely related to temporal and/or spatial differences between the crops involved. Where the components differ widely, particularly in terms of duration, the complementary effects (i.e. intercropping advantage) can be increased by having more than 2 crops (eg. castor and moco cotton based systems). However, more than three crops may complicate the system and eliminate flexibility. Once the promising systems are identified the strategy for improvement should be the same as for a sole crop. As a matter of fact, the intercrop is nothing but a combination of difefrent species of plants. One would need some physiological studies for understanding the competition between species, growth and resource use. These studies would enable to identify the scope for further yield improvement through agronomic manipulation. The agronomic studies should include plant population and spacing, genotype evaluation, studies on fertilization, interaction of water x nutrients and pests and diseases. Besides these, studies specific to intercropping are those meant for understanding the role of legumes and evaluation of yield stability (Willey, 1979).

PARAMETERS AND INDICES FOR EVALUATING INTERCROPPING SYSTEMS

Intercrop systems can not be evaluated adequately by the criterion of yield or economics alone, and one must use alternative methods depending on the crop combination and objectives with which they are grown.

(i) Yields:

Yield being the ultimate product of economic value, it is the most important parameter that is normally considered for evaluation of these systems. Apart from grain yield, biproducts of economic importance such as straw of cereals (eg. sorghum etc.), haulms of legumes (eg. groundnut), stalks of woody plants (eg. pigeonpea, castor) and green foliage (eg. moco cotton) must also be considered for evaluating the systems. The yield of each component in intercropping has to be calculated on the basis of the total area occupied by the system, and they must be expressed at a constant moisture while comparing different treatments.

The yield per ha adjusted to a constant moisture (eg. 12%) is computed from the plot yield as follows:

$$\text{Yield per ha adjusted to 12\% moisture} = \frac{\text{Yield per plot(Kg)}}{\text{plot area in m}^2} \times 10000 \times \frac{100 - (\text{\% moisture in the sample})}{100 - 12}$$

The yields of the components can be combined and the systems evaluated on the basis of the combined yields if both the components produce similar end product, eg. cereal grain in the case of maize/sorghum, oil seeds in the case of castor/groundnut, legume grain in the case of pigeonpea/cowpea etc. If the end products of the components are of different nature (eg. maize/cowpea, castor/maize, etc), yields of the components can not be combined directly.

One way to is to transform the yield of one component into the other by a suitable conversion factor (K) i.e. yield of crop B = K x yield of crop A. The K can be derived on the basis of cash value (eg. $K = \frac{\text{value of 1 Kg of B}}{\text{value of 1 Kg of A}}$), calorific value or by equating the yields of the two crops at their maximum production ($K = \frac{\text{maximum yield of B}}{\text{maximum yield of A}}$). If sole maize and sole cowpea produce 2,500 Kg and 1,000 Kg per ha respectively, then the multiplying factor required for expressing cowpea yields in the form of maize yields is $\frac{\text{maize yield}}{\text{cowpea yield}}$ is 2.5. To calculate K on the basis of cash or calorific value sole crops are not needed but in the other sole crops are required to note their maximum yields. The transformed yields of the intercrop treatments along with those of the sole crops can be analysed by normal univariate methods.

(ii) Land equivalent ratio (LER):

It is defined as sum of the land areas required for sole crops to produce the same yields as obtained from 1 ha of intercropping and can be calculated as follows:

$$\text{LER} = \frac{\text{Yield of crop A in intercropping}}{\text{Yield of crop A in sole}} + \frac{\text{Yield of crop B in intercropping}}{\text{Yield of crop B in sole}}$$

Suppose, a maize/cowpea intercrop in alternate rows produces 2000 kg/ha of maize and 400 kg of cowpea compared to 2500 kg/ha of sole maize 1000 kg/ha of sole cowpea, the LER will be $\frac{2000}{2500} + \frac{400}{1000} = 1.20$. It means that 20% more land area is needed as sole crops to match the 1 ha of intercrop yields; in other words, the intercrop is 20% more productive than growing the two crops seperately. This refers to the biological advantage as a result of complementary use of the growth resources. The land productivity can be expressed in a different way by calculating $(1 - \frac{1}{\text{LER}})$, which gives the proportion of area that can be used for other purposes after satisfying the sole crop yields. For the above example the area available for cultivating other crops after satisfying the yields of 1 ha of sole crops is 0.17 ha $(1 - \frac{1}{1.2})$. This is important in subsistence agriculture with limited land/labour resources. The value of higher productivity of intercropping can also be computed in terms of economic returns by the following expression.

$$\text{Monetary advantage} = \begin{array}{c}\text{Value of combined}\\ \text{intercrop yields}\end{array} \times \frac{\text{LER} - 1}{\text{LER}}$$

If maize and cowpea cost Cr$ 100 and 200 per kg respectively, the value of the 20% yield advantage in the cited example is Cr$ 46,666/ha.

If the farmer is required to produce a predetermined proportion of a component, Mead and Willey (1980) argued that a straightforward LER comparison is not valid because of differences in yield proportions across treatments. They suggested a method of obtaining an 'effective LER' for any desired proportion of crops which may be employed for comparing different treatments without bias because that keeps the yield proportion of crops constant across all the treatments.

To illustrate the method, let us consider two intercrop situations of maize/cowpea, one the alternate rows given above and another of 1 maize: 2 cowpea row arrangement with yields of 1500 kg maize and 800 kg cowpea. The LERs are as follows:

Standardised yields (or component LERs)	1 Maize: 2 Cowpea	1 Maize: 1 Cowpea
Maize (M)	1500/2500 = 0.6	2000/2500 = 0.8
Cowpea (C)	800/1000 = 0.8	400/1000 = 0.4
Total	1.4	1.2
Proportion of maize $(\frac{M}{LER})$ =	0.43	0.67

If the farmer is interested in a maize proportion of 0.5, he would have to grow some of sole maize while practising 1:2 intercrop system and some of sole cowpea with 1:1 system.

Area of sole maize (E) required for 0.5 maize proportion (λ) with 1 ha of 1:2 system is given by

$$\frac{M + E}{LER + E} = \lambda \quad \text{where } \lambda > \frac{M}{LER} \qquad \frac{0.6 + E}{1.4 + E} = 0.5 \quad \text{or} \quad E = 0.2 \text{ ha}$$

The standardised yields from 1 ha of 1:2 intercrop plus 0.2 ha of sole maize are equal to (0.6 M + 0.8 C + 0.2 M) = 1.6. The yield from 1 ha (effective LER) is $\frac{1.6}{1.2} = 1.33$

Area of sole cowpea required to produce only a maize proportion of 0.5 with 1 ha 1:1 system is $\frac{C + E}{LER + E} = 0.5$ or E = 0.4 ha. The yields from 1 ha intercrop plus 0.4 ha sole crop add upto 1.6 (0.8 M + 0.4 C + 0.4 C) and the effective LER is $(\frac{1.6}{1.4}) = 1.14$.

Therefore, IM: 2C system is more productive than IM: IC system even for producing the 50:50 proportion of maize and cowpea. The general formula for effective LER of any particular proportion (λ) of component 'a' is

$$LER\ \lambda_a = \frac{Lb\ Sa}{(Sa - La) + (La + Lb - Sa)\ \lambda_a} \quad \text{where } \lambda_a > \frac{La}{La + Lb}$$

If $\lambda_a < \frac{La}{La + Lb}$, the formula is same but La and Lb are to be reversed.

La and Lb are standardised yields (or LERs) of components 'a' and 'b', Sa = standardised yield of the extra sole crop of 'a' to be grown with the intercrop, which will be 1.0 if it yields at the same rate as the optimum sole crop.

LER calculation may be somewhat less meaningful in perennial crops which generally permit intercropping with annual crops without being affected. However, it may be useful in some situations, particularly to compare different treatments of a system and to understand the time course of the performence of the system. If the perennial crop has not entered into production, LER can be calculated using some secondary characters related to yield such as thickness of bark in the case of rubber, stem girth in the case of agro-forestry crops, etc.

LER criterion is particularly relevant where the producer requires some of all the components of the intercropping system. It expresses yields on a relative basis and thus facilitates to combine not only yields of diverse crops in an intercropping system but to pool results of a given combination across experiment/sites.

