OPTIMUM SIZE OF PLOTS IN COCOA (*Theobroma cacao* L.) - A MULTIVARIATE CASE

By

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THESIS

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To my loving parents

DECLARATION

I hereby declare that this thesis entitled" OPTIMUM SIZE OF PLOTS IN COCOA(*Theobroma cacao* L.) - A MULTIVARIATE CASE " 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, associateship, fellowship or other similar title, of any other University or Society.

Mannuthy,
October 1987

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CERTIFICATE

Certified that this thesis, entitled " OPTIMUM SIZE OF PLOTS IN COCOA (Theobroma cacao.L) - A MULTIVARIATE CASE" is a record of research work done independently by Smt. SHEELA.M.A. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her.

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Introduction

INTRODUCTION

The success of any field experiment very much depends on the amount of experimental error which is a function of very many factors. The size and constitution of the experimental unit is a major factor contributing to the experimental error. Hence attention of researchers has been laid on determination of size and constitution of the experimental units so as to minimize the experimental error within the available resources. All attempts in the methodology as well as its application to various crops have so far been solely based on a single important character. But any crop is characterised by many characters and all of them have to be considered while studying it. In other words, it will be more meaningful to determine the optimum size of experimental unit based on simultaneous consideration of the various important characters of the crop.

Cocoa (Theobroma cacao L.) is a perennial crop that gains importance, especially among the Kerala farmers. It belongs to the family ' Sterculiaceae ' and originated in the Amazon river basin in Brazil. Owing to its shade loving nature, it is raised as an intercrop in coconut gardens. Moreover, demand for cocoa is on the increase due to the competetion that now exists in the market. Hence research on various aspects of the crop is being taken up extensively. Therefore determination of the optimum size of plots for cocoa is all the more important.

Cocoa is a cross fertilized crop, and genetic variability among trees is predominant over environmental variance. Any attempt on the formation of experimental plots for cocoa has to take this aspect also into consideration. Therefore the present investigation was taken up with the following objectives.

(1) To evolve a procedure to determine optimum size of plots, with respect to more than one character.

(2) To determine optimum size of plots for cocoa in multivariate case with and without blocking using the procedure evolved.

(3) To compare the optimum so determined with that obtained with respect to a single variable in the case of cocoa.

Review of Literature

REVIEW OF LITERATURE

Any attempt on determination of optimum size of experimental units based on consideration of more than one character is not available in literature. Even in the univariate case, few work had been done in methodology, though the same had been extensievely used . A brief review of the work in methodology as well as its application is given in this chapter.

Multivariate case

Determinant of the scatter matrix had been used as a measure of variation in multivariate case by various research workers. Friedman and Rubin(1967), Scott and Symons(1971b), Harriot(1971), Everitt(1979) and Suresh(1986) used the determinant of the scatter matrix as a measure of variation for clustering. Suresh(1986) used the determinant of the pairwise scatter matrix also as a measure of distance between genotypes.

Univariate case

Smith(1938) proposed the first theoretical model i.e., $V_x = V_1 \; x^{-b}$ where V_x is the variance of the mean yield per plot based on the plots of x units in size, and b, the index of soil heterogeneity which lies between 0 and 1. 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 a strong linear relationship between adjacent units.

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, 'a' the coefficient of variation of plots of size unity and 'b' an index of soil heterogeneity.

Smith's equation was modified by Freeman(1963) as

$$V_x = V_1'/x^b + V''/x$$ where,

V_x is the total variance per plant of a plots of x units, V_1' is the variance due to environment of plots of different size and V''/x is the variance among plants within plots of x units.

Methods of estimation of plot size

Maximum curvature method consists of representing the relationship between plot size and coefficient of variation graphically by using a free-hand curve and choosing the size of the plot just beyond the point of maximum curvature as the optimum. Federer(1967) had 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.

Prabhakaran and Thomas(1974) on tapioca, Hariharan(1981) on brinjal and Lucyamma(1986) on cahew and several others used this method to determine optimum plot size.

Raghava Rao(1983) suggested calculus method of determination of optimum plot size by maximising curvature. Gopakumaran(1984) used this procedure to find out the optimum plot size in turmeric. He found that optimum plot size was $3m^2$ for conducting field trials on turmeric. Lucyamma(1986) using this procedure, found seven tree plots as optimum for field experiments in cashew.

Smith(1938) suggested that the optimum plot size for unguarded plots as $X_{opt} = bk_1/(1-b)k_2$ where X is the number of basic units per plot, k_1-the cost associated with number of plots and K_2- the cost associated with unit area, b - the index of soil heterogeneity.

Several workers such as Saxena et al.(1972) on oat, Sreenath(1973) on sorghum, Prabhakaran and Thomas(1974) on tapioca, Hariharan(1981) on brinjal, Gopakumaran(1984) on turmeric, worked out optimum plot size using this approach.

Pearce and Thom(1950) conducted experiments in apple trees with no guard rows. They observed that larger plots gave more information per replicate while smaller ones gave more information per tree and obtained single tree plots as optimum.

Optimum plot size was also obtained by maximising information per unit area by various workers. Butters(1964) used this procedure and found nine tree plots to be most suitable for robusta coffee. Several workers like Menon and Tyagi(1971) on mandarian orange, Bharghava and Sardana(1975) on apple, Prabhakaran et al.(1978) on banana, Bharghava et al.(1978) on banana, Nair(1981) on cashew had tried this method. They found that single tree plots were the most efficient for conducting field trials on respective crops.

Pearce and Thom(1951) investigated the plot size for experiments in cocoa. They found that a plot should be as small as 0.15 acre for an acurate experiment.

Gomez (1972) defined optimum plot size as that which requires minimum experimental material for a given precision.

Agarwal(1973) recommended single tree plot for apple as the best on the consideration of minimum experimental material for given precision.

Kalamkar(1932a) defined efficiency of a plot of x units as $1/xC_x$ where C_x is the coefficient of variation of plots of x units.

Kripashanker et al.(1972) found that efficiency of the plot decreased with increase in size of the plot in the case of soyabean for any given shape of plot. He found that a plot of about $9m^2$ with three replication was found suitable.

Prabhakaran and Thomas(1974) had shown that efficiency of a plot decreased with an increase in size of the plot in the case of tapioca. Similar results were obtained by Agarwal et al.(1968) on arecanut, Hariharan(1981) on brinjal, Gopakumaran(1984) on turmeric.

Jayaraman(1979) tried out Fairfield Smith method and Maximum curvature method and recommended a plot size of 17.28 sq.m(7.2 m x 2.4 m) for conducting field experiments in sunflower.

Lessman and Atkins(1963a) empirically found that $\log C_x = a/(a+\log x)^b$ where C_x is the coefficient of variation of plots of x units, was superior to Smith's model i.e., $Y=ax^{-b}$ in the case of grain sorghum.

Gopakumaran(1984) worked out the following three nonlinear models for describing the relationship between coefficient of variation and plot size x.

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

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

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

He found that the first model was superior to Smith's model, i.e., $Y=ax^{-b}$ in the case of turmeric.

Koch and Rigney(1951) developed a method called variance component heterogeneity index method for estimating plot size by utilising data from actual field experiments with different treatments instead of conducting uniformity tirals. This method consisted in estimation of different sizes by reconstructing the ANOVA of the specified design and using these estimated variance for fitting Smith's function.

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.

Sundararaj(1977) proposed a technique for estimating optimum size and shape of plot from fertilizer trial data. The technique involved substraction of treatment effect from each observation and treating the resulting data as data from uniformity trial.

Formation of plots and blocks

Shrikande(1958) observed that genetic variation between trees was more potential source of error than environmental variation in coconut. This was based on the assumption that genetic and environmental effects on the phenotype are additive and independent and that the average yield 'Y' of a tree over an even number of consecutive years can be expressed as Y=G+E where G is the contribution due to genotype, and E that due to environment.

He proposed three methods of plot formation to control error variation. First method is to divide the land into compact blocks and within each block the adjacent trees are grouped together to form plots. This method aims at reducing within block variation, and increasing the between block variation, as far as 'E'component is concerned.

In second method the trees are arranged in descending order of magnitude of total yield for an even number of consecutive years. Suppose there are v treatments to be tried in k tree plots. The ordered trees are divided into groups of kv trees. These group of kv trees form blocks. In each block of ordered trees, apply v treatments at random to the first k trees, then to the next k trees and so on, till all the trees in the block are exhausted. In each block, k trees recieving a treatment forms a plot. This method aims at reducing within block variation and increasing the between block variation as far as the G component is concerned.

The two methods were combined into a third method as follows. First divide the land into compact block of kv trees. The trees within blocks are arranged according to the total production per tree and plots are formed as in the second method. This method aims at reducing the within block variation, by making plots within compact blocks as homogeneous as possible for G components while compact blocks are used to control the environmental variation.

Lucyamma(1986) tried formation of plots by selecting trees at random from the entire area.

<u>Size and shape of the block</u>

Abraham and Vachani(1964) observed that shape of the block did not have any consistent effect on block efficiency for experiments in rice.

