OPTIMUM PLOT SIZE FOR INTERCROPPING EXPERIMENTS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Optimum Plot Size for Intercropping Experiments" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title, of any other University or Society.

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REJI,K

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Introduction

1. INTRODUCTION

Intercropping is an age old practice of the traditional system of agriculture in the underdeveloped parts of the world. In India as many as 84 different crops are used in mixed cropping, but seldom do we find more than four at a time, and a relatively simple mixture of only two or three crops is most common. Intercropping is defined as any cropping system where there is significant amount of intercrop competition. Food crops are usually mixed with cash crops. Cereals and legumes are often mixed. The crops may be grown as random mixtures. The main consideration for mixing crops together is to reduce the risk of failure. Other advantages are higher yields in a given season and greater stability of yield in different seasons. Nowadays the aim of intercropping is more towards augmenting the total productivity per unit area of land per unit time by growing more than one crop in the field. The available documents show the superiority of intercropping over sole cropping in terms of gross returns per hectare as well as per man day used during labour scarcity period of the crop season.

Mixing different vegetable crops has been an accepted practice. Two crop intercropping are found to be most common. One such widely practised common mixture in Kerala is Bhindi and cowpea.

Cowpea (*Vigna unguiculata* L) is a highly nutritious leguminous vegetable crop. It is a rich and cheap source of vegetable protein. Hence it deserves a place in every vegetable farm and kitchen garden. Vegetable cowpea being a warm season crop, can withstand a considerable degree of drought and therefore fits every farm every season. It can tolerate moderate shade and hence can be grown as an intercrop. A number of varieties of vegetables cowpea are grown throughout India.

Bhindi (*Abelmoschus esculentus*) is a popular warm season vegetable. The tender fruits are used as a cooked vegetable. Tender bhindi pods are rich in vitamins, calcium, phosphorus, magnesium, and iron. Bhindi is a direct sown crop whose seeds are sown directly in the main field. The plants flower within 30 to 45 days after sowing. Frequent harvests promote production of more fruits per plant and increase the yield. Bhindi is very much suited for intercropping due to the slow initial growth and wider spacing. Bhindi, being a soil exhausting crop, the inclusion of the quick growing leguminous crops like cowpea as an associate crop will benefit not only the companion crop through current nitrogen transfer but also the succeeding crop through residual effect.

Experiments on intercropping systems are complex and require innovative approach in design and analysis of data. Research into intercropping is expanding rapidly and data from intercropping experiments are being analysed in different ways. No single form of analysis is appropriate for all intercropping experiments and several different analyses should be used for most intercropping experiments (Mead and Stern 1979). The statistical aspects of intercropping system is with regard to its design and analysis for the experiments to be conducted. The involvement of different crops, different proportions of the crops should be a main consideration for suggesting several analyses of the data. Willey and Osiru (1972) pointed out the danger of comparing a combined intercrop yield with a combined sole crop yield on the basis of same sown proportions, because competition in intercropping usually results in a different proportion of final yields than from sole cropping. The popular method of analysing data from these experiments is as a univariate problem by converting the bivariate situation to univariate one such as some function of combined yield which characterise the competition between crops. Willey (1979) concluded that the most generally useful single index for expressing the yield advantage is probably the Land Equivalent Ratio (LER), defined as the relative land area required as sole crops to produce the same yields as intercropping. LER puts different crops, different situations on a comparable basis, and in addition to giving a measure of yield advantage, it can be used to indicate the competitive effects. LERs essentially indicate the physiological efficiency of intercropping compared with sole cropping. It provides a standard basis so that crops can be added to form combined yields; in theory it also means that LERs themselves can be compared between different situations, and even between different crop combination (Mead and Willey 1980).

Statistical methodology plays an important role in evolving appropriate agrotechniques for the enhancement of crop production. Field experimentation is the most powerful tool of agricultural research and it can be successfully conducted if and only if the experimenter has got some idea regarding the variability of the experimental material. There are two principal sources of variation in field experiments.

1. Variation due to soil heterogeneity
2. Genetic variability within the crop species

Due to the above two inherent variability in any experimental material, the outcome of any biological experiment becomes a stochastic variable and statistical principles are to be applied in the study of such phenomenon. Experimental error which is the plot to plot variation due to uncontrollable factors will affect the experimental material if left uncontrolled.

There are many ways of minimising experimental error in a trial. One of the simplest and most effective ways of controlling soil heterogeneity is to have a proper choice of plots and blocks. For any agricultural experiment with any crop,the first decision is to select a convenient plot size. Arbitary selection of plot size vitiate the findings. Very small plot sizes even though appreciable from the economic point of view may over estimate and hence give biased results. Extremely large plot sizes result in wastage of resources. Thus it is always advantageous to use the optimum plot size for conducting field trials. For a given size of plot different geometrical configurations of the units are possible leading to various shapes of plots. It is known that the size and shape of experimental units will have a direct effect on the magnitude of error variance and the consequent precision of treatment comparison and also on the total cost of experimentation. Hence the primary concern in finding out the optimum plot size should be that it gives the estimates of treatment effects with a pre assigned degree of precision utilising only the minimum amount of experimental material.

Studies on optimum plot sizes for experiments with monocrop are plenty, but the same on intercropping experiments are scarce. More over optimum plot size for intercropping of vegetables has not been attempted before. Therefore, in the present study a uniformity trial was conducted with Bhindi as the main crop intercropped with Cowpea with the following objectives.

1. To determine the optimum plot size for conducting field experiments in intercropping of vegetables Bhindi and Cowpea.

2. To compare the estimates of optimum plot size obtained through different methods.

Review of Literature

2. REVIEW OF LITERATURE

Several attempts were made in estimating the optimum size and shape of plots for many cereal, annual and perennial crops, in India and abroad. Though literature on estimation of optimum plot size and shape are plenty in monocrops, those with intercrops are rarely reported.

In this chapter an attempt has been made to give an account of the literature avaiable on the methods of estimation of plot size in the experimental fields of different crops under various headings.

2.1 Univariate case

2.1.1Magnitude of soil heterogeneity

An adequate characterisation of soil heterogeneity in an experimental site is a good guide and at times even a prerequisite for choosing a good experimental technique. Soil heterogeneity can be measured as the difference in performance of plant growth in a uniformly treated data.

Harris (1920) initiated studies on the statistical treatment of soil heterogeneity and its relation to the accuracy of experimental results. He proposed the intra class correlation coefficient of yields from adjacent areas as an index of soil heterogeneity and concluded that soil heterogeneity was the most potent source of variation in plot yield and the chief difficulty in their interpretation. He showed that the correlation between the yields of adjacent areas was either due to initial, physical and chemical similarities of the soil or to the influence of previous crops upon the nature and composition of soil. The intraclass correlation coefficient of Harris served only to demonstrate the degree of difference in soil heterogeneity of adjacent plots.

Bose (1935) found that an experimental site which was uniform for one crop in one season was not necessarily uniform for another crop in another season. He showed that analysis of variance was more useful than Harris' intra class correlation coefficient, because it provided both the nature of soil heterogeneity and identification of fertility gradients.

Smith (1938) proposed a quantitative measure of soil heterogeneity. This index is based on the empirical relationship between plot size and variability of mean per plot which was given by

$$V_x = V_1 x^{-b}$$

where V_x is the variance of mean yield per plot based on plots of x units in size, V_1 is the variance among plots of size unity and 'b' is the index of soil heterogeneity which ranges between zero and one. Index of soil heterogeneity 'b' indicates the degree of correlation between adjacent plots. A value of `b' nearer to one indicates that there was no significant correlation among contiguous units where as a value nearer to zero indicates strong correlation between adjacent units. In the case of self fertilised crops intra plot variation is mainly due to genetic make up of the plants within plots which also had some effect on the value of `b'. A high value of `b' tending to one thus indicated that genetic variation was more predominant over positional variation.

Clews *et al.* (1963) showed that the value of 'b' was higher for yield, than for other characters based on the uniformity trial on tobacco.

Federer (1963) found that the value of b lies between 0.3 to 0.7 in most cases. Gupta and Raghavarao (1971) found the Smith's relation $Y = ax^{-b}$ was satisfactory in the case of onion bulbs, and also found that the value of b was significant. Similar results were obtained by Bhargava *et al.* (1973) on apple, Sreenath (1973) on sorghum, Bist *et al.* (1975) on potato, Rambabu *et al.* (1980) on grass. From a uniformity trial on cashew Nair (1982) obtained the value of b as high as 0.97.

Whereas on oat, Handa *et al.* (1982) obtained the value of b within the range of 0.084 to 0.187. From a uniformity trial on turmeric Nair (1984) obtained the value of b more nearer to zero which implies that there is strong correlation between neighbouring plots. From a uniformity trial on colocasia Lizzy *et al.* (1987) obtained the value of b for all biometrical characters within the range 0.1 to 0.6.

2.2 Methods of estimation of plot size

2.2.1 Maximum curvature method

This method was suggested by Federer (1963). It consists in representing the relationship between plot size and coefficient of variation graphically by a smooth hand curve taking plot size along the X-axis and coefficient of variation along the Y-axis. In this method the optimum plot size is the abscissa of the point just beyond the point of maximum curvature.

Gupta and Raghavarao (1971) obtained the optimum plot size as X=9 using the method of maximum curvature using this method in the case of onion. Prabhakaran and Thomas (1974) used this method to get an initial grade estimation of optimum plot size for field experiments on tapioca.

Jayaraman (1979) obtained the optimum plot size as 17.28m^2 in the case of sunflower.

Hariharan *et al.* (1986) adopted this method for obtaining optimum plot size for experiments in brinjal. He established the optimum plot size for brinjal as $8.64 m^2$.

Raghavarao (1983) estimated the optimum plot size of radish as 4 to $8 m^2$. He used Smith's law in the modified form mathematically using the calculus method by maximising the curvature of the variability function.

Nair (1984) estimated the optimum plot size for turmeric as six units ([illegible] m^2) using this method.

Lucyamma (1986) obtained the maximum curvature at [illegible], 6.14, 6.23, and 6.03 respectively for each year pair for cashew.

Lizzy *et al.* (1987) obtained the optimum plot size as $3.34 m^2$ in the case of colocasia using this method.

2.2.2 Heterogeneity index method

This method was suggested by Smith (1938) for determining optimum plot size from uniformity trial data. It is based on an empirical law which is given by

$$V_x = V_1 x^{-b}$$

Smith also considered the cost of experimentation in determining the optimum plot size which is given by $C = C_1 + C_2 x$ where C_1 is the cost associated with number of plots and C_2 the cost associated with a unit area within the plot and x the number of basic units per plot. The estimate of optimum plot size is given by

$$x_{opt} = bC_1/ (1-b)C_2$$

Smith's equation in the modified form is given by $Y = ax^{-b}$ where Y is the coefficient variation per plot based on plots of x units in size, 'a' is the coefficient of variation of plots of size unity and 'b' index of soil heterogeneity.

Smith's modified equation was used by several workers. They include Gupta and Raghavarao (1971) on onion bulbs, Saxena *et al.* (1972) on oat, Prabhakaran and Thomas (1974) on tapioca, Bist *et al.* (1975) on potato, Hariharan *et al* (1986) on brinjal, Nair (1984) on turmeric, and Lizzy *et al.* (1987) on colocasia. Smith's cost concept had been misused by several workers because he had not specifically defined the basis for calculating C_1 and C_2 in the cost function. Marani (1963) pointed out that the two types of costs should be proportional to C_1 and C_2x and not to C_1 and C_2 which give rise to correct definition of the cost function.

The correct definition of the cost function were used by Hondett (1953) on groundnut, Wallace and Chapman (1956) on oat forage, Crews *et al.* (1963) on tobacco, Sardana *et al.* (1967) on potato and Binns *et al.* (1983) on tobacco.

2.2.3 Hatheway's method

Hatheway and Williams (1958) used the method of weighting the observed variances of plots of different sizes for getting an unbiased estimate of 'b'with asymptotically minimum variance.

Inaccurate estimates of plot size obtained using the method of Koch and Rigney (1951) lead to the invention of this method. They assigned equal weights to the different components of variation even though they are based on different degrees of freedom and also used the the regression coefficient 'b' as the index of soil heterogeneity. Hatheway and Williams (1958) developed the relation

$$E(\log V_x) = E(\log V_1) - B \log x$$

where B is the regression coefficient of V(x) on logx, V(x) is the among plot variance, x is the number of units per plot, V_1 is the variance among plot of size unity and V_x is the variance of mean per unit area for plots of size x units.

Hatheway (1961) developed a procedure to determine optimum plot size, where the number of replications and expected magnitude of difference between the treatments were specified without taking into consideration the cost of experimentation.

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Hatheway (1961) developed a procedure to determine optimum plot size, where the number of replications and expected magnitude of difference between the treatments were specified without taking into consideration the cost of experimentation.

Hatheway used a relation of the form

$$x^b = 2(t_1 + t_2)^2 x C_x{}^2 / rd^2$$

which depends on the relationship between coefficient of variation and Smith's 'b'. In the equation `x' is the plot size, 'b' is an index of soil heterogeneity $t_1$ is the observed value of `t' in the test of significance, t_2 is the tabulated value of `t' corresponding to 2(1-p) where p is the probability of obtaining a significant result, C_x is the coefficient of variation of plots of size x units, 'd' is the true difference to be detected between two means expressed as percentage and r is the number of replications.