LERs have to be calculated using the highest sole crop yields particularly for assessing yield advantages of different systems and evaluation of different plant populations. In genotype studies, if the objective is to identify the plant characters related to high relative yields in intercropping, LER of each genotype has to be calculed using the corresponding sole crop yield. On the other hand, if the objective is to identify the highest yielding genotype for intercropping, the best sole crop yield is used for all genotypes. In fertilizer and moisture studies LERs are calculated at each level of fertilization or water application using the corresponding sole crop yields in order to determine the advantage of intercropping for farmers operating at different levels of these inputs.

The disadvantages of LER are that it i) doesn't indicate the size of the absolute yields and ii) doesn't permit comparison of systems with different crops.

(iii) Competition indices:

A number of competition functions are available to quantify the competition of crops in intercropping such as relative crowding coefficient, agressivity, competition index and competitive ratio (Mead and Riley, 1981). Willey compared the first three indices on a sorghum/millet system and found them all to predict the same species as dominant or otherwise, but all of them have the disadvantage that they can not express the relative advantage of intercropping as explicitly as LER. The competitive ratio suggested by Willey and Rao (1980) ($CRa = \frac{\text{LER of crop a}}{\text{LER of crop b}}$) on the other hand is based on land equivalents of the components and can quantify how many times one component is more or less competitive than the other. In the maize/cowpea example given earlier, the competitive ratio of maize is 2.0 signifying that maize is twice as much competitive as cowpea.

(iv) Area-time equivalent ratio (ATER):

LER does not take into account the time span of the crops in sole Vs intercrop comparison, so can not precisely work out the land use efficiency especially where sequential sole crops can be grown as an alternative to intercropping. Hiebsch (1978) suggested 'area-time equivalent ratio' to quantify crop production in different systems per unit area and per unit of time. It is calculated from

$$ATER = (RY_a \times t_a) + (RY_b \times t_b) \ .... \ (RY_n \times t_n)/T$$

where RY = relative yield, t = duration 'days' of the component crops a, b, ... n, and T = duration of the intercrop system.

Consider the case of a cassava/maize/bean intercrop system with yields of 20 t/ha of cassava 2.7 t/ha of maize and 0.75 t/ha of beans compared to the respective sole crop yields of 25 t/ha, 3.0 t/ha and 10 t/ha. Cassava matured in 300 days, maize in 100 days and beans in 80 days. Then the

ATER =

$$\left| \frac{20}{25} \times 300 + \frac{2.7}{3.0} \times 100 \; \frac{0.75}{1.0} \times 80 \right| /300 = 1.3$$

which means that the intercrop is only 30% more productive. But by simple LER this intercrop works out to be 145% more productive (LER = 2.45) than sole cropping.

ATER can be employed in situations of high rainfall and long growing season where more than one crop can be planted in sucession as an alternative to intercropping. However, it has the limitation that it does not take into account the time required for land preparation and planting of successive sole crops.

In rainfed situations, many a times, sequential planting may not be possible, inspite of having sufficient moisture in the lower profiles because of drying out of top layers. In fact the advantage of intercropping lies in that it avoids planting of second crops and ATER undersestimates its advantage to this extent. This can not be employed where crops of the sequential system are different from those involved in the intercrop system.

(v) Monetary returns:

The yields of different species in intercropping can also be combined on the basis of market value of the crops, which is an important consideration because the farmer ultimately realises the advantage of intercropping only through cash returns. Net returns are more appropriate than calculating simply the gross returns because of differential input costs across treatments. But a realistic estimate of net returns can not be obtained in small-plot agronomic experiments (which usually have plot areas of 25 – 100 m^2) because of difficulties in costing for operations such as land preparation, weeding, haversting, threshing etc.

However,it is advisable to deduct from gross returns at least the costs of variable inputs such as seeds, fertiliser, number of weedings, pesticide sprays etc. Returns are highly dependent on the market prices of the crops which vary over seasons as well as locations. It is preferable therefore to examine the returns of various systems at variable price ratios between the component crops so that optimum combinations for different price situations can be known before hand. Sometimes economically viable systems may not be advantageous from LER point of view and vice versa. So one has to be careful while deciding the advantage by choosing appropriate criteria.

Consider the hypothetical situations given in Table 1 where four intercropping systems of crop A and crop B are evaluated by yields, LER and economics. The intercrop system 1 is disadvantageous from the point of yields and returns compared to the best sole crop of A. The LER criterion also indicates that this system is only as good as the sole crops Therefore, it is not worth considering. The second system has a 20% higher land productivity (LER) over the sole crop while there is hardly any economic or yield advantage. Such a system may not be important for those interested only in cash returns or absolute yields but is very important to those required to produce both the crops. When component B is dominant as in the third system,there is a 20% LER advantage and 10% economic advantage. Such systems which show both LER and economic advantages are worth recommending in most situations. However, this may not satisfy those interested in "full" yield of crop A and for them system 4, though presents no economic advantage may be preferable as it has equal advantage as systems 2 or 3 and produces nearly "full" yield of 'A' with some bonus yield of 'B'. So what constitutes an advantage depends on the situation, and to evaluate intercropping systems more than one criterion

TABLE 1. Evaluation of intercropping systems by yields, LER and economics.

System/ Components		Yields (kg/ha)	Advantage over A	LER	Advantage	Returns (Cr$/ha)	Advantage over B
1	A	600		0.4		600	
	B	600		0.6		1200	
		1200	-20%	1.0	0	1800	-10%
2	A	1050		0.7		1050	
	B	500		0.5		1000	
		1550		1.2	+20%	2050	
3	A	600		0.4		600	
	B	800		0.8		1600	
		1400	-7%	1.2	+20%	2200	+10%
4	A	1350		0.9		1350	
	B	300		0.3		600	
		1650	+10%	1.2	+20%	1950	

Sole crop A - 1500 kg/ha, value Cr$ 1/kg;

Sole crop B - 1000 kg/ha, value Cr$ 2/kg.

should be employed.

(vi) Yield stability:

Intercropping is often reported to give more stable yields (i.e. less risk) over years compared to sole crops and that is one of the reasons why small farmers practise it more in erratic rainfall conditions as in the semi-arid tropics. There are two closely related aspects, viz. the performance of a system over time (stability) and over space or regions (adaptability). For understanding stability one needs time series data, and in fact both stability and adaptability can be quantified if one has multilocation tests repeated 4 to 5 years at each place. Rao and Willey (1980) have used a number of methods for evaluating stability in a sorghum/pigeonpea system, the important ones being coeficient of variation, regression techniques and calculation of probabilities of failure of different systems for specified incomes. The regression technique is similar to the one breeders have generally been using for testing the stability of genotypes. The yield of each system (grain yield, relative yield or cash returns) is regressed against an environmental index in a linear model ($Y = a + bx$). The index is derived by substracting mean yields of various systems (soles, and intercrops) at an environment from the overall mean of various environments, positive values indicate favourable environments while negative values indicate unfavourable environments. The regression parameters, mean (a), slope (b) and deviation from regression are used to evaluate relative merits of the systems. This has the disadvantage that unlike in the case of plant breeding experiments the index is based only on a fewer systems, and interpretation is also not strainghtforward. Of all the methods the last approach seemed to quantify the risk more clearly and easily. If data are available covering a reasonable period the, probabilities of success or failure can be estimated by calculating the 'standard normal deviate z ($z = \frac{(\overline{X} - L)}{s}$ $\overline{X}$ - mean, s - standard deviation, L - required level) and referring to the tables of normal curve. If maize in a maize-cowpea intercrop yields 2000 kg with a standard deviation of 400 kg and the minimum yield required is 1500 kg/ha, then the probability of the system failing to produce this critical yield of maize is 10.5%. If the components are required to serve different purposes, the probability of failure of one or the other or both can also be calculated (Pearce and Edmondson, 1982).

Stability is still a new field and requires the attention of statisticians especially in devising better methods of evaluation.

(vii) Farmer's objectives:

It is important to consider whether a new crop combination or an improved practice satisfies the specific objectives of the farmer if any, such as fulfilling the family food needs, feed for cattle, easiness in handling etc; otherwise the improved systems, however good they may be from yield poing of view, may not find favour with farmers.

(viii) Other criteria:

Yield of total calories or protein, returns per unit of labour and reduction in runoff and soil loss are some other useful criteria in certain cases.