Agarwal <u>et al.</u>(1968) found that blocking was not effective to control variation in arecanut. Similar results were obtained by Abraham <u>et al.</u>(1969) on pepper, Kripashanker <u>et al.</u>(1972) on soyabean, Saxena <u>et al.</u>(1972) on oat, Sreenath(1973) on M.P. chari sorghum, Bist <u>et al.</u>(1975) on potato.

Bhargava and Sardana(1975) observed a decrease in efficiency of the experiment with increase in blocksize for apple trees.

Kaushik <u>et al.</u>(1977) observed that coefficient of variation increased with increase in block size for experiments in mustard. They also reported that, blocks elongated in east-west direction were able to reduce error to a greater extent than those elongated in north-south direction.

Rambabu <u>et al.</u>(1980) coducted field trials on natural grasslands in hills and found that C.V decreased with increase in block size.

Nair(1981) observed that two plot blocks were the most efficient for conducting field experiments on cashew. He also found that the efficiency of blocking decreased with increase in plot size.

Brar *et al.*(1983) investigated optimum plot size for sweet orange and found that the efficiency of blocking decreased with increase in block size. They also found a relation between variation Y and plot size X i.e., $XY^m=K$.

Saraswathi(1983) found that two plot blocks were the most efficient for conducting field experiments on coconut. She also found that the efficiency of blocking decreased with increase in plot size.

Gopakumaran(1984) found that two plot blocks were the most efficient in controlling error in the case of turmeric.

Calibrating variables

Cheesman and Pound(1938) reported eightfold increase in precision using the records for three-years yield prior to the experimental year in the case of cocoa.

Pearce and Thom (1951) observed that for analysis of covariance for cocoa, preceeding two or four years yield was optimum to reduce error.

Longworth and Freeman(1963) conducted experiments with cocoa trees and recommended girth as a calibrating variate for young trees, and as a supplement to pre-treatment yield on mature trees.

Shrikande(1958) recommended calibration by two year's yield data when there is a biennial tendency for experiments with coconut.

Abraham and Kulkarni (1963) found that about two years data immediately prior to the experimental period as sufficient for covariance analysis in coconut.

Sen(1963) pointed out that calibration was most effective when blocking was less effective. He found that there was little to choose between calibration and blocking as a means of allowing for known past differences for experiments on tea.

Butters(1964) found that stem diameters measured at the first internode on bearing stems, was of limited use as a calibrating variate for robusta coffee.

Agarwal et al.(1968) reported positive correlation between the total yield of pre-experimental years with that of experimental year for arecanut . The highest correlation for yield was obtained with yield of two consecutive years.

Menon and Tyagi(1971) reported spread and height of the tree to be good for analysis of covariance.

Nair(1981) suggested selection index as an efficient calibrating variate for cashew.

Saraswathi(1983) found that analysis of covariance was not effective in reduction of coefficient of variation when plots were formed with negative intraclass correlation coefficient in the case of coconut.

Lucyamma(1986) recommended yield data of one year prior to the start of the experiment as a covariate for conducting experiments with cashew.

Materials and Methods

MATERIALS AND METHODS

The material for the present study consists of 738 Forastero variety of cocoa(*Theobroma cacao* L.) planted in October 1979 with a spacing of 3mx3m in the Kerala Agricultural Development Project(KADP) farm, Vellanikkara of the Kerala Agricultural University. The crop was raised under rainfed conditions in the inter spaces of an existing rubber plantation. The manurial and cultural practices were done as per the package of practices recommendation of the Kerala Agricultural University.

Observations were recorded on the following three characters.

1. Yield.

Number of pods harvested from December 1985 to November 1986 was recorded as yield for each tree.

2. Trunk girth

Trunk girth was measured in cm at 15cm height for every tree.

3. Canopy spread

North-South and East-West canopy spread were measured in cm for each tree and their arithmetic mean was recorded as the measure of canopy spread.

Methods

Individual trees are of prime importance than groups of plants for conducting experiment in perennial crops.

Therefore the size of the experimental plot was considered in terms of the number of trees.

Measure of variation in multivariate case.

Determinant of the dispersion matrix is in wide use as a measure of variation in multivariate case. But as in the univariate case it depends on the unit of measurement as well as tho magnitude of the observations. Hence the matrix of relative dooispersion of the vector variable

$$X = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ \cdot \\ \cdot \\ X_p \end{bmatrix} \qquad \ldots.(3.1)$$

was defined as $S = (S_{ij})_{pxp}$ ....(3.2)

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

X_{ik} is the observation on i^{th} character of the k^{th} unit,

$\bar{X}_i$ is the mean per unit of the i^{th} character and

N is the total number of units.

Thus /S/ which is independent of units of measurement and magnitude of observations was proposed as the measure of relative variation in multivariate case for determination of optimum size of experimental unit.

Different methods of plot formation

Plots were formed by 3 different methods and their efficiencies were compared empirically. The different methods of plot formation with no blocking and with blocks of size 5,10 and 15 are described below.

Method I

The whole set of trees were divided into compact blocks of required size and plots of one to 15 trees were formed by combining adjacent trees in the field. In the case of no blocking, the whole set of trees were considered as a single block.

Method II

All trees were arranged in descending order of magnitude of (1) the trunk girth and of (2) the spread separately and were divided into blocks of required size. Plots of one to 15 trees were formed by combining adjacent trees in the list in each block for each arrangement. For no blocking, the whole set of trees were considered as a single block.

Method III

The trees were first arranged as described in Method II. Plots of different sizes were formed by the following procedure. Let there be nk trees in a block. Divide the nk trees into 'n' groups of 'k' trees bearing continous serial numbers each. When 'n' is even, the i^{th} plot was formed by combining i^{th} tree from each of the first 'n/2' groups and $(k-i+1)^{st}$ tree from each of the remaining 'n/2' groups. In other words the trees having serial number i, i+k, i+2k, ...$i+((n/2)-1)k$, $((n/2)+1)k-i+1$,........$nk-i+1$ form i^{th} plot in each block, where i=1,2,3,.......n.

When 'n' is odd, i^{th} plot was formed by combining the i^{th} tree from each of the first$((n-1)/2)$ groups and $(k-i+1)^{st}$ tree from each of the remaining $((n-1)/2)$ groups, where i=1,2,.....n. In other words the trees having serial number i, i+k,.... . $i+((n-1)/2)k$, $(((n+1)/2)+1)k-i+1$, $(((n+1)/2)+2)k-i+1$, ... $nk-i+1$ form i^{th} plot in each block, where i=1,2,3,......n.

Determination of optimum plot size

Optimum sizes of plots were determined by three different approaches for different block sizes and for without blocking under each of the three methods of plot formation.

(1) Optimum plot size is the one which requires minimum experimental units for a specified precision.

Number of trees to achieve P% error

Multivariate case

Let

$$X = \begin{bmatrix} \bar{X}_1 \\ \bar{X}_2 \\ \cdot \\ \cdot \\ \bar{X}_p \end{bmatrix} \qquad .....(3.3)$$

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

$$D(\bar{X}) = (S_{ij}/r) \quad .....(3.4)$$

Hence the determinent of relative dispersion matrix is given by

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

Analoguous to fixing C.V at P % level in univariate case, for P% error in multivariate case,

$$|S| / r^p = (P/100)^{2p}$$

ie $$|S|^{1/p} / (P/100)^2 = r \quad .....(3.5)$$

is the number of replications required to achieve P% error. In other words, the number of replications, r, to achieve P% error has to be at least $|S|^{1/p}/(P/100)^2$. However when the number of replications so obtained was less than two, the same was taken as two. The number of trees required to achieve P% error was obtained by multiplying the number of replication with the corresponding plot size.

Univariate Case.

The co-efficient of variation (CV) was considered as the measure of variation. The number of replications, r, required to achive P% standard error was determined as

$$r = (CV)^2 / (P/100)^2 \qquad .....(3.6)$$

where CV refers to co-efficient of variation. The number of trees required to achieve P% standard error was obtained by multiplying the number of replications with the corresponding plot size.

(2) Efficiency of a plots of x units was taken as 1/xCV where CV is the co-efficient of variation for plots of x trees in the univariate case and $1/x \sqrt[p]{|S|}$ in the multivariate case. The plot size which gave maximum value for efficiency was taken as the optimum plot size under this method.

(3) Method of maximum curvature

The following four models were fitted for /S/ against plot size in multivariate case and for CV against plot size in uvivariate case.

$$Y = ax^{-b} \qquad .....(3.7)$$

$$Y = a+b/\sqrt{x}+c/x \qquad .....(3.8)$$

$$Y^{-1} = a+b\log x \qquad .....(3.9)$$

$$Y^{-1} = a+b\sqrt{x}+cx \qquad .....(3.10)$$

where, Y is the CV in univariate case and /S/ in multivariate case, and x the plot size. Optimum plot size was determined by calculus method of maximum curvature for the best fitting model. Optimum plot size for model (3.7) was found to be

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

Optimum plot size for model (3.8) was obtained as the solution of the polynomial equation $1.875b(\sqrt{x})^9+6a(\sqrt{x})^8 -.375b^3(\sqrt{x})^3-2.8125ab^2(\sqrt{x})^2-7.125a^2b(\sqrt{x}) -6a^3=0$

[Optimum plot size had to be calculated only for these two models.]