2.2.4 Method of estimation of plot size for perennial crops

Perennial plants are large and they are to be treated seperately. They last for many years and data usually collected from the same plant for a large number of years. There is large variation from tree to tree which is due to the fact that this variation is made up of two types of variation, namely one arising due to genetic variation and the other due to positional variation which is commonly known.

Freeman (1963) suggested a modification to Smith's law by taking into consideration, the genetic variation in the case of perennial crops. His new equation is of the form

$V_x / V_1 = \alpha/x^b + 1-\alpha/x$, α, the proportion of variance due to environment, V_x is the total variance of mean yield per tree of a plot containing x trees, V_1 is the variance of single tree plot, x is the number of trees per plot and 'b' is the index of soil heterogeneity given by Smith. If $\alpha = 1$ the above equation represents Fairfield Smith equation. If this hypothesis is justified then $\alpha = 0$ for plots of small number of plants and unity for plots with many plants but intermediate in other cases.

2.2.5 Method of modified maximum curvature

This method was suggested by Lessman and Atkins (1963) because of the failure of Smith's equation to describe the pattern of variability in some cases. The equation is of the form $\log C_x = a/(a + \log x)^b$ where C_x is the coefficient of variation of plots of size x units and found that this equation was more efficient than Smith's equation in representing the relationship between plot size and variability.

George *et al.* (1979) established the relationship $Y = ar^{-g}$ in turmeric to find out the relationship between plot size and coefficient of variation where 'g' is the heterogeneity coefficient.

Generalised form of this law

$Y = ar^{-g_1} c^{-g_2}$ was also tried by them to compare the heterogeneity of rows and coloumns where g's denote corresponding heterogeneity coefficients. They found that the rowwise heterogeneity significantly higher than coloumnwise heterogeneity, thereby emphasising that formation of the plots with more number of rows will give more homogeneous blocks for experiments.

Prabhakaran (1983) proposed three non-linear models for representing the relationship between plot size and variability which were found to be more efficient than Smith's equation at least for three different crops tapioca, banana and cashew.

The models are

1. $Y = a + b/\sqrt{x} + c/x$
2. $Y^{-1} = a + b\log x$
3. $Y^{-1} = a + b/\sqrt{x} + c/x$

2.3 Percentage relative efficiency concept

Optimum plot size is the one which gives maximum precision for a given cost. The efficiency of a plot can be defined as $1/xc_x$ where c_x is the coefficient of variation. Therefore relative efficiency of plot size X_2 as compared to X_1 is given by $RE_{12} = X_1\, CX_1/X_2CX_2 \times 100$

Gopinath *et al.* (1970) on groundnut, Saxena *et al.* (1972) on oat, Sreenath (1973) on sorghum, Prabhakaran and Thomas (1974) on tapioca, Rambabu *et al.* (1980) on fodder grass and Hariharan *et al.* (1986) on brinjal had shown the efficiency of a plot increased with an increase in size of plot.

Another method for determining optimum plot size was by maximising information per unit area. It has been showed by various workers such as Menon and Tyagi (1971) on mandarin orange; Bhargava and Sardana on apple and Prabhakaran *et al.* (1978) on banana that single tree or plant plots were the most efficient one for conducting field trials on these crops by this method.

Gomez (1972) proposed another method for estimating plot size which is to select the size of the plot which required minimum experimental material for a given precision.

2.4 Size and shape of plots

Plot is defined as the ultimate experimental unit on to which the random assignment of treatments was done. Size of the plots refer to the whole area receiving the treatment, shape of the plot refers to the ratio of its length to its width.

The first theoretical consideration on the shape of the plot was given by Christidis (1931). He derived an expression for estimating the effect of plot shape on variability with the help of the assumption of a linear fertility gradient and concluded that long and narrow plots are always better than square ones. Several research workers agreed with his findings. They include Kripasankar *et al.* (1972) on soyabean, Saxena *et al.* (1972) on fodder oat, Sreenath (1973) on sorghum, Hariharan *et al.* (1981) on brinjal, Nair (1984) on turmeric,and Lizzy *et al.* (1987) on colocasia.

Smith (1938) proposed the first theortical formula for assessing the effect of plot size on variation. He had derived a linear relationship between variance and plot size with regression coefficient describing the degree of correlation between adjacent area of land.

Koch and Rigney (1951) proposed a new method known as `Variance Component Heterogeneity index Method' for estimating plot size. This method utilises data from actual field experiments and not from uniformity trial data. This method consisted in estimating the components of variance due to plots of different size by reconstructing ANOVA of the specified designs and using estimated variance for fitting Smith's equation.

Cochran (1940) also considered the variations in the shape of plot for various types of field experiments. He attributed the cause of variation with small and large bands fertility gradients present in the experimental field. When the variation in fertility gradient was small the selected plot shape did not exert considerable effect. When there is significant variation in fertility pattern long and narrow plots found to give better control of error variance than square plot.

Sardana *et al.* (1967) found that the optimum plot size for potatoes was about 8.5m^2.

Agarwal *et al.* (1968) conducted a uniformity trial on arecanut and they found that the magnitude of coefficient of variation decreases with the time interval. The coefficient of variation decreases with the increase in plot size.

Abraham and Vachani (1964) conducted uniformity trials on rice to determine the size and shape of plots. He reported that coefficient of variation for five or ten plot blocks decreased With an increase in plot size irrespective of the shape of the plots. Plots elongated in the east-west direction showed less variability than plots elongated in the north-south direction.

Menon and Tyagi (1971) reported that single tree plots was optimum in the case of mandarin orange which gave maximum relative information per tree.

Joshi (1972) conducted uniformity trials with chafa gram to ascertain the optimum size and shape of plots for the unirrigated areas under cultivation. He found that plot variance and coefficient of variation were decreased with the increase in plot size. He also found that long and narrow plots reduced error more rapidly and a plot of size of $16.2m^2$ with length and breadth ratio 6:1 seemed to be ideal plot size giving maximum accuracy, from statistical point of view.

Saxena *et al.* (1972) conducted uniformity trial on fodder oat to determine the optimum size and shape of the plots and found that coefficient of variation decreased with an increase in plot size.

Bist *et al.* (1975) conducted uniformity trial on potato and found that the shape of plot had no consistent effect on coefficient variation. This result was supported by Rambabu *et al.* (1980) on fodder grass and Biswas *et al.* (1982) on cabbage.

Singh *et al.* (1975) analysed the data of bhindi by leaving single and double guard rows for different plot sizes and blocks of six and eight plots. It will be observed with the single and double guard rows a plot of 192 sq. ft. for six and eight plot blocks required the minimum area. It was also found block shape did not exert any influence on coefficient of variation. They conducted uniformity trial on tomato and found that the coefficient of variation decreased gradually as plot size increased for all sizes of the blocks. The coefficient of variation decreased upto 24 plants plot and any further increase in the plot size did not result in the decrease in the coefficient of variation and they concluded that smallest plot size is the optimum plot size. Based on uniformity trials on cabbage and khol khol they found that the coefficient of variation decreased with an increase in plot size.

Pahuja and Mehra (1981) conducted field experiments with chickpea and maximum precision was obtained for a plot size 1.8mx5m with four replications.

Sasmal and Katyal (1980) reported that from a uniformity trial conducted on tossa jute it was found that the coefficient of variation of dry fibre decreased as plot size increased either east-west or north-south direction. The decline was substantial upto 30 basic units and afterwards it was marginal. Smith's equation was fitted to coefficient of variation values and the variation explained by that equation was 86% and the fit is satisfactory. Blocking reduced the variability of a plot of fixed size to greater extent. For a few fixed sizes and shapes of plots, the efficiency of the block was found to increase as the number of plots per block decreased.

Chetty and Reddy (1987) reported that a plot size between $35m^2$ and $45m^2$ with an approximate rectangularity of 3 appeared adequate for experiment with dry land sorghum as a test crop on interceptisols. Longer side of the plot, in general, should be across the crop seed rows for minimising experimental error unless seed rows are sown along the fertility gradient. The optimum dimensions of the plot were 12m across and 3.5m along the seed row.

Patil *et al.* (1987) conducted uniformity trial as Indian mustard during winter season. Smaller and narrow plots was found more efficient in controlling soil variation and required 7 or more replication to acheive 95% accuracy but occupied much less total area than bigger plots. The optimum plot size varied between $7.7m^2$ and $23m^2$ depending on the percentage cost per unit area. The value of Smith's coefficient of heterogeneity was 630 blocks of 20 plots in a single row or 20 plots of the same arranged in 2 rows of 10 plots showed less variation.

Bajpai and Sikarwar (1992) used Fairfield Smith's law and its modified form to determine the optimum plot size of sugarcane. It was observed that generally coefficient of variation decreased with increase in plot size upto 30 units The estimates of regression coefficient lie between 0.5 - 0.6

indicating that the inherent variation is more than the positional variation. The study showed that a net plot of size 19 to $57m^2$ regardless of its shape will be optimum.

2.5 Multivariate case

Determinant of scatter matrix had been used as a measure of variation in multivariate case by various research workers. Friedman and Rubin (1967), Scott and Symon (1971), Everitt, (1979) and Sheela and Unnithan (1987) used the de determinant of the scatter matrix as a measure of variation for clustering.

2.6 Intercropping

Intercropping is defined as any cropping system where two more crops are grown together on the same area of ground . It can often produce higher yields than sole crops, but there can be problems in assessing the degree of yield advantage. The possible advantages of intercropping include

1. Higher yields in a given season
2. Greater stability of yield in different seasons.

Experiments on intercropping with many different combinations or mixtures of crops have been reported in literature.

2.7 Analysis

Research into intercropping is expanding rapidly and data from intercropping experiments are being analysed in many different ways. It has been reported by Mead and Stern (1979) that no single form of analysis is appropriate for all intercropping experiments and that several different analysis should be used for most intercropping experiments. Analysis of intercropping experiments involves more complications compared to sole cropping. The popular method in analysing these experiments is as a univariate problem by converting the bivariate situation to univariate one such as the total monetary values or some function of the combined yields (indices) which characterise competition between crops. Among such indices, Land Equivalent Ratio (LER) is widely used. Another is the bivariate analysis which is a two variate special case of standard multivariate analysis.

2.7.1 Land Equivalent Ratio (LER)

Willey (1979) concluded that most generally useful single index for expressing the yield advantage in intercropping is the Land Equivalent Ratio (LER) defined as the relative land area required to produce the same yields as intercropping. Using the notations of Mead and Willey (1980)

$$LER = L_A + L_B = Y_A/S_A + Y_B/S_B$$

Where L_A and L_B are the LERs for the individual crops, and S_A and S_B are their yields as sole crops. The advantages of the LER are that

1. It provides standardised basis so that crops can be added to form the combined yields.
2. Comparison between individual LERs can indicate competitative effects and
3. The total LER can be taken as a measure of relative yield advantage ie. an LER of 1.2 indicates a yield advantage of 20%.

They have discussed the need to use different standardising sole crop yields in forming LERs. A method of calculating an `Effective LER' is proposed to evaluate situations where the yield proportions acheived in intercropping are different from those that might be required by a farmer.

Oyjeola and Mead (1982) have discussed the use in analysis of variance of six different ways calculating Land Equivalent Ratio. It was observed that seperate standardisation in each block had no advantage over using the same standardisation in all blocks. The use of many different divisors can lead to problems in the statistical analysis of LERs.

and Relative net return index with the help of intercropping experimental data conducted at different locations. It was found that Bivariate ,LER and MA methods gave similar conclusions for 4 out of 9 experiments based on F-test.

Ramachander and Prabhakar (1988) conducted field experiments in which okra and french beans were intercropped to determine the optimum plot size for intercropping experiments. A plot of 16 units each unit consisting of 2 okra plants planted 15cm apart and 3 bean plants sown 10cm was found optimal for analysis based on LER. For analysis of individual crop yields and calorie content per plot, a large plot size was required.

Chetty and Reddy (1989) conducted uniformity trials with sorghum + pigeonpea intercropping for two seasons. Methodology suited to the two existing procedures of analysing intercropping experiments viz. LER which is a linear function of the yields of the two species and the Bivariate analysis advocated by Pearce and others have been worked out and exemplified with the help of data generated.

2.7.2 Bivariate analysis

Pearce and Gilliver (1978) have suggested the bivariate analysis of data from intercropping experiments which is a two variate special case of standard multivariate analysis. One difficulty in the statistical analysis of intercropping experiments is the correlation between X_1 and X_2, the yields of the two crops . Two types of transformation were suggested to overcome the possible correlation between X_1 and X_2.

1. Let V_{11} = Error s.s. of X_1

V_{22} = Error s.s. of X_2

V_{12} = Error s.p of $(X_1, \quad X_2)$

$V_{11}' = V_{12}^2/V_{22}$

$V_{22}' = V_{22} - V_{12}^2/V_{11}$

Let $Y_1 = X_1/\sqrt{V_{11}'}$ and $Y_2 = (X_2 - V_{12} * X_1/V_{11})/\sqrt{V_{22}'}$, then Y_1 and Y_2 are independent and orthogonal.