SELECTION OF EXPERIMENTAL TREATMENTS - SOME CONSIDERATIONS

Whether or not to include sole plots and how many to include has often been a subject of discussion. Much of the early intercropping studies did not have sole crops of all the components resulting in inefficient use of the experimental results. Sole crops serve as checks as well as standardising units for combining yields of the components in an intercrop system. Sole crops are must, preferably at more than one population, in the early stages of experimentation for assessing the intercrops against the best sole crop systems so that only the genuinly advantageous intercrop systems are identified for further work. Sole crops are not that important in the later stages, particularly when different treatments within a given combination are to be compared. Mead and Stern (1980) observed that inclusion of sole crops within the experiment is not essential for the above purpose and yields from similarly managed areas adjacent to the experiment or general yields of the experiment station can be used as standardising units. However, the concern for sole crops is unjustified if the experiment contains only one sole plot for each of the components. Inclusion of such minimum number of sole plots will provide a at the advanced stage of experimentation and in operational testing.

When sole crop plant population responses are not known, one should examine the population response of a component both in sole and intercropping simulataneously. This is because intercrop responses can be different from that under sole cropping and there would be uncertainty in choosing an optimum sole crop for evaluating the intercrop. Where sole crop responses are known only one sole plot at its optimum population is sufficient. There are three aspects of plant population in intercropping viz. total population (population of both crops combined), proportional population (population of individual components) and relative spatial allocation, each of which may have indipendent effects and show interaction among themselves. Studies therefore must indentify their optimum combination for any intercrop system. At this stage it is worth mentioning that 'replacement series design' most commonly used in competition studies and in early intercropping research does not help to distinguish the various population effects independent of each other. 'Additive populations' with a range of populations of one crop against a range of populations of the other and/or a range of spatial arrangements in a factorial structure are desirable to estimate the independent and interaction effects of population.

In the case of fertiliser studies it is advisable to include sole crops at each level of fertiliser being studied so as to i) identify differences in fertiliser needs of intercrops from that of sole crops and ii) to calculate relative advantage of intercropping at each level of fertility. Similar is the case in studies dealing with moisture. The relation between relative intercropping advantage and water is particularly important in semi-arid conditions where intercropping is more common. To evaluate how efficiently the intercrop uses water, sole crops are required at all levels that the intercrop is examined. Sole crops are also essential in pest and disease control trials to assess the effects of intercropping on pests.

Another point to be noted is that for quantitative factors such as plant population, fertiliser etc one must examine sufficient range of levels to be able to establish quantitative relationships between yield and the concerned factor to work out optimum levels. The minimum levels required for fitting such response curves are three but four would ensure good precision.

In genotype studies the need for sole crops depends on the stage of evaluation and objective of the study. While evaluating the intercrop performance of genotypes in relation to their plant type for identifying the plant characters that may be useful as selection criteria one would need sole crops for all the genotypes under the study. For such studies genotypes of a species representing as wider a range of plant characters as possible with a similar yield potential or more preferably same genetic back-ground have to be examined against a standard genotype or a few genotypes of the other representing typical characteristics. If the the objective is only to identify the promissing genotypes for intercroping the sole crops can be dispensed. Then the relative advantages of different genotype combinations can be evaluated by comparing with the best genotype under sole cropping.

In practice a number of crop production factors exhibit strong interactions with one another, and the benefits of positive interactions cost nothing. Where interactions exist, recommendations based on single factor studies may not be valid. To realise the maximum benefits out of interactions we must study them and be able to define the optimum level of a factor in conjunction with appropriate levels of one or more of the other factors. In intercropping studies the interactions of plant populations x spatial arrangements of component crops, genotypes x populations, water x populations x nutrients, cropping systems x land management are some of the most important interactions. In this context multidisciplinary studies are suggested so that the expertise and resources are best utilised. The treatment setup should be such that the independent and interaction effects are sorted out clearly.

In factorial experiments the treatments increase rapidly with increase in the number of factors and/or levels. The number of interacting factors and hence the treatments to be examined are generally more in intercropping because of the presence of two or more crops. The full factorial treatments are not only unweildy to evaluate but sometimes are unnecessary. In such situations the treatments can be reduced and efforts should be to select as fewer treatments as possible without the risk of losing the information. Some possible approaches are given below.

i) Use of fractional factorial: Only a fraction of the total treatment combinations (say 1/2 or 1/4) is selected. For details one can refer to Anderson and McLean (1974) but the basis for selection of treatments is illustrated by a simple example. In a 2^3 factorial, if the higher order interaction ABC is assumed zero, then by modulus 2 concept we can write the defining contrast as u (mean) = I = ABC, where I means the identity and all effects and interactions may be multiplied by it to show the results of the design. Then

$A = A^2BC = BC$

$B = AB^2C = AC$

$C = ABC^2 = AB$

A, B, C, ABC are aliases of BC, AC, AB and mean (u) respectively or the effects of one set will be calculated as the same those of the other. The analysis of variance for 1/2 fractional replication of 2^3 is as follows.

Source	df
A and/or BC	1
B and/or AC	1
C and/or AB	1
Total	3

There is no error term in the above example, but in larger factorials, the interaction of 3 or more factors can be grouped as error. The analysis of variance for half replicate of 2^6 factorial (32 treatments) will be

Source	df
Main effects	6
2- factor interactions	15
Remainder (error)	10
Total	31

The fractional factorials are more efficient and are advisable when there are more number of factors.

ii) Select only those treatments that would give the superficial response or directions of the response of the factors under study. Plan Puebla schemes developed by Fernandez (1979) would be quite handy for this purpose. If there are three factors each with four levels, the total treatments will be 64, but with the Plan Puebla scheme only 14 treatments are selected (Table 2). First, all the combinations of the middle two levels of each factor are included in the experiment (treatments 1 to 8). Later, the lowest and the highest levels of each factor are combined respectively with the lower and higher levels of the central two of the other factors i.e. 30 kg N is combined with densities of 30 and 50 thousand plants/ha of crop A and crop B respectively while the 120 kg N is combined with densities of 40 and 75 thousand plants/ha. This is repeated similarly with densities of crop A and crop B.

    Treatments T_1, T_5 and T_9 can provide the N response in the range of 30 to 90 kg N at a constant density of 30,000 and 50,000 plants/ha of A and B respectively. Response to a higher range of nitrogen, say 60 to 120 kg N, can be observed from T_4, T_8 and T_{10} which have populations of 40,000 and 75,000 plants/ha of A and B respectively. Similarly, the responses for other factors can be known. This scheme is particularly useful when there are four or more factors.

iii) Select treatments on the basis of practical considerations. This is illustrated in Fig. 1. If there are four populations of crop A and crop B to be examined in two different row arrangements (1:1 and 1:2), the total treatments will be 32 which is rather a large number. However, the regions of treatments that are of most interest in each arrangement are indicated in Fig. 1. In an alternate row system combinations of

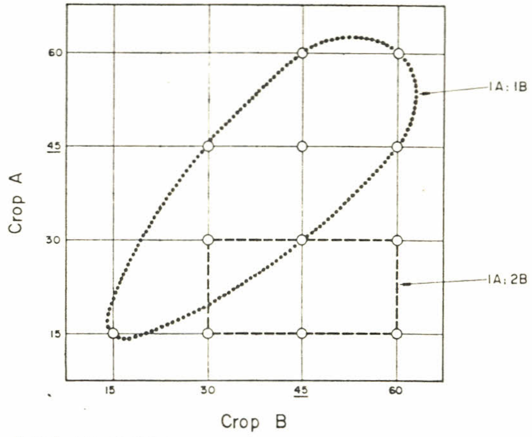
Table 2. Selection of treatments according to the plan Puebla scheme

Factors	Levels			
1. Nitrogen (Kg N/ha)	30	60	90	120
2. Density of crop A (1000 plans/ha)	20	30	40	50
3. Density of crop B (1000 plants/ha)	25	50	75	100

SELECTED TREATMENTS

	N	Density of A	Density of B
T_1	60	30	50
T_2	60	30	75
T_3	60	40	50
T_4	60	40	75
T_5	90	30	50
T_6	90	30	75
T_7	90	40	50
T_8	90	40	75
T_9	30	30	50
T_{10}	120	40	75
T_{11}	60	20	50
T_{12}	90	50	75
T_{13}	60	30	25
T_{14}	90	40	100