Results

RESULTS

The data were analysed by the methods described in 'Materials and Methods' and the results obtained are presented below.

4.1. Method I

4.1.a Multivariate case.

The determinant of the relative dispersion matrix (/S/) of plots of size ranging from one to 15 adjacent trees have been evaluated with no blocking and with blocks of size 5, 10 and 15 and are presented in Table 4.1. The number of trees required to achieve atmost five percent error along with the number of replications along with efficiency for the different plot sizes were determined and are also presented in Table 4.1. Four models fitted for /S/ against plot size (x) along with R^2 value are given in the Table 4.11

/S/ decreased from $.47 \times 10^{-3}$ for single tree plots to $.82 \times 10^{-6}$ for 15 tree plots when blocking was not adopted. The minimum number of trees required to achieve atmost five percent error was found to be for single tree plots. Single tree plots were also found to have maximum efficiency. Among the four models considered, R^2 was highest for model (3.7) and was 99%. Optimum plot size determined from the method of maximum curvature of this model was unity.

/S/ had an over all decreasing trend with increase in size of plots, though it was not regular when blocking was adopted.

In the case of five plot blocks, value of /S/ ranged from $.5573 \times 10^{-5}$ to $.41 \times 10^{-8}$. The minimum number of trees required to achieve atmost five percent error was found to be for single tree plots. Nine tree plots were found to give maximum efficiency. R^2 was highest for model (3.8) and was 73%. Three tree plots were found to be optimum using this model.

In the case of 10 plot blocks, /S/ ranged from $.4279 \times 10^{-4}$ to $.6 \times 10^{-7}$ for 12 tree plots. Two tree plots were found to be optimum with respect to the number of trees required to get five percent error. Maximum efficiency was for two tree plots. With an R^2 value of 92%, model (3.8) was the best fitting one in this case and optimum plot size determined was 18.

When blocks were formed with 15 plots, /S/ ranged from $.4726 \times 10^{-4}$ for single tree plots to $.12 \times 10^{-6}$ for 12 tree plots. The minimum number of trees required to get five percent error was for single tree plots. Single tree plots were found to give maximum efficiency. Model (3.8) had the highest R^2 value of 86% and the corresponding optimum plot size was one.

4.1.b <u>Univariate case</u>.

The coefficient of variation (CV), of plots of size ranging from one to 15 adjacent trees have been calculated for yield, with no blocking and with blocks of size 5,10 and 15 and are presented in Table 4.2. The number of replications and trees required to achieve five percent standard error and efficiency for plots of different sizes are also given in the same Table. Four models were fitted in this case also and the details are given in Table 4.12.

CV decreased from .873 for single tree plots to .400 for 15 tree plots when no blocking was adopted . The CV decreased with increase in plot size. The minimum number of trees required to achieve five percent SE was found to be for single tree plots. Single tree plots also gave maximum efficiency. The highest R^2 value of 99% was recorded for models (3.8) and (3.10) and the corresponding optimum plot size for model (3.8) was found to be two.

When block size was five, CV decreased from 0.822 for single tree plots to 0.158 for 15 tree plots. CV had an overall decreasing trend with increase in plot size, though it was not regular. The minimum number of trees required to get five percent SE was found for 12 tree plots. Single tree plots had maximum efficiency. The value of R2 was highest 93% for model (3.8) and it gave an optimum plot size of unity.

When blocks of ten plots were formed, CV decreased from 0.854 for single tree plots to .137 for 15 tree plots. Generally CV was found decreasing with an increase in plot size, but for plot sizes 3,7,11,13 and14. The minimum number of trees reqired to get five percent SE was found to be for 12 tree plots. Single tree plots had maximum efficiency. The value of R^2 was highest(96%) for model(3.8) and optimum plot size was one.

When block size was 15 , the CV decreasd from 0.800 for single tree plots to 0.157 for 12 tree plots and then increased to .251 for 15 tree plots. CV decreased with increase in plot size except for 4,11,13 and 15 tree plots. The minimum number of trees required to get five percent SE was found to be for 10 tree plots. Single tree plots had maximum efficiency. R^2 was highest (94%) for model(3.8)and optimum plot size was one.

4.2. Method II

The trees were arranged in descending order of magnitude of trunk girth and of canopy spread separately and plots were formed by combining trees adjacent in the list.

4.2.1. Arrangement by trunk girth

4.2.1.a Multivariate case

/S/ of plots of size varying from one to 15 trees have been calculated with no blocking and with blocks of size 5,10 and 15 and are given in Table 4.3. The number of replications required to get five percent error along with the corresponding number of trees and efficiency are also provided in the same Table. The four models fitted and R^2 are given in the Table 4.13.

/S/ decresed from 0.00047 for single tree plots to 0.348×10^{-5} for 15 tree plots when no blocking was adopted. The minimum number of trees required to get five percent error was for single tree plots. Single tree plots also had maximum efficiency. Model (3.8) was found to be the best fit with an R^2 value of 99% and three tree plots was found to be optimum from this model.

When the block size was five, value of /S/ decreased from .00742 to $.103 \times 10^{-6}$. /S/ was found decreasing with increase in plot size except for 3,6,8 and 12 tree plots. The minimum number of trees required to get five percent error was found for two tree plots. Two tree plots also had maximum efficiency. R^2 value was highest (95%) for model (3.8) and optimum plot size for this model was 13.

When the block size was 10, /S/ decreased from 0.00465 for single tree plots to 0.420×10^{-6} for 15 tree plots. /S/ was found decreasing with increase in plot size except for 8,12 and 13 tree plots. The minimum number of trees required to get five percent error was found for 11 tree plots. It was found that 11 tree plots also had maximum efficiency. R^2 value was highest (98%) for model(3.8) and optimum plot size for this model was 10.

When block size was 15, /S/ decreased from 0.00486 for single tree plots to 0.157×10^{-5} for 15 tree plots. /S/ was found to decrease with increase in plot size except for 8 and 12 tree plots. The minimum number of trees required to achieve five percent error was found for 11 tree plots. Eleven tree plots also had maximum efficiency. R^2 value was highest (99%) for model(3.7) and optimum plot size using this model was one.

4.2.1.b Univariate case

The CV of plots of size ranging from one to 15 adjacenttrees have been calcuated, for yield with no blocking and with blocks of size 5, 10, and 15 and are given in Table 4.4. The number of trees required to achieve five percent SE along with the number of trees needed are given. Efficiency was found out for different plot sizes and are given in the same Table. Four models were fitted and the details are given in Table 4.14.

CV decreased from .873 for single tree plots to .413 for 15 tree plots when no blocking was adopted. The minimum number of trees required to achieve five percent SE was for single tree plots. It was found that maximum efficiency also was for single tree plots. Model(3.8) gave the best fit with 98% value for R^2, and single tree plot as optimum.

When block size was five, the CV decreased from 1.348

for single tree plots to .270 for 11 tree plots. In general, CV had a decreasing trend with increase in plot size, but for 4,5,8,10,12,14 and 15 tree plots. The minimum number of trees required to get five percent error was for nine tree plots. Two tree plots were found to give maximum efficiency. R^2 was highest (89%) for model (3.8) giving an optimum plot size of unity.

When blocks of ten plots were formed, CV decreased from 1.050 for single tree plots to .268 for 13 tree plots. Generally, CV was found decreasing with increase in plot size except for plot sizes 4,12,14 and 15. The minimum number of trees required to get five percent error was found to be for 13 tree plots. Single tree plots were found to provide maximum efficiency. The highest value of R^2 (97%) was for model (3.8) giving an optimum plot size of one.

In the case of block size 15, CV decreased from 1.245 for single tree plots to .298 for 15 tree plots. In general CV decreased with an increase in plot size except for 4,8 and 12 tree plots. The minimum number of trees reqired to get five percent error was found to be for six tree plots. Single tree plots had maximum efficiency. The value of R^2 was highest (97%) for model (3.8) giving an optimum plot size of unity.

4.2.2. Arrangement by canopy spread.

4.2.2.a Multivariate case

/S/ of plots of size varying from one to 15 trees have been calculated with no blocking and with blocks of sizes 5,10 and 15 and are given in Table 4.5. The number of trees required to achieve five percent error along with the number of replications and efficiency for different plot sizes are also given in the same Table. Four models fitted along with R^2 values are given in the Table 4.15.

/S/ decreased from $.47 \times 10^{-3}$ for single tree plots to $.238 \times 10^{-5}$ for 15 tree plots. /S/ was found to decrease with increase in plot size. The minimum number of trees required to get five percent error was found to be for single tree plots. Single tree plots were found to give maximum efficiency. Model (3.8) was the best fit with 99% R^2 and three tree plots as optimum.