2. $Z_1 = X_1/\sqrt{V_{11}'}$, $Z_2 = X_{22}/\sqrt{V_{22}'}$

The test of significance for comparison of treatments was done by using F test suggested by Rao(1983).

Nageswara Rao compared the Bivariate analysis and Land Equivalent Ratio method with four standardisation methods viz. Effective LER, stable Land Equivalent Ratio, Monetary Advantage and Relative net return index with the help of intercropping experimental data conducted at different locations. It was found that Bivariate ,LER and MA methods gave similar conclusions for 4 out of 9 experiments based on F-test.

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Chetty and Reddy (1989) conducted uniformity trials with sorghum + pigeonpea intercropping for two seasons. Methodology suited to the two existing procedures of analysing intercropping experiments viz. LER which is a linear function of the yields of the two species and the Bivariate analysis advocated by Pearce and others have been worked out and exemplified with the help of data generated.

Materials and Methods

introduced an additional cowpea crop as an intercrop. Hence the row ratio for the intercrop was 1:1. The planting geometry is shown in Fig-1 for all the three crops. For the intercrop, one basic unit consists of one bhindi plant and one cowpea plant with an area of 0.27 m^2.

Harvesting was done on alternate days. Yield of bhindi and cowpea was recorded for each plant in grams for the intercrop and the sole crops.

A second crop was raised on similar lines during the winter season of 1993 for confirmation of the results. But unfortunately the entire crop was damaged due to severe infestation of pests and hence no observations could be recorded.

3.2 METHODS

Analysis of the uniformity trial data in intercropping was mainly carried out by adopting the following two approaches.

1. Converting an essentially bivariate situation to that of univariate problem through the use of a single index for expressing the yield advantage such as the Land Equivalent Ratio (LER) and analysing it using the standard uni-variate techniques.
2. Bivariate analysis which is a two variate special case of

standard multivariate analysis given by Pearce and Gilliver (1978) and exemplified by Chetty and Reddy(1988).

LER Analysis

Willey (1979) found that the most generally usefull single index for expressing the yield advantage in intercropping is the Land Equivalent Ratio (LER) defined as the relative land area required as sole crops to produce the same yields as intercropping. Using the notations of Mead and Willey (1980)

$$LER = L_A + L_B = M_A/ S_A + M_B/S_B$$

where M_A and M_B are the component crop yields from an intercropping mixture, S_A and S_B are the corresponding sole crop yields, which can be thought of as standardising factors for the mixture yields.

L_A and L_B are the component LERs of the two individual crops. There are different philosophies concerned with the selection of S_A and S_B. It has been shown by Marsaglia (1965) that the distribution of the ratio of the two non-negative normal variables can take many different forms ranging from unimodal symmetrical curves to bimodal positively skewed curves with extreme kurtosis. LER values which are obtained as sum of two such ratios might therefore be expected to show some positivie skewness. Oyjeola and Mead (1982) recommended that unless there are good agronomic grounds against the choice, calculation of LERs for comparative purposes should use a single sole crop yield for each crop. Also using different sole crop yields for different treatments can lead to rather imprecise results. Here the standardising factor is taken as the yield acheived when the two crops are treated exactly like the intercrop mixture of two crops by growing them in the adjacent plots.

LER values were calculated for each basic unit and the standard univariate techniques were applied on these values.

Maximum curvature method

This is a graphical method to determine the optimum plot size. In this method the coefficient of variation of LER values for different plot sizes were plotted against the plot size, and the resulting co-ordinates are joined by using a smooth freehand curve. The optimum plot size is taken as that size which is just beyond the point of maximum curvature and the shape of the plot that gives least coefficient of variation for that optimum size will be recommended.

Heterogeneity index method

Smith (1938) established an empirical relationship between plot size (x) and plot variance (V_x). He proposed the relationship

$$V_x = V_1/x^b$$

Where V_x is the variance of the yield per unit area among plots of x units in size, V_1 is the variance among plots of one basic unit in size and 'b' is the index of soil heterogeneity which varies between zero and one. Index of soil heterogeneity indicates the correlation among contiguous units. The larger the value of the index the lower is the correlation between contiguous units, indicating that fertile spots are distributed randomly.

$$\log V_x = \log V_1 - b\log x$$

$$\log V_x - \log V_1 = -b\log x$$

$$Y = CX$$

where $Y = \log V_x - \log V_1$, $X = \log x$, $C = -b$

C can be estimated using the formula

$$C = \Sigma W_i X_i Y_i / \Sigma W_i X_i^2$$

Where W_i is the number of plot shapes used in computing the average variance per unit area of ith plot and 'm' is the total number of plots of different size and the fitted equation is

$$V_x = V_1 x^{-b}$$

Using Smith's empirical relation in the case of LER values it can be written as

$$V_x(\text{LER}) = V_1(\text{LER})/x^b$$

where $V_x(LER)$ is the variance per plot of LER values among the plot of size x basic units, $V_1(LER)$ is the value of $V_x(LER)$ when x is unity and `b' is the index of soil heterogeneity and it can be estimated using the formula described above.

Optimum plot size

To select the optimum plot size the convenient plot size method suggested by Hatheway (1952) was adopted. The relationship between plot size, and number of replication and difference to be detected is given by

$$d^2 = 2(t_1 + t_2)^2 \times C_1{}^2/rx^b$$

where `d' is the true difference to be detected between two treatment means expressed as percentage, $t_1$ is the tabulated value of `t' in the test of significance, t_2 is the tabulated value of `t' corresponding to 2(1-p), where `p' is the probability of obtaining a significant result, `b' is the index of soil heterogeneity, `r' the number of replications and C_1 is the coefficient of variation due to basic size plots. Plotting `d' values against plot sizes `x' by varying `r' will help in arriving at a plot size for a required `d' value.

Modified maxium curvature method

It is a method which locates exactly the region of maximum curvature mathematically by maximising the curvature of the function relating to plot size(x) and coefficient of variation(cv). In this study the Smith's model

$$y = ax^{-b}$$

where `y'is the coefficient of variation, `x'plot size and `b' is the index of soil heterogeneity was fitted to the data and the parameters were estimated by

converting it into linear form as

$$\log y = \log a - b \log x$$

The estimates of `a' and `b' are given by

$$b = n \Sigma XY - \Sigma X \Sigma Y/[n \Sigma X^2 - (\Sigma X)^2]$$

$$a = \text{antilog } (\bar{Y} - b\bar{X})$$

Then the fitted equation will be

$$y = ax^{-b}$$

The curvature at any point can be determined by

$$C = Y_2/(1 + Y_1{}^2)^{3/2}$$

where `C' is the curvature of the curve $y = ax^{-b}$ and Y_1 and Y_2 denote the first and second derivatives with respect to x of this function.

The maximum curvature is obtained when the first derivative of `C' with respect to x is zero and second derivative with respect to x is negative.

$$y = ax^{-b}$$

$$\log y = \log a - b\log x$$

$$Y_1 = dy/dx = -abx^{-(-b+1)}$$

$$Y_2 = d^2y/dx^2 = ab(b+1)x^{(-b+2)}$$

Substituting the value of Y_1 and Y_2 in 'C'

$$C = ab(b+1)x^{(-b+2)}/[1+(ab)^2x^{-2(b+1)}]^{3/2}$$

By maximising this curvature the optimum plot size can be obtained as

$$X_{opt} = [(ab)^2(2b+1)/(b+2)]^{1/2(b+1)}$$

The following models were also tried to express the relationship between plot sizes(x) and average coefficient of variation(y)

1. $Y = a + b\log x$
2. $Y^{-1} = a + b\log x$
3. $Y = a + b\log\sqrt{x}$
4. $Y = a + b/\sqrt{x} + c/x$
5. $Y = a + b\sqrt{x} + cx$
6. $Y^{-1} = a + b\sqrt{x} + cx$
7. $Y^{-1} = a + b/\sqrt{x} + c/x$

The parameters of these models were estimated by the method of least squares. The maximum curvature method to find out the optimum plot size was also tried for the following two models.

a. $y = a + b\log x$

b. $y = a + b\log\sqrt{x}$

a. $Y = a + b\log x$

$$Y_1 = b/x$$

$$Y_2 = -b/x^2$$

$$C = Y_2/(1+Y_1^2)^{3/2}$$

$$= (\ -b/x^2\ )/(1+b^2/x^2)^{3/2}$$

By maximising this curvature, the optimum plot size is obtained by substituting the value of 'b' in $x = +b/\sqrt{2}$ or $x = -b/\sqrt{2}$

b. $Y = a + b\log\sqrt{x}$

$$Y_1 = b/2x$$

$$Y_2 = -b/2x^2$$

$$C = Y_2/(1+Y_1^2)^{3/2}$$

$$= -4bx/(4x^2 + b^2)^{3/2}$$

By maximising this curvature, the optimum plot size can be obtained by substituting the value of`b'in $x = +b/\sqrt{8}$ or $x = -b/\sqrt{8}$.

Bivariate Analysis

Pearce and Gilliver (1978) suggested bivariate analysis which is a two variate special case of standard multivariate analysis.

Chetty and Reddy (1988) developed a methodology for finding the optimum plot size for precise comparison of treatment means based on bivariate analysis and exemplified with the help of uniformity trial with sorghum + pigeonpea intercropping system for two seasons.

In a uniformity trial with intercropping of two crops, the observed yields follow the bivariate model. From the Wilks criterian for testing the deviation from hypothesis when the number of variable p = 2 and considering an appropriate bivariate model for intercropping with two crops, Chetty and Reddy (1988) have developed a technique for obtaining the optimum plot size similar to the Smith's empirical law in the univariate case.

In the case of multivariate Gauss-Markoff set up (Rao 1983)

$\wedge \quad = \quad IR_nI/IR_1I$ with parameters (p, t-q, q) is distributed as the product of independent beta variables under the assumption of normality with parameters(t-q-p+1/2,q/2)....(t-q/2, where `p' is the number of variables `t' is the total degrees of freedom `q' is the degrees of freedom due to deviation from hypothesis.

R_0 = $R_0(i,j)$ is the matrix of residual sum (pxp) of squares and products

R_1 = $R_1(i,j)$ is the matrix of (residual + (pxp) deviation from hypothesis) sum of squares and products.

$|R_0|$ and $|R_1|$ are the determinants of R_0 and R_1

when p = 2 the ratio

$$1-\sqrt{\Lambda}/\sqrt{\Lambda} \times (t-q-1)/q$$

follows F-distribution with 2q and 2(t-q-1) degrees of freedom.

By considering the above criterian it is clear that a smaller value of $\sqrt{\Lambda}$ will result in the greater precision of testing the treatment means. Since the total variability remains the same $|R_1|$ is constant. Hence the criterion for selecting experimental plot should be such that the value of $\sqrt{|R_0|}$ should be small. The information of R_0 for different plot sizes can be obtained from uniformity trial by growing two crops in recommended geometry under uniform treatment, in an intercropping system.

In intercropping system the observed yields can be written as

$$Y_{xk}' = \mu_{xk}' + \epsilon_{xk}' \quad k = 1,2,\ldots\ldots n_x$$

where $Y_{xk}' = (Y_{xk1}, Y_{xk2})$ $\quad \mu_{xk}' = (\mu_{xk1}, \mu_{xk2})$

$\epsilon_{xk}' = (\epsilon_{xk1}, \epsilon_{xk2})$

Y_{xk1} and Y_{xk2} are the observed yields of crop 1(bhindi) and crop2 (cowpea) from kth plot of size x basic units.

μ_{xk1} and μ_{xk2} are the expected yields of crop 1 (bhindi) and crop 2 (cowpea) from kth plot of size x basic units and ϵ_{xk1} and ϵ_{xk2} are errors of crop 1 (bhindi) and crop 2 (cowpea) from kth plot of size x basic units. The assumption underlying this linear model are

$$E(\epsilon_{xk1}) = 0, \; E(\epsilon_{xk2}) = 0, \; cov(\epsilon_{xk1}, \epsilon_{xk2}) = \sigma_{12x},$$
$$V(\epsilon_{xk1}) = \sigma_{11x} \qquad V(\epsilon_{xk2}) = \sigma_{22x}$$

and they are independent for different plots. n_x is the number of plots of size x basic units. Let R_{x0} be the corresponding R_0 for plots of size x basic units.

From the linear model and also from assumptions it follows that

$$_{x0} = R_{x0(i,j)}/n_x - 1 = V_{(x)i,j} \quad i,j = 1,2$$

Hence minimising $\sqrt{IR_{x0}I}$ is same as minimising

$$U_x = (V_{(x)11} \times V_{(x)22} - V_{(x)12}{}^2)^{1/2}$$

In the univariate case, Smith proposed the empirical law as

$$V_x = V_1/x^b$$

where V_x is the variance of yield per unit area among plots of x basic units, V_1 is the variance among plots of size unity, and `b' is the index of soil heterogeneity.

Let W_x be the value of U_x per unit area among plots of size x basic units. Then

$$W_x = U_x/x^2 = \{(V_{(x)11} x V_{(x)22}/x^4) - (V_{(x)12})^2/x^4\}^{1/2}$$

$$= \{V_{x11} x V_{x22} - V_{x12}{}^{2}\}^{1/2}$$

where $V_{xij} = V_{(x)ij}/x^2 \quad i,j = 1,2$

$V_{(x)11}$ is the variance between plots of size x basic units for crop 1(bhindi).

