OPTIMUM PLOT SIZE FOR FIELD EXPERIMENTS ON TURMERIC *(CURCUMA LONGA. L.)*

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THESIS

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DECLARATION

I hereby declare that this thesis entitled Optimum Plot Size for Field Experiments on Turmeric (Curcuma Longa. L.) 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 to me of any degree, diploma, assciate-ship, fellowship, or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled Optimum Plot Size for Field Experiments on Turmeric (*Curcuma Longa. L.*) is a record of research work done independently by Sri.Gopakumaran Nair. B., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Statistical methodology plays an important role in evolving appropriate agrotechniques for the enhancement of crop production. The formulation of proper methodology for collection of data, their analyses and interpretations help in this regard. As is well known, 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. They are (i) variation due to soil heterogeneity and (ii) variation due to inherent variability (genetic variability) within the crop species.

These two types of variabilities are inherent in any experimental material and because of their inheritance, it has become difficult to compare the differences between treatments. Even if treatments are different in their effect, no one is sure as to whether the differences are due to the treatment effects or due to inherent variation in soil heterogeneity. Thus the outcome of any biological experiment becomes a stochastic variable and statistical principles based on the laws of probability are to be applied in the study of such phenomenon. Plot-to-plot variation due to uncontrolled factors such as soil fertility is generally called experimental error and if left uncontrolled, it can off-set experimental findings.

The basic principles of the theory of experimental designs involving the well known concepts of replication, randomisation and local control were originated by Fisher (1926) during the course of his experimental work at the Rothamsted Experimental Station between the years 1921-25.

With the introduction of these principles, field experimentation was based on a scientific footing and methods of logical construction of the experiment were known to the experimenter enabling him to draw objective(s) and reliable conclusions with pre-assigned degree of precision. Of these three principles, replication and local control were meant for reducing variation and improving precision of the estimates. Randomisation along with replication provided a valid estimate of error variance.

All these procedures are collectively called "The Direct Methods" of controlling error and are distinctively different from the statistical control of error through analysis of covariance. The direct methods of controlling error include in addition to replication and local control, such devices as selection of uniform site for experimentation, provision for border rows to eliminate border effect, maintaining uniformity in the physical conduct of the experiment, replanting of dead hills or missing plants, eliminating off-types, controlling the incidence of pest and disease, proper orientation of plots and blocks and adoption of an optimum size and shape of plots and blocks for the conduct of the experiment. Of these, the simplest and the most effective means of coping with the variation in soil hetrogeneity is to have a proper choice of plots and blocks.

The experimental plot is the total amount of experimental material to which a treatment is applied in a single replicate. Any experimenter who wishes to conduct an experiment with any crop has to select a convenient plot size for conducting the experiment. In many situations a decision on the size and shape of plot is made arbitrarily depending solely up on the judgement and experience of the research worker. But it is to be noted that an improper choice of the experimental unit (plot) can offset the experimental findings greatly. A very small plot even though appreciable from the economic point of view may give highly biased results. On the contrary, extremly large plots result in mere wastage of resources at the cost of very little gain in precision. Thus, it is always advantageous to use the most efficient plot size for conducting field trials. For a given size of plots, different geometerical configurations of the units are possible leading to various shapes of plot. Alternately, shape of the plot can be defined by the ratio

L:B, where L is the length of the plot and B is the breadth of the plot. It is also desirable to have an idea about the best shape of the plot which result in maximum precision for a given size of the plot. "Block" is a group of plots which are more or less homogeneous. Efficiency of blocking depends on the uniformity of plots within the block and heterogeneity between blocks. The investigator must know the best criterion for grouping or blocking the units inorder to achieve maximum precision. For a given size of the plot the efficiency of local control depends largely on the size and shape of blocks. An extremely large block can be as inefficient in error control as there was no blocking. The orientation of plots and blocks in a field is usually determined on the basis of the direction of the fertility gradient. A fertility contour map of the field is very helpful in this respect.

The statistical considerations governing the choice of suitable dimensions of the plot are the effect of size and shape of experimental units on the magnitude of error variance and consequent precision of treatment comparison and on the total cost of experimentation. Theoretically the best size and shape of plot is one which should give minimum variability in the estimate of population mean. This concept is referred to as the unconstrained optimisation of the variability function. Looking on the same problem from another angle of vision, the best size of the plot is the one which gives maximum information per unit cost. For an experimenter with limited resources, these two approaches will not be appealing. He may be interested in finding the optimum plot size in the sense that it gives estimates with pre-assigned degree of precision utilizing only the minimum amount of experimental material.

Replication or blocks should be so set up to control as much of the variation as possible resulting in the smallest experimental error variance. If a knowledge of the soil heterogeneity of the field is available, it could be utilised in setting up the blocks. Size of the block for a given design is determined by the number of treatments and the size of the plots. The upper limit on the replicate size depends largely on the character studied and nature of variability. Since an increase in block size is follwed by a consequent enhancement of error it is not desirable to have too much entries in a block. This problem can be delt with by using incomplete block designs. However, a crtical study of the experimental material alone will help the experimenter to formulate appropriate criteria for determining the size of the replicate.

Turmeric, curcuma longa.L. belongs to natural order Scitaminae and family Zingiberaceae to which the familiar ginger and cardamom also belong. In India, it is mainly used as spices and in medicines. But, in foreign countries, it is well known for its curcumin content and is used as a natural colouring material especially for colouring food products and costly textiles. It has a good export value and is a regular foreign exchange earner for the country. The estimated world production of turmeric is around 1.6 lakh tonnes, of which India's contribution is about 1.5 lakhs tonnes. In India 92 per cent of the produce is consumed within the country and remaining is exported to foreign countries. The foreign exchange earning by turmeric ranks fourth among the spices first three places being occupied by black pepper, cardamom and ginger respectively. In India, turmeric is cultivated in an area of about 77,400 ha. of this 4335 ha (5.6%) is in Kerala State. Kerala contributes to about 15.1 per cent of India's total export on turmeric and earns arround 76 lakhs of rupees annually. Besides Kerala, the states of Andhra Pradesh, Tamil Nadu, Bihar and Orissa are the other important turmeric producing states of India. The contribution of turmeric by Kerala works out only to 2.8 percent of that of India. The quality of turmeric expressed as curcumin content is very important in export market. But most of the Indian turmeric types contain less than 5 percent curcumin. The foregoing details stress the importance of turmeric in Indian economy. Therefore it is essential to conduct research with the objectives of improving the quality and yield of turmeric. Information on the statistical designing of field experiments on turmeric is rather scanty. Field trials on turmeric are usually conducted by using the same size and shape of the plot required for ginger - a similar crop. Thus, there is an urgent necessity to have a deep investigation in the field plot technique of experimentation exclusively on turmeric.

The present study undertaken on turmeric has the following objectives :-

(i) To study the nature and magnitude of soil heterogeneity of the experimental field.

(ii) To determine the optimum size and shape of plots for conducting field experiments on turmeric under normal field conditions.

(iii) To determine the maximum number of plots of a given size which can be accommodated in a single block without confounding.

(iv) To determine the direction of the blocks to increase the efficiency of field experiments.

(v) To compare the estimates of optimum plot sizes obtained through different criteria of estimation.

(vi) To estimate the relative efficiency of alternate designs in laying out field trials.

(vii) To seek for alternate models for describing the relationship between plot size and variability.

(viii) To determine minimum number of replications required for estimating treatments effects with given degree of accuracy.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

In this chapter an attempt has been made to give an account of the research information on the technique of field experimentation of different crops.

2.1 Magnitude of Soil Heterogeneity

Harris (1920) initiated studies on the statistical treatment of soil heterogeneity and its relation to the accuracy of experimental results. Through the estimation of intraclass correlation coefficient, he concluded that soil heterogeneity is the most potent source of variation in plot yields and the chief difficulty in their interpretations. He showed that the correlation between the yields of adjacent plots 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 the soil. The intraclass correlation coefficient of Harris (1915) served only to demonstrate the degree of difference in soil heterogeneity of adjacent plots. But Bose (1935) found that an experimental site which was reasonably uniform for one crop in one season was not necessarily uniform for another crop in another season. He concluded that analysis of variance was more useful than the intraclass correlation coefficient of Harris, because it provided the nature of soil heterogeneity and permitted the identification of fertility gradients.

Smith (1938) proposed a quantitative measure of soil heterogeneity based on his empirical relationship between plot size and variability of mean per plot given by the equation,

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

Where V_x is the variance of mean yield per plot based on plots of x unit in size, V_1 is the variance among plots of size unity and b is the index of soil heterogeneity, which assumed values only in the range between zero and one. A value of 'b' nearer to one indicated that there was no significant correlation among contiguous units, whereas a value in the neighbourhood of zero indicated strong linear relationship between adjacent units. In the case of self-fertilised crops the value 'b' was largely a function of the effect of soil heterogeneity, but with cross-fertilized crops intra-plot variation mainly due to genetic make up of the plants with plot also had some effect on the value of 'b'. A high value of 'b' tending to one thus indicated that genetic variation (intra-plot variation) was more predominant over positional variation. From a uniformity trial on cashew, Nair (1981) obtained the value 'b' as high as 0.97 whereas on oat, Handa et al (1982) obtained the values within the range 0.084 to 0.187.

Federer (1955) observed that in most cases the value of heterogeneity coefficient calculated from the Smith's equation were in the range 0.3 to 0.7. He further remarked that a change in plot size from one-fourth to four times the optimum will not greatly affect the cost or variance of heterogeneity in the normal range of 0.3 to 0.7.

2.2. Uniformity Trials and Fertility Contour Maps

An overall idea about the magnitude and distribution of soil heterogeneity of the experimental field can be obtained by conducting an experiment called "uniformity trial" which consists of growing a bulk crop with a uniform treatment all over the field and harvesting and recording the produce in small units of suitable size (Panse, 1941).

Cochran (1937) had given an account of 191 uniformity trials conducted on various crops by several workers. He noticed considerable variability in the estimates obtained from different crops and for the same crop in different locations.

Numerous reports on uniformity trials on various crops are available in India and abroad. To cite a few are those conducted by Baker et al (1952) on barley; Gopini et al (1970) on ground nut; Prabhakaran and Thomas (1974) on tapioca; Katyal and Sasmal (1982) on jute and Binns et al (1983) on tobacco.

Uniformity trial data can be presented graphically in what are called fertility contour map showing lines passing through areas of equal fertility. Fertility contour maps for numerous crops have been published by various workers. Some of them are those published by Hutchinson and Panse (1935a) on cotton; Kadam and Patel (1937) on bajari; Agarwal *et al* (1968) on arecanut; and Hariharan (1981) on brinjal.

2.3. Methods of Estimation of Plot Size

Several methods have been suggested from time to time by various workers for the estimation of convenient plot size for the conduct of successful field experiments. A brief account of the various methods of estimation of optimum plot size is given below.

2.3.1. Maximum Curvature Method

Maximum curvature method consists in representing the relationship between plot size and coefficient of variation graphically by using a smooth free-hand curve and choosing the size of the plot just beyond the point of maximum curvature as the optimum (Federer, 1955). He has pointed out two weaknesses of this method. They are (i) the relative costs of various plot sizes are not considered and (ii) the point of maximum curvature is not independent of the smallest unit selected or the scale of measurement used. In spite of its inherent drawbacks several workers have used it for getting a suitable plot size due to its simplicity. Prabhakaran and Thomas (1974) used this technique for getting an initial crude estimate of plot size for field experiments on tapioca and Hariharan (1981) used it for estimating the plot size for field trials on brinjal.