When block size was five, /S/ decreased from $.556 \times 10^{-2}$ for single tree plots to $.4 \times 10^{-7}$ for 15 tree plots. /S/ had an over all decreasing trend with increase in plot size, though it was not regular. The minimum number of trees required to get five percent error was found for two tree plots. It was found that two tree plots also gave maximum efficiency. Model (3.8) was the best fit with 94% R^2 and single tree plots as optimum.

When block size was 10, /S/ decreased from $.111 \times 10^{-2}$

for single tree plots to $.100 \times 10^{-5}$ for 15 tree plots. /S/ was found to be decreasing with increase in plot size, but for plot sizes 8,12 and 13. The minimum number of trees required to get five percent error was found to be for single tree plots. Six tree plots were found to be optimum with respect to maximum efficiency. Model (3.8) was found to be the best fit with an R^2 value of 99% . Four tree plots were found to be optimum from this model.

When block size was 15, /S/ decreased from $.96 \times 10^{-3}$ for single tree plots to $.151 \times 10^{-5}$ for 15 tree plots. /S/ decreased with increase in plot size, but for 7,10 and 13 tree plots. The minimum number of trees required to get five percent error was found to be for six tree plots. Six tree plots were also found to give maximum efficiency. R^2 was highest for model (3.8) with 99% R^2 and four tree plots as optimum.

4.2.2.b <u>Univariate case</u>

CV of yield determined for different plot sizes are given in Table 4.6. The minimum number of trees required to achieve five percent SE along with the corresponding number of replications are also provided in the same Table. Efficiency found for different plot sizes are also provided in Table 4.6. Four models fitted and the R^2 values are given in the Table 4.16

CV decreased from .873 for single tree plots to .443 for 15 tree plots. The minimum number of trees reqired to get five percent SE was found to be for single tree plots. Single tree plots also provided maximum efficiency. Models (3.8) and (3.10) fitted the data best with 99% R^2 and model (3.8) gave an optimum plot size of unity.

When block size was five, CV decreased from 1.022 for single tree plots to .200 for 15 tree plots. It had an over all decreasing trend, though was not regular. The number of trees required to achieve five percent SE was found to be for 15 tree plots. Maximum efficiency was found to be for single tree plots. The value of R^2 was highest (85%) for models (3.7) & (3.8) and two tree plots as optimum in the case of model (3.8.)

When block size was 10, CV decreased from .838 for two tree plots to .232 for 11 tree plots. CV was found to decrease with increase in plot size, though it was not regular. The minimum number of trees required to achieve five percent SE was found to be for 11 tree plots. Single tree plots was found to provide maximum efficiency. Model (3.8) gave the best fit with 93% R^2 and three tree plot as the optimum.

When block size was 15, CV decreased from .840 for single tree plots to .290 for nine tree plots. CV had an over all decreasing trend with increase in plot size, but it was not regular. The minimum number of trees required to achieve five percent SE was found to be for six tree plots. Single tree plots was found to be optimum with respect to maximum efficiency. Model (3.8) was the most fitting one with 86% R^2 and an optimum plot size of unity.

4.3. Method III

The trees were arranged in a descending order of magnitude of trunk girth and of canopy spread separately and plots wre formed as described in 'Materials and Methods'

4.3.1 Arrangement by Trunk girth.

4.3.1.a Multivariate case.

/S/ of plots of size varying from one to 15 trees have been calculated with no blocking and with blocks of 5,10 and 15 and are given in Table 4.7. The number of replications required to get five percent error along with the corresponding number of trees and efficiency for different plot sizes are also provided in the same table. The four models fitted and R^2 value determined for each model are given in the Table 4.17.

/S/ decreased from .00047 for single tree plots to $.7 \times 10^{-9}$ for 15 tree plots when no blocking was adopted. The minimum number of trees required to get five percent error was found to for two tree plots. Eleven tree plots had maximum efficiency. Model (3.8) was found to be the best fit with an R^2 value of 95%. Fourteen tree plots found to be optimum using this model.

When block size was five, /S/ decreased from .0074 for single tree plots to $.1\times10^{-8}$ for 15 tree plots. /S/ was found to be decreasing with increase in plot size, but for plot sizes 5,11 and 14. The minimum number of trees required to get five percent error was found to be for six tree plots. Fifteen tree plots were found to provide maximum efficiency. The value of R^2 was highest (97%) for model(3.7)and optimum plot size was one.

When block size was 10, /S/ decreased from .0046 for single tree plots to $.12\times10^{-7}$ for 15 tree plots. /S/ was found to decrease with increase in plot size except for six tree plots. The minimum number of trees required to achieve five percent error was found to be for five tree plots. Thirteen tree plots were found having maximum efficiency. R^2 was highest (98%) for model(3.7)and single tree plots were found to be optimum using this model.

In the case of 15 plot blocks, /S/ decreased from .0044 for single tree plots to $.14\times10^{-7}$ for 15 tree plots. /S/ decreased with an increase in plot size. The minimum number of trees required to achieve five percent error was found to be for eight tree plots. Fourteen tree plots were found to provide maximum efficiency. Model (3.7) was the best fit with an R^2 value of 99% and optimum plot size from this model was unity.

4.3.1.b <u>Univariate case.</u>

The CV for plots of size varying one to 15 trees have been determined for yield with no blocking and with blocks of sizes 5,10 and 15 and are given in the Table 4.8. The number of replications required to achieve five percent SE along with the number of trees needed are also given in the same Table. Efficiency determined for different plot sizes are also provided in the same Table. Four models fitted and R^2 determined for each model are provided in the Table 4.18.

CV decreased from 0.873 for single tree plots to .226 for 12 tree plots in the case of without blocking. CV was found to decrease with increase in plot size, except for 7,13 and 14 tree plots. The minimum number of trees required to achieve five percent SE was found to be for six tree plots. Single tree plots were found to be optimum with respect to efficiency. The highest(99%) R^2 was recorded for model(3.8)and the corresponding optimum plot size was found to be one.

In the case of block size five, the CV decresed from 1.348 for single tree plots to 0.140 for 12 tree plots. Generally it was found that CV decreased with increase in plot size, but for plot sizes 3,4,10 and 13. The minimum number of trees required to achieve fivepercent SE was found to be for 12 tree plots. Maximum efficiency wao found to be for two tree plots. With an R^2 value of 88% model (3.10)was the best fitting one in this case. Optimum plot size determined was two using model(3.8).

For blocks of size ten, CV decreased from 1.050 for single tree plots to 0.217 for nine tree plots. Generally the CV decreased with an increase in plot size except for plot sizes 2,6,10,11,13 and 15. The minimum number of trees required to achieve five percent SE was found to be for nine tree plots. Maximum efficiency was found to be for single tree plots. Model(3.7)had the highest R^2 value of 92% and the corresponding optimum plot size was one.

In the case of block size 15, CV decreased from 1.240 for single tree plots to 0.227 for 14 tree plots. CV was found to decrease with increase in plot size except fot plot sizes 5,11,12,13, and 15. The minimum number of trees required to achieve five percent SE was found for 10 tree plots. Single tree plots was found to provide maximum efficiency. R^2 was highest for models(3.8) & (3.10) and it was 99%. Single tree plots was found to be optimum using model(3.8).

4.3.2 Arrangement by canopy spread.

4.3.2.a Multivariate case.

/S/ of plots of size varying from one to 15 trees have been calculated with no blocking and with blocks of sizes 5, 10 and 15 and are given in the table 4.9. The number of replications required to achieve five percent error along with the number of trees and efficiency for different plot sizes are also given in the same table. Four models fitted for /S/ against plot sizes along with R^2 values are given in the table 4.19.

/S/ decreased from .00047 for single tree plots to $.9\times10^{-9}$ for 15 tree plots in the case of without blocking. /S/ decreased with increase in plot size. except for seven and 13 tree plots. The minimum number of trees required to get five percent error was found to be for four tree plots. Six tree plots were found to provide maximum efficiency. The best fitting model (3.7) with an R^2(96%) had single tree plots as optimum.

When block size was five, /S/ decreased from .0055 for single tree plots to $.14\times10^{-8}$ for 15 tree plots. /S/ decreased with increase in plot size except for 13 tree plots. The minimum number of trees required to get 5% error was found to be for six tree plots. Twelve tree plots were found to provide maximum efficiency. R^2 was highest (96%) for model (3.7) and single tree plots was optimum.

When block of 10 plots were considered, /S/ decreased from .00111 for single tree plots to $.41\times10^{-8}$ for 15 tree plots. The minimum number of trees required to achieve five percent error was found for seven tree plots. Fifteen tree plots were found to give maximum efficiency. Model(3.7) was the best fit with 99% R^2 and single tree plots as optimum.