FIG. 1. SELECTION OF RATIONALE TREATMENTS



Total treatments

1A : 1B		1A : 2B	
T_1 A_{15} B_{15}	T_5 A_{45} B_{45}	T_9 A_{15} B_{30}	T_{13} A_{30} B_{45}
T_2 A_{30} B_{30}	T_6 A_{45} B_{60}	T_{10} A_{15} B_{45}	T_{14} A_{30} B_{60}
T_3 A_{30} B_{45}	T_7 A_{60} B_{45}	T_{11} A_{15} B_{60}	
T_4 A_{45} B_{30}	T_8 A_{60} B_{60}	T_{12} A_{30} B_{45}	

Replications = 3

Analysis of Variance

Source		Degrees of freedom	
Replication			1
Treatments			13
Rowarrangements		1	
$T_2 - T_5$	A	1	
	B	1	
	AB	1	
$T_5 - T_8$	A	1	
	B	1	
	AB	1	
$T_9 - T_{14}$	A	1	
	B	2	
	AB	2	
Error			26
Total			41

very high populations of one component with very low populations of the other may not be very ideal and similarly, in an arrangement of 1A: 2B, high populations of crop A with low populations of crop B may not be required to be tested. With some care the treatments may be selected such that they form orthogonal contrasts and can be broken down to one degree freedom sums of squares. On this basis, the treatments selected in our example were eight in 1:1 and six in 1:2 arrangements. The analysis of variance is shown in Fig. 1.

PLOT SIZE

Not many studies are available to suggest ideal plot sizes for various intercrop systems and the general principles of sole crop experimentation are applicable to intercrops only to a limited extend. The variation in intercrop trials is generally high because of (i) high soil heterogenity under rainfed conditions in tropics where this system is commonly grown and (ii) of the inherent variability in the intercrop system due to competition between species. Intercrops require bigger plots than for sole crops to provide a reasonable harvest area for each crop which naturally increases the variability. It is difficult to keep the same plot size for all treatments particularly if different row arrangements are involved. The plot size and number of replications can be worked out fairly easily if previous knowledge of the variability in the experimental material and the minimum percentage difference between treatments to be detected as significant are known. Only the minimum plot sizes required are adopted so that the blocks remain small and relatively more homogeneous. Generally rectangular plots are prefered over square plots as they have less variability and are more convenient for field operations.

The plot size in intercropping is more often determined by the tall, competitive or widely spaced crop. In a maize/climbing beans system, Davis et al (1981) observed that to detect a 24% difference between treatments as significant the net plot, with three replications, should be 8 m^2 for sole beans, 11 m^2 for intercropped beans, 15 m^2 for sole maize and more than 25 m^2 for intercropped maize. If the interest is on comparison of both the crops then the maximum plot size of the above with three replications have to be used. Zimmerman (1982) observed that a plot area of 18 sq m with dimensions as 3 m wide and 6 m length would be the optimum for comparison of maize/beans intercrop treatments. Similar plot sizes would be required for other cereal/low canopy legume combinations. But for crops such as pigeonpea, cotton, castor etc. plot sizes bigger than the above area needed. A general guideline could be to harvest at least a minimum of two rows of 6 to 7 m long. In studies with sorghum/pigeonpea at ICRISAT, the standard practice is to have a plot of four pigeonpea rows of 9m long, of which 2.7 m x 7 m comprising two pigeonpea rows is harvested for yield. This plot size has given fairly good results on different soil types. In row arrangement studies harvest plot should have at least two units of the basic proportion. That is for an arrangement of, say 1A:3B, the net plot suggested is 2 rows of crop A and 6 rows of crop B, for the two units will average out the variability otherwise encountered in yields estimated from only one unit, particularly of crop A. Plot size for intercrop systems of perennial crops with annuals would be more or less the same as for sole cropping of the perennial crops. Since the perennial crops are widely spaced, the minimum number of plants required for their yield determination in sole cropping would naturally provide more than the required area for the associated intercrops also.

Plant protection studies demand large plots to avoid contamination from adjacent plots while spraying and where the pests concerned are mobile (eg. Heliothis, rust spores). Small-plots do not represent the natural environment of the system essential for monitoring the pest-parasite dynamics in various cropping systems. Entomologists at ICRISAT used plots of 40 m x 40 m for studies on Heliothis in sorghum/pigeonpea intercropping. Such big plots may not be essential for all pests or combinations but plots of at least 200 to 300 m^2 would be required to give a reasonable picture of pests/diseases in most situations. However, if the concerned pathogen is less mobile as in the case of soil born diseases or insects, plots of less than the above size can be used. While determining the plot yields more border has to be left on all sides of the plot.

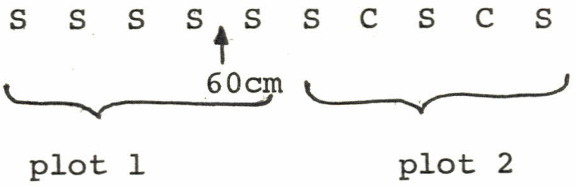
While testing promising systems/practices for their economic viability (at research station or on farmer's fields) plots must be large enough to provide realistic estimates of the costs for various operations such as ploughing, weeding, harvesting etc. Bigger the plot area, greater is the precision in understanding the performance of the system. Similarly for evaluating intercrops on different soil management practices such as beds, flat, ridge and furrows etc or testing implements for intercrops bigger plots are required for, their effects can not be integrated on small plots. Considering the practical convenience and resources one can use plots of 500 to 1000 m^2 for the above experiments. These trials generally involve fewer treatments and replications. When they are located on farms the replications can be spread over the farms. For determining yields the entire plot need not be harvested instead, it can be estimated from subsamples of 20 to 25 m^2. In fact these subsamples serve as replications to get an idea of the experimental error.

In experiments where growth analysis is carried out, large plots are required for periodical sampling and final yield. At each sampling a small border (0.5 m) is harvested. A plot of 17 m lengh is required to provide five intermediate samples, each of 1 m length (with 0.5 m border) and a final harvest plot of 7 m length (with 1 m border on either ends).

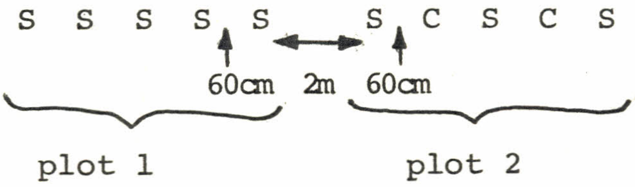
Each plot should normally have a border of one row on either side and one meter on either ends. The need for side border will be more for low canopy crops especially if they are adjacent to a tall and competitive crop. A bigger border is also required in studies dealing with different levels of water application.

The border effects and the area required can be reduced in plant population, genotypes or row arrangement studies by continuous planting of crops over the experimental plots (see a) without leaving extra space between plots as shown in (b).

(a)



(b)



This reduces the experimental area and avoids complications while planting with machine. However, sufficient space between plots is required in irrigation studies to avoid seepage and facilitate irrigations.

The intercrop plots require more area than the sole plots. Some space can be saved by placing the dominant crop row at the beginning and end of the plot; eg. to harvent 2 maize and 4 cowpea rows in a 1 maize : 2 cowpea arrangement a ten row plot is sufficient as shown below.

$$M\quad C\quad \underbrace{C\quad M\quad C\quad C\quad M\quad C}_{\text{Harvest area}}\quad C\quad M$$

An additional row of cowpea on each side is not required to complete the row arrangement pattern. While evaluating a large number of genotypes of a dominated species (cowpea, beans etc) against a standard genotype of a dominant species (maize, sorghum etc) the plot area can be reduced by arranging the genotypes as shown below provided, the dominant crop is little affected by the genotypes and its yield is not required to note.

$$\underset{\text{Cowpea genotypes}}{}\quad M\quad \underbrace{C_1\quad C_1}_{1}\quad M\quad \underbrace{C_2\quad C_2}_{2}\quad M\quad \underbrace{C_3\quad C_3}_{3}\quad M\quad \text{etc}$$

But if the effect of the genotypes on the dominant crop is important, the row arrangement can be as follows.

$$\underbrace{M\ C_1\ C_1}_{\text{Border}}\ \underbrace{M\ C_1\ C_1\ M}_{1}\ \underbrace{C_1\ C_2}_{\text{Discard}}\ \underbrace{M\ C_2\ C_2\ M}_{2}\ \underbrace{C_2\ C_3}_{\text{Discard}}\ \underbrace{M\ C_3\ C_3\ M\ C_3}_{3}$$

This provides two rows of maize and cowpea for each genotype. The genotypes are randomised.