From the Smith's empirical law we have

$$V_{xij} = V_{ij}/X^{bij} \quad \text{where } V_{11} = V_{xij} \text{ for } x = 1$$

$$W_x = V_{11} \cdot V_{22}/X^{b11+b22} [1 - \rho^2 X^{b11+b22}/(X^{b12})^2]^{1/2}$$

$$= W_1/x^g$$

ρ is the correlation coefficient between crop 1 and crop 2 yields among plots of size unity. When $\rho = 0$ then 'g' is the arithemetic mean of the individual crop heterogeneity coefficients b_{11} and b_{22}. When $\rho \neq 0$, 'g' is a function of b_{11}, b_{22} and b_{12}. The above relation is fitted to the data and `g' value estimated. This 'g' value is then used to find the optimum plot size using the Hatheway's convenient plot size method.

One difficulty in the statistical analysis of intercropping experiment is the correlation between the yields of the two crops. Pearce and Gilliver suggested the following transformation for making the two independent.

Let V_{11} = variance of (x_1) between plots of size one basic unit

V_{22} = variance of (x_2) between plots of size 1 basic unit

V_{12} = covariance of (x_1,x_2) between plots of size 1 basic unit

$V_{11}' = V_{11} - V_{12}^2/V_{22}$

$V_{22}' = V_{22} - V_{12}^2/V_{11}$

Let $Y_1 = x_1/\sqrt{V_{11}'}$, and $Y_2 = (x_2 - V_{12} \times x_1/V_{11})/\sqrt{V_{22}'}$

then Y_1 and Y_2 are independent and orthogonal.

The above transformation was carried out on the trial data, and the individual heterogeneity coefficients b_{11} and b_{22} were estimated. $g = (b_{11} + b_{22})/2$ and this value of 'g' is used for finding the optimum plot size.

All the methods of estimation of optimum plot size made use with LER values were also tried for W_x values.

Sheela and Unnithan (1992) used the determinant of the relative dispersion matrix for estimating the optimum plot size in cocoa plants using the multiple character. The dispersion matrix was defined as $(S_{ij})_{pxp}$ where

$$S_{ij} = (\Sigma X_{ik}X_{jk} - N\bar{X}_i\bar{X}_j)/N\bar{X}_i\bar{X}_j \quad i,j = 1,2,\ldots p$$

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_p \end{bmatrix}$$

X_{ik} is the observation on ith character of the kth unit.

$\bar{X}_i$ is the mean per unit of ith character. N is the total number of units.

$|S|$ is independent of units of measurment and magnitude of observations and is proposed as the measure of variation for determining the optimum plot size. Optimum plot size is the one which requires minimum experimental units for a specified precision

Let $$\bar{X} = \begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \\ \vdots \\ \bar{x}_p \end{bmatrix}$$

be the mean vector for the p-dimensional vector variable X for plots of size r. The relative dispersion matrix of $\bar{X}$, say $D(\bar{x})$ is given by

$$D(\bar{X}) = (S_{ij})/r)$$

$$D(\bar{X}) = S/r^p$$

for P% error in multivariate case

$$S/r^p = (p/100)^2.p$$

$$S^{1/P} = r$$

is the number of replication required to acheive p% error

Efficiency of a plot of size x units was taken as $1/x \sqrt{|S|}$ in the multivariate case. The plot size which gave maximum value of for efficiency was taken as the optimum plot size under this method.

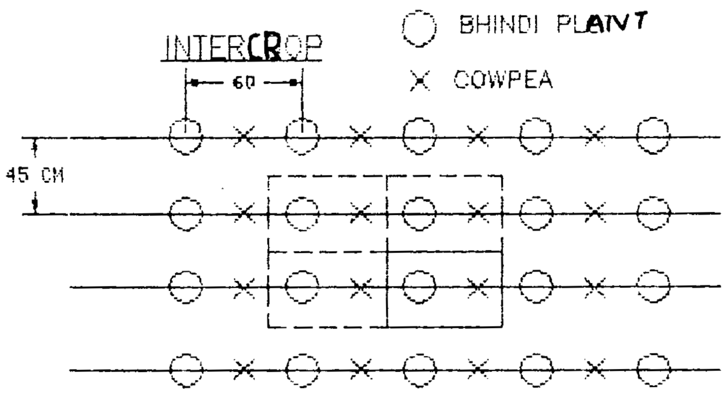
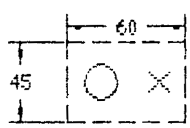


Fig 1. a

Size of Basic unit.



Sole crop — Bhindi

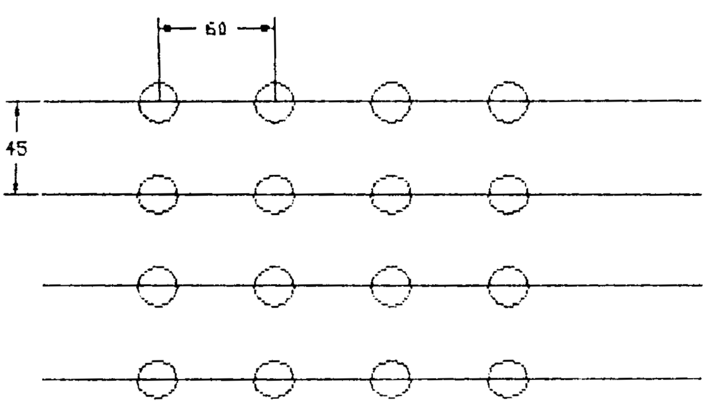


Fig 1. b

Sole crop — Cowpea

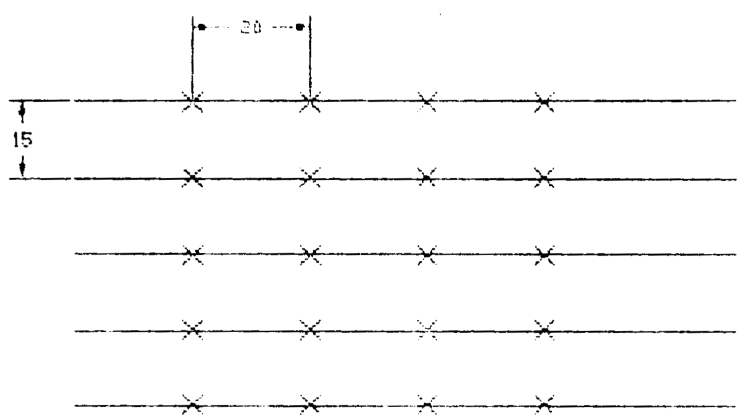


Fig 1. C

Fig - 1

Results

4. RESULTS

The data generated from the intercropping experiment and monocrop experiment were analysed by the methods described in `Materials and Methods' and the results obtained are presented below.

4.1 LER analysis

One frequently used index of combined yield from the intercropping experiment is Land Equivalent Ratio (LER) which converts the bivariate situation into a univariate one. A basic unit in the intercrop experiment consisted one bhindi plant and one cowpea plant with an area of $0.27m^2$. LER values were calculated for each basic unit using the separate monocrop yield obtained from crops raised in adjacent area as standardising factors. The individual LER values ranged from 0.377 to 2.01 with an overall average of 1.05. The coefficient of variation was 34.3%. These individual LER values were analysed using the methods available for uniformity trial with a single crop.

Maximum curvature method

Adjacent units were combined to form plots of different sizes and shapes. The coefficient of variation for plots of different sizes and shapes are given in table 1. It can be seen that the coefficient of variation decreases when there is an increase in plot size. Minimum value of coefficient of variation noticed was 5.3% for plots of 32 basic units. The between plot variance for plots of size x units and the between plot variance per unit area were also worked out and are given in the same table. Smooth freehand curves were drawn to represent the relationship between plot size (x) and coefficient of variation of LER values and are given in fig-2. It was found that the coefficient of variation decreased rapidly at first when the size of the plot increased but after a certain point the rate of decrease was slow and ultimately the curve was almost like a straight line parallel to X-axis. In this case the point just beyond the maximum curvature was taken as the optimum plot size which was obtained as 10 basic units ($2.7m^2$).

Heterogeneity Index Method

Smith's equation was fitted to the LER values and the value of the index of soil heterogeneity `b' was obtained by the formula given in the materials and methods as 0.9667. Since the value of `b' was nearer to unity it implies that there is no correlation between contiguous units and the fertile spots are distributed randomly or in patches.

For determining the optimum plot size the convenient plot size method suggested by Hatheway was also tried. In this method, the relation between the plot size(x) and the number of replications(r) required to detect at 5% level of significance a true difference between any two treatment means expressed as per cent(d)in 80% of the experiments (p=0.8) and in 90% of the experiments (p=0.9) are worked out and are given in Table 2 and Table 3 respectively. Curves showing the above relations are given in figures 3 and 4. To find the optimum plot size the experimenter needs to specify the number of replications he is willing to use and the magnitude of treatment difference he wishes to detect. It can be seen that for detecting a treatment difference of 20% to be significant with 4 replications the plot size required will be approximately 10 basic units (when p=0.80).

Optimum plot size was worked out using Smith's modified equation $Y = ax^{-b}$ by maximising the curvature, using the calculus method. The optimum plot size obtained by this method was 7 basic units (1.9m^2). The coefficient of determination for this model was 0.97.

Seven other models were also fitted to LER values.

1. $Y = a + b\log x$
2. $Y^{-1} = a + b\log x$
3. $Y = a + b\log\sqrt{x}$
4. $Y = a + b/\sqrt{x} + c/x$

5. $Y^{-1} = a + b/\sqrt{x} + c/x$

6. $Y = a + b\sqrt{x} + cx$

7. $Y^{-1} = a + b\sqrt{x} + cx$

where `Y' is the coefficient of variation and `x' is the plot size and the parameters are estimated by the method of least squares. The values of parameters obtained together with R^2 values are given in table 4. It could be seen that among the models fitted the models $Y = a + b\sqrt{x} + cx$, $Y^{-1} = a + b\sqrt{x} + cx$ and $Y = a + b/\sqrt{x} + c/x$ were best fit to the LER values than Smith's equation in the modified form in describing the relationship between plot size and coefficient of variation. The coefficient of determination for these three models were 0.99 which was fairly high. For models 2 and 4, R^2 value was 0.96. For model 3 the R^2 value was 0.84 and that for model 6 it was 0.88.

For models 2 and 4 the optimum plot size was worked out by maximising the curvature and the optimum plot size obtained was 12 basic units ($3.2 m^2$) in both cases.

4.2 Bivariate Analysis

The data from intercropping mixture were also analysed using the bivariate analysis suggested by Pearce and Gilliver (1978) and exemplified by Chetty and Reddy (1988) which is a two variate special case of the standard multivariate analysis.

W_x values were calculated for the intercropping mixture by the method given in `Materials and Methods' and the index of soil heterogeneity was found out as g = 1.003.

Optimum plot size was worked out using convenient plot size method suggested by Hatheway. In this method, the true difference to be detected between treatment means (d) were calculated for various plot sizes and for different number of replications (r) at 5% level of significance and for p = 80% and p = 90% are given in tables 5 and 6. The plotted curves are shown in figures 5 and 6.

Different models fitted to the LER values were also fitted in this case. The parameters were estimated by the principle of least squares. The values of parameters together with R^2 values are given in table 7. Among the various models fitted, the models 5 and 8 gave very good fit to the data. The coefficient of determination for these two models were 0.99.

The correlation between component crop yields which creates problem in the statistical analysis of intercropping experiments was overcome by using the transformations described in `Materials and Methods'. W_x values were calculated and the index of soil heterogeneity was worked out for two crops seperately and since there was no correlation between two crop yields the mean of the two heterogeneity coefficients were taken as the index of soil heterogeneity for the intercropping mixture, which was obtained as g = 0.946.

The optimum plot size was worked out by the convenient plot size method suggested by Hatheway (1952). In this method, the true difference to be detected between two treatment means(d) were calculated for various plot sizes and for different number of replications (r) at 5% level of significance and for p = 0.80 and p = 0.90 are given in tables 8 and 9. The plotted curves are shown in figures 8 and 9.

4.3 Multivariate case

The determinant of the relative dispersion matrix (ISI) of plots of different sizes and shapes have been evaluated and presented in table-10. The number of replications along with efficiency for different plot sizes are also given in the same table.

ISI decreased from .02866 to .00007 when blocking was not adopted. Here the plot with 10 basic units ($2.7m^2$) has given the maximum efficiency and hence is taken as the optimum plot size.

In the case of Bhindi (monocrop) adjacent units were combined to form plots of different sizes and shapes. The basic unit of observation was .27m^2. The coefficient of variation for plots of different sizes and shapes were worked out and are given in table 11. It can be seen that generally coefficient of variation decreased with an increase in plot size except for the plot size 6 basic units. The between plot variance for plots of size x units and the between plot variance per unit were also worked out and given in the same table.

Smith's equation $V_x = V_1 x^{-b}$ was fitted and the index of soil heterogeneity was obtained as b = .8541 which implies that there was no strong correlation between contiguous units.