For blocks of size 15, /S/ decreased from .00096 for single tree plots to $.9 \times 10^{-9}$ for 12 tree plots. /S/ was found to decrease with increase in plot size except for nine tree plots. The minimum number of trees required to get five percent error was for six tree plots. Thirteen tree plots gave maximum efficiency. R^2 was highest (99%) for model (3.7) giving an optimum plot size of unity.

4.3.2.b Univariate case.

CV was determined for yield for different plot sizes and was given in the Table 4.10. The number of trees required to achieve five percent SE along with the efficiency for different plot sizes are also provided in the same Table. Four models fitted and the details are given in the Table 4.20.

CV decreased from .873 for single tree plots to .181 for 15 tree plots when no blocking was adopted. CV was found to decrease with increase in plot size except for plots of 7,9,11 and 14 trees. The minimum number of trees required to achieve five percent SE was found for 15 tree plots. Single tree plots were found to have maximum efficiency. Model (3.8) was the best fit with 98% R^2 and six tree plots as the optimum plot size.

When block size was five, CV decreased from 1.022 for single tree plots to .115 for 11 tree plots. CV decreased with increase in plot size ,but for 6,7,8 and 13 tree plots. The minimum number of trees required to achieve five percent SE was for 12 tree plots. Twelve tree plots were found to give maximum efficiency. Model (3.8) was the best fit with 91% R^2 and single tree plots as optimum.

When block size was 10, CV decreased from .803 for single tree plots to .174 for 12 tree plots. The CV was found to be decreasing with increase in plot size except for 4,5 and 14 tree plots. The minimum number of trees required to achieve five percent SE was found to be for three tree plots. Single tree plots were found to provide maximum efficiency. R^2 was highest (85%) for model (3.8) providing an optimum plot size of one.

When block size was 15, CV decreased from .840 for single tree plots to .167 for 15 tree plots. CV was found to be decreasing with increase in plot size except for 4,9,10 and 14 tree plots. The minimum number oftrees required to achieve five percent SE was found to be for 15 tree plots. Single tree plots were found to give maximum efficiency. R^2 was highest (96%) for model (3.8) providing an optimum plot size of one.

Table. 4.1.

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots & blocks using method I

Plot size	Without blocking /S/x10^5	No.of Repli-cation for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$	5 plot block /S/x10^7	No.of Repli-cation for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$
1	47.477	29	29	12.86	34.760	6	6	66.50
2	8.295	17	34	11.51	55.739	7	14	28.32
3	3.110	13	39	10.61	28.781	6	18	23.64
4	1.768	10	40	9.72	4.180	3	12	33.65
5	1.019	9	45	9.28	11.048	4	20	19.37
6	0.738	8	48	8.59	0.633	2	12	41.88
7	0.453	7	49	8.65	11.444	4	28	13.83
8	0.313	6	48	8.57	0.282	2	16	41.16
9	0.272	6	54	7.97	0.041	2	18	69.99
10	0.249	5	50	7.46	3.000	3	30	14.93
11	0.198	5	55	7.34	0.268	2	22	33.68
12	0.147	4	48	7.45	0.176	2	24	32.40
13	0.130	4	52	7.05	0.574	2	26	19.98
14	0.119	4	56	6.92	0.586	2	28	18.45
15	0.082	4	60	7.12	0.216	2	30	24.16

Table. 4.1 (cont.....)

/S/, No.of trees & replicatons required to attain 5% error and efficiency for different sizes of plots & blocks using method I

Plot size	10 plot block /S/x10^5	10 plot block No.of Repli-cation for 5% error	10 plot block No.of trees for 5% error	10 plot block $1/x\sqrt[3]{/S/}$	15 plot block /S/x10^5	15 plot block No.of Repli-cation for 5% error	15 plot block No .of trees for 5% error	15 plot block $1/x\sqrt[3]{/S/}$
1	4.279	14	14	28.59	4.726	14	14	27.67
2	0.229	5	10	37.93	0.872	8	16	24.29
3	0.544	7	21	18.95	2.508	12	36	11.39
4	0.699	8	32	13.07	1.136	9	36	11.14
5	0.394	6	30	12.66	0.465	7	35	11.98
6	0.152	5	30	14.50	0.351	6	36	10.97
7	0.159	5	35	12.23	0.185	5	35	11.64
8	0.019	2	16	21.74	0.051	3	24	15.74
9	0.014	2	18	21.39	0.034	3	27	15.91
10	0.023	2	20	16.32	0.024	3	30	16.09
11	0.013	2	22	17.94	0.021	2	22	15.29
12	0.006	2	24	21.28	0.012	2	24	16.89
13	0.037	3	39	10.71	0.064	3	39	8.92
14	0.013	2	28	14.10	0.016	2	28	13.31
15	0.007	2	30	16.17	0.027	3	45	10.31

Table. 4.2

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots & blocks using method I

	Without blocking				5 plot block			
Plot size	CV	No.of Replication for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Replication for 5% SE	No.of trees for 5% SE	1/xCV
1	0.873	305	305	1.14	0.822	270	270	1.21
2	0.688	189	378	0.72	0.612	150	300	0.81
3	0.583	136	408	0.57	0.446	80	240	0.74
4	0.533	114	456	0.46	0.409	67	268	0.61
5	0.515	106	530	0.38	0.449	81	405	0.44
6	0.480	92	552	0.34	0.277	31	186	0.60
7	0.474	90	630	0.30	0.371	55	385	0.38
8	0.461	85	680	0.27	0.197	16	128	0.63
9	0.441	78	702	0.25	0.247	24	216	0.44
10	0.434	75	750	0.23	0.201	16	160	0.50
11	0.427	73	803	0.21	0.184	14	156	0.49
12	0.410	67	804	0.20	0.162	10	120	0.51
13	0.411	67	871	0.18	0.178	13	169	0.43
14	0.417	68	952	0.17	0.272	30	420	0.26
15	0.400	64	960	0.16	0.158	10	150	0.42

Table. 4.2 (cont.....)

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots and blocks using method I.

	10 plot block				15 plot block			
Plot size	CV	No.of Repli- cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli- cation for 5% SE	No.of trees for 5% SE	1/xCV
1	0.854	292	292	1.17	0.800	256	256	1.25
2	0.490	96	192	1.02	0.611	149	298	0.81
3	0.494	98	294	0.67	0.415	69	207	0.80
4	0.421	71	284	0.59	0.445	79	316	0.56
5	0.326	43	215	0.61	0.351	49	245	0.56
6	0.284	32	192	0.58	0.321	41	246	0.51
7	0.346	48	336	0.41	0.315	40	280	0.45
8	0.291	34	272	0.42	0.253	26	208	0.49
9	0.242	23	207	0.45	0.211	18	162	0.52
10	0.183	13	130	0.54	0.166	11	110	0.50
11	0.230	21	231	0.39	0.195	15	165	0.46
12	0.156	10	120	0.53	0.157	10	120	0.53
13	0.193	15	195	0.39	0.255	26	338	0.30
14	0.198	16	224	0.39	0.233	22	308	0.30
15	0.137	8	120	0.48	0.251	25	375	0.26

Table. 4.3

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots & blocks using method II after arranging with Trunk girth

Plot size	Without blocking /S/x10^5	No. of Replication for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$	5 plot block /S/x10^5	No.of Replication for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$
1	47.475	29	29	12.86	742.687	78	78	5.13
2	13.159	20	40	9.87	10.783	19	38	10.53
3	7.968	17	51	7.76	25.392	25	75	5.27
4	4.785	14	56	6.92	3.677	13	52	7.57
5	2.371	11	55	7.03	2.390	12	60	7.03
6	2.595	12	72	5.69	4.229	14	84	4.79
7	1.760	10	70	5.55	1.293	9	63	6.23
8	1.346	9	72	5.31	2.347	11	88	4.39
9	1.469	4	36	4.61	1.032	9	81	5.10
10	0.808	8	80	5.00	0.465	7	70	6.01
11	0.803	8	88	4.54	0.262	5	55	6.61
12	0.725	8	96	4.31	0.912	8	96	3.99
13	0.572	7	91	4.30	0.103	4	52	7.61
14	0.549	7	98	3.79	0.059	3	42	8.51
15	0.348	6	90	4.43	0.036	3	45	9.37

Table. 4.3 (cont.....)