RECORDING OF OBSERVATIONS

Often only grain yields are measured ignoring the secondary data necessary for proper interpretation of results. To make efficient use of the experimental material the following minimum data sets are suggested for various studies.

Agronomic experiments:

Date of sowing, days to emergence, flowering and maturity, days to ground cover, grain and total dry matter yields, seasonal rainfall, ratings for pest and disease incidence.

In addition to the above, specific studies in intercropping require the following additional observations.

Fertiliser studies:

Initial soil fertility, nutrient uptake at harvest, soil nutrient status after harvest of crops particularly in studies of residual effects and nodulation of legumes.

Genotype studies:

Measurements on various plant characters.

Moisture studies:

Periodical soil moisture observations to compute water use and to have an idea of rooting pattern.

Weed control studies:

General weed intensity, dry matter of weeds.

Physiological studies:

Periodical observations on dry matter, leaf area, light interception, water and nutrient uptake.

For representing growth curves of 80 to 100 day crops observations at 7 to 10 day interval are ideal and for long cycle crops such as pigeonpea, castor, etc. observations at fortnight interval are sufficient. Statistically, more than 5 to 6 observations would not be required but for precise identification of shifts in competitive balance between crops in intercropping more observations at shorter interval are preferable. The plant samples for growth analysis should preferably be taken on an area basis at least from 1 to 2 m^2. If the entire material can not be handled, a convenient sub-sample may be used for determining leaf area and dry matter. For accurate measurements one should use a leaf area meter[1] but where it is not available, leaf area can be estimated by conventional means such as planimeter or from length and bredth measurements with appropriate constants. The sample used for dry matter is used for determining nutrient content and uptake.

Light interception is best measured by tube solarimeters[2] of appropriate length as they provide a spatial average of the irradiance (Szeicz et al 1964). One solarimeter is placed in the open to measure the incoming radiation and another underneath the crop to measure light transmitted through the canopy and from these readings, the % light intercepted by the crop is calculated. Multichannel integrators[3] are required for integrated light values over time but where such facilities are not available, spot readings are helpful for understanding the light use pattern of sole and intercrops. T - metter[4] is a versatile instrument for spot readings and it measures directly the percentage transmission on of photo synthetically active radiation (PAR). Light use efficients of different systems, can be calculated using the percent interception and absolute radiation recorded at the nearest observatory. Some

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Available with

[1] Lambda Instruments Corp.
P.O. Box 4425, Lincoln, Nebraska, 68504, USA

[2] Delta-T Devices, 128. Low Road, Burwell, Cambridge, CB5 0EJ, England.

[3] Time Electronics Ltd., Botany Industrial Estate, Tonbridge, Kent, England.

[4] Fellcross Ltd., Fairfield Works, Viaduct Road, Chelmsford, Essex, EM1 1JG. England.

typical resource use studies in intercropping are those of Natarajan and Willey (1980) and Reddy and Willey (1981).

Moisture use is measured gravimetrically or by tensiometers or neutron probe. When neutron probe is used measurements in the top 0-20 cm should be measured by gravimetric method. Root studies provide an understanding of the competition between the components for below ground resources. Of the various techniques, core sampling method is commonly used. Soil cores of 5 to 10 cm diamter are taken across the row spacing. The samples are washed and the roots are spread on a grid square, and the intercepts of roots with the total lengh of vertical and horizontal grid lines are counted. The root length (R) = $\frac{11}{14}$ x Number of intercepts (N) x Grid unit.

Disease or insect studies:

Pest number, scores on infestation and control. Microclimatological observations such as wind speed, canopy temperature and humidity wherever appropriate.

EXPERIMENTAL DESIGNS AND STATISTICAL ANALYSIS

Selection of Experimental Site: The principles generally followed in the conduct of sole crop studies are applicable to intercrop trials also. The basic aim of the researcher is to minimise the experimental error arising due to controllable (eg. crop management) and uncontrollable (eg. soil heterogenity, climatic variability, etc) factors so that the treatment effects are evaluated well. While there is very little one can do about the variation resulting from uncontrollable factors, carefulness on the part of the experimenter can help to minimise the variation due to controllable factors. The experimental area has to be as nearly uniform as possible in terms of soil depth, fertility and texture to establish the treatment effects precisely. This necessarily requires the experimental site to be of known cropping history. A newly cleared area can not be used for field experiments without a uniform crop at least for one year. In many tropical countries it is not uncommon to use newly cleared areas straightaway for experimentation which finally results in variable results and waste of time and resources. While developing research fields care must be taken to avoid excessive soil movement. It is preferable to take the native vegetation out of the field, lest burning or incorporation in the field creates patches of high fertility. Even the areas that have been under cultivation can not be used for experiments continuously because the residual effects of one experiment may vitiate the results of the other. The carryover effects from cereal/legume intercrop experiments are particularly problematic because the sole plots of the cereal and the legume and intercrop plots with varying proportions of the cereal and the legume normally present in an intercrop trial would leave different degrees of residual effects. Such sites must be cover cropped without any fertilisation before they can be reused for new experiments. If scores on the growth of the cover crop corresponding to the experimental plots are available, they can be useful for correcting whatever soil heterogenity that may still persists in the results of the following experiments by the analysis of covariance technique. Repeated use of a site for the same crop may also result in building up of certain soil born insects and diseases. A good example is the Fusarium wilt of pigeonpea which shows up in 2-3 years and affects later trials if the same area is used for pigeonpea experiments without a break. However, the areas of sole crop experiments especially with trials such as genotype evaluation, plant population, planting date etc, conducted generally at a uniform fertility, can be used without a cover crop for trials in the subsequent season provided the crops involved do not have any rotational problems.

The selected experimental area should be a representative of the conditions where finally the results are to be used. Generally the conditions at research stations are better than those in the farmer's fields and it is often argued that the results based on research station experiments may not be applicable to real farm situations. This may not be too big a problem in the case of genotypes, plant population or moisture studies but there is a reason to be concerned with the applicability of research station results to the farms regarding fertiliser and pest control studies. This is because intensive cultivation with annual application of fertilisers and pesticides may change the soil fertility and pest complex at research stations. It is advisable, therefore, to carryout the work related to the above aspects on farmer's fields. By doing so, not only we get a more realistic information but enables to interact with farmers, understand their problems and the trials serve as demonstration to them.

Soils and climate vary greatly in the semi-arid environments which restricts the spread of information from one place to another. This calls for multilocation experiments for any study in a minimum set of agroclimatic environments covering 2-3 seasons. This helps to integrate the affect of a wide range of climates on the production factors under study and to arrive at conclusions much faster than can be obtained with single site experimentation.

Crop Management: Selection of a good site by itself doesn't result in a good experiment and what is equally essential is proper management of crops by the experimenter. Every effort must be made to minimise the background variation in the experimental material so that the observed variation is a reflection of the treatment effects. The good management includes application of necessary soil amendments (micronutrients, liming, control of nematodes and root insects), timely planting of crops (wich is particularly important in rainfed experiments), timely thinning (very important in the case of tillering crops and in population experiments), early gap filling, timely plant protection, timely weeding, and timely harvest of the early maturing component in intercrop to minimise competition to the later maturing component. Planting of an experiment should preferably be completed in one day. But where it extends more than a day it is advisable to spread planting of replicates over days rather than portions of a replicate. The legume crops must be inoculated with a suitable rhizobium if the soil is suspected to be lacking in sufficient rhizobium population. Application of a small dose of nitrogen to non-legumes helps to boost early plant growth and thereby avoid pests in the early stage.

Establishment of a good crop stand is a prerequisite for any experiment. The best approach to acheive this is to plant 2-3 times the normal seed rate and thin to the required population later after the seedlings have passed the vulnerable stage for insects and drought. The analysis of covariance technique, commonly suggested for adjusting yields against irregular stands across treatments, doesn't help much because the yield - density relationship is not linear particularly at high populations. Moreover, most crops exhibit a fair degree of compensation for the loss of plants, so no adjustment is suggested if deviations from the expected stands are not more than 10 to 15 percent. However, where greater deviations are observed it is preferable to estimate yield by harvesting only a portion of the plot that has a reasonable stand instead of the total planned harvest area.