Eight other non-linear models were fitted in this case also and the parameters were estimated by the principle of least squares. The values of parameters obtained together with R^2 values are given in table 12. Among the models fitted, Smith's modified equation (model 1) and model 5 gave the R^2 values as .97. The optimum plot size was determined using modified maximum curvature method and the optimum plot size was found to be 1.348m^2.

In the case of cowpea (monocrop) adjacent units were combined to form plots of different sizes and shapes. The coefficient of variation were worked out and are given in table 13. It can be seen that generally coefficient variation decreased with an increase in plot size. The between plot variance for plots of size x and the between plot variance per unit area were also worked out and are given in the same table.

Smith's equation $V_x = V_1 x^{-b}$ was fitted and the index of soil heterogeneity was estimated as b = .6267.

Eight other non-linear models were also fitted and the parameters were estimated by the principle of least squares. The values of parameters obtained together with R^2 values were given in table 14. Among the models fitted model 8 has the maximum value of R^2 as .99. The optimum plot size was determined by the modified maximum curvature method and the optimum plot size was found to be $.774 m^2$.

Discussion

5. DISCUSSION

Optimum plot size for intercropping experiments are rarely reported in literature. For the present investigation a uniformity trial was conducted in Bhindi intercropped with Cowpea with the objective of finding out the optimum plot size for increasing the efficiency of experiment with intercropping. Basically three different approaches have been attempted to estimate the optimum plot size and a comprehensive discussion of the results obtained from the investigation are given below.

5.1 Land Equivalent Ratio (LER) method

The LER values convert an essentially bivariate situation into a univariate one. Hence all the univariate methods for estimating the plot size can be tried using the LER values. LER values were calculated for each of the basic units. The sole crop yields of the two crops raised in an adjacent area were used for standardising. The LER values ranged from 0.377 to 2.01 with an average of 1.05 and a coefficient of variation of 34.3%. LER is defined as the relative land area required as in sole crops to produce the same yields as intercropping. It can also be taken as a measure of relative yield advantage in intercropping. It represents the increased biological efficiency acheived by growing two crops together in a particular environment. In the present investigation a mean LER value of 1.05 shows only a marginal yield advantage in intercropping. The comparatively low value of LER value coupled with the high coefficient of variation could be partly because of the fact that the intercrop yield was slightly affected by pest infestation even though control measures were taken in time. The distribution of the LER values was not skewed (β_1 = 0.007) but platicurtic (β_2 = 2.5) compared to the normal. The following widely used univariate techniques were adopted for finding the optimum plot size with the LER values.

Maximum curvature method

Adjacent units were combined together to form plots of different sizes and shapes. In general the coefficient of variation decreased with the increase of the plot size. The shape of the plot was not found to have any consistent effect on coefficient of variation (Table 1). Similar results were observed in uniformity trials with monocrops by many authors. From the smooth free hand curve drawn the optimum plot size was fixed as approximately 10 basic units ($2.7 m^2$) (Fig-2)

Heterogeneity Index method

Smith's empirical relation $V_x = V_1 x^{-b}$ fitted to the LER values. The index of soil heterogeneity was estimated as 0.966. The high value of `b' indicates that the contiguous plots are not correlated and the fertile spots are distributed randomly or in patches. The curve was a good fit for the data as the coefficient of determination was highly significant.

For determining the optimum plot size the convenient plot size method by Hatheway was used. Relationship between plot size (x), number of replications (r) and the true difference to be detected (d) in an experiment expressed in percent of the mean are given for p = 0.80 and p =0.90 at 5% level of significance in table 2 and table 3 respectively. The relationship is also shown by plotting curves and shown in Fig-3 and Fig-4. It can be seen that for detecting a true difference of 20% between treatment means in an experiment with 4 replications, the plot size would be around 10 basic units(2.7m^2)when p = 0.80 and 16(4.3m^2) with p = 0.90.

Modified maximum curvature

This is a more precise method proposed by Meir and Lessman (1971) which locates mathematically the exact region of maximum curvature. The parameters were estimated by the least square method (Table 4) and optimum plot size by maximising the curvature was 7(1.9m^2) basic units.

Seven more alternate models were also fitted to the LER values. The parameters were estimated by the least square method and the R^2 values are given in the same table. All the models have exhibited high R^2 values. However one could not attribute any physical meaning to the parameters of the equations. The optimum plot size were worked out for the two models $Y = a + b\log x$ and $Y = a + b\log\sqrt{x}$ using the calculus method of maximising curvature and in both the cases the optimum plot size was estimated as 12 basic units ($3.2m^2$).

5.2 Bivariate Analysis

The method of Chetty and Reddy (1988) extending the Smith's empirical variance model to the bivariate situation was tried with the data generated in the investigation. The model given was

$$W_x = V_{11} x \, V_{22} / x^{b_{11} + b_{22}} \left[1 - \rho^2 (x^{b_{11} + b_{22}}) / (x^{b_{12}})^2\right]^{1/2}$$

$$= W_1 / x^g$$

where ρ is the correlation coefficient between crop 1(bhindi) and crop 2 (cowpea)yields among plots of size unity. 'g' is the index of soil hetereogeneity which is a function of the individual crop heterogeneity coefficients b_{11}, b_{22} and b_{12}. The coefficient of variation has also been worked out for this situation.

The index of soil heterogeneity `g' in the present case was estimated to be 1.003. As an index of soil heterogeneity in the Smith's variance law, it should vary from zero to unity. Clearly the estimate obtained here can have no unambiguous physical interpretation. However occassional abnormal values of 'b' have been reported in literature. Hatheway and Williams (1958) reported a situation where the index value was more than one. Wiedermann and Leinninger reported an abnormal value of -0.1 in uniformity trial with safflower.

Hatheway's convenient plot size method was used to find the optimum plot size. The results are presented in Tables 5 and 6. The plotted curves are shown in figures 5 and 6.

Further, using the coefficient of variation and the plot size a number of models have been fitted. The parameter values and R^2 values are given in table 7.

Pearce and Gilliver observed that correlation in yields between component crops in an intercropping experiment could create problems in statistical analysis. Hence the individual crop yields could be transformed so that the crop yields are uncorrelated. Using the above method the crop yields were transformed and the Smith's extended equation for bivariate case was used. In this case the index of soil heterogeneity `g' is the average of the individual crop heterogeneity coefficients $b_{11}$ and $b_{22}$. The `g' value was observed as 0.945.

Hatheway's convenient plot size method was used to determine optimum plot size. The results obtained are given in Tables 8 and 9 and the corresponding curves plotted in figures 7 and 8.

The following table gives a comparison between the LER method and the two bivariate situations described above making use of the convenient plot size method. It gives the optimum plot sizes (estimated in basic units, 1 basic unit-.27m^2)for finding a true difference of 20% between treatment means to be significant with 4 replications for p = 0.80 and p = 0.90.

Replications - 4

Methods	p = 0.80	p =0.90
LER	10	16
Biv(1)	16	20
Biv(2)	20	24

It can be seen that for the same level of precision the LER method gives smaller plot size compared to the bivariate method. ie. the unit cost of experimentation will be larger in the case of bivariate analysis. Alternatively, for any choosen plot size, the precision attained through LER analysis is larger than through bivariate analysis. From the coefficient of variation values and from the curves shown in figures 5,6,7 and 8 the above results can be seen to be true for any choosen plot size.

Similar results were obtained by Chetty and Reddy (1988) in uniformity trials with sorghum + pigeonpea intercropping.

5.3 Multivariate analysis

The determinant of the relative dispersion matrix was used by Sheela and Unnithan (1992) to estimate the optimum plot size for experiment in cocoa plants using multiple characters. Considering the two crop yields as multiple characters from a plot, relative dispersion matrices for plots of different sizes and shapes were calculated. The determinant of the relative matrix, the number of replications for 5% standard error and the efficiency meassured were tabulated for different plot sizes in Table 10. It could be seen that maximum efficiency for a given precision was obtained for the plots of 10 basic units($2.7m^2$).Thereforethe optimum plot size can be taken to be 10 basic units ($2.7m^2$).

Conclusion

The individual LER values calculated for each basic unit was found to vary greately with a coefficient of variation of 34.3% and a mean of 1.05. The rather low value of LER indicates only marginal yield advantage due to intercropping. Univariate techniques normally adopted for estimating the optimum plot size were employed with LER values. The maximum curvature method gave an optimum plot size of 10 basic units ($2.7m^2$). The modified maximum curvature yielded an optimum plot size of 7 basic units ($1.9m^2$) was obtained based on Smith's equation. A number of models fitted using the relation between coefficient of variation and plot size. The optimum plot sizes were calculated for the two models $Y = a + b\log x$ and $Y = a+b\log\sqrt{x}$ using the calculus method of maximising the curvature. For both models the optimum plot size was estimated as 12 basic units($3.2m^2$). Hatheway's c onvenient plot size method was attempted using the heterogeneity coefficient.

The bivariate analysis making use of the Smith's empirical law was fitted to the data. The index of soil heterogeneity was found to be very high (g=1.003). Various models relating coefficient of variation and plot size were also fitted. The same bivariate analysis was tried on yields of the two crops after making them uncorrelated after a transformation. The index of soil heterogeneity was high (g=.9467) which is in agreement with the value obtained in the case of LER values (b= .9667). Hatheway's convenient plot size method were used for both the situations.

Comparisons of the LER and the bivariate analysis method showed that for the same level of precision the LER method gives smaller plot size. For any choosen plot size, the precision attained through LER analysis is larger than through bivariate analysis. The multivariate method adopted also yielded the optimum plot size as 10 basic units(2.7m^2).

Therefore, the optimum plot size for intercropping experiments with bhindi + cowpea can be taken to be 10 basic units giving the plot size as 2.7m^2. Further, for the same level of precision the LER method gives smaller plot size compared to the bivariate method implying that the per unit cost of experimentation will be larger in the case of bivariate analysis.

Table 1. Between plot variance $V_{(x)}$, LER values, variance/basic unit V_x and cv_x for plots of various sizes and shapes

Units/ plot Row x col.	Total No. of plots having x units	Between plot variance($V_{(x)}$)	Variance/ unit area V_x	Coefficient of variation cv_x
1 x 1	320	.1028	.1028	34.3
1 x 2	160	.1089	.0545	24.4
2 x 1	160	.1076	.0538	24.2
2 x 2	80	.1202	.0300	18.1
1 x 4	80	.1194	.0299	18.0
4 x 1	80	.1064	.0266	17.0
2 x 4	40	.1287	.0161	13.2
4 x 2	40	.1022	.0128	11.8
5 x 2	32	.1224	.0122	11.5
2 x 8	20	.1461	.0091	9.9
4 x 4	20	.0844	.0053	7.6
5 x 4	16	.1257	.0063	8.3
4 x 8	10	.0828	.0026	5.3

Table 2. The true difference expressed in percent (d) between treatment means to be detected as significant shown for various number of replications(r) and plot size(x) in bhindi+cowpea intercropping using LER analysis (p=80%)

x	r=2 d	r=4 d	r=6 d	r=8 d	r=10 d
5	43.1	30.5	24.9	21.5	19.3
10	30.8	21.8	17.8	15.4	13.8
15	25.3	17.9	14.6	12.7	11.3
20	22.0	15.6	12.7	11.0	9.9
25	19.8	14.0	11.4	9.9	8.9
30	18.1	12.8	10.5	9.1	8.1
35	16.8	11.9	9.7	8.4	7.5
40	15.8	11.2	9.1	7.9	7.1
45	14.9	10.5	8.6	7.5	6.7
50	14.2	10.0	8.2	7.1	6.3
55	13.5	9.6	7.8	6.8	6.0
60	13.0	9.2	7.5	6.5	5.8

Table 3. The true difference expressed in percent (d) between treatment means to be detected as significant shown for various number of replications(r)and the plot size(x) in bhindi+cowpea intercropping using LER analysis (p=90%).

x	r=2 d	r=4 d	r=6 d	r=8 d	r=10 d
5	49.8	35.2	28.8	24.9	22.3
10	35.7	25.2	20.6	17.8	15.9
15	29.3	20.7	16.9	14.7	13.1
20	25.5	18.0	14.7	12.8	11.4
25	22.9	16.2	13.2	11.5	10.2
30	21.0	14.8	12.1	10.5	9.4
35	19.5	13.8	11.2	9.7	8.7
40	18.3	12.9	10.5	9.1	8.2
45	17.2	12.2	10.0	8.6	7.7
50	16.4	11.6	9.5	8.2	7.3
55	15.6	11.1	9.0	7.8	7.0
60	15.0	10.6	8.7	7.5	6.7

Table 4. Different models fitted to coefficient of variation (Y) of LER values along with R^2

Model	a	b	c	R^2
$Y = ax^{-b}$	35.61	.52		97
$Y = a + b\log x$	31.99	19.01		96
$Y^{-1} = a + b\log x$	.004	.09		84
$Y = a + b\log\sqrt{x}$	30.59	-36.04		96
$Y = a + b/\sqrt{x} + c/x$	-.99	40.59	6.27	99
$Y^{-1} = a + b/\sqrt{x} + c/x$	.24	.56	.35	88
$Y = a + b\sqrt{x} + cx$	1.74	.02	-.26	99
$Y^{-1} = a + b\sqrt{x} + cx$	.02	.003	.009	99