/S/, No. of trees & replications required to attain 5% error and efficiency for different sizes of plots & blocks using method II after arranging with Trunk girth

	10 plot block				15 plot block			
Plot size	/S/x10[5]	No.of Repli-cation for 5% error	No.of trees for 5% error	$1/x\ \sqrt[3]{/S/}$	/S/x10[5]	No.of Repli-cation for 5% error	No.of trees for 5% error	$1/x\ \sqrt[3]{/S/}$
1	465.125	67	67	5.99	486.887	68	68	5.92
2	67.249	35	70	5.71	50.176	32	64	6.29
3	20.738	24	72	5.69	14.136	21	63	6.41
4	10.209	19	76	5.38	8.304	17	68	5.73
5	5.438	15	75	5.29	3.286	13	65	6.29
6	2.417	12	72	5.77	1.776	10	60	6.48
7	0.830	8	56	7.05	0.841	8	56	7.02
8	1.019	9	72	5.80	0.914	8	64	5.98
9	0.772	8	72	5.62	0.582	7	63	6.18
10	0.642	7	70	5.38	0.448	7	70	6.10
11	0.134	4	44	8.24	0.189	5	55	7.47
12	0.482	7	84	4.94	0.454	7	84	5.04
13	0.829	8	104	3.80	0.264	6	78	5.59
14	0.670	8	112	3.78	0.200	5	70	5.66
15	0.420	6	90	4.13	0.157	5	75	5.82

Table. 4.4

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots & blocks using method II after arranging with Trunk girth

Plot size	Without blocking: CV	Without blocking: No.of Repli- cation for 5% SE	Without blocking: No.of trees for 5% SE	Without blocking: 1/xCV	5 plot block: CV	5 plot block: No.of Repli- cation for 5% SE	5 plot block: No.of trees for 5% SE	5 plot block: 1/xCV
1	0.873	305	305	1.14	1.348	727	727	0.74
2	0.681	186	372	0.73	0.639	163	326	0.78
3	0.627	157	471	0.53	0.591	140	420	0.56
4	0.568	129	516	0.44	0.605	146	584	0.41
5	0.506	102	510	0.39	0.658	173	865	0.30
6	0.506	102	612	0.32	0.510	104	624	0.32
7	0.519	108	756	0.27	0.378	57	399	0.37
8	0.480	92	736	0.26	0.380	58	464	0.32
9	0.480	92	828	0.23	0.272	30	270	0.41
10	0.454	82	820	0.22	0.274	30	300	0.36
11	0.456	83	913	0.19	0.270	29	319	0.33
12	0.450	81	972	0.18	0.424	72	864	0.19
13	0.445	79	1027	0.17	0.317	40	520	0.24
14	0.444	79	1106	0.16	0.345	48	672	0.20
15	0.413	68	1020	0.16	0.412	68	1020	0.16

Table. 4.4 (cont.....)

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots & blocks using method II after arranging with Trunk girth

	10 plot block				15 plot bock			
Plot size	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV
1	1.050	441	441	0.95	1.245	620	620	0.80
2	0.790	250	500	0.63	0.839	282	564	0.59
3	0.629	158	474	0.52	0.582	135	405	0.57
4	0.691	191	764	0.36	0.668	178	712	0.37
5	0.524	110	550	0.38	0.510	104	520	0.39
6	0.463	86	516	0.35	0.387	60	360	0.43
7	0.396	63	441	0.36	0.370	55	385	0.38
8	0.371	55	440	0.33	0.378	57	456	0.33
9	0.353	50	450	0.31	0.337	45	405	0.32
10	0.351	49	490	0.28	0.326	43	430	0.30
11	0.318	40	440	0.28	0.303	37	407	0.30
12	0.366	54	648	0.22	0.380	58	696	0.21
13	0.268	29	377	0.28	0.342	47	611	0.22
14	0.282	32	448	0.25	0.331	44	616	0.21
15	0.301	36	540	0.22	0.298	36	540	0.22

Table. 4.5

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots and blocks using method II after arranging with Canopy spread

Plot size	Without blocking /S/x105	No.of Repli-cation for 5% error	No.of trees for 5% error	1/x $\sqrt[3]{/S/}$	5 plot bock /S/x10[5]	No.of Repli-cation for 5% error	No.of trees for 5% error	1/x $\sqrt[3]{/S/}$
1	47.475	29	29	12.86	556.547	71	71	5.64
2	12.684	20	40	9.97	1.247	9	18	21.83
3	5.729	15	45	8.65	11.457	19	57	6.95
4	3.500	13	52	7.64	33.441	27	108	3.61
5	2.206	11	55	7.13	6.484	16	80	5.00
6	1.134	9	54	7.49	0.438	7	42	10.24
7	1.056	9	63	6.52	0.288	6	42	10.13
8	0.786	8	64	6.30	0.559	7	56	7.08
9	0.606	7	63	6.11	0.581	7	63	6.18
10	0.542	7	70	5.46	0.264	6	60	7.27
11	0.468	7	77	5.84	0.140	4	44	8.12
12	0.293	6	72	5.82	0.061	3	36	9.82
13	0.361	6	78	5.01	0.229	5	65	5.91
14	0.340	6	84	4.75	0.042	3	42	9.53
15	0.238	5	75	5.29	0.004	2	30	19.49

Table. 4.5 (cont.....)

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plos & bloeks using method II after arranging with Canopy spread

Plot size	10 plot block /S/x10^5	No.of Repli-cation for 5% error	No.of trees for 5% error	1/x $\sqrt[3]{/S/}$	15 plot bock /S/x10^5	No.of Repli-cation for 5% error	No.of trees for 5% error	1/x $\sqrt[3]{/S/}$
1	111.950	41	41	9.65	96.177	39	39	10.13
2	47.375	31	62	6.43	20.010	23	46	8.54
3	12.344	20	60	6.75	10.410	19	57	7.18
4	8.240	17	68	5.75	6.816	16	64	6.12
5	3.290	13	65	6.29	2.208	11	55	7.13
6	0.430	7	42	10.24	0.416	6	36	10.36
7	0.302	6	42	9.90	0.670	8	56	7.57
8	0.536	7	56	7.16	0.488	7	56	7.37
9	0.462	7	63	6.68	0.385	6	54	7.08
10	0.387	6	60	6.40	0.393	6	60	6.33
11	0.129	4	44	8.55	0.237	5	55	6.81
12	0.208	5	60	6.61	0.204	5	60	6.57
13	0.274	6	78	5.52	0.307	6	78	5.29
14	0.185	5	70	5.87	0.242	5	70	5.32
15	0.100	4	60	6.67	0.151	5	75	5.81

Table. 4.6

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots & blocks using method II after arranging with Canopy spread

Plot size	Without blocking CV	No.of Replication for 5% SE	No.of trees for 5% SE	1/xCV	5 plot block CV	No.of Replication for 5% SE	No.of trees for 5% SE	1/xCV
1	0.873	305	305	1.14	1.022	418	418	0.97
2	0.693	192	384	0.72	0.668	178	356	0.74
3	0.611	149	447	0.54	0.662	175	525	0.50
4	0.573	131	524	0.43	0.860	296	1184	0.29
5	0.545	119	595	0.36	0.622	155	775	0.32
6	0.513	105	630	0.32	0.380	58	348	0.43
7	0.511	104	728	0.27	0.353	50	350	0.40
8	0.483	93	744	0.25	0.424	72	576	0.29
9	0.470	88	792	0.23	0.359	52	468	0.30
10	0.468	88	880	0.21	0.331	44	440	0.30
11	0.459	84	924	0.19	0.276	30	330	0.32
12	0.455	83	996	0.18	0.324	42	504	0.25
13	0.454	82	1066	0.16	0.281	32	416	0.27
14	0.465	86	1204	0.15	0.234	22	308	0.30
15	0.443	78	1170	0.15	0.200	16	240	0.33

Table. 4.6 (cont.....)

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots & blocks using method II after arranging with Canopy spread

	10 plot block				15 plot block			
Plot size	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV
1	0.803	258	258	1.24	0.840	282	282	1.19
2	0.838	281	562	0.59	0.720	207	414	0.69
3	0.609	148	444	0.54	0.608	148	444	0.54
4	0.637	162	648	0.39	0.612	150	600	0.40
5	0.555	123	615	0.36	0.477	91	455	0.41
6	0.367	54	324	0.45	0.307	38	228	0.54
7	0.326	43	301	0.43	0.303	37	259	0.47
8	0.327	43	344	0.38	0.335	45	360	0.37
9	0.287	33	297	0.38	0.290	34	306	0.38
10	0.283	32	320	0.35	0.313	39	390	0.31
11	0.232	22	242	0.39	0.318	40	440	0.29
12	0.277	31	372	0.29	0.346	48	576	0.24
13	0.286	33	429	0.26	0.364	53	689	0.21
14	0.259	27	378	0.27	0.362	52	728	0.20
15	0.244	24	360	0.27	0.340	46	690	0.20

Table. 4.7

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots & blocks using method III after arranging with Trunk girth

	Without blocking				5 plot block			
Plot size	$/S/ \times 10^7$	No.of Repli-cation for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$	$/S/ \times 10^6$	No.of Repli-cation for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$
1	4747.535	29	29	12.86	7426.875	78	78	5.13
2	5.521	3	6	61.02	18.705	10	20	18.07
3	2.910	2	6	56.99	5.046	7	21	19.49
4	0.421	2	8	73.10	1.008	4	16	25.00
5	0.271	2	10	73.68	1.362	4	20	18.32
6	0.171	2	12	77.35	0.235	2	12	27.20
7	0.069	2	14	78.61	0.223	2	14	23.66
8	0.042	2	16	78.74	0.091	2	16	27.89
9	0.027	2	18	88.18	0.036	2	18	35.75
10	0.024	2	20	79.37	0.019	2	20	46.41
11	0.016	2	22	90.90	0.031	2	22	28.93
12	0.013	2	24	83.33	0.004	2	24	52.49
13	0.024	2	26	61.05	0.002	2	26	61.05
14	0.007	2	28	80.64	0.005	2	28	41.77
15	0.007	2	30	75.18	0.001	2	30	66.66

Table. 4.7 (cont....)