2.3.2. Heterogeneity Index Method

Smith (1938) proposed a method for determining the optimum plot size from uniformity trial data. Smith's equation is given by $V_x = V_1 x^{-b}$. Since the cost of experimentation is also to be considered in determining a suitable plot size, he used the cost function of the form $K = K_1 + K_2 x$ where K_1 is the cost associated with number of plots and K_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 x_{opt}, as suggested by Smith (1938) was given by, $x_{opt} = bk_1/(1-b)k_2$.

Smith's equation has also been used by several workers to describe the non-linear relation between size of the plot and coefficient of variation (CV). Smith's equation in the modified form is given by $y = ax^{-b'}$ where y is the coefficient of variation per plot based on plots of x units in size a is the coefficient of variation of plots of size unity and b' an index of soil heterogeneity related to Smith's 'b'.

Smith's equation in the modified form was used by Saxana et al (1972) on [illegible]oat[illegible]; Prabhakaran and Thomas (1974) on tapioca; and Hariharan (1981) on brinjal for estimating optimum plot size.

Raghavarao (1983) suggested that the optimum plot size could be determined from Smith's law in the modified form mathematically using calculus method by maximising curvature of the variability function. He estimated the optimum plot size of Radish using the new technique as 4 to 8 square meters.

Smith (1938) had not specifically defined the basis for calculating the factors K_1 and K_2 in the cost function. Marani (1963) pointed out that Smith's cost concept had been misused by several workers and indicated that the two types of costs should be proportional to K_1 and K_2x and not to K_1 and K_2 .

The correct definition of the cost functions were used for estimating optimum plot size by Hodnett (1953) in groundnut; Sen (1963a) in tea; Sreenath (1973) in sorghum; Prabhakaran and Thomas (1974) in tapioca; Biswas et al (1982) in cabbage and Binns et al (1983) in tobacco.

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

2.3.3. Hatheway's Method

Hatheway (1961) developed a procedure, to determine optimum plot size, where the number of replication and the expected magnitude of difference betwen treatments were specified, but no attention was given to experimental cost. He used the relationship between coefficient of variation and Smith's 'b' in estimating plot size. The basic equation of Hatheway is of the form $x^b = 2(t_1+t_2)^2 \, C_x^2 / rd^2$ where 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 a per centage and r is the number of replications. He developed a set of curves for a specific set of conditions from which an experimentercan determine the proper plot size and number of replication for specified value of 'd'

2.3.4. Method of Estimation of Plot Size for Perennial Crops

Freeman (1963) suggested a modification to Smith's law to take care of genetic variation among trees of the same plot. His new function is of the form

$\frac{V_x}{V_1} = \frac{\alpha}{x^b} + \frac{(1-\alpha)}{x}$ where V_x is the total variance of mean yield per tree of a plot containing x trees, V_1 is the variance of the single tree plots, α is the proportion of the variance that is due to enviornment, x is the number of basic units (trees) per plot and 'b' is the Smith's index of soil heterogeneity. Putting $\alpha = 1$ in this equation, we get the familiar Smith's equation (1938). Freeman (1963) has also described the method of estimating α by using serial correlations.

2.3.5. Method of Modified Maximum Curvature

Situations may often arise where the familiar Smith's law (1938) fails to describe the pattern of variability satisfactorily. Then either a change of scale or the need of fitting other sophisticated models is indicated. Lessman and Atkins (1963a) found that the equation $\log C_x = \frac{a}{(a+\log x)^b}$, where C_x is coefficient of variation of plots of size of x units, is more efficient in representing the relationship between plot size and variability than Smith's law.

Prabhakaran (1983) suggested three non-linear models for describing the relationship between coefficient of variation and plot size (x). He has shown empirically that all these three models were superior to Smith's law in describing the proposed relationship between plot size and coefficient of variation at least for three different crops viz. tapioca, banana and cashew.

The suggested models are

(i) $Y = a + b/\sqrt{x} + c/x$

(ii) $Y^{-1} = a + b \log x$

(iii) $Y^{-1} = a + b\sqrt{x} + cx$

2.3.6. Variance Component Heterogeneity Index Method

Koch and Rigney (1951) developed a new method called Variance Component Heterogeneity Index Method for estimating plot size by utilizing data from actual field experiments with different treatments and not from uniformity trial data. This method consisted in estimating the components of variance due to plots of different sizes by reconstructing the ANOVA of the specified design and using these estimated variances for fitting the Smith's functions.

But Hatheway and Williams (1958) pointed out that the method of Koch and Rigney (1951) often resulted in inaccurate estimates of plot size because they assigned equal weights to the different components of variation even though they were based on different degrees of freedom.

2.3.7. Percentage Relative Efficiency Concept

Another approach in estimating plot size is to select the plot size which gives maximum precision for given cost as optimum. If the reciprocal of the coefficient of variation can be considered to be an index of precision, the efficiency of a plot can be defined as $1/x\, C_x$, where C_x is the coefficient of variation of plot size x estimated from the mathematical model (Kalamkar, 1932). Therefore relative efficiency of plot size x_2 as compared with plot size x_1 is given by

$$RE_{12} = \frac{x_1\, C_{x1}}{x_2\, C_{x_2}} \times 100$$

Gopini et al (1970) had shown that efficiency of a plot decreased with an increase in size of the plot in the case of groundnut. Similar results were obtained by Saxana et al (1972) on oat; Sreenath (1973) on sorghum; Prabhakaran and Thomas (1974) on tapioca; Rambabu et al (1980) on fodder grass and Hariharan (1981) on brinjal.

Optimum plot size can be obtained 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 (1973) on apple and Prabhakaran et al (1978) on banana that single tree or plant plots were the most efficient ones for conducting field trials on these crops as they provided maximum amount of relative information.

It is to be noticed that both these approaches are identical and produce identical results.

The third approach of estimating the plot size is to select the size of the plot which required minimum experimental material for a given precision (Gomez, 1972).

2.4. Shape of Plots

Taylor (1907-09) who summarised a large number of contemporary field experiments with various crops found that rectangular plots were the most desirable and convenient for experimentation with field crops.

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 more efficient than square ones. Many research workers agreed with his findings. They include, Saxana et al (1972) on oat; Sreenath (1973) on sorghum, Prabhakaran and Thomas (1974) on tapioca and Hariharan (1981) on bringal.

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

Marcer and Hall (1911) working with mangoes found no superiority of long and narrow plots over square ones. Bist et al (1975) on potato found that shape of the plot had no consistent effect on estimates of error. Similar results have been reported by Rambabu et al (1980) on fodder grass and Biswas et al (1982) on cabbage.

Pan (1930) obtained contradictory results about plot shape of rice in China. At Hangehow increasing plot width was more efficient than increasing length whereas at Wufe the opposite was true.

2.5. Size and Shape of Blocks

Panse (1941) considered the effect of size and shape of blocks and their arrangement on the magnitude of soil variation. He developed a concept of block efficiency for computing the relative efficiency of blocks of different sizes and shapes with regard to the power of sorting out the assignable component of variation due to difference among blocks from experimental error. He concluded, however, that size and shape of plots exerted greater influences on error variation than that of the blocks of a given experimental field and hence greater attention to be given on the appropriate choice of plots than that on blocks.

Iyer and Agarwal (1970) found that compact blocks are more efficient than rectangular blocks in laying out experiments on sugarcane. Similar results were also obtained by Saxana *et al* (1972) on oat and Handa *et al* (1982) on oat.

Sreenath (1973) found that shape of the blocks ha no consistent effect on block efficiency on sorghum and this result was supported by Bist *et al* (1975) on potato and Rambabu *et al* (1980) on fodder grass.

Gopini *et al* (1970) found that block efficiency decreased for given size and shape of plots with increase in the block size in groundnut and the result has been supported by the findings of Saxana *et al* (1972) on oat; Kripashankar *et al* (1972) on soyabean; Sreenath (1973) on sorghum; Bist *et al* (1975) on potato and Hariharan (1981) on brinjal.

2.6. Minimum Number of Replications

Hayes (1925) proposed the formula $r = Cv^2/p^2$ for determining the minimum number of replications (r), needed to estimate population mean with 'p' percent standard error, where Cv is the coefficient of variation. He showed that an increase in number of replications decreased standard error more rapidly than an increase in the size of the plot. Many research workers on various crops experienced the same result. They include Iyer and Agarwal (1970) on sugarcane; Kripashankar *et al* (1972) on soyabean; Bist *et al* (1975) on potato; Prabhakaran *et al* (1978) on banana; Hariharan (1981) on brinjal and Suman and Wahi (1982) on cabbage.

According to Gomez (1972) one of the simplest means of increasing the precision of treatment comparison is to increase the number of replications for different treatments but beyond a certain level, the improvement in precision attainable through the increase in number of replication is too small to worth the additional cost, other means of enhancing precision have to be employed.

Prabhakaran *et al* (1978) on banana observed that the expected number of replications decreased with an increase in plot size but total number of experimental trees (plots) increased with an increase in plot size.

2.7. Relative Efficiency of Different Designs

Fisher (1951) had used the concept of relative efficiency for the choice of appropriate designs for conducting field trials. According to him relative efficiency is the ratio of amount of information supplied by one design to the amount of information supplied by another design.

Malhotra *et al* (1979) found that the relative efficiency of latin square designs of different orders for different plot sizes compared with completely randomised designs ranged from 122 to 262 percentage whereas those when compared with randomised block design using either row or column as blocks ranged from 100 to 292 percentage. Jayaraman (1979) found that the efficiency of randomised blocks design over completely randomised design depended largely on the orientation of blocks, and that of latin square design over randomised block design also depended on the orientation of the blocks of randomised block design. He found that on an average the relative efficiencies of latin square design over randomised block design was 107.8 and 238.5 percentage for row as blocks and column as blocks respectively and for combined analysis (Federer, 1955) eliminating the between set sum of squares the efficiencies are 118.7 and 222.4 percentage for row as blocks and column as blocks respectively.

MATERIALS AND METHODS

MATERIALS AND METHODS

The study was taken up at the College of Horticulture, Vellanikkara during the period from June 1983 to January 1984 by conducting an uniformity trial on turmeric. The weather and seasonal conditions during the period of study were more or less normal. The experimental field selected was uniform with non-undulating topography and no shade trees and pathways around the margin. The soil was red lateretic loam. Adequate drainage was provided. The variety of turmeric under study was "Wyanad Local".

The crop was raised in raised beds adopting manurial and cultural operations as per package of practice recommended by Kerala Agricultural University.

The gross experimental area consisted of a rectangular field with sides of 74.2 meter length and 15.2 meters breadth. Small elevated beds of height of 0.25 cm and of size 0.6 m x 1.5 m were raised providing channels of width 0.4 m around each to prevent soil erosion and water logging. There were altogether 494 beds in the field. One row of beds all around the margin of the field was discarded to eliminate external border effect. After discarding the border rows, there were 432 beds in the net experimental area.