Table 5. The true difference expressed in percent (d) between treatment means to be detected as significant shown for various number of replications(r) and plot size(x)in Bhindi + cowpea intercropping using bivariate analysis taking into consideration the covariance between two component crops(p=80%).

	r=2	r=4	r=6	r=8	r=10
x	d	d	d	d	d
5	51.4	36.4	29.7	25.7	23.0
10	36.3	25.7	21.0	18.2	16.2
15	29.6	21.0	17.1	14.8	13.3
20	25.7	18.1	14.8	12.8	11.5
25	22.9	16.2	13.2	11.5	10.3
30	20.9	14.8	12.1	10.5	9.4
35	19.4	13.7	11.2	9.7	8.7
40	18.1	12.8	10.5	9.1	8.1
45	17.1	12.1	9.9	8.5	7.6
50	16.2	11.5	9.4	8.1	7.2
55	15.5	10.9	8.9	7.7	6.9
60	14.8	10.5	8.5	7.4	6.6

Table 6. The true difference expressed in per cent (d) between treatment means to be detected as significant shown for various number of replications(r)and plot size(x)in bhindi+ cowpea intercropping using bivariate analysis taking into consideration the covariance between two component crops (p=90%).

x	r=2 d	r=4 d	r=6 d	r=8 d	r=10 d
5	59.5	42.1	34.4	29.8	26.6
10	42.0	29.7	24.3	21.0	18.8
15	34.3	24.3	19.8	17.2	15.3
20	29.7	21.0	17.1	14.8	13.3
25	26.6	18.8	15.3	13.3	11.9
30	24.2	17.1	14.0	12.1	10.8
35	22.4	15.9	12.9	11.2	10.0
40	21.0	14.8	12.1	10.5	9.4
45	19.8	14.0	11.4	9.9	8.8
50	18.8	13.3	10.8	9.4	8.4
55	17.9	12.6	10.3	8.9	8.0
60	17.1	12.1	9.9	8.6	7.7

Table 7. Different models fitted to coefficient of variation along with R^2 values for intercropping data (Bivariate Analysis)

models	a	b	c	R^2
$Y = ax^{-b}$	.3247	.5578		96
$Y = a + b\log x$	.3939	-.2398		95
$Y^{-1} = a + b\log x$	.1155	8.6419		84
$Y = a + b\log\sqrt{x}$	.3768	-.4558		96
$Y = a + b/\sqrt{x} + c/x$	-.0238	.5182	-.0827	99
$Y^{-1} = a + b/\sqrt{x} + c/x$	21.4842	-50.3870	31.9300	89
$Y = a + b\sqrt{x} + cx$	.5617	.0201	-.0200	97
$Y^{-1} = a + b\sqrt{x} + cx$	1.3753	.2808	1.0061	99

Table 8. The true difference expressed in percent (d) between treatment means to be detected as significant shown for various number of replications(r) and plot size(x) in bhindi+cowpea intercropping using bivariate analysis(after transformation)(p=80%).

x	r=2 d	r=4 d	r=6 d	r=8 d	r=10 d
5	53.9	38.1	31.1	27.0	24.1
10	38.9	27.5	22.4	19.4	17.4
15	32.1	22.7	18.5	16.0	14.3
20	28.0	19.8	16.2	14.0	12.5
25	25.2	17.8	14.5	12.6	11.3
30	23.1	16.3	13.3	11.6	10.3
35	21.5	15.2	12.4	10.7	9.6
40	20.2	14.3	11.6	10.1	9.0
45	19.1	13.5	11.0	9.5	8.5
50	18.1	12.8	10.5	9.1	8.1
55	17.3	12.3	10.0	8.7	7.8
60	16.6	11.8	9.6	8.3	7.4

Table 9. The true difference expressed in percent (d) between treatment means to be detected as significant shown for various number of replications(r) and plot size(x) in bhindi+cowpea intercropping using bivariate analysis(after transformation)(p=90%).

x	r=2 d	r=4 d	r=6 d	r=8 d	r=10 d
5	62.4	44.1	36.0	31.2	27.9
10	45.0	31.8	26.0	22.5	20.1
15	37.1	26.2	21.4	18.6	16.6
20	32.4	22.9	18.7	16.2	14.5
25	29.1	20.6	16.8	14.6	13.0
30	26.7	18.9	15.4	13.4	12.0
35	24.8	17.6	14.3	12.4	11.1
40	23.3	16.5	13.5	11.7	10.4
45	22.1	15.6	12.7	11.0	9.9
50	21.0	14.8	12.1	10.5	9.4
55	20.1	14.2	11.6	10.0	9.0
60	19.3	13.6	11.1	9.6	8.6

Table 10. Number of replications required to attain 5% standard error and efficiency for different sizes of plots

plot size	$\lvert s \rvert \times 10^5$	Number of replication for 5% S.E.	Efficiency $1/(x\sqrt{\lvert s \rvert})$
1	2866.86	68	5.90
2	829.60	36	5.49
4	219.60	19	5.33
8	48.90	9	5.65
10	22.50	6	6.67
16	13.96	5	5.29
20	7.00	3	5.98

Table 11. Between plot variance [$V_{(x)}$] Bhindi (Monocrop) variance per unit area V_x and CV_x for plots of various sizes and shapes

Units per plots	Total no. of plots having x units	Between plot Variance $V_{(x)}$	Variance per unit area V_x	Cofficient of Variation CV_x
1 x 1	120	1732.83	1732.83	34.96
1 x 2	60	2221.76	1110.88	28.11
1 x 4	30	1782.42	445.60	17.80
3 x 1	40	1909.40	636.46	21.27
2 x 3	20	2754.56	459.09	18.07
4 x 3	10	2340.88	195.07	11.78

Table 12. Different models fitted to coefficient of variation along with R^2 values for Bhindi (monocrop)

Models	a	b	c	R^2
$Y = ax^{-b}$	24.598	.524		97
$Y = a + b\log x$	33.591	-21.479		95
$Y^{-1} = a + b\log x$	.023	.050		93
$Y = a + b\log\sqrt{x}$	33.594	-42.977		95
$Y = a + b/\sqrt{x} + c/x$	.486	41.183	-7.085	97
$Y^{-1} = a + b/\sqrt{x} + c/x$	.137	.231	.122	95
$Y = a + b\sqrt{x} + cx$	57.716	-27.227	4.073	96
$Y^{-1} = a + b\sqrt{x} + cx$	.007	.021	.0001	96

Table 13. Between plot variance [$V_{(x)}$] Cowpea (Monocrop) variance per unit area V_x and CV_x for plots of various sizes and shapes

Units per plots	Total no. of plots having x units	Between plot Variance $V_{(x)}$	Variance per unit area V_x	Cofficient of Variation CV_x
1 x 1	64	2662.88	2662.88	34.00
1 x 2	32	3617.35	1808.67	28.02
2 x 1	32	2981.38	1490.69	25.44
1 x 4	16	3979.23	994.80	20.78
4 x 1	16	4007.06	1001.76	20.85
2 x 2	16	4107.56	1026.89	21.11
4 x 2	8	6142.32	767.79	18.25
2 x 4	8	5955.17	744.39	17.97
4 x 4	4	8363.58	522.74	15.06

Table 14. Different models fitted to coefficient of variation along with R^2 values for cowpea (monocrop)

Model	a	b	c	R^2
$Y = ax^{-b}$	15.268	.264		82
$Y = a + b \log x$	31.668	-14.420		83
$Y^{-1} = a + b \log x$	.027	.030		78
$Y = a + b \log \sqrt{x}$	31.669	-28.888		84
$Y = a + b/\sqrt{x} + c/x$	13.571	-7.571	13.280	94
$Y^{-1} = a + b/\sqrt{x} + c/x$	.074	.053	.006	83
$Y = a + b\sqrt{x} + cx$	55.668	-25.943	4.135	99
$Y^{-1} = a + b\sqrt{x} + cx$	-.013	.047	.007	94

of LER Values

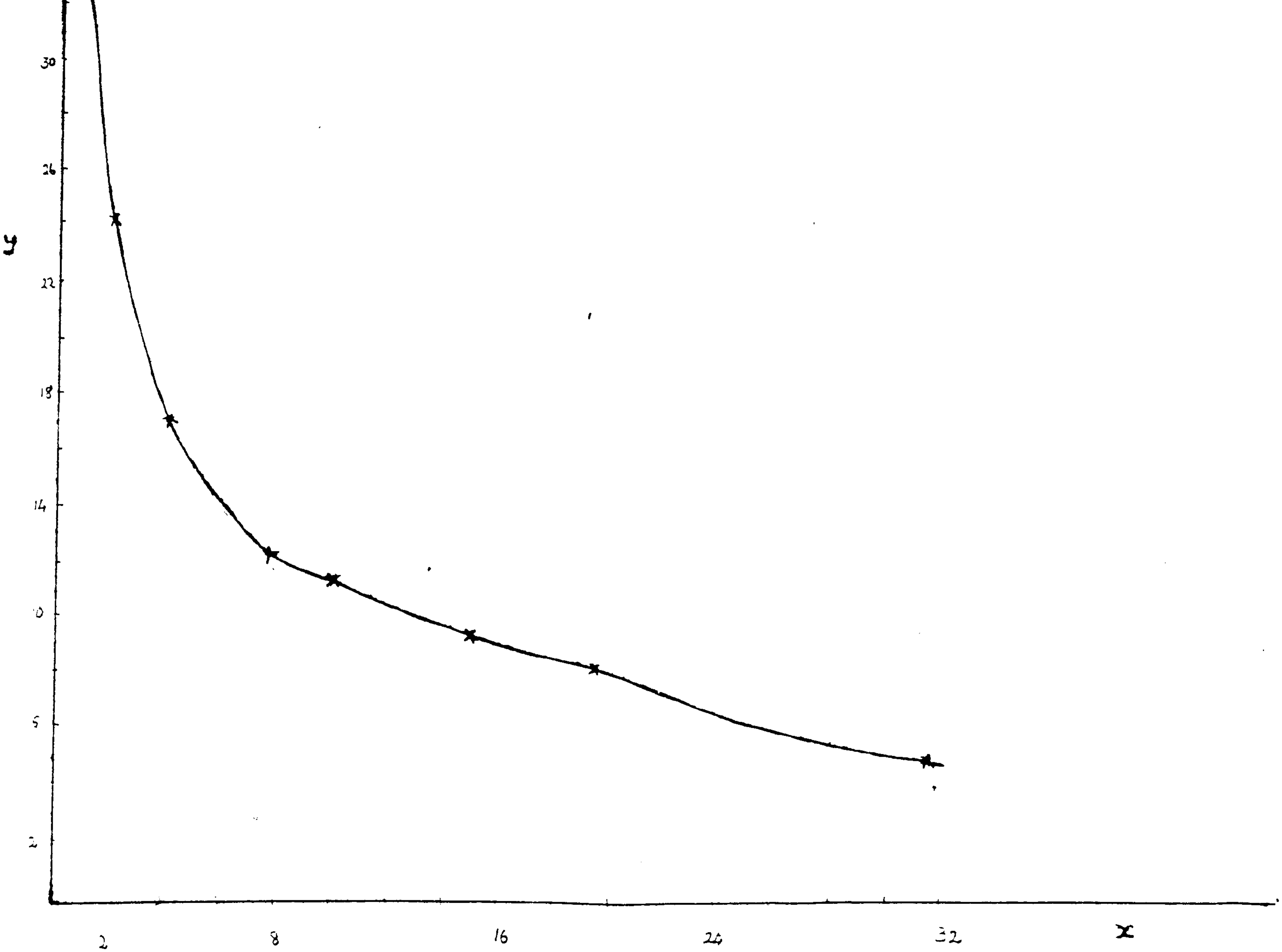


Fig - (2)

Relationship between plot size(x),number of replications(r) and true difference to be detected(d) between any two treatments expressed as percentage in bhindi + cowpea intercropping using LER analysis (p = 80%)