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots & blocks using method III after arranging with Trunk girth

	10 plot block				15 plot block			
Plot size	$/S/ \times 10^6$	No.of Replication for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$	$/S/ \times 10^6$	No.of Replication for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$
1	4651.252	67	67	5.99	4468.878	66	66	6.07
2	308.848	27	54	7.40	154.357	21	42	9.32
3	12.136	9	27	14.55	21.734	11	33	12.08
4	2.020	5	20	19.84	4.102	6	24	15.61
5	0.356	3	15	28.37	2.328	5	25	15.15
6	0.404	3	18	22.62	0.729	4	24	18.59
7	0.319	3	21	21.10	0.388	3	21	19.72
8	0.243	2	16	20.11	0.162	2	16	23.02
9	0.108	2	18	23.93	0.085	2	18	25.27
10	0.080	2	20	23.20	0.058	2	20	25.83
11	0.044	2	22	25.75	0.058	2	22	23.48
12	0.029	2	24	27.12	0.031	2	24	26.52
13	0.017	2	26	29.91	0.030	2	26	24.75
14	0.014	2	28	29.63	0.016	2	28	28.34
15	0.012	2	30	29.11	0.014	2	30	27.66

Table. 4.8

CV, No.of trees & replications required to achieve 5% SE and efficiency for different sizes of plots and blocks using method III after arranging with Trunk girth

Plot size	Without blocking				5 plot block			
	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV
1	0.873	305	305	1.14	1.348	727	727	0.74
2	0.568	130	260	0.88	0.502	101	202	0.99
3	0.449	81	243	0.74	0.755	228	684	0.44
4	0.396	63	252	0.63	0.842	284	1136	0.29
5	0.356	51	255	0.56	0.797	254	1270	0.25
6	0.302	36	216	0.55	0.713	203	1218	0.23
7	0.313	39	273	0.45	0.452	82	574	0.31
8	0.277	30	240	0.45	0.372	55	440	0.33
9	0.269	29	261	0.41	0.275	30	270	0.40
10	0.263	28	280	0.38	0.297	35	350	0.33
11	0.246	24	264	0.36	0.187	14	154	0.48
12	0.226	20	240	0.36	0.140	8	96	0.59
13	0.230	21	273	0.33	0.183	14	182	0.42
14	0.233	22	308	0.30	0.174	13	182	0.41
15	0.227	21	315	0.29	0.149	9	135	0.44

Table.4.8(cont....)

CV, No.of trees & replications required to achieve 5% SE and efficiency for different sizes of plots and blocks using method III after arranging with Trunk girth

	10 plot block				15 plot bock			
Plot size	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV
1	1.050	441	441	0.95	1.240	615	615	0.80
2	1.140	520	1040	0.43	0.848	288	576	0.58
3	0.645	166	498	0.51	0.620	154	462	0.53
4	0.528	112	448	0.47	0.426	73	292	0.58
5	0.340	46	230	0.58	0.438	77	385	0.45
6	0.356	51	306	0.46	0.357	51	306	0.46
7	0.320	41	287	0.44	0.324	43	301	0.44
8	0.302	37	296	0.41	0.314	40	320	0.39
9	0.217	19	171	0.51	0.255	26	234	0.43
10	0.242	23	230	0.41	0.240	23	230	0.41
11	0.245	24	264	0.37	0.248	25	275	0.36
12	0.232	22	264	0.35	0.250	26	312	0.33
13	0.233	22	286	0.33	0.256	26	338	0.30
14	0.222	22	286	0.32	0.227	21	294	0.31
15	0.247	24	360	0.26	0.230	21	315	0.28

Table. 4.9

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots and blocks using method III after arranging with Canopy spread

Plot size	Without blocking /S/x10^7	No.of Repli- cation for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$	5 plot block /S/x10^7	No.of Repli- cation for 5% error	No.of trees for 5% error	$1/x \sqrt[3]{/S/}$
1	4747.535	29	29	12.86	55654.743	70	70	5.64
2	20.438	5	10	39.68	196.948	11	22	18.54
3	11.935	4	12	32.29	166.452	10	30	13.06
4	1.785	2	8	53.86	47.264	7	28	14.92
5	1.221	2	10	43.08	4.650	3	15	25.90
6	0.159	2	12	77.35	2.019	2	12	28.49
7	0.421	2	14	41.77	1.803	2	14	25.30
8	0.081	2	16	36.55	1.275	2	16	25.34
9	0.077	2	18	58.08	0.340	2	18	34.29
10	0.044	2	20	62.99	0.144	2	20	41.49
11	0.039	2	22	63.03	0.048	2	22	57.26
12	0.026	2	24	66.14	0.007	2	24	90.90
13	0.032	2	26	53.33	0.018	2	26	76.92
14	0.022	2	28	56.69	0.014	2	28	71.42
15	0.009	2	30	69.44	0.014	2	30	66.66

Table. 4.9 (cont.....)

/S/, No.of trees & replications required to attain 5% error and efficiency for different sizes of plots & blocks using method III after arranging with Canopy spread

Plot size	10 plot block /S/x10^6	No.of Repli- cation for 5% error	No.of trees for 5% error	$1/x\sqrt[3]{/S/}$	15 plot block /S/x10^6	No.of Repli- cation for 5% error	No.of trees for 5% error	$1/x\sqrt[3]{/S/}$
1	1119.507	42	42	9.63	961.715	39	39	10.13
2	100.913	19	38	10.77	25.145	12	24	17.09
3	3.857	6	18	21.36	2.860	6	18	23.64
4	2.556	5	20	18.42	0.751	4	16	27.51
5	1.644	5	25	17.09	0.395	3	15	27.37
6	0.592	3	18	19.87	0.182	2	12	29.51
7	0.114	2	14	29.81	0.105	2	14	30.77
8	0.098	2	16	27.11	0.034	2	16	38.58
9	0.047	2	18	30.78	0.035	2	18	33.96
10	0.029	2	20	32.54	0.026	2	20	33.75
11	0.021	2	22	32.95	0.016	2	22	36.07
12	0.010	2	24	38.67	0.009	2	24	40.06
13	0.010	2	26	35.70	0.006	2	26	42.33
14	0.010	2	28	33.15	0.006	2	28	39.30
15	0.004	2	30	41.99	0.005	2	30	38.98

Table. 4.10

CV, No.of trees & replications required to achieve 5% SE and efficiency for different sizes of plots & blocks using method III after arranging with Canopy spread

Plot size	Without blocking				5 plot block			
	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV
1	0.873	305	305	1.14	1.022	418	418	0.98
2	0.563	127	254	0.88	0.468	88	176	1.06
3	0.458	84	252	0.72	0.385	59	177	0.86
4	0.381	58	232	0.65	0.348	48	192	0.71
5	0.319	41	205	0.62	0.274	30	150	0.72
6	0.309	38	234	0.53	0.287	33	198	0.58
7	0.316	40	280	0.45	0.344	47	329	0.41
8	0.252	25	200	0.49	0.349	49	392	0.35
9	0.272	30	270	0.40	0.270	29	261	0.41
10	0.245	24	240	0.40	0.250	25	250	0.40
11	0.271	29	319	0.33	0.115	6	66	0.79
12	0.224	20	240	0.37	0.065	2	24	1.28
13	0.204	17	221	0.37	0.206	17	221	0.37
14	0.243	24	336	0.29	0.191	15	210	0.37
15	0.181	13	195	0.36	0.180	13	195	0.37

Table. 4.10 (cont....)