Harvesting was done on 220th day after planting, when the leaves had dried completely in most of the plants. At the time of harvest each bed was divided into equal plots of size 0.6 m x 0.75 m and the yield was recorded from each plot for statistical analysis.

3.1. Fertility Contour Map

In order to construct fertility contour map, the percentage deviation of each observation from the grand mean was calculated by the relation,

$$d_i = \frac{(Y_i - \bar{Y})}{\bar{Y}} \times 100 \qquad (1)$$

where d_i = Percentage deviation of the ith unit from the grand mean

Y_i = Yield on the ith unit

$\bar{Y}$ = Grand mean

The units are then grouped into different classes according to the magnitude of the observed variation around the overall mean yield. The experimental units which produced the same amount of deviation from the overall mean yield was assumed to be similar in fertility. Regions of similar fertility status were identified and marked with different system of grading.

3.2. Size and Shape of Plots

Plots of different sizes and shapes were formed by grouping adjacent units in various possible ways. The mean, standard deviation and coefficient of variation of plots of different sizes and shapes were worked out. Optimum size and shape of plots were determined by using several methods as indicated below.

3.2.1. Maximum Curvature Method

A freehand curve was drawn by joining the points ploted with abscisae equal to the sizes of the plot and ordinate equal to the corresponding coefficients of variation. The optimum plot size was determined from the curve as the one just beyond the point of maximum curvature.

3.2.2. Heterogeneity Index Method

Smith's (1938) empirical law is given by,

$$V_x = \frac{V_1}{x^b} e^{u'} \qquad (2)$$

where V_x = the variance of the yield per unit area among plots of x unit in size.

V_1 = the variance among plot of one unit in size.

x = the number of basic units in a plot.

b = the index of soil heterogeneity.

$e^{u'}$ = random error component, where u' is N $(0,\sigma^2)$

Smith's empirical law expressed in the modified form is given by

$$\hat{Y} = ax^{-b'} \qquad (3)$$

where Y = expected coefficient of variation of the yield per unit area among plots of x units in size.

a = the coefficient of variation among plots of one unit in size.

b'= index of soil heterogeneity.

It is evident that,

$$\hat{Y}^2 = \frac{\hat{V}_x}{M^2} \qquad (4)$$

where M is the grand mean per unit basis.

and

$$a^2 = \frac{\hat{V}_1}{M^2} \qquad (5)$$

Substitute (4) and (5) in square of (3),

$$\hat{V}_x = \hat{V}_1 x^{-2b'} \qquad (6)$$

Therefore from (2) and (6),

b = 2b', Smith's index of soil heterogeneity.

The coefficient 'b' and the constant 'a' are obtained from the mathematical model

$$Y = ax^{-b'} e^{u} \qquad (7)$$

where 'u' is distributed as independent N $(0, \sigma^2)$

Taking logarithms of (7)

$$\log Y = \log a - b' \log x + u \qquad (8)$$

ie. $$\underset{\sim}{Y}_1 = \underset{\sim}{A} + \underset{\sim}{B}\, \underset{\sim}{X}_1 + u \qquad (9)$$

where $\underset{\sim}{Y}_1 = \log Y$

$\underset{\sim}{A} = \log A$

$\underset{\sim}{B} = -b'$

and $\underset{\sim}{X}_1 = \log x$

By the method of least squares A and B can be obtained from the normal equations

$$\underset{\sim}{X}_1' \underset{\sim}{Y}_1 = (\underset{\sim}{X}_1' \underset{\sim}{X}_1) \underset{\sim}{A}_1 \qquad (10)$$

where $\underset{\sim}{A}_1 = \begin{pmatrix} A \\ B \end{pmatrix}$

From this normal equation, the coefficient b' and constant 'a' are obtained.

For calculating an optimum plot size consider the cost function of the form,

$$K = K_1 + K_2x$$

where K = total cost of the experimental unit of size x.

K_1 = overall cost of the experimental unit which is independent of the size of the unit

K_2 = the cost of an individual item within the experimental unit.

The optimum plot size is obtained by minimising total cost per unit of information. That is, by minimising C,

where $$C = (K_1 + K_2x)/\frac{1}{V_x}$$

ie. $$C = a^2M^2(K_1+K_2x)/x^b \qquad (11)$$

On differentiating C with respect to x and equating to zero the optimum size of the plot which give maximum information per unit cost is obtained.

ie. $$\frac{dC}{dx} = 0$$

or $$\frac{d \log C}{dx} = 0$$ gives

$$\frac{K_2}{K_1+K_2x} = \frac{b}{x}$$

$$\therefore \quad \hat{x} = \frac{bK_1}{(1-b)K_2} \tag{12}$$

put b = 2b' in (12)

$$\hat{x} = \frac{2b'K_1}{(1-2b')K_2} \tag{13}$$

and C is minimum at $x = \hat{x}$ only if $\frac{d^2 \log C}{dx^2}$ at $x = \hat{x}$ is greater than zero.

Optimum plot sizes for different cost ratios can be determined from the formula (13) by assigning different values for the cost components K_1 and K_2.

3.2.3. Modified Maximum Curvature Method using Smith's Equation

The curvature C of a line at a given point is defined as the limit of the average curvature of the arc, when the length of the arc approaches zero. Average curvature means $\varphi/\widehat{AB}$, where $\widehat{AB}$ is the arc and φ is the angle formed by the tangents at A and B. That is, by definition $C = \frac{d\varphi}{ds}$, where $s = \widehat{AB}$

$$\therefore \quad C = \frac{d\varphi/dx}{ds/dx}$$

let Y = f(x), the function of x, then

$$\tan \varphi = \frac{dy}{dx} \tag{14}$$

Defferentiating (14) with respect to x

$$\frac{d\varphi}{dx} = \frac{d^2y}{dx^2} \Big/ 1 + \left(\frac{dy}{dx}\right)^2 \tag{15}$$

If $ds = \underset{B \to A}{Lt} \widehat{AB}$

$$ds = \sqrt{dy^2 + dx^2}$$

$$\therefore \quad \frac{ds}{dx} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2}$$

Put $\frac{dy}{dx} = Y_1$ and $\frac{d^2y}{dx^2} = Y_2$, then

$$C = \frac{Y_2}{(1 + Y_1^2)^{3/2}} \tag{16}$$

The optimum plot size is the point at which the curvature is maximum. That is, C is maximum. The point of maximum curvature is obtained by equating

$$\frac{dC}{dx} = 0 \quad \text{or} \quad \frac{d \log C}{dx} = 0$$

Smith's empirical law in the modified form is

$$Y = ax^{-b'}$$

$$\therefore \quad Y_1 = -ab'x^{-(b'+1)} \quad \text{and} \quad Y_2 = ab'(b'+1)x^{-(b'+2)}$$

$$\text{ie.} \quad C = \frac{ab'(b'+1)x^{-(b'+2)}}{\{1+(ab')^2x^{-2(b'+1)}\}^{3/2}}$$

$$\therefore \quad \frac{d \log C}{dx} = \frac{-(b'+2)}{x} + \frac{3(ab')^2(b'+1)x^{-(2b'+3)}}{1+(ab')^2x^{-2(b'+1)}}$$

Equating to zero, gives

$$x^{2(b'+1)} = \frac{(ab')^2(2b'+1)}{(b'+2)} \tag{17}$$

If this value of x is substituted in $\frac{d^2 \log C}{dx^2}$ it will be less than zero. Then the optimum plot size can be determined from the equation (17).

3.2.4. Alternate Models

Three other non-linear models were also tried to express the relation between coefficient of variation and plot sizes.

The three models are,

(i) $Y = a + b/\sqrt{x} + C/x + u$

(ii) $Y^{-1} = a + b \log x + u$

(iii) $Y^{-1} = a + b\sqrt{x} + cx + u$

In all the three models the parameters were estimated by principles of least squares.

The mathematical method by using calculus to find the optimum plot size is still applicable to these models also.

3.3. Relative Efficiency of Plot Sizes

Kalamkar (1932) defined efficiency of a plot of size x units as $1/xCx$, where C_x is the coefficient of variation of a plot of size x unit. The relative efficiency of plot of size P_2 as compared with a plot of size P_1 is defined as the ratio of the efficiency of P_2 over that of P_1 and is denoted by $RE(P_2/P_1)$.

Thus if x_1 and C_{x1} are the number of basic units and coefficient of variation of a plot of size P_1 and x_2 and C_{x2}

are the number of basic unit and coefficient of variation of a plot of size P_2, then

$$RE(P_2/P_1) = \frac{x_1 C_{x1}}{x_2 C_{x2}} \tag{18}$$

3.4. Relative Efficiency of Blocks

The advantage of using blocks of different sizes in reducing experimental error by removing a portion of variability due to them is called block efficiency. This can be measured by finding the inverse of error mean square obtained after the elimination of difference due to blocks of specified size from the total variation.

The relative efficiency of a block of size P_2 when compared with a block of size P_1 is defined as the ratio of the efficiency of block of size P_2 over that of P_1. This can be expressed in percentages.

Smith (1938) deduced the following relationship for the variance per unit area between plots of x units in blocks of m plots. $V_{xm} = \frac{m(1-m^{-b})}{m-1} V_x$, where V_x is the variance in an infinite land and b is the Smith's index of soil heterogeneity.

Therefore the efficiency of blocks of m plots relative to blocks of n plots is equal to

$$RE(m/n) = \frac{V_{xn}}{V_{xm}}$$

ie. $$RE(m/n) = \frac{n(m-1)(1-n^{-b})}{m(n-1)(1-m^{-b})} \quad (19)$$

This concept has also been used for calculating the efficiency of different block sizes.

3.5. Number of Replications and Area Required

The minimum number of replication for estimating means with P% standard error was worked out for different sizes of plots and blocks by using the formula

$$r = CV^2/P^2 \quad (20)$$

where r = minimum number of replication

CV = estimated coefficient of variation

and P = the percentage standard error of the mean

The total area required for experimentation can be obtained by multiplying the area of the plot with the number of replication at P% standard error of the mean.

Assuming a simple cost function of the form, C = rkx, where r is the number of replication, k is the cost per unit plot size and x is the number of basic unit per plot. The size of the plot which requires minimum experimental material is also the best plot size in the sense that it results in a minimum experimental cost for a given degree of precision. The optimum plot size has also been estimated on the basis of this concept.

3.6. Relative Efficiency of Designs

Relative efficiency (RE) of a design D_1 over another design D_2 is primarily defined as the ratio of the amount of information supplied by D_1 over D_2.

$$\text{i.e.}\quad RE(D_1/D_2) = \frac{1/\sigma_1^2}{1/\sigma_2^2} \qquad (21)$$

Where σ_1^2 = the expected value of error variance of experimental design D_1

and σ_2^2 = the expected value of error variance of experimental design D_2

σ_1^2 and σ_2^2 are estimated as S_1^2 and S_2^2 with respective degrees of freedom V_1 and V_2. Then relative efficiency (RE) can be estimated by the formula suggested by Fisher (1951) as,

$$RE(D_1/D_2) = \frac{S_2^2(V_1+1)(V_2+3)}{S_1^2(V_2+1)(V_1+3)} \qquad (22)$$

In this study the relative efficiency of three types of design alone were compared viz. completely Randomised

Design (CRD), Randomised Block Design (RBD) and Latin Square Design (LSD).