For assessing the effect of intercropping on weeds, insects or diseases there must be a reasonable and uniform level of pest incidence. If weeds are not uniform, weed seeds may be planted in the experimental area. In the case of soil borne diseases, the effect of intercrops is best evaluated on disease sick plots developed by incorporating the inoculum of the specific pathogen.

Experimental Designs: The principles governing the choice of an experimental design are same for both sole crops and intercrops. The standard statistical text books of Federer (1955), Cochram and Cox (1957) can be consulted for details of various designs and their analysis. However, two problems are generally encountered with intercropping studies; (i) the presence of more than one crop rapidly increases the factorial combinations required to be studied and (ii) sole crops often do not form a part of the factorial structure.

In intercropping work randomised block and split-plot designs have been more commonly employed than other types of designs. The latin square is little used because of the restriction on the number of treatments that can be included in this design. The factorial experiments are particularly important for intercropping considering that the intercrop trials generally have more factors to be examined and that they have the advantage of hidden replication and understanding the interaction effects. The information obtained, say, from a study of four plant populations of each component crop with three replications is much more valuable than that from a study with four populations of one of the component in five replications. When both factors are included, the error will have 30 degrees of freedom compared to

12 degrees of freedom with only one factor. At the same time, we know very well that optimum population for intercropping can not be defined by studying the response of the system to changes in the population of just one of the component.

In the context of factorial experiments, the split-plot and strip-plot (split block) designs are of particular use to intercrop studies. But, Mead and Riley (1981) cautioned researchers of the inherent disadvantages of split plot due to its multiple standard errors and less precision in the comparisons of the main-plot factor. However, practical considerations such as irrigation, plant protection, dates of planting, machine operations etc outweigh the disadvantages of less precision and require its adoption. The precision in the main-plot comparisons can be improved by allocating two or more factors in main-plots thereby increasing the degrees of freedom for main-plot error. The analysis of variance of a split-plot design with two factors in the main-plot along with standard errors for various treatment comparisons is given in Table 4 . If the mainplot has only nitrogen or planting date, the error (a) would have 6 degrees of freedom, but with both of them in the main-plot the error has 24 degrees of freedom which are reasonable to distinguish the effects of nitrogen and planting dates.

The split-plot and strip-plot designs are very convenient for genotype work in intercropping. Where large number of genotypes are to be evaluated in sole and in intercropping against a standard genotype of the other component, split-plot can be employed with genotypes in main-plot and the cropping system in sub-plots(Table 4) . It facilitates planting of genotypes in the field and allows visual comparison of the effect of intercropping vs sole cropping on each genotype. The sole plot of the other component is included as a main plot, planting the same in both the sub-plots. Where a limited number of genotypes say 4 to 6 of one component are to be evaluated against a limited number of the other, the strip-plot design is handy (Table ~~1~~ 5). In these designs

TABLE 4. Analysis of variance of split-plot design having two factors in the mainplots.

Mainplots: A. Nitrogen levels - 3 Subplots: C. Row arrangements - 4
B. Planting dates - 3 Replications: r - 4

Analysis of Variance

Source	Degrees of freedom
Replications (r-1)	3
Planting dates (A-1)	2
Nitrogen levels (B-1)	2
Planting dates x Nitrogen levels (A-1)(B-1)	4
Error (a) (AB-1)(r-1)	24
Row arrangements (C-1)	3
Planting dates x Row arrangement (A-1)(C-1)	6
Nitrogen levels x Row arrangement (B-1)(C-1)	6
Planting dates x Row arrangements x Nitrogen levels (A-1)(B-1)(C-1)	12
Error (b) AB(r-1)(C-1)	81
Total (rABC-1)	143

SE of planting dates (or) nitrogen levels $= \sqrt{\dfrac{Ea}{rC(B \text{ or } A)}}$

SE of row arrangements $= \sqrt{\dfrac{Eb}{rAB}}$

SE of row arrangements for the same planting dates or nitrogen levels $= \sqrt{\dfrac{Eb}{r(B \text{ or } A)}}$

SE of planting dates or nitrogen levels at the same or different row arrangements $= \sqrt{\dfrac{(C-1)Eb + Ea}{rC(B \text{ or } A)}}$

TABLE 5. Strip-plot (or split-block) design

Genotypes of A = A_0, A_1, A_2, A_3, A_4
Genotypes of B = B_0, B_1, B_2, B_3, B_4
Replications = 4

(i) Lay-out of a replicate

A_1B_2	A_3B_2	A_4B_2	B_2	A_2B_2
A_1B_4	A_3B_4	A_4B_4	B_4	A_2B_4
A_1B_1	A_3B_1	A_4B_1	B_1	A_2B_1
A_1	A_3	A_4	BLANK	A_2
A_1B_3	A_3B_3	A_4B_4	B_3	A_2B_3

(ii) Analysis of variance

Component A

Source	Degrees of freedom
Replication	3
Genotypes A	3
Error (a)	9
Genotypes B	3
Sole (A) vs intercop (A)	1
Error (b)	12
Genotypes A x Genotypes B	9
Sole Genotypes A	3
Error (c)	36
Total	79

Component B

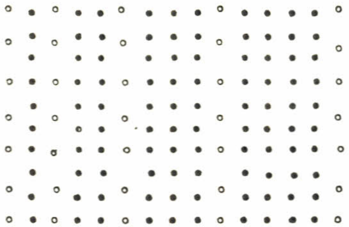
Source	Degrees of freedom
Replication	3
Genotypes B	3
Error (a)	9
Genotypes A	3
Sole (B) vs intercop (B)	1
Error (b)	12
Genotypes A x Genotypes B	9
Sole Genotypes B	3
Error (a)	36
Total	79

the sole plots can be included within the experiment without difficulty if they are required to be examined at all the levels of the concerned factor. In a trial of 4 genotypes of A x 4 genotypes of B, sole crops of all genotypes can be obtained by considering the factorial of 5 x 5, the fifth level being a'nil genotype' in each component. The 4 genotypes of A in combination with 'nil genotype' of B results in sole crops of A and vice versa. The combination of 'nil genotypes' of both crops can remain as a blank. However, where only one sole crop of each component are needed they can not be included within these experimental designs and have to be grown outside the experiment for the purpose of standardising the intercrop yields.

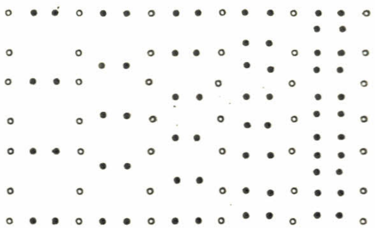
The major difficulty of the factorial experiments is that the treatment numbers increase rapidly with increase in factors and/or levels becoming too unweildy to examine in a randomised block design. This problem can be overcome by incomplete block designs and confounding, or systematic designs. Standard text books such as cochran and Cox (1964) and Federer (1955) can be referred to the details on confounding and incomplete block designs. Confounding can be employed even when the total treatments are not unusually large for the purpose of improving the precision of treatment comparisons. However, the analysis of these designs is somewhat complex and they must be used where the help of a statistician is available.

Systematic designs are particularly relevant to the plant population/spacing studies in intercropping (Fig. 2). These designs facilitate to examine any given factor at a wide range of levels which is very important in preliminary stage of experimentation when no information is available. In these designs the population/spacing of the component under study is varied systematically by a small constant change (10 to 20%) from one end to to the other thereby avoiding the need for borders except at the ends. Significant advantages of these designs are that they demand less experimental area and a greater proportion

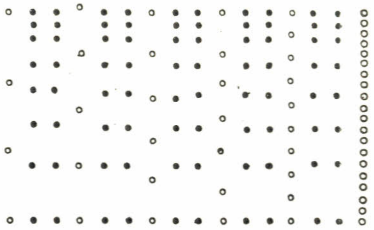
a. Variation in spatial arrangement with constant population within the rows.



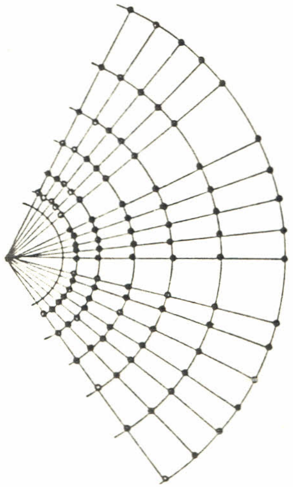
b. Variation in plant population of one of the components at a constant row arrangement.