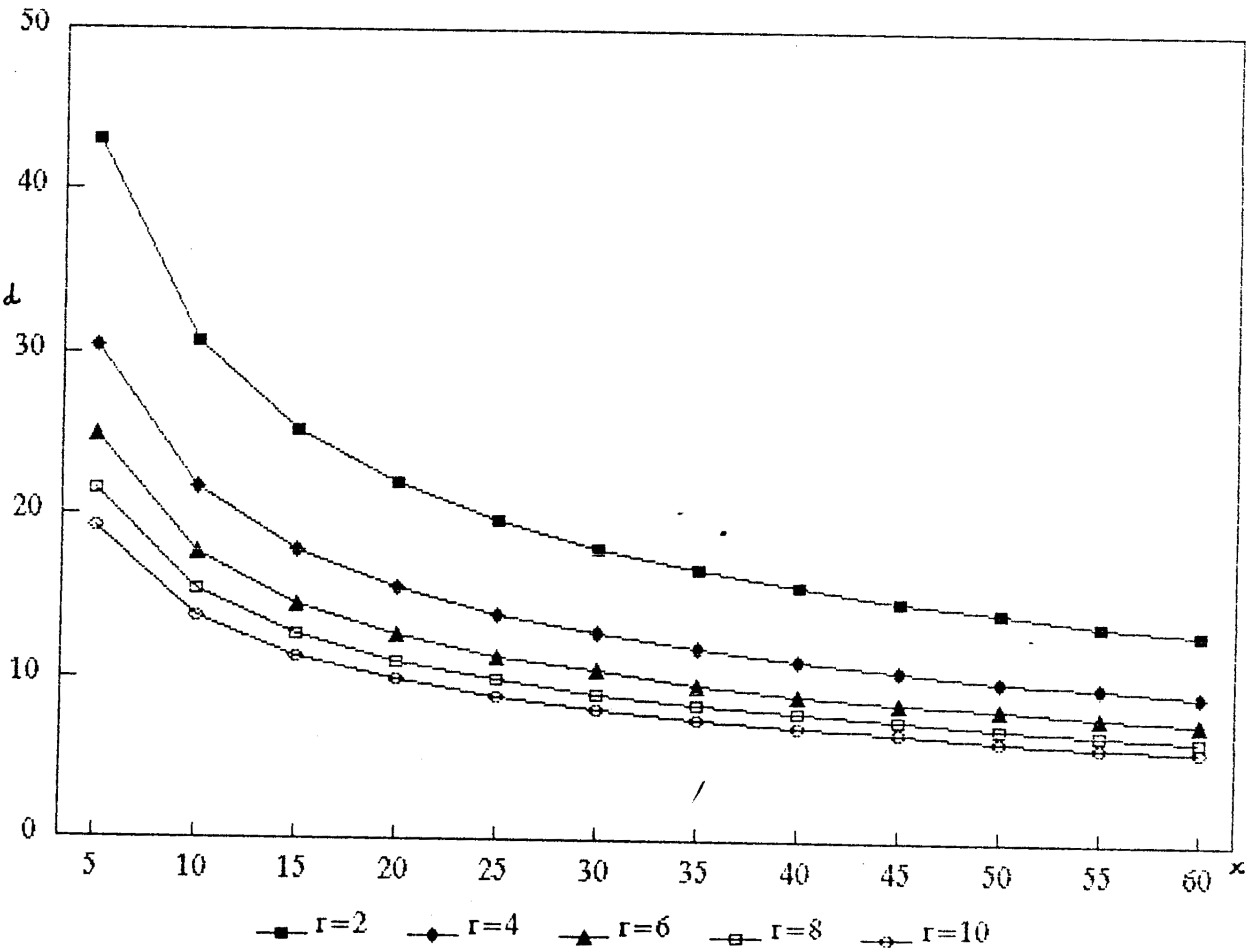


Fig. 3

Relationship between plot size(x), number of replications(r) and true difference to be detected(d) between any two treatments expressed as percentage in bhindi +cowpea intercropping using LER analysis (p = 90%)

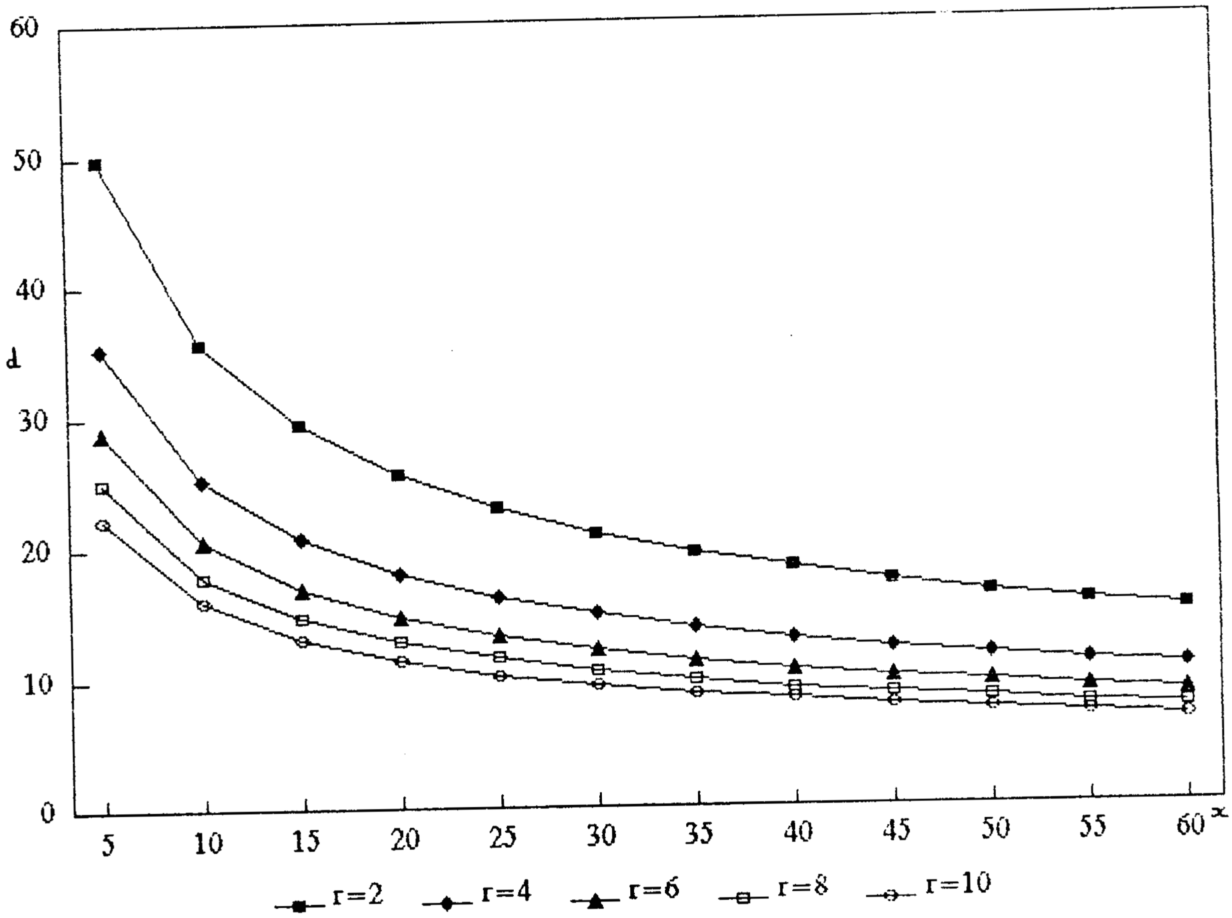


Fig-4

Relationship between plot size(x), number of replications(r) and true difference to be detected(d) between any two treatments expressed as percentage in bhindi + cowpea intercropping using bivariate analysis taking into consideration the covariance between two component crops (p = 80%)

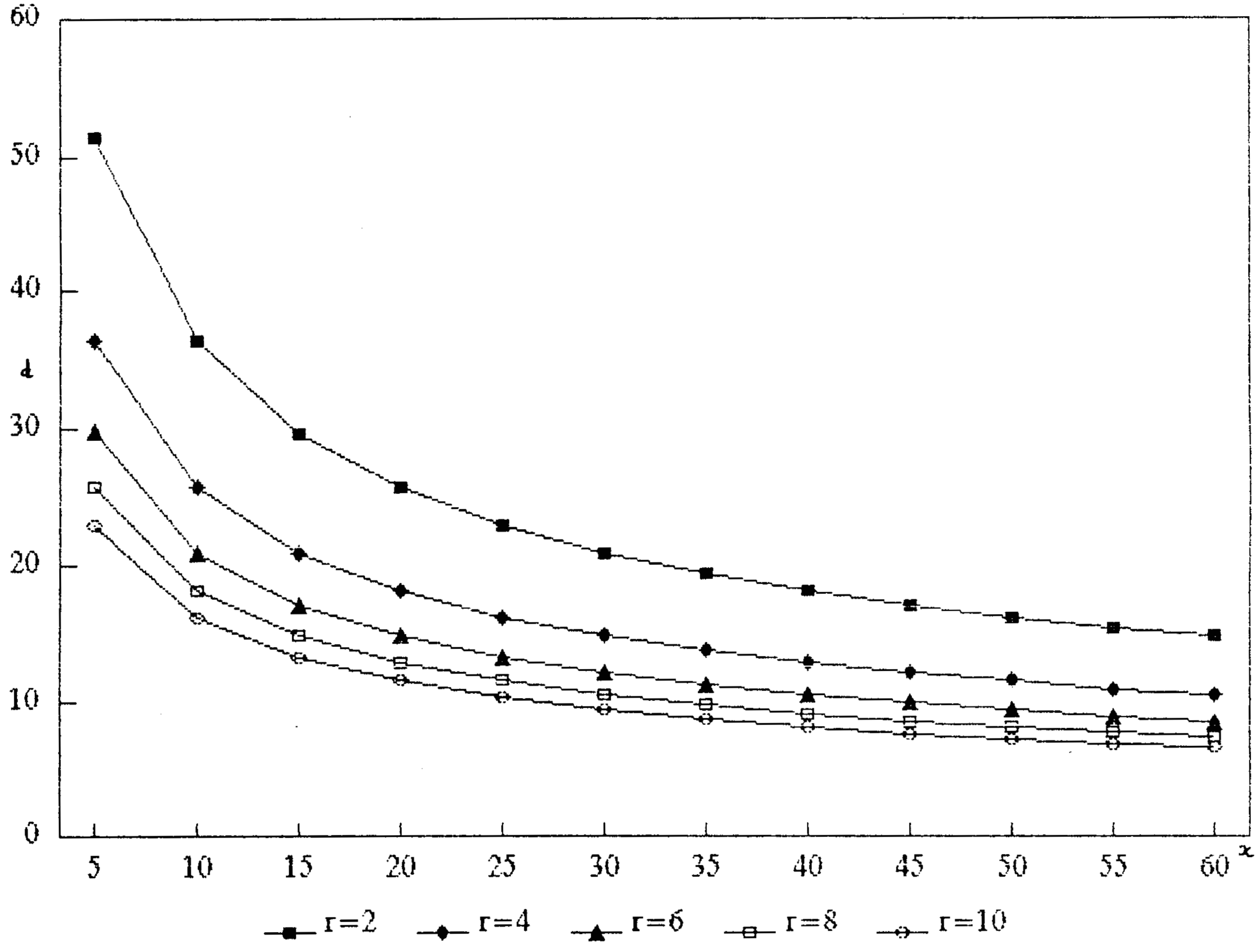


Fig - 5

Relationship between Plot size(x).number of replications(r) and true difference to be detected(d) expressed as percentage in bhindi+cowpea intercropping using bivariate analysis taking into consideration the covariance between two component crops(p=90%)

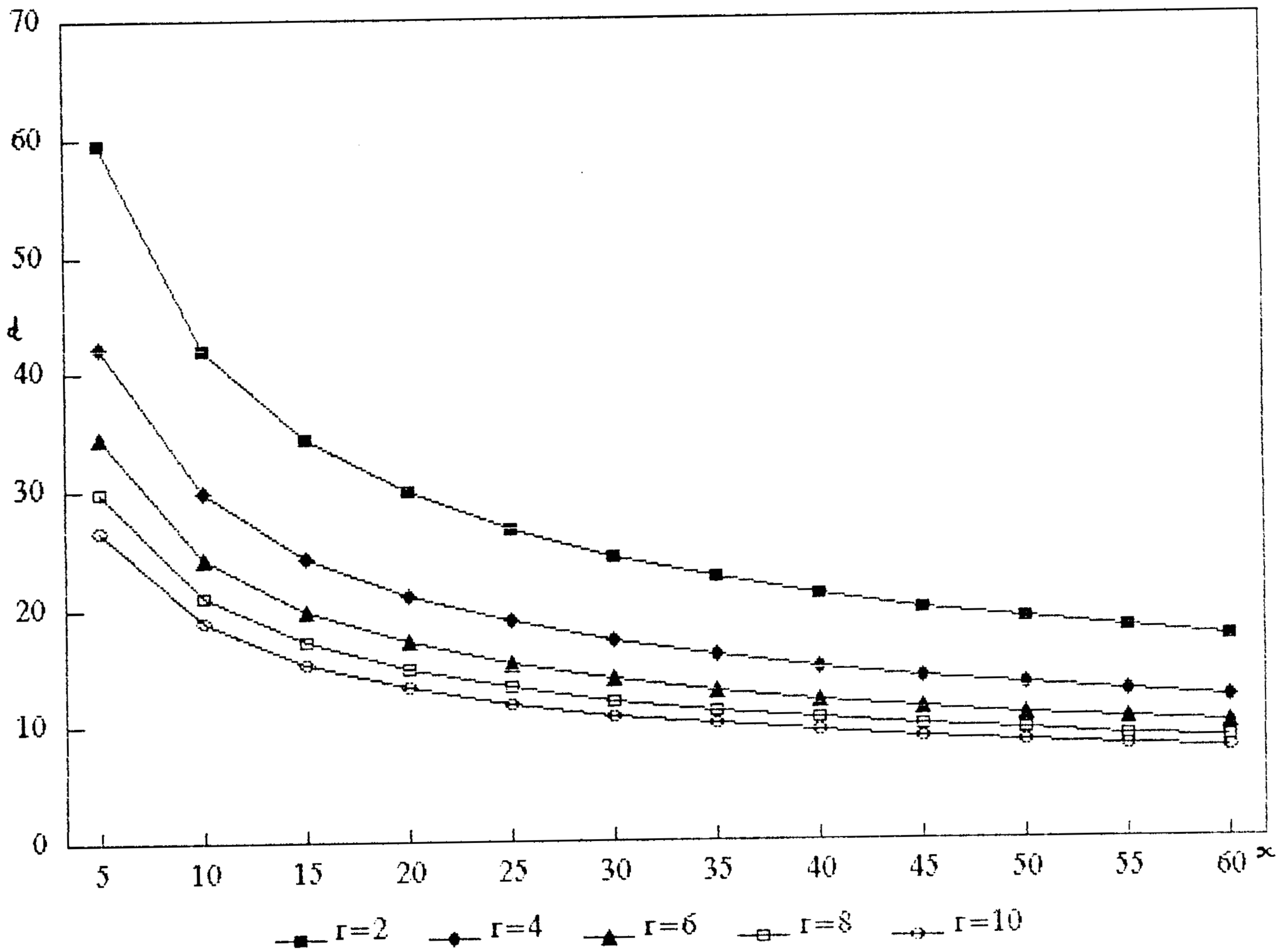


Fig - 6

Relationship between plot size(x), number of replications(r) and true difference to be detected(d) between any two treatment means expressed as percentage in bhindi + cowpea intercropping using bivariate analysis (after transformation) (p = 80%)