For the comparison of relative efficiencies plots of size 6 units with all possible shapes also were considered. In the case of plot size 1 x 6, nine latin squares of order 4 x 4 and one latin square of order 12 x 12 can be formed whereas in the cases of 2 x 3 plot arrangements four latin squares of order 6 x 6 and for 3 x 2 plot arrangements nine latin square of order 4 x 4 can be formed. The relative efficiency can be obtained in two ways for each dimension of the plot.

(i) The relative efficiency is first determined for each of the squares and average of these taken as the representative for the entire area using the formula in the modified form as suggested by Federer (1955).

$$RE(LSD/CRD) = \frac{(V_1+1)(V_2+3)(R+C+(k-1)E)}{(V_2+1)(V_1+3)(K+1)E} \quad (23)$$

and

$$RE(LSD/RBD) = \frac{(V_1+1)(V_2+3)(R+(k-1)E)}{(V_2+1)(V_1+3)kE} \quad (24)$$

Where R = mean sum of squares of row

C = mean sum of squares of column

E = mean square error in LSD

k = the order of the LSD

and V_1 and V_2 as defined above

(ii) A combined analysis of sets of latin squares (Federer, 1955) also attempted and relative efficiency is determined after eliminating variation between sets of latin squares. Here,

$$RE(LSD/CRD) = \frac{(s-1)S+s(k-1)(R+C)+s(k-1)^2E}{s(k^2-1)E} \times \frac{(V_1+1)(V_2+3)}{(V_2+1)(V_1+3)} \qquad (25)$$

and $$RE(LSD/RBD) = \frac{(s-1)S+s(k-1)C+s(k-1)^2E}{(sk(k-1)+(s-1))E} \times \frac{(V_1+1)(V_2+3)}{(V_2+1)(V_1+3)} \qquad (26)$$

for row as blocking.

It is hoped that this relative efficiency would reflect the overall relative efficiencies of Latin Square Design over Completely Randomised Design and Latin Square Design over Randomised Block Design, when the experiment involves sets of latin squares in a single experiment.

RESULTS

RESULTS

The results of investigation carried out to estimate the optimum size and shape of plots and blocks in turmeric are presented below.

4.1. Fertility Contour Map of the Experimental Field

The fertility contour map of the experimental field is given in Figure 1. An inspection of the fertility contour map indicated that there was appreciable variation in soil fertility but this variation did not follow any systematic pattern. Fertility variations were distributed over the entire field in an erratic fashion. It could also be seen that small areas were relatively more homogeneous with regarded to soil fertility than large areas.

4.2. Estimation of Optimum Plot Size

Adjacent units were combined together to form plots of different sizes and shapes. Plot length was defined as the length in the North-South direction and plot breadth that in the East-West direction. The basic unit of observation consisted of the plant population in an area of size 0.6m x 0.75m. There were ten plants in the basic unit. The co-efficients of variation (cv) for plots of different sizes and shapes when they are not grouped into blocks are given in

Table 1. It can be seen that cv decreased on either direction with an increase in plot size but the decrease was not proportional. Moreover reduction in cv in the North-South (column) direction was more rapid than that in the East-West (row) direction. Minimum cv noticed was around 21 percent and the maximum was 77 percent.

4.2.1. Method of Maximum Curvature

Smooth freehand curves were drawn (Fig.2) to represent the relationship between plot size x and average cv when plots were not grouped in to blocks and when they were grouped into blocks of various sizes such as 2, 8, and 12 plots. It was found that in all the cases cv decreased rapidly at first when the size of the plot was increased, but after a certain point the rate of decrease was low and ultimately tended to zero making the curve almost like a straight line parallel to the x-axis. The optimum plot sizes estimated from such freehand curves by the method of maximum curvature by visual inspection were 6 units for blocks of various sizes and 8 units without blocking. In original unit the optimum plot sizes for blocks of different sizes and without blocking were $2.7 m^2$ and $3.6 m^2$ respectively.

4.2.2. Smith's Equation in the Modified Form

The Smith's equations fitted to the uniformity trial data on turmeric are given in Table 5a. The expected percentage variation which could be explained by the fitted models was determined by calculating the coefficient of determination (R^2) and their significance tested through the variance ratio, (F) test. All the regression equations fitted to different blocks of sizes 2,4,8,12 and 24 plots were found to be significant. Values of coefficient determination ranged from 0.8586 to 0.9883. The parameters of the fitted models viz. 'b'' and 'a' assumed value in the range 0.1223 to 0.1946 and 47.76 to 78.1088 respectively. Thus the Smith's index of soil heterogeneity (b = 2b') varied between 0.2446 to 0.3882. Since the value of 'b' was nearer to zero than unity there appeared to be strong correlation between neighbouring plots. Hence proper orientation of plots and blocks is very important in controlling experimental error. The expected cv (minimum cv was around 32, for block size 12 and the maximum was 78) was given in Table 3a. There was close agreement between observed and expected value of cv.

4.2.3. Other non-linear Models

Three other models viz.

(i) $Y = a + b/\sqrt{x} + c/x$

(ii) $Y^{-1} = a + b \log x$

and (iii) $Y^{-1} = a + b\sqrt{x} + cx$

Where Y is the coefficient of variation of plots of size x units were fitted to the data. The expected percentage of variation which could be explained by the fitted regressions (the coefficients of determination) and F-ratios resulted from the above models are given in Table 5 & 6. It could be seen that all these three models were more efficient than the familiar Smith's equation in describing the proposed relationship between plot size and coefficient of variation. Among the three models, Model 1 viz. $Y = a + b/\sqrt{x} + c/x$ was found to be the best choice. It gave a very good fit to the uniformity trial data as the coefficient of determination calculated from that model was fairly high (R^2 ranging from 0.9403 to 0.9904). The expected cv determined from, this model is given in Table 3b. For Model 2, R^2 varied from 0.8832 to 0.9842 and for Model 3, it varied between 0.8766 and 0.9765.

4.2.4. Optimum Plot Sizes under Consideration of Cost

The optimum plot sizes calculated on the basis of arbitrary values for the ratio $k_1:k_2$ where k_1 is the overall cost of experimental unit of size x, k_2 is the cost of individual item within the experimental unit area are presented in Table 4. In calculating the optimum plot sizes, estimates of 'b' from blocks of different sizes and without blocking and an average value of 'b' were used. When the ratio k_1/k_2 varied from 1/13 to 13 the optimum plot sizes varied from 0.0342 to 5.78863 units in two plot blocks, whereas the range of variation of blocks of sizes 4, 8, 12, 18 and without blocking were 0.037 to 6.253, 0.0263 to 4.4408, 0.0249 to 4.2094, 0.0281 to 4.7450 and 0.049 to 8.2836 units respectively. For the average value of 'b' the optimum plot sizes varied from 0.0333 to 5.6199 units ($0.015m^2$ to $2.53m^2$). It was found that the optimum size of the plot increased with an increase in the magnitude of cost ratio. If k_1 were the major contributor to the total cost than k_2 it would be more advantageous to use larger plots. In any case there was no significant advantage by using very large plots.

4.2.5. Optimum Plot Sizes using Smith's Modified Equation by Mathematical Methods

The optimum sizes of the plots for blocks of different sizes and without blocking determined by maximising curvature of the Smith's equation, $Y = ax^{-b}$, using the method of calculus are presented in Table 8. The estimated optimum plot sizes ranged between 4.443 units for blocks of size 8 unit and 8.1 units in case of no blocking. On an average the optimum plot size is about 6 units ($2.7m^2$).

4.3. Concept of Percentage Relative Efficiency of Different Plot Sizes

Taking the efficiency of the smallest plot size as unity, the percentage relative efficiencies of various plot sizes are given in Table 7. As plot size increased the percentage relative efficiency decreased for blocks of different sizes and without blocking. When plots are not grouped the rate of decrease in efficiency was from 100 percent with unit plot size to 13 percent with plots of size 12 units. The percentage relative efficiency of plot of size 12 units compared with unit plot size for block of size 2,4,8,12 and 18 and without blocking were 12.46, 12.30, 11.54, 11.31, 11.88 and 13.28 respectively. Thus size of block had no significant effect in the efficiency of plots of different sizes. However, small sized blocks were more efficient.

4.4. Shape of the Plot

For a given size of the plot the shape of the plot which gives least cv may be selected for experimentation. The plot shape with least cv for different plot sizes and shapes are given in the Table 9. Thus for the optimum plot size viz. 6 units the optimum shape is 6 x 1 (3.6m x 0.75m). In general, plot shape did not seem to exert any consistent effect on cv. However for a given plot size, long and narrow plots give lower cv than approximately square plots.

4.5. Size and Shape of Blocks

The relative efficiencies of blocks of different sizes viz. 2,4,8,12 and 18 compared with no blocking calculated on the basis of percentage reduction in error sum of squares are given in Table 10. It can be seen that there was significant reduction in uncontrolled variation due to grouping of plots into blocks. Smaller the block size greater was the efficiency of blocking. In 2 plot blocks relative efficiency ranged from 207 to 262, whereas in 12 plot blocks it varied between 110.23 and 159.68 depending on the size of the plots. In general, size of the plot did not seem to exert any appreciable effect on block efficiency. Whereas for a given plot size, size of block had a significant effect on block efficiency. Thus for a plot of size unity, relative efficiency decreased from 244.74 to 141.41 as the block size increased from 2 to 18. This fact indicated the need for reducing block size by way of using incomplete block designs.

Relative efficiency of blocks of different sizes as estimated from Smith's equation is given in Table 12. The entries in the second column of the table were calculated on the basis of assuming an average coefficient of heterogeneity (Smith's index of soil heterogeneity) $b = 0.3018$ and those in the third column were estimated by assuming the index of soil heterogeneity 0.3819, which was the index of soil heterogeneity for Smith's function fitted for plots which were not grouped. Block efficiency was found to decrease as the size of the block increased. Four plots blocks were almost 85% as efficient as 2 plot blocks whereas 6 plots blockswere less efficient than 4 plots blocks. The relative efficiencies of blocks of size 4,6,8 and 12 compared with blocks of size 2 were in the order 85, 78, 75 and 70 percentages when the index of soil heterogeneity for the ungrouped data was used. The corresponding figure with average index of soil heterogeneity were 83, 75, 70 and 60 percentages.

The shape of the block did not seem to exert any significant and consistent influence on the efficiency of blocking (Table 11) whereas block efficiency was found to be a function of the plot size. For 2 plot blocks of shape 2 x 1 the relative efficiency with plots of 2 units was 194.2 percent but that of 8 units was 298 percent. For 12 plot blocks in different shapes relative efficiency varied between 125.9 to 198.75 with plots of different sizes. No consistent differences were observed between oblong blocks and compact blocks with regards to their relative efficiencies in controlling error. However long and narrow blocks appear to be slightly more advantageous.