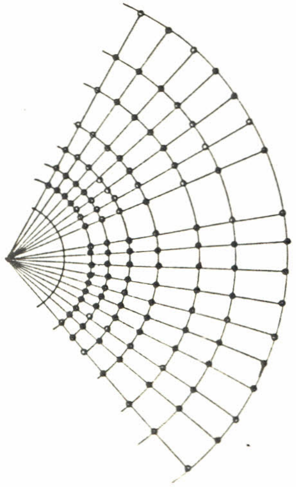
c. Variation in plant population of both components at a constant row arrangement (2-way systematic).

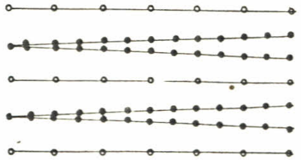


d. Variation in population of crops at constant row arrangement.

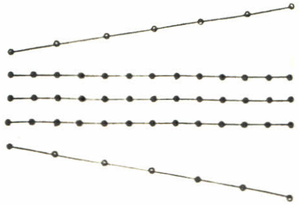


e. Variation in row arrangement and population of both components.





f. Systematic change in paired rows of a component between fixed rows of the other component.

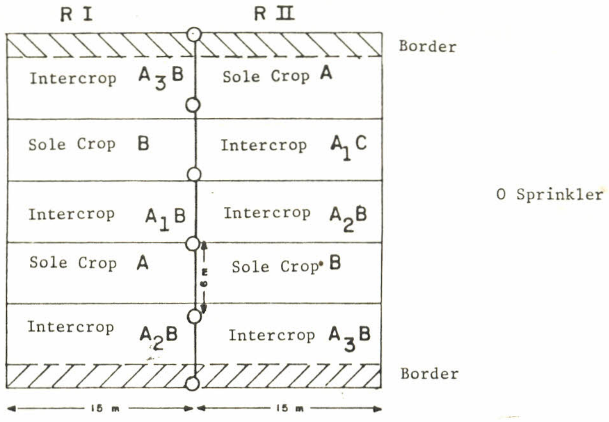


g. Systematic change in row spacing between the two components.

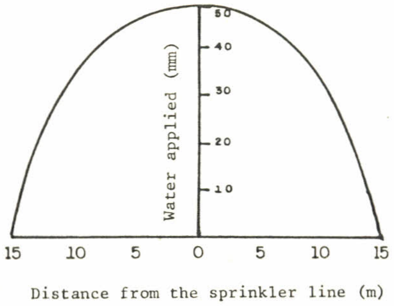
FIG. 2. SYSTEMATIC DESIGNS RELEVANT FOR INTERCROPPING STUDIES.

of sown area is harvested for yield. But the disadvantages are that systematic fertility variation can vitiate results, and in the absence of randomisation normal analysis of variance can not be employed. However, the results are best analysed by fitting appropriate response functions which can be compared for different situations. The parallel row systematic designs (Figure 1 a-c) are more practical than the fan designs for they provide reasonable harvest area for each point, subject to less head border effects and the rows represent the normal field scale sowing pattern. More details about them can be had from Nelder (1962), Bleasdale (1962), Willey and Rao (1981), Huxely and Maingu (1980) and Wahua and Miller (1978).

Similarly for studying the response of intercrops to a wide range of moisture regimes a line source sprinkler system can be employed (Figure 3). This produces a water application pattern which is uniform parallel to a line of close-spaced sprinklers (at 6 m interval) but which systematically diminishes with distance away from the line applying no water at about 15 m (Hanks et al, 1976). The system provides an excellent apportunity for studying the interaction of nutrients, plant population or genotypes with a wide range of moisture environments. Figure 2 illustrates the layout of a simple intercropping experiment with line-source system involving five treatments, two sole crops and three intercrop treatments. In intercropping three populations of one of the component (A) are examined at a constant population of the other (B). Note that each side of the sprinkler line forms a replication and that treatments can be randomised in strips perpendicular to the line. Water applied at different distances away from the line can be measured by placing small bucket collectors at regular intervals and the available moisture and crop water use can be estimated by any of the standard methods of soil moisture determination. The major limitation of this method is that wind speeds greater than 8 Km/hr (though the sprinkler line is parallel to the wind) can seriously alter the water application pattern.



a. Field layout of the sprinkler line and two replications one on either side of the line.



b. Water application pattern by the line-source sprinkler system.

FIG. 3. USE OF LINE-SOURCE SPRINKLER SYSTEM FOR STUDYING RESPONSE OF SOLE VS INTERCROPS TO A MOISTURE GRADIENT.

Statistical Analysis: Intercrop data poses complex problems because of the presence of more than one crop and since ready-made methods are not available for combined analysis of all the component crops. So the first step could be to analyse each crop seperately, with or without the respective sole crops, ignoring the presence of the other as per the standard analysis of variance procedures. The yields can be combined later by land equivalent ratio, cash value, protein or calories etc. and the total yields are analysed including all the sole crops. Since LERs are ratios some doubts have been expressed about their normal distribution and the applicability of analysis of variance tests. Oyejola and Mead (1982) in a recent study observed that the residuals of LERs tendend to be normal if the standardising unit is same for all the treatments. So for calculation of plot-wise LERs they suggested to use a single sole crop yield for each which could be the average of the best sole crop across all replications. Use of separate divisors for each replication did not give good results. Pearce and Gilliver (1878, 1979) suggested a bivariate method of analysis to deal with the two yields of a binary mixture taking into account the correlation between the components. Federer (1982) in fact advocates multivariate analysis for intercropping data, but the use of these methods can be assessed only when they are more widely used.

As an example the analysis of variance of a maize/cowpea experiment conducted at CPATSA is illutrated in Table 6. There are ten treatments comprising six of factorial combinations of 3 cowpea populations (C_1 - 20000, C_2 - 40000 and C_3 - 60000 plants/ha) and 2 maize populations (M_1 - 25000 and M_2 - 50000 plants/ha) in 1 maize: 2 cowpea row arrangement, two treatments with the above two maize populations at a constant cowpea population (C_2) in 1 maize: 1 cowpea arrangement and one sole plot of each crop (cowpea at C_2 and maize at M_2). The additional treatments such as sole crops and 1:1

TABLE 6 . Analysis of variance of yields in a maize/cowpea intercropping experiment.

Source	Degrees of Freedom	Mean sum of sqaures for yield		Combined yield (LER)	
		Cowpea (kg/ha)	Maize (t/ha)	Degrees of freedom	Mean sum of squares
Replications	3	59990.83*	20.73	3	0.1552*
Treatments	8	494584.67**	48.35*	9	0.0378
Error	24	18257.29	14.04	27	0.0427

TABLE 7 . Analysis of variance of yields in a maize/cowpea intercropping experiment.

Source	Degrees of freedom	Mean sum of squares	
		Cowpea yield (kg/ha)	Maize yield (t/ha)
Replication	3	55990.83*	20.73
Treatments			
1M:2C			
M_1C Linear	1	54400.51	4.35
M_1C Quadratic	1	4819.50	6.14
M_2C Linear	1	943.95	1.22
M_2C Quadratic	1	13015.38	4.82
M_1 vs M_2	1	116733.66*	66.47*
1M:1C			
M_1 vs M_2	1	52991.40	91.67*
1M:2C vs 1M:1C	1	67580.40	50.72
Sole(s) vs intercrop	1	3646192.60**	161.43**
Sole cowpea vs sole maize	-	—	—
Error	24	18257.29	14.04

* Significant at 5%.

**Significant at 1%.

TABLE 8 . Breaking sum of squares of cowpea yield into single degree freedom contrasts.