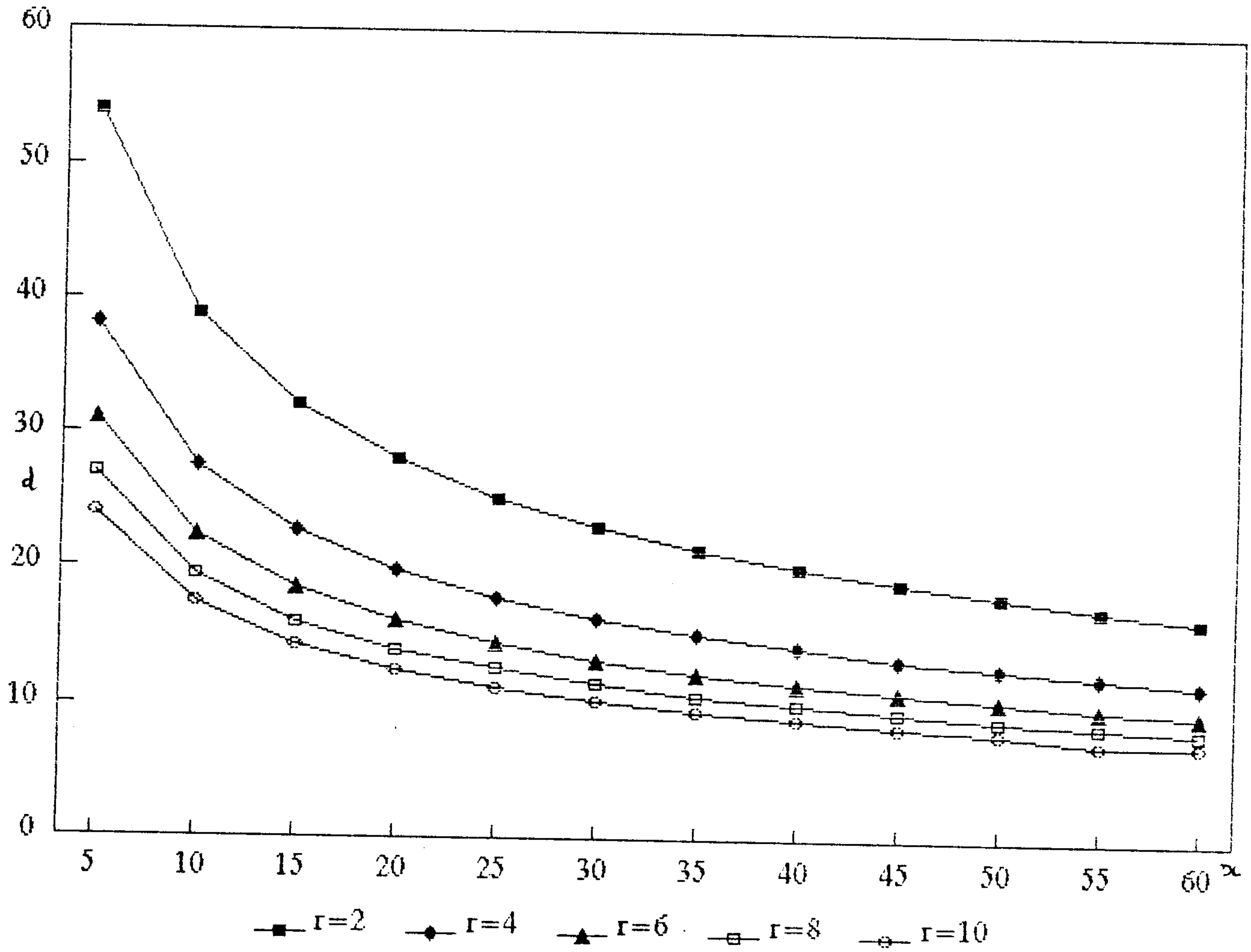


Fig - 7

Relationship between plot size(x), number of replications(r) and true difference to be detected(d) between any two treatment means expressed as percentage using bivariate analysis (after transformation) (p = 90%)

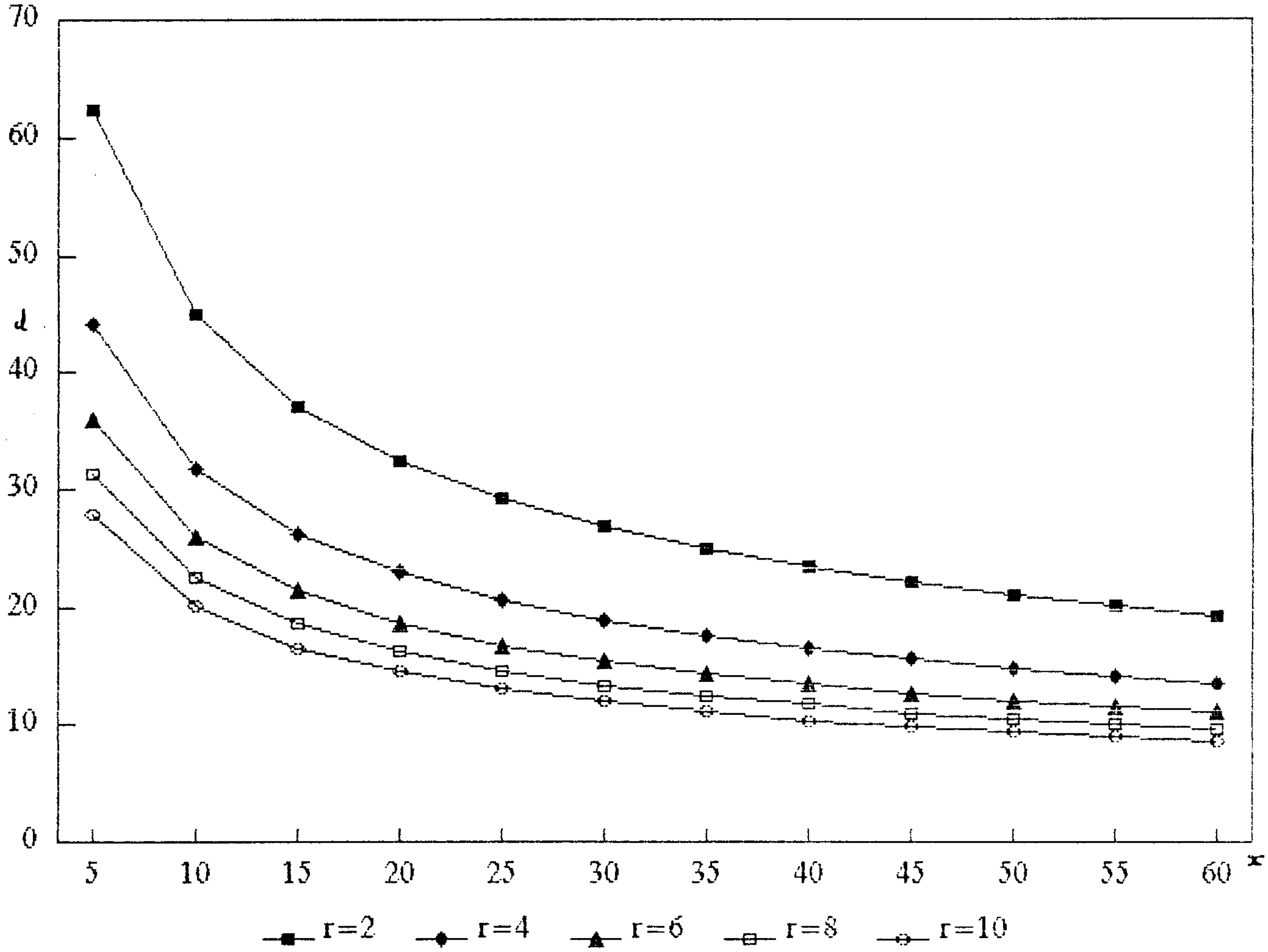


Fig - 8

Summary

6. SUMMARY

A uniformity trial was conducted in bhindi intercropped with cowpea with the objective of finding out the optimum plot size for increasing the efficiency of experiments with intercropping. The experiment was conducted at the experimental field, College of Horticulture, Kerala agricultural University, Vellanikkara. At the time of harvest, the yield data from 320 plots each of size 0.60m x 0.45m (consisting of one bhindi plant and one cowpea plant) were recorded seperately after discarding the border rows. Basically three different approaches have been attempted in the analysis. The salient results of the different approaches are given below.

LER values were calculated for each of the basic units which ranged between 0.377 to 2.01 with an average of 1.05 and a coefficient of variation of 34.3%. A mean LER value of 1.05 shows only a marginal yield advantage in intercropping. All the univariate techniques which were used to estimate the optimum plot size was tried in the case of LER values also.

An increase in the plot size in either direction generally decreased the coefficient of variation but the decrease was not proportional.

Smith's empirical law gave satisfactory fit to the data. The index of soil heterogeneity estimated in this case was fairly high. The empirical models suggested by various other authors were found to be more efficient than Smith's model.

Optimum plot size calculated using maximum curvature method was found to be 10 basic units ($2.7m^2$). The optimum plot size calculated using modified maximum curvature was found to be 7 basic units($1.9m^2$) and for the models Y = a + blogx and Y = a + blog x it was 12 basic units($3.2m^2$). Optimum plot size estimated using Hatheway's convenient plot size method were found to be 10 and 16 basic units ($2.7m^2$ and $4.3m^2$) for $p = 0.80$ and $p = 0.90$ for detecting a true difference of 20% between two treatment means with 4 replications.

The bivariate analysis making use of Smith's empirical law was fitted to the data. The index of soil heterogeneity was found to be high. Various models fitted in the case of LER were also tried in this case. All the models gave satisfactory fit to the data. The same bivariate analysis was tried on yields of the two crops after making them uncorrelated after a transformation. The index of soil heterogeneity was still high.

Optimum plot size was found out using Hatheway's convenient plot size method in both cases. The optimum plot sizes (estimated) for finding a true difference of 20% between two treatment means to be significant with 4 replications when $p = 0.80$ and $p = 0.90$ were 16 and 20 basic units in the first case, and 20 and 24 basic units in the second case.

Comparison of the LER and the bivariate analysis method showed that for the same level of precision the LER method gives a smaller plot size indicating that per unit cost of experimentation will be larger in the case of bivariate analysis.

Considering the two crop yields as multiple characters from a plot, relative dispersion matrices for plots of different sizes and shapes were calculated. The multivariate method also yielded the optimum plot size as 10 basic units($2.7m^2$) which has the maximum efficiency.

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OPTIMUM PLOT SIZE FOR INTERCROPPING EXPERIMENTS

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ABSTRACT OF THE THESIS

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ABSTRACT

A uniformity trial was conducted in bhindi intercropped with cowpea at the experimental field of College of Horticulture, Kerala Agricultural University, Vellanikkara during July 1993 to December 1993 to assess the nature and magnitude of soil heterogeneity, and to determine the optimum size of plot for increasing the efficiency of experiment with intercropping. Three different approaches have been attempted in the statistical analysis. At the time of harvest, the yield data from 320 plots each of size 0.60m x 0.45m were recorded seperately after discarding the border rows.

It was observed that the index of soil heterogeneity was very high in all these approaches indicating that the contiguous plots are not correlated and the fertile spots are distributed randomly or in patches. It was also observed that an increase in the plot size in either direction decreased the coefficient of variation but the decrease was not proportional in all these approaches.

The empirical law suggested by Smith gave a satisfactory fit to the data. All the other non - linear models tried also gave a satisfactory fit to the data in all these approaches.

The optimum plot size obtained by following different approaches indicated that 10 basic units plots ($2.7m^2$) are optimum for conducting the intercropping experiment with bhindi and cowpea.

Comparison of the LER and the bivariate analysis method showed that for the same level of precision the LER method gives a smaller plot size implying that per unit cost of experimentation will be higher in bivariate analysis. For any choosen plot size the precision attained through LER analysis is larger than that through bivariate analysis. However, when the multivariate approach is adopted the optimum plot size was obtained as 10 basic units ($2.7m^2$) as in the case of LER.