4.6. Number of Replications

The minimum number of replication and the total experimental area required for estimating treatment means with 5 percent standard error are given in Table 13. From the table it could be seen that with an increase in plot size, the expected number of replications decreased but the decrease was not proportional. The area required for the experiments also increased along with an increase in plot size. For example the number of replication with a plot of size unity in blocks of size 2 was 91 and that with a plot of size 12 was 42. Consequently the sizes of the experimental area required were 40.95m^2 and 226.8m^2 respectively. Thus if the size of the field is fixed it was found to be more beneficial to use larger number of replications with the smallest possible plot size than increasing the plot size at the risk of reducing the number of replications.

4.7. Efficiency of Experimental Designs

Relative efficiency of a Latin Square Design (LSD) over the other two single factor designs viz. Completely Randomised Design (CRD) and Randomised Block Design (RBD) were calculated by using two methods (i) averaging the relative efficiencies of different sets of squares and (ii) eliminating the variation between sets of squares and then calculating the relative efficiencies. The results are given in Table 14.

The average relative efficiencies of 6 x 6 Latin Square Design over Randomised Block Designs with rows as blocks and those with columns as blocks were 178.24 and 131.72 respectively. The relative efficiencies of the Latin Square of the same order by eliminating variation between squares compared with Randomised Block Designs with rows as blocks and columns as blocks were 267.33 and 147.05 respectively. The relative efficiencies of Latin Square Designs over Completely Randomised Designs are given in Table 14b. It could be seen that Latin Square Designs were more efficient than Completely Randomised Designs in both the cases of eliminating variations among sets of squares and averaging the relative efficiencies of different sets of squares. For the plot size 1 x 6 Randomised Block Designs with columns as blocks was found to be 84% more efficient than Completely Randomised Designs. Whereas for the same plot size Randomised Block Designs with rows as blocks was slightly more efficient (1.94%) than Completely Randomised Designs. Thus, the relative efficiency of Randomised Block Designs depended upon the orientation of blocks.

TABLE 1. Observed Coefficients of Variation for plots of different sizes when plots are not grouped

Number of units along the North-South direction (columns)	Number of units along the East-West direction (rows): 1	2	3	4	6	8	9	12	18	24	36	72
1	77.19	72.63	62.52	61.01	55.62	52.52	50.95	48.47	41.01	35.72	28.29	17.90
2	64.92	61.91	55.11	54.02	50.24	47.33	46.27	43.99	37.25	31.33	24.71	13.62
3	58.60	56.83	51.67	50.94	47.07	45.22	42.75	41.57	33.73	29.45	21.91	11.17
4	56.38	54.97	50.65	49.97	46.90	45.19	43.56	42.07	35.33	29.24	21.32	13.45
6	48.68	47.63	44.92	44.01	42.78	41.18	39.51	38.53	32.17	26.24	21.32	12.08
12	43.55	43.13	41.50	41.08	40.90	39.62	38.02	38.13	32.95	26.83	23.15	-

TABLE 2. Observed Coefficient of Variation of plots of different sizes, when plots are grouped into different sizes and without grouping

Plot size (in units)	Without blocking	Block sizes										
		2	3	4	6	8	9	12	18	24	36	72
1	77.19	49.34	58.64	56.27	60.39	59.32	61.35	62.82	64.91	65.63	67.70	72.58
2	68.89	46.86	52.27	50.83	53.59	52.47	55.74	57.34	58.45	58.51	62.62	64.84
3	60.59	38.58	40.99	42.03	45.59	45.80	46.09	48.95	50.34	53.04	53.62	57.34
4	59.81	38.71	43.18	41.63	46.28	42.90	48.38	47.33	51.97	51.06	56.73	57.64
6	54.16	33.81	37.76	38.17	40.76	40.84	41.46	46.97	46.46	48.85	50.45	52.22
8	53.85	33.24	39.65	34.76	39.02	-	46.53	45.95	49.37	-	51.55	-
9	51.31	35.60	35.40	38.47	40.10	41.87	-	45.72	-	47.80	-	-
12	48.65	30.44	34.87	34.06	38.33	38.17	40.67	42.51	44.61	44.56	47.25	-
18	44.88	30.53	32.56	35.23	36.30	39.76	-	42.74	-	43.36	-	-
24	43.31	27.76	33.72	31.53	36.83	-	39.79	40.81	42.03	-	-	-
36	39.51	28.97	30.79	33.54	33.93	36.96	-	39.79	-	-	-	-
72	32.16	26.23	28.24	25.66	31.61	-	-	-	-	-	-	-

TABLE 3a. Estimated Coefficients of Variation for plots of different sizes in blocks of different sizes and without blocking as obtained from the Smith's equation, $Y = ax^{-b}$

Block sizes	Plot sizes 1	2	4	6	8	12
Without blocking	78.101	68.253	59.640	55.115	52.115	48.161
2	47.764	42.928	38.582	36.246	34.676	32.577
4	53.444	47.754	42.670	39.951	38.127	35.698
8	54.954	50.313	46.064	43.746	42.173	40.052
12	59.457	54.624	50.184	47.756	46.105	43.875
18	62.561	57.023	51.976	49.234	47.376	44.876

TABLE 3b. Estimated Coeffcients of Variation for plots of different sizes in blocks of different sizes and without blocking as obtained from the model,

$$Y = a + b/\sqrt{x} + c/x$$

Block sizes	Plot sizes 1	2	4	6	8	12
Without blocking	68.617	61.005	52.005	47.062	43.835	39.736
2	50.417	44.095	38.606	35.906	34.217	32.137
4	56.600	48.371	41.932	38.916	37.071	34.835
8	59.906	50.057	44.298	42.065	40.828	39.451
12	63.133	54.872	49.185	46.707	45.242	43.516
18	65.091	56.758	50.867	48.258	46.702	44.857

TABLE 4 Optimum plot sizes as estimated from Smith's equation considering different cost ratios

K_1/K_2	Without blocking	Block sizes					Average b = 0.3018 Smith's index of soil heterogeneit
		2	4	8	12	18	
1	0.6372	0.4451	0.4810	0.3416	0.3238	0.3650	0.4323
3	1.9116	1.3353	1.4430	1.0248	0.9714	1.0950	1.2969
5	3.1860	2.2255	2.4050	1.7080	1.6190	1.8250	2.1615
7	4.4604	3.1157	3.3670	2.3912	2.2666	2.5550	3.0261
11	7.0092	4.8961	5.2910	3.7576	3.5618	4.0150	4.7553
13	8.2836	5.7863	6.2530	4.4408	4.2094	4.7450	5.6199
1/3	0.2124	0.1484	0.1603	0.1139	0.1079	0.1217	0.1441
5/3	1.0620	0.7420	0.8015	0.5695	0.5395	0.6085	0.7205
7/3	1.4868	1.0388	1.1221	0.7973	0.7553	0.8519	1.0087
11/3	2.3364	1.6324	1.7633	1.2529	1.1869	1.3387	1.5851
13/3	2.7612	1.9292	2.0839	1.4807	1.4027	1.5821	1.8733
1/5	0.1274	0.0890	1.0962	0.0683	0.0648	0.0730	0.0865
3/5	0.3822	0.2670	0.2886	0.2049	0.1944	0.2190	0.2595
7/5	0.8918	0.6230	0.6734	0.4781	0.4536	0.5110	0.6055
11/5	1.4014	0.9790	1.0587	0.7513	0.7128	0.8030	0.9515
13/5	1.6562	1.1570	1.2506	0.8879	0.8424	0.9490	1.1245
1/7	0.0910	0.0636	0.0687	0.0488	0.0463	0.0521	0.0618
3/7	0.2730	0.1908	0.2061	0.1464	0.1389	0.1563	0.1854
5/7	0.4550	0.3180	0.3435	0.2440	0.2315	0.2605	0.3090
11/7	1.0010	0.6996	0.7557	0.5368	0.5093	0.5731	0.6798
13/7	1.1830	0.8268	0.8931	0.6344	0.6019	0.6773	0.8034
1/11	0.0579	0.0405	0.0437	0.0311	0.0294	0.0332	0.0393
3/11	0.1737	0.1215	0.1311	0.0933	0.0882	0.0996	0.1179
5/11	0.2895	0.2025	0.2185	0.1555	0.1470	0.1660	0.1965
7/11	0.4053	0.2835	0.3059	0.2177	0.2058	0.2324	0.2751
13/11	0.7527	0.5265	0.5681	0.4043	0.3822	0.4316	0.5109
1/13	0.0490	0.0342	0.0370	0.0263	0.0249	0.0281	0.0333
3/13	0.1470	0.1026	0.1110	0.0789	0.0747	0.0843	0.0999
5/13	0.2450	0.1710	0.1850	0.1315	0.1245	0.1405	0.1665
7/13	0.3430	0.2394	0.2590	0.1841	0.1743	0.1967	0.2331
11/13	0.5390	0.3762	0.4070	0.2893	0.2739	0.3091	0.3663

Estimates of Parameters .. Coefficients of determination R^2 and F-ratios from various models

TABLE 5a. Smith's equation, $Y = ax^{-b}$

Block sizes	a	b	R^2	F
Without blocking	78.1088	0.1946	0.9883	843.04
2	47.7639	0.1540	0.9244	122.25
4	53.4441	0.1624	0.9127	10.457
8	54.9541	0.1273	0.8586	42.50
12	59.4566	0.1223	0.9183	101.14
18	62.5605	0.1337	0.9099	60.57
24	63.8999	0.1417	0.9723	210.75

TABLE 5b. Model $Y = a + b/\sqrt{x} + c/x$

Block sizes	a	b	c	R^2	F
Without blocking	17.9375	85.5918	-34.9122	0.9827	255.39
2	21.8821	38.3626	-9.8279	0.9518	88.93
4	24.2817	38.2772	-5.9535	0.9403	70.85
8	34.5100	13.7545	11.6410	0.9664	78.90
12	35.9879	25.6430	1.5022	0.9520	79.31
18	36.6494	28.4288	0.0131	0.9440	42.11
24	35.9489	32.7503	-2.9381	0.9904	257.31

Estimates of Parameters and Coefficients of determination R^2 and F-ratios from various models fitted to the data with blocks of different sizes without blocking

TABLE 6a. Model $Y^{-1} = a + b \log x$

Block sizes	a	b	R^2	F
Without blocking	0.0188	0.0099	0.9196	114.33
2	0.0206	0.0101	0.9413	160.38
4	0.0178	0.0099	0.9044	94.62
8	0.0180	0.0064	0.8832	52.94
12	0.0161	0.0058	0.9435	150.33
18	0.0159	0.0060	0.9243	73.26
24	0.0158	0.0062	0.9822	331.82

TABLE 6b. Model $Y^{-1} = a + b\sqrt{x} + cx$

Block sizes	a	b	c	R^2	F
Without blocking	0.0085	0.0038	-0.0004	0.9350	64.77
2	0.0157	0.0060	-0.0004	0.9333	62.96
4	0.0168	0.0039	-0.0003	0.8766	31.96
8	0.0125	0.0059	-0.0006	0.8928	24.98
12	0.0190	0.0045	-0.0004	0.9328	55.49
18	0.0112	0.0051	-0.0005	0.9146	26.77
24	0.0106	0.0056	-0.0006	0.9765	101.93

TABLE 7. Percentage relative efficiencies of plots of different sizes in blocks of different sizes and without blocking