Contrast	Treatment	1 Maize : 2 Cowpea (1M : 2C)						1Maize : 1Cowpea (1M:1C)		Sole Cowpe
		M_1C_1	M_1C_2	M_1C_3	M_2C_1	M_2C_2	M_2C_3	M_1C_2	M_2C_2	C
	Yield of 4 Reps (kg/ha)	1111	1610.9	1770.7	989.3	753.3	1076.2	1119.6	468.5	5163.1
1M : 2C										
C_1 M_1C linear		-1	0	1	0	0	0	0	0	0
C_2 M_1C quadratic		1	-2	1	0	0	0	0	0	0
C_3 M_2C linear		0	0	0	-1	0	1	0	0	0
C_4 M_2C quadratic		0	0	0	1	-2	1	0	0	0
C_5 M_1 vs M_2		1	1	1	-1	-1	-1	0	0	0
1M : 1C										
C_6 M_1 vs M_2		0	0	0	0	0	0	1	-1	0
C_7 1M : 2C vs 1M : 1C		1	1	1	1	1	1	-3	-3	0
C_8 Sole cowpea vs intercrop		-1	-1	-1	-1	-1	-1	-1	-1	8

$$C_1 = \frac{|(-1 \times 1111) + (1 \times 1770.7)|^2}{4\ (-1^2 + 1^2)} = 54400.51$$

$$C_2 = \frac{|(1 \times 1111)+(-2 \times 1610.9)+(1 \times 1770.7)|^2}{4(1^2 + (-2)^2 + 1^2)} = 4819.50$$

$$C_5 = \frac{|(1 \times 1111)+(1 \times 1610.9)+(1 \times 1770.7)+(-1 \times 989.3) + (-1 \times 753.3)+(-1 \times 1076.2)|^2}{4|1^2+ 1^2+ 1^2+(-1^2)+(-1)^2+(-1)^2|}$$

$$= 116733.66$$

sums of squares of other contrasts are calculated similarly.

arrangement in the above example slightly complicate the analysis. First the yield of cowpea and maize were analysed separately and later, the combined yields in the form of LER were analysed. If the treatments form a factorial combinations, the effects of the concerned factors can be evaluated easily by breaking the treatment sums of squares into appropriate components. But where they are not it is advisable to break treatment sums of squares for appropriate single degree freedom contrasts. In our example, (Table 7 & 8) the meaningful comparisons, in addition to the linear and quadratic effects of cowpea populations, are intercrop vs sole crop, 1:1 vs 1:2 row arrangement, and maize populations M_1 vs M_2 within each arrangement. Of all the comparisons, only the sole vs intercrop, M_1 vs M_2 in 1:2 arrangement were significant for cowpea yields, but in maize yield the sole vs intercrop effect and M_1 vs M_2 in both arrangements were significant. In the case of LERs none of the comparisons were significant. No particular response function was required for cowpea yield-population relationship as there were no significant differences between the three cowpea populations. The treatment effects would not have been clearly understood if the treatment sum of squares were not to be broken into single degree freedom contrasts.

Some of the techniques of expressing the crop responses to quantitative factors such as plant population, fertiliser etc in sole crops can be extended to intercrop systems also. The yield-plant population relationships are best expressed by inverse polynomials of the form $\frac{1}{w} = a + bx$ where w is yield per plant and x is plant number (Willey and Heath, 1969). The quadratic form of the equation appropriate for situations where yield declines at higher populations $\frac{1}{w} = a + bx + cx^2$. In intercropping the response of each component to population can be expressed by these functions and optimum levels worked out.

The method is illustrated for maize yields of 1046, 1069, 1181 and 1048 kg/ha observed at plant populations of 17500, 25000, 32500 and 40000 plants/ha in a maize/cowpea intercrop study at CPATSA (Fig. 4). The quadratic equation seem to be an appropriate model for this data set as yield reached a peak and dropped later. First, reciprocals of yield per plant (1/w) are calculated for each population (16.73, 23.38, 27.52 and 38.16 respectively) then the function is fitted in normal way (Figure 2). The optimum population is given by $\sqrt{a/c}$ and the maximum yield that can be obtained at this population is given by $[1/(2\sqrt{ac} + b)]$ which in our example worksout 26700 plants/ha and 1107 kg/ha respectively.

Wright (1981) extended this model for taking into account the competitive effect of one component over the other in a 2 - crop intercrop system as follows: $1/w_i = a_i + b_{ii}x_i + b_{ij}x_j$ and $1/w_j = a_j + b_{jj}x_j + b_{ji}x_i$ where x_i and x_j are the densities and w_i and w_j are yields per plant of the components i and j respectively. The parabolic relationships would require the additional terms x_i^2, x_ix_j and x_j^2.

In fertiliser studies the response of individual components can be expressed by the generally used response functions in sole crops such as quadratic, Mitcherlich, square root or Cobb-Douglas. Then the optimum dose for the system can be worked out considering the responses of both the components into accout. For example, the profits in a maize/cowpea intercrop system will be maximum when $Pm \frac{d(Ym)}{dx} + Pc \frac{d(Yc)}{dx} = Px$ where Pm and Pc are prices of maize and cowpea, Px = price of the input, Ym and Yc are the response functions of maize and cowpea to the input x which may be in any form of the above types, and d = derivative symbol. Suppose if the response functions of maize and cowpea respectively are $Ym = a_1 + b_1x + c_1x^2$ and $Yc = a_2 + b_2x + c_2x^2$, the profit function is written as

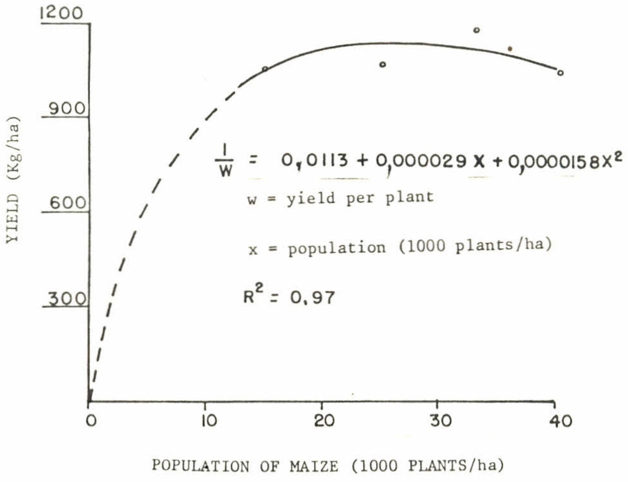


FIG. 4. An inverse polynominal fitted to the yield - population results of intercroped maize.

$$Pm \frac{d}{dx} (a_1 + b_1 x + c_1 x^2) + Pc \frac{d}{dx} (a_2 + b_2 x + c_2 x^2) - Px = 0$$

$$Pm (b_1 + 2c_1 x) + Pc (b_2 + 2c_2 x) - Px = 0$$

or optimum dose of $x = \dfrac{Px - Pm\, b_1 - Pc\, b_2}{2\,(Pm\, c_1 + Pc\, c_2)}$ (1)

Since the components in intercropping often are of different nature, enough range of levels must be examined so that both crops reach their peak yields. But however, if the components respond differently, one curvilinearly ($Ym = a_1 + b_1 x + c_1 x^2$) and the other in linear form ($Yc = a_2 + b_2 x$) the optimum dose can be calculated from

$$x = \frac{Px - Pm\, b_1 - Pc\, b_2}{2\, Pm\, c_1} \qquad (2)$$

Responses to nutrients vary depending on the nature of crops involved in the system. For example, both the components in legume/legume and cereal/legume systems respond positively to phosphorus. But with N fertilisation, while the cereal in cereal/legume combinations responds positively ($Ym = a_1 + b_1 x + c_1 x^2$), the consequent effect is detrimental to the associated legume because of strong competition and shading from the cereal ($Yc = a_2 - b_2 x$). In such a case the sign of Pc b_2 will change in equation 2.

The two yield response functions of the respective components in intercropping can be combined into one by calculating the returns after deducting the variable costs of x. Then an appropriate function can be fitted to the returns and the optimum dose of x for maximum profits is worked out. However, the disadvantage of such an approach is that a different function has to be calculated each time with change in the value of the products or price of the input.

The experimental results must be reported in an easily comprehensible form along with the results of statistical analyses. The treatment differences can be compared with any of the most commonly used tests suchas LSD, Duncan's multiple range test or Tukey's. The relative merits of these tests can be found in Federer (1955) and Chew (1976). The multiple range tests are appropriate in the case of qualitative factors but where the factors concerned are quantitative, it is appropriate to express the response by suitable functions. The treatment means should accompany the standard error and the coefficient of variation of the experiment. It is not necessary to present the results both as tables and graphs. Graphical presentation is particularly desirable for quantitative factors and where the data are enormous. As indicated earlier, the coefficient of variation (CV) of rainfed intercropping experiments is generally higher compared to the irrigated and sole crop experiments. Then the question is upto what percentage of CV the results are acceptable. Experiments with around 20% CV can be regarded as well conducted and their results are of good quality. CVs of 20 to 30% are reasonable and acceptable, with CVs around 30 to 35% one has to be careful in interpreting the results but, if the CV exceeds 35% it is better not to report the results of such trials.

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