Block sizes	Number of basic units (x) in a plot							
	1	2	3	4	6	8	9	12
Without blocking	100	57.03	41.41	32.81	23.44	18.75	17.19	13.28
2	100	55.50	39.71	31.10	22.01	17.22	15.79	12.46
4	100	56.15	40.11	31.55	22.46	17.65	16.04	12.30
8	100	54.40	38.46	29.67	20.88	16.48	14.84	11.54
12	100	54.76	38.10	29.76	20.83	16.07	14.29	11.31
18	100	55.00	38.75	30.00	21.25	16.25	15.00	11.88

TABLE 8. Optimum plot sizes estimated from the Smith's equation by modified maximum curvature method

Number of plots in a block	Optimum plot sizes (in units)	Area of the plot (m^2)
Without blocking	8.100	3.65
2	4.540	1.84
4	5.198	2.34
8	4.443	1.98
12	4.618	2.07
24	5.504	2.48

TABLE 9. Effect of size and shape of plots on coefficients of variation for blocks of different sizes and without blocking

Plot dimensions		Size of blocks					
Size	Shape L x B	Without blocking	2	4	8	12	18
2	1 x 2	72.63	54.84	56.42	57.95	61.26	64.15
	*2 x 1	64.92	37.21	41.02	46.35	49.84	52.13
4	1 x 4	61.01	42.26	42.90	44.57	49.57	55.91
	2 x 2	61.91	41.76	44.57	45.96	50.78	52.30
	*4 x 1	56.38	20.80	31.81	37.70	41.37	47.97
6	1 x 6	55.62	36.59	41.94	45.01	48.14	50.51
	2 x 3	55.11	31.80	36.62	44.28	45.11	45.21
	3 x 2	56.83	40.25	41.86	42.14	47.21	51.91
	*6 x 1	48.69	24.54	26.05	29.26	31.47	36.66
8	*1 x 8	52.45	32.68	31.96	-	42.49	50.07
	2 x 4	54.02	33.66	35.12	-	44.48	48.26
	4 x 2	54.97	32.95	37.01	-	45.72	52.26
12	1 x 12	48.47	38.88	36.82	42.18	43.42	47.15
	2 x 6	50.24	30.97	39.82	44.46	45.54	44.99
	3 x 4	50.94	35.30	35.65	36.47	42.63	49.79
	4 x 3	50.65	27.97	33.80	44.97	43.27	42.62
	6 x 2	47.63	27.97	29.01	31.01	38.29	41.91
	*12 x 1	43.55	11.13	18.16	23.31	26.81	33.45

L = length (number of unit plot)

B = breadth(number of unit plot)

* The shape which has minimum coefficient of variation for particular plot size.

TABLE 10. Percentage relative efficiencies of blocks of different sizes compared with without blocking for plots of different sizes

Plot sizes		Size of blocks								
Units	(Area m^2)	Without blocking	2	3	4	6	8	9	12	18
1	(0.45)	100.00	244.74	173.25	188.17	163.39	169.69	158.29	150.97	141.41
2	(0.90)	100.00	216.07	173.67	183.68	164.24	172.33	152.71	144.33	138.89
3	(1.35)	100.00	246.62	218.55	207.82	176.65	175.04	172.81	153.22	144.88
4	(1.80)	100.00	238.78	191.90	206.45	167.06	194.43	152.83	159.68	132.46
6	(2.70)	100.00	256.61	205.68	201.27	176.52	175.81	170.66	132.98	135.89
8	(3.60)	100.00	262.40	184.40	240.00	190.43	-	133.90	137.35	118.96
9	(4.05)	100.00	207.76	210.12	177.94	163.71	150.17	-	125.96	-
12	(5.40)	100.00	255.38	194.64	204.02	161.08	162.46	143.08	130.93	118.91
18	(8.10)	100.00	216.08	189.97	162.29	152.84	127.38	-	110.23	-

TABLE 11. Percentage relative efficiencies of blocks of different shapes compared with without blocking for plots of different sizes

Block dimensions		Size of plots				
Size	Shape L x B	2	4	6	8	12
Without blocking	-	100.00	100.00	100.00	100.00	100.00
2	1 x 2	243.50	254.13	286.39	234.63	231.86
	2 x 1	194.20	218.95	232.44	297.61	250.30
4	1 x 4	185.15	225.95	188.94	211.65	160.61
	2 x 2	198.67	187.00	223.38	235.11	187.29
	4 x 1	157.42	214.04	188.58	283.91	222.78
8	1 x 8	206.94	209.95	180.67	-	184.48
	2 x 4	172.33	169.39	175.81	-	161.08
	4 x 2	147.64	-	171.21	-	152.24
12	1 x 12	137.07	148.23	166.08	118.98	128.14
	2 x 6	159.66	133.33	154.96	124.70	119.73
	3 x 4	155.43	171.99	136.75	166.24	134.19
	4 x 3	139.20	161.39	149.27	147.49	133.51
	6 x 2	150.59	151.95	168.37	177.63	143.64
	12 x 1	125.90	156.00	174.67	198.75	196.30

L = length (number of plots)

B = breadth (number of plots)

TABLE 12. Relative efficiencies of blocks of different sizes without considering the size of the plot using Smith's Variance Law

*P Vs Q	Relative efficiencies	
	Using average Smith's index of soil hetero-geneity, b	using Bmith's index of soil heterogeneity, b, of without blocking
4 Vs 2	0.8280	0.8505
6 Vs 2	0.7532	0.7849
8 Vs 2	0.7087	0.7458
12 Vs 2	0.6558	0.6993
6 Vs 4	0.9096	0.9228
8 Vs 4	0.8558	0.8768
12 Vs 4	0.7920	0.8222
8 Vs 6	0.9409	0.9502
12 Vs 6	0.8707	0.8910
12 Vs 8	0.9255	0.9377

* Block of size P compared with block of size Q

TABLE 13 Minimum number of replications (r) and total experimental area (a) required for estimating treatment means with 5 percent standard error

Block sizes		Plot sizes (m^2)					
		0.45	0.9	1.8	2.7	3.6	5.4
Without blocking	r	244	186	142	122	109	93
	a	109.8	167.4	255.6	329.4	392.4	502.2
2	r	91	74	60	53	48	42
	a	40.95	66.6	108	143.1	172.8	226.8
4	r	114	91	73	64	58	51
	a	51.3	81.9	131.4	172.8	208.8	275.4
8	r	121	101	85	77	71	64
	a	54.45	90.9	153	207.9	255.6	345.6
12	r	141	119	101	91	85	77
	a	63.45	107.1	181.8	245.7	306	426.8
18	r	157	130	108	97	90	81
	a	70.65	117	194.4	261.9	324	437.4

TABLE 14a. Percentage relative efficiencies of Latin Square Design over Randomized Block Design

Plot dimensions		Order of LSD		Percentage relative efficiencies	
Size	Shape L x B			Row as blocking	Column as blocking
6	1 x 6	12 x 12		201.80	111.86
	2 x 3	6 x 6	A	178.27	131.72
			B	267.33	147.05
	1 x 6	4 x 4	A	399.87	168.07
			B	349.22	193.58
	3 x 2	4 x 4	A	131.01	121.37
			B	221.34	129.43

TABLE 14b. Percentage relative efficiencies of Lating Square Design over Completely Randomized Design

Plot dimensions		Order of LSD		Percentage relative efficiencies
Size	Shape L x B			
6	1 x 6	12 x 12		204.78
	2 x 3	6 x 6	A	193.46
			B	271.78
	1 x 6	4 x 4	A	386.80
			B	354.38
	3 x 2	4 x 4	A	140.60
			B	354.38

A - Average

B - Combined analysis by eliminating between sets of sum of squares of LS.

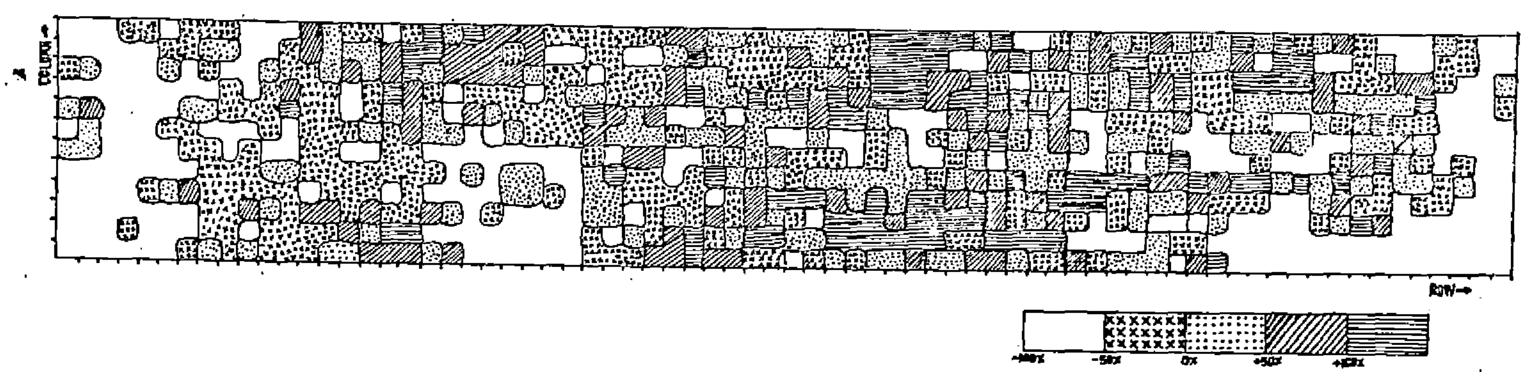
TABLE 15. Percentage relative efficiencies of Randomized Block Design over Completely Randomized Design

Plot dimensions		Percentage relative efficiencies	
Size	Shape L x B	Row as blocking	Column as blocking
6	1 x 6	101.94	184.04
	3 x 2	100.41	172.37
	2 x 3	101.66	184.83

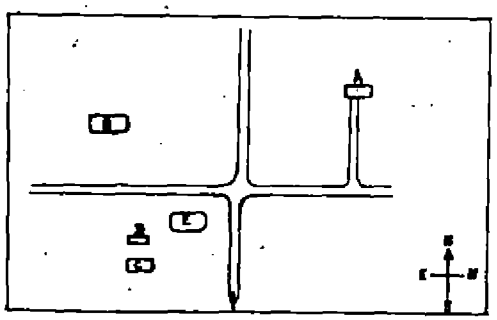
Fig. 1. FERTILITY CONTOUR MAP

SCALE

COLUMN : 1 DIVISION = 0·75 m
ROW : 1 DIVISION = 0·6 m



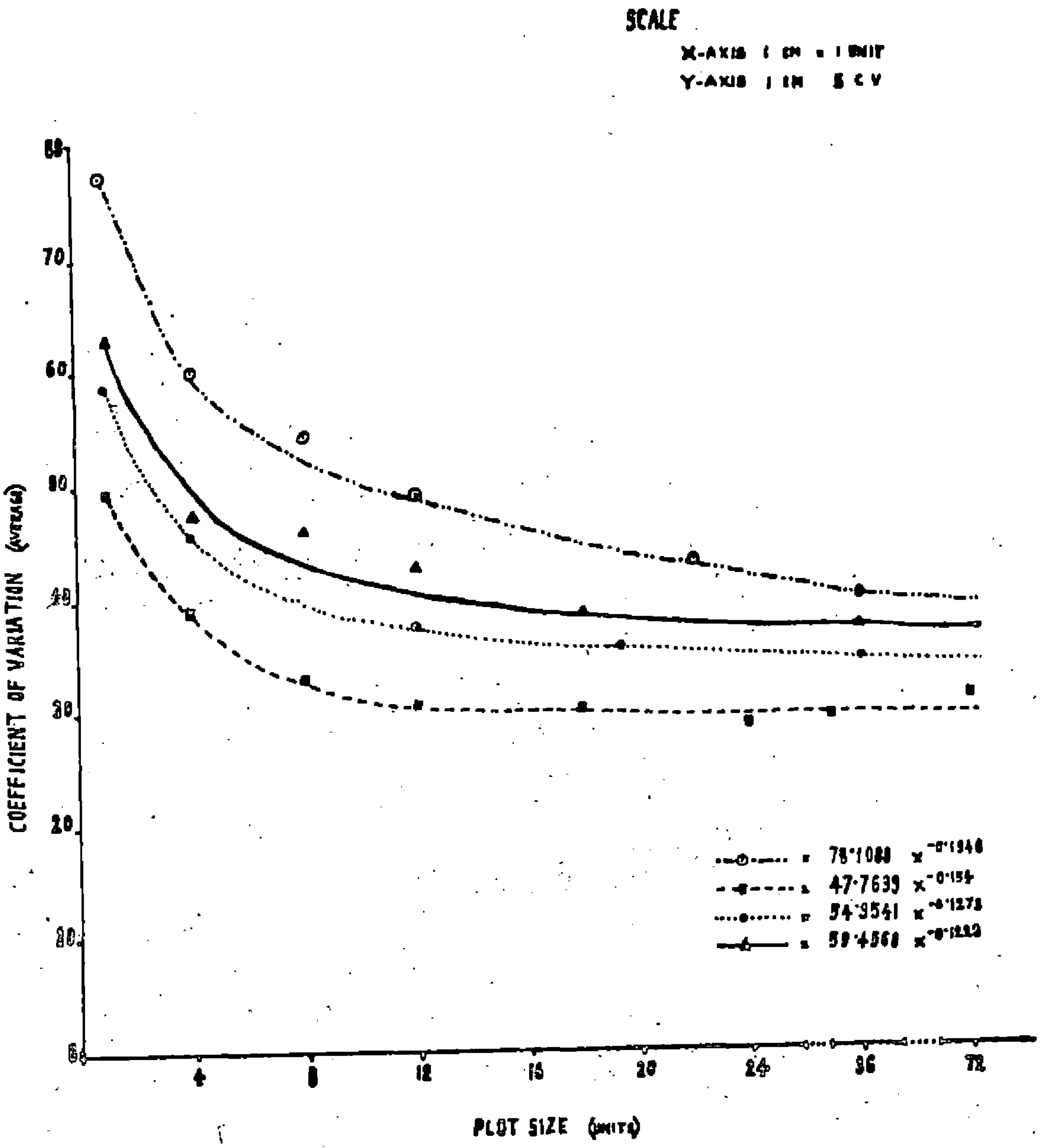
PERCENTAGE DEVIATION BASED ON GRAND MEAN



A - ADMINISTRATIVE BLOCK OF KAU
B - COLLEGE OF HORTICULTURE
C - LADIES HOSTEL
D - EXPERIMENTAL PLOT
E - FOOT-BALL GROUND

POSITION OF THE FIELD

FIG.2: EFFECT OF PLOT SIZE ON VARIABILITY



DISCUSSION

DISCUSSION

The determination of size and shape of experimental units or plots and their arrangements in groups or blocks of suitable size is of great importance in field experimentation. As the magnitude of experimental error depends largely on the dimensions of the experimental unit a clear insight on the proper size and shape of experimental unit is of immense use in increasing the efficiency of field experimentation. Optimum size and shape of the experimental units have been determined statistically for most of the field crops. But no such studies are known to have been reported on turmeric, an important commercial crop of India. At present field trials on crop improvements and agronomic practises on turmeric are being conducted using plots of widely different sizes and shapes depending on the availability of resources and practical convenience of the research worker. Therefore a uniformity trial was laid out at the experimental farm at the College of Horticulture, Vellanikkara with the main purpose of determining the suitable size and shape of experimental plots in conducting field trials on turmeric and the results of the trial are discussed here under various sections.

5.1. Soil Heterogeneity and Fertility Contour Map

The fertility contour map of the experimental field revealed that there were no specific trends of fertility variation in the field. On the whole the field can be considered to be heterogeneous. But for small plots homogeneity can be maintained and therefore smaller plots arranged in blocks of relatively small size are expected to be more efficient than large plots arranged in blocks of relatively large size. As the variation in soil fertility of the field appeared to be patchy it would be better to use multi-way classified designs, such as latin square, Youden square etc. From a uniformity trial on brinjal conducted on an adjacent field at Vellanikkara, Hariharan (1981), obtained similar results on the distribution of soil heterogeneity. Results also indicated the necessity of proper orientation of plots and blocks. If randomised block design is to be used orientation of blocks should be of prime consideration for the reduction of experimental error.

5.2. Estimation of Optimum Plot Size

Coefficient of variation (cv) for plots of different sizes and shapes were found to decrease with an increase in plot size but the decrease was not proportional. This finding appears to be an aspect of the general law relating to size of the plot and variability and has been inaccordance with all the previous findings on the same line. It was also seen that reduction in cv in the North-South direction (column) was more rapid than that in the East-West direction (row). This may be due to slight slope in the field in the North-South direction.

5.2.1. Method of Maximum Curvature (Free-hand Curve)

The optimum plot size estimated from the free-hand curves by the method of maximum curvature is about 6 units for blocks of various sizes and 8 units for ungrouped data. These values were almost in agreement with the present popular plot size for turmeric viz. 3.6m^2. The results obtained through free-hand curve method and mathematical method were not very much different. But mathematical method indicated the possibility of further reduction in plot size than that obtained through free-hand method.

5.2.2. Smith's Law and Modified Maximum Curvature Method

Smith's equation in the modified form gave a satisfactory fit to the data in both the cases where the plots were grouped into blocks of suitable sizes and there was no blocking. The estimated values of 'b', the Smith's Index of Soil Heterogeneity, were nearer to zero. The result indicated that there was strong correlation between contiguous units (Smith, 1938). Hande et al (1982) obtained similar values of 'b' in their studies on oat. The study revealed the need for grouping plots into blocks of appropriate sizes for effective error control. As most of the variation is positional than genetic, direct methods of controlling error are of great importance than that of the indirect methods especially through covariance technique. Results obtained from studies on various other annual crops also are in agreement with these findings.

5.2.3. Alternate Models to Smith's Law

The three non-linear models other than that due to Smith's also gave promising results. Among them the equation $Y = a + b/\sqrt{x} + c/x$ was found to be the best choice. In most of the cases this equation was an improvement to the familiar Smith's equation in the modified form. But unlike Smith's function the parameters of the function cannot be attributed to any physical meaning. But these models can be conveniently utilised for estimating optimum plot size by various methods. Lessman and Atkins (1963a) found the function $\text{Log } Y = \frac{a}{(a+\log x)^b}$ was an improvement over Smith's function in describing the proper relationship between plot size and variability. In this study the three functions decribed here were found to be at least as efficient as the Smith's function.

5.2.4. Optimum Plot Size from Smith's Function by considering Cost of Experimentation

As mentioned earlier, size of a plot is also governed by cost of experimentation. Looking at this problem from the angle of economy, the plot size which gives maximum information per unit cost would be considered to be optimum for a given experiment. Hence optimum plot size was worked out by assuming various arbitrary values for the cost components of an assigned law. Saxana et al (1972) on oat; Prabhakaran and Thomas (1974) on tapioca; Biswas et al (1982) on cabbage and Binns et al (1983) on tobacco have followed the same procedure. The results showed that plots of smaller size are more efficient than larger ones in case the cost ratio K_1/K_2 is less than unity. Thus for an experimenter with limited resources it would be always advantageous to select the smallest possible size of the plot where agricultural operations can be conveniently carried out for the conduct of the experiment. The loss in precision due to the use of such smaller plots will be negligible when compared to the overall saving of experimental material and other resources.

5.2.5. Modified Maximum Curvature Method

The optimum plot size was also determined from the Smith's equation mathematically by maximising the radius of curvature of the Smith's curve. An expression for estimating the optimum was derived using differential calculus and it was further used for locating the optimal point. The result indicated that plot sizes in the range from $1.9m^2$ to $3.7m^2$ were optimal with blocks of various sizes and without blocking. As a single overal estimate, plots of size $2.7m^2$ can be considered to be optimal. Thus, if sufficient resources are available the experimenter may use plot of size $2.7m^2$ or $3m^2$ for conducting field trials on turmeric. With the use of local control size of the plot can be further reduced to $2m^2$ or less. Optimum plot size determined by the above technique are expected to be stable and produce consistent results in the long run. The recommended plot size for turmeric as mentioned above is closer to the existing popular plot size for turmeric viz. $3.6m^2$. Thus there was no need for increasing the size of the plot beyond $3.6m^2$ but it can be further reduced to $2m^2$ or even less without any appreciable loss in precision. The estimate of plot size obtained here is in agreement with that of radish suggested by Raghavarao (1983) who worked on the same lines.

5.2.6. Concept of Percentage Relative Efficiency

The percentage relative efficiency decreased as plot size increased for blocks of different sizes and without blocking. As a rule small plots were found to be more efficient than large ones and the most efficient plot size was that with a single basic unit ($0.45m^2$). The result also was in close agreement with that of Menon and Tyagi (1971) on Mandarin orange; Bhargava and Sardana (1973) on apple; and Prabhakaran et al (1978) on banana. Thus, if the cost of the experimentation is proportional to the population of plants or area of the experimental plots it would be beneficial to use the smallest possible plot size. But for crops like turmeric such assumption is far from true. Further, with very small plots agronomic operations cannot be carried out with added convenience.

5.3. Shape and Orientation of the Plots

In general plot shape did not seem to exert any consistent effect on cv. However, for a given plot size long and narrow plots gave lower cv than approximately square plots. This result was supported by Sreenath (1973) on sorghum; Prabhakaran and Thomas (1974) on tapioca and Hariharan (1981) on brinjal. The findings of Cochran (1940) that long and narrow plots have better control of error than a square plot are also on the same side.

Orientation of plots in a block is very important in deciding the efficiency of field experimentation. Proper orientation of plots was found to result in internal homogeneity of the blocks and subsequent reduction in experimental error. In general orientation b x a, where 'b' is the number of units in the column wise (North-South direction) and 'a' is the number of unit in the row wise (East-West direction) was found to be better than the orientation a x b (b > a).

5.4. Size, Shape and Orientation of Blocks

Block efficiency was found to decrease with an increase in the number of plots per block. Similar results on other crops have been reported by Gopini et al (1970) on groundnut; Saxana et al (1972) on oat; Sreenath (1973) on sorghum; Bist et al (1975) on potato; Hariharan (1981) on brinjal and Nair (1981) on cashew. Two plot blocks were found to be the most efficient ones. The result called for the use of incomplete block designs in laying out field trials. Size and shape of plots in blocks did not exert any appreciable effect on block efficiency. This may be due to the fact that homogeneity of the plots can be achieved in smaller blocks even by using relatively large plots. The result is also in agreement with several earlier findings.

Orientation of block was also important in controlling error variation. From the study it was seen that orientation b x a, where 'b' is the number of units in the column wise

(North-South direction) and 'a' is the number of unit in the row wise (East-West direction) was found to be better than the orientation a x b ($a > b$). That is the orientation of blocks perpendicular to the direction of the gradient and that of plots parallel to the gradient are advantageous.

5.5. Number of Replications

For a fixed area of land, large number of replications with smallest possible plot size was found to give lower standard error than smaller number of replications with relatively large plots. Thus it was more beneficial to use smaller plots with adequate number of replicates than large plots with fewer number of replications. The findings of Iyer and Agarwal (1970) on sugarcane; Bist et al (1975) on potato; Prabhakaran et al (1978) on banana and Suman and Wahi (1982) on cabbage are in confirmity with this result.

5.6. Efficiency of Experimental Design

In general Latin Square Design (LSD) was more efficient than Randomised Block Design (RBD) and Completely Randomised Design (CRD). Similar results have been reported by Malhotra et al (1979) on potato.

Randomised Block Designs with columns as blocks was also found to be equally efficient with Latin Square Designs. The result indicated the need for proper orientation of plots and blocks in Randomised Block Designs to make the design as efficient as Latin Square Designs. If nothing is known about the direction of the fertility gradient it would be better to use Latin Square Design. The results are in agreement with the findings of Jayaraman (1979) on sunflower.

SUMMARY

SUMMARY

A uniformity trial on turmeric was conducted at the experimental field of the College of Horticulture, Vellanikkara during the period from June 1983 to January 1984. At the time of harvest, the yield data from 864 plots each of size 0.6m x 0.75m were recorded separately, discarding the external border row. The salient results of the statistical analysis of the uniformity trial data are given below.

6.1 The fertility contour map of the field showed that there was appreciable variation in soil fertility but this variation did not follow any systematic pattern. As a matter of fact, small areas were relatively more homogeneous with regard to soil fertility than large areas.

6.2 An increase in the plot size in either direction decreased the coefficient of variation, but the decrease was not proportional. Further, the reduction in cv in the North-South (column) direction was more rapid than that in the East-West (row) direction.

6.3 The empirical law suggested by Smith (1938) gave a satisfactory fit to the data for blocks of different sizes and without blocking. The empirical models suggested by Prabhakaran were found to be more efficient than Smith's function.

6.4. The optimum plot sizes estimated through Smith's index of soil heterogeneity method, maximum curvature method and modified maximum curvature method were not much different. For a general recommendation a plot size $2.7m^2$ (3.6m x 0.75m) or approximately $3m^2$ was found advisable for conducting field trials on turmeric. But for with block designs the plot size can be reduced even to $2m^2$ without much loss in overal precision of treatment comparison.

6.5. The shape of the plot did not exert any consistent effect on coefficient of variation. However, long and narrow plots gave lower cv than approximately square plots in most situations.

6.6. Efficiency of blocking may be considered to be a function of the block size. Two plot blocks were the most efficient in controlling error.

6.7. The shape of the blocks had no consistent effect on the variability whereas proper arrangement of plots and blocks resulted in a considerable reduction of experimental error.

6.8. An increase in plot size was followed by a decrease in the expected number of replications per treatment but the decrease was not proportional. Increasing the number of replications rather than plot size was found to be more advantageous for the enhancement of precision.

6.9. In general Latin Square Design was found to be more efficient than Randomised Block Design and Completely Randomised Design. But with proper arrangement of blocks and plots within the block, the efficiency of Randomised Block Design can be considerably increased.

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APPENDICES

APPENDIX I - THE YIELD DATA

Weight of turmeric in grams.

R \ C	1	2	3	4	5	6	7	8	9	10	11	12
1	155	195	110	305	450	225	437	283	300	186	139	133
2	25	40	14	67	157	260	283	707	500	134	237	389
3	323	615	98	20	125	510	140	295	129	232	609	370
4	25	75	0	0	205	95	167	150	276	153	385	831
5	502	807	202	127	95	160	640	490	310	490	278	987
6	105	505	207	205	143	330	286	235	115	231	251	83
7	515	507	78	140	0	0	262	269	219	337	225	162
8	0	26	0	0	140	20	96	252	323	323	600	692
9	30	30	0	0	310	540	771	340	282	280	384	329
10	100	78	100	30	0	40	214	291	292	825	547	245
11	76	35	113	280	0	0	219	447	258	162	278	387
12	0	50	0	45	0	0	351	607	385	605	313	384

R \ C	13	14	15	16	17	18	19	20	21	22	23	24
1	784	618	415	438	234	304	973	495	1315	947	865	760
2	778	568	553	569	755	978	1095	930	736	797	370	855
3	387	630	850	503	902	1270	502	809	777	737	743	486
4	272	311	227	381	1250	871	267	122	402	321	435	222
5	248	555	238	282	660	826	550	439	930	507	457	460
6	388	288	432	650	468	876	510	563	318	210	675	450
7	272	302	232	130	272	434	121	97	80	85	220	143
8	382	418	377	304	401	429	378	176	490	143	560	617
9	233	318	270	335	509	373	27	152	160	215	540	603
10	854	763	396	831	362	351	960	595	152	407	87	40
11	367	447	802	660	1054	1340	203	66	20	176	0	0
12	352	723	500	940	807	775	644	802	0	0	118	129

R \ C	25	26	27	28	29	30	31	32	33	34	35	36
1	429	289	432	275	273	292	837	856	689	727	396	496
2	80	122	300	305	107	80	619	1163	259	453	424	330
3	280	333	200	300	254	310	741	500	594	375	318	318
4	344	510	676	409	373	361	762	1040	550	622	1100	355
5	379	468	989	965	498	834	178	238	625	119	588	670
6	310	400	877	600	528	607	283	528	515	829	560	237
7	0	0	314	103	738	824	226	203	463	265	524	748
8	111	137	495	1068	290	400	223	350	1028	703	417	559
9	274	110	570	670	427	303	375	404	230	407	895	995
10	0	35	657	661	171	324	524	290	945	379	887	530
11	0	0	344	236	525	276	770	1143	469	498	1247	1204
12	0	0	417	346	250	849	809	1255	754	823	365	780

(contd..ii/-)

Weight of turmeric in grams

R \ C	37	38	39	40	41	42	43	44	45	46	47	48
1	570	705	494	296	1207	1310	1133	1006	1158	500	1107	1017
2	885	628	400	249	1300	1375	1220	1520	123	123	772	1034
3	419	624	767	434	1423	1042	1295	891	825	1333	365	60
4	1262	967	1058	925	1620	997	972	890	1245	1475	557	1210
5	497	840	1175	1225	709	230	179	175	965	1417	814	630
6	232	564	209	108	344	580	192	277	705	396	1112	450
7	344	439	328	92	400	581	0	0	379	627	125	638
8	422	554	550	687	543	627	500	475	574	905	540	1110
9	1440	1032	964	669	1124	710	1608	1000	857	1518	814	340
10	325	181	1118	1032	1468	927	1130	1113	1113	1545	803	474
11	500	582	1017	1690	1102	1197	1264	1349	375	310	1600	1375
12	184	327	550	350	500	491	768	610	645	795	750	675

R \ C	49	50	51	52	53	54	55	56	57	58	59	60
1	133	370	500	735	553	307	860	608	413	545	1828	615
2	592	842	380	760	1212	997	430	467	570	542	828	240
3	430	290	562	398	626	1340	888	1215	370	279	1230	1112
4	705	940	530	358	532	1008	830	1119	335	267	613	534
5	1317	835	145	187	399	335	305	833	200	325	410	428
6	560	740	710	229	633	646	318	243	30	85	575	555
7	600	620	223	50	260	63	680	1057	87	115	220	374
8	537	440	1175	1157	1015	1428	968	835	1450	868	1712	1580
9	802	1245	1153	1043	448	665	583	648	785	246	270	436
10	520	803	448	150	382	675	1185	981	137	590	130	80
11	1180	1015	225	142	92	170	676	417	348	166	50	0
12	247	259	770	392	491	623	597	175	905	1235	25	60

R \ C	61	62	63	64	65	66	67	68	69	70	71	72
1	1298	453	668	900	280	231	0	0	496	473	0	0
2	1198	1133	152	145	485	525	0	0	390	370	0	0
3	1003	1629	750	361	262	373	880	822	270	200	230	568
4	585	617	893	618	573	668	514	1035	0	0	133	302
5	125	225	584	455	819	1012	350	255	0	0	0	150
6	783	515	235	100	669	568	855	635	0	0	0	0
7	35	170	177	342	865	1034	505	275	100	273	0	94
8	443	1237	616	988	635	309	620	624	440	542	0	120
9	0	100	638	782	321	333	205	392	479	230	0	0
10	0	203	283	521	1018	830	175	40	0	0	0	0
11	35	0	0	50	0	0	0	0	0	0	0	0
12	30	0	0	170	0	0	0	0	0	0	0	0

C - Columns.

R - Rows.

OPTIMUM PLOT SIZE FOR FIELD EXPERIMENTS ON TURMERIC *(CURCUMA LONGA. L.)*

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ABSTRACT OF A THESIS
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ABSTRACT

A uniformity trial on turmeric (Curcuma longa. L.) was conducted at the experimental field of College of Horticulture, Vellanikkara, during the period from June 1983 to January 1984 to assess the nature and magnitude of soil heterogeneity of the experimental field, and to determine the optimum size and shape of experimental plots and blocks in conducting field trials on turmeric by different methods. At the time of harvest, the yield data from 864 plots each of size 0.6m x 0.75m were recorded separately, discarding the external border row.

The fertility contour map of the field showed that the experimental field was not homogeneous as far as the fertility variation was concerned. It was observed that an increase in the plot size in either direction decreased the cv but the reduction in cv was not proportional.

The empirical law suggested by Smith (1938) gave a satisfactory fit to the data for blocks of different sizes and without blocking and those suggested by Prabhakaran(1983) were found to be better than the Smith's law.

As a general recommendation, the optimum plot size for conducting field trials on turmeric was found to be $2.7m^2$, but with blocks of small sizes, the optimum plot size can be reduced to $2m^2$ or even less. Shape of the plot did not exert

any consistent effect on cv. However, long and narrow plots gave lower cv than approximately square plots. Thus for $2.7m^2$, the plot shape 3.6m x 0.75m was found to be optimum.

As the size of the block increased efficiency of blocking decreased. Two plot blocks were the most efficient ones. Shape of the block had no consistent effect on variability whereas proper arrangement of plots and blocks resulted in a considerable reduction of experimental error.

An increase in plot size was followed by a decrease in the expected number of replications but the decrease was not proportional. Increasing the number of replications was found to be more advantageous than that of increasing the plot size.

In general Latin Square Design (LSD) was found to be more efficient than Randomised Block Design (RBD) and Completely Randomised Design (CRD). But by the proper orientation of plots and blocks in Randomised Block Design was found to be as efficient as Latin Square Design.