CV, No.of trees & replications required to attain 5% SE and efficiency for different sizes of plots & blocks using method III after arranging with Canopy spread

	10 plot block				15 plot block			
Plot size	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV	CV	No.of Repli-cation for 5% SE	No.of trees for 5% SE	1/xCV
1	0.803	258	258	1.24	0.840	282	282	1.19
2	0.751	226	452	0.66	0.551	121	242	0.90
3	0.304	37	111	1.09	0.399	64	192	0.83
4	0.438	77	308	0.57	0.408	67	268	0.61
5	0.454	82	410	0.44	0.404	66	330	0.49
6	0.424	72	432	0.39	0.338	46	276	0.49
7	0.370	55	385	0.38	0.243	24	168	0.58
8	0.357	51	408	0.35	0.235	22	176	0.53
9	0.263	28	252	0.42	0.267	29	261	0.41
10	0.225	20	200	0.44	0.302	36	360	0.33
11	0.203	16	176	0.44	0.242	23	253	0.37
12	0.174	12	144	0.47	0.228	21	252	0.36
13	0.174	12	156	0.44	0.192	15	195	0.40
14	0.202	16	224	0.35	0.199	16	224	0.35
15	0.201	16	240	0.33	0.167	11	165	0.39

Table. 4.11

Different models fitted to /S/ along with the R^2 values for Method I

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	$410x10^{-6}$	$-226x10^{-2}$		99**
$Y = a/x+b/\sqrt{x}+c$	$127x10^{-5}$	$-99x10^{-5}$	$186x10^{-6}$	98**
$Y^{-1}= a+blogx$	$-320x10^{3}$	$862x10^{3}$		65**
$Y^{-1}= ax+b\sqrt{x}+c$	$204x10^{3}$	$-657x10^{3}$	$515x10^{3}$	96**
5 plot block				
$Y = ax^{-b}$	$119x10^{-7}$	$-229x10^{-2}$		64**
$Y = a/x+b/\sqrt{x}+c$	$-812x10^{2}$	165x10	$-423x10^{3}$	73**
$Y^{-1}=a+blogx$	$-134x10^{5}$	$560x10^{5}$		10
$Y^{-1}=ax+b/\sqrt{x}+c$	$-122x10^{5}$	$823x10^{5}$	$-925x10^{5}$	11
10 plot block				
Y = ax-b	48x10-6	-225x10-2		82**
$Y = a/x+b/\sqrt{x}+c$	10x10-5	-75x10-6	142x10-7	92**
Y-1=a+blogx	-365x104	981x104		47*
Y-1=ax+b$\sqrt{x}$+c	181x104	-495x104	312x104	63*
15 plot block				
$Y = ax^{-b}$	$10x10^{-5}$	$-231x10^{-2}$		84**
$Y = a/x+b/\sqrt{x}+c$	$5x10^{-5}$	$-11x10^{-7}$	$-36x10^{-7}$	86**
$Y^{-1}=a+blogx$	$-194x10^{4}$	$522x10^{4}$		48*
$Y^{-1}=ax+b\sqrt{x}+c$	$718x10^{3}$	-142x104	$373x10^{3}$	61*

** Significant at 1%

* Significant at 5%

Table. 4.12

Different models fitted to CV along with the R^2 values for Method I

	a	b	c	R^2
<u>Without blocking</u>				
$Y = ax^{-b}$	0.821	-0.276		98**
$Y = a/x+b/\sqrt{x}+c$	0.110	0.501	0.265	99**
$Y^{-1} = a+b\log x$	1.140	1.150		98**
$Y^{-1} = ax+b\sqrt{x}+c$	-0.114	1.009	0.268	99**
<u>5 plot block</u>				
$Y = ax^{-b}$	0.904	-0.607		86**
$Y = a/x+b/\sqrt{x}+c$	-0.268	1.224	-0.131	93**
$Y-1=a+b\log x$	0.342	4.301		75**
$Y-1=ax+b\sqrt{x}+c$	0.048	1.466	-0.526	79**
<u>10 plot block</u>				
$Y = ax-b$	0.885	-0.608		91**
$Y = a/x+b/\sqrt{x}+c$	-0.009	0.905	-0.061	96**
$Y^{-1}=a+b\log x$	0.265	4.485		77**
$Y^{-1}=ax+b\sqrt{x}+c$	0.389	-0.135	1.138	88**
<u>15 plot block</u>				
$Y = ax^{-b}$	0.817	-0.541		84**
$Y = a/x+b/\sqrt{x}+c$	-0.049	0.904	-0.043	94**
$Y-1=a+b\log x$	0.726	3.636		68**
$Y-1=ax+b\sqrt{x}+c$	-0.375	3.279	-2.181	71**

** Significant at 1%

* Significant at 5%

Table. 4.13

Different models fitted to /S/ along with the R^2 values for Method II after arranging with Trunk girth

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	$480x10^{-5}$	$-172x10^{-2}$		98**
$Y = a/x+b/\sqrt{x}+c$	$980x10^{-6}$	$-62x10^{-5}$	$106x10^{-6}$	99**
$Y^{-1} = a+blogx$	$-652x10^{2}$	$192x10^{3}$		66**
$Y^{-1} = ax+b\sqrt{x}+c$	$428x10^{2}$	-133x103	$107x10^{3}$	93**
5 plot block				
Y = ax-b	432x10-5	$-303x10^{-2}$		89**
$Y = a/x+b/\sqrt{x}+c$	23x10-3	-20x10-3	4x10-3	95**
Y-1=a+blogx	-596x103	127x104		29
Y-1=ax+b$\sqrt{x}$+c	621x103	-254x104	231x104	72**
10 plot block				
$Y = ax^{-b}$	$76x10^{-4}$	$-334x10^{-2}$		96**
$Y = a/x+b/\sqrt{x}+c$	$13x10^{-3}$	-10x10-3	$2x10^{-3}$	98**
$Y^{-1}=a+blogx$	$-578x10^{3}$	$126x10^{4}$		36
$Y^{-1}=ax+b\sqrt{x}+c$	543x103	$-216x10^{4}$	$192x10^{4}$	79**
15 plot block				
$Y = ax^{-b}$	39x10-4	$-294x10^{-2}$		99**
$Y = a/x+b/\sqrt{x}+c$	$143x10^{-4}$	$-119x10^{-2}$	$23x10^{-4}$	97**
$Y^{-1}=a+blogx$	$-188x10^{3}$	$479x10^{3}$		58**
Y-1=ax+b$\sqrt{x}$+c	115x103	-373x103	285x103	87**

** Significant at 1%

* Significant at 5%

Table. 4.14

Different models fitted to CV along with the R^2 values for Method II after arranging with Trunk girth

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	0.823	-0.250		97**
$Y = a/x+b/\sqrt{x}+c$	0.078	0.497	0.297	98**
$Y-1= a+b\log x$	1.157	1.002		97**
$Y-1= ax+b\sqrt{x}+c$	-0.092	0.842	0.433	97**
5 plot block				
$Y = ax^{-b}$	1.110	-0.488		76**
$Y = a/x+b/\sqrt{x}+c$	1.073	-0.033	0.272	89**
$Y^{-1}=a+b\log x$	0.707	2.117		64**
$Y^{-1}=ax+b\sqrt{x}+c$	-0.323	2.416	-1.519	67**
10 plot block				
$Y = ax^{-b}$	1.130	-0.509		95**
$Y = a/x+b/\sqrt{x}+c$	0.274	0.038	0.111	97**
$Y^{-1}=a+b\log x$	0.522	2.379		89**
$Y-1=ax+b\sqrt{x}+c$	0.023	0.826	0.029	94**
15 plot block				
$Y = ax-b$	1.154	-0.516		92**
$Y = a/x+b/\sqrt{x}+c$	0.465	0.704	0.083	97**
$Y-1=a+b\log x$	0.625	2.220		90**
$Y-1=ax+b\sqrt{x}+c$	-0.205	1.875	-1.001	91**

** Significant at 1%

* Significant at 5%

Table. 4.15

Different models fitted to /S/ along with the R^2 values for Method II after arranging with Canopy spread

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	$470x10^{-6}$	$-195x10^{-2}$		98^{**}
$Y = a/x+b/\sqrt{x}+c$	$108x10^{-5}$	$-74x10^{-5}$	$131x10^{-6}$	99^{**}
$Y^{-1} = a+b\log x$	$-112x10^{3}$	$329x10^{3}$		71^{**}
$Y^{-1} = ax+b\sqrt{x}+c$	$596x10^{2}$	$161x10^{3}$	$111x10^{3}$	95^{**}
5 plot block				
$Y = ax^{-b}$	$306x10^{-5}$	$-325x10^{-2}$		77^{**}
$Y = a/x+b/\sqrt{x}+c$	$170x10^{-4}$	$-147x10^{-2}$	$292x10^{-5}$	94^{**}
$Y^{-1}=a+b\log x$	$-314x10^{4}$	$636x10^{4}$		13
$Y^{-1}=ax+b\sqrt{x}+c$	$379x10^{4}$	$-160x10^{5}$	$149x10^{5}$	40
10 plot block				
$Y = ax^{-b}$	$181x10^{-5}$	$-275x10^{-2}$		93^{**}
$Y = a/x+b/\sqrt{x}+c$	$23x10^{-4}$	$-135x10^{-5}$	$196x10^{-6}$	99^{**}
$Y^{-1}=a+b\log x$	$-238x10^{3}$	$660x10^{3}$		56^{**}
$Y^{-1}=ax+b\sqrt{x}+c$	$124x10^{3}$	$-344x10^{3}$	$232x10^{3}$	76^{**}
15 plot block				
$Y = ax^{-b}$	$280x10^{-5}$	$-125x10^{-2}$		95^{**}
$Y = a/x+b/\sqrt{x}+c$	$23x10^{-4}$	$-174x10^{-5}$	$312x10^{-6}$	99^{**}
$Y^{-1}=a+b\log x$	$-169x10^{3}$	$497x10^{3}$		70^{**}
$Y^{-1}=ax+b\sqrt{x}+c$	$739x10^{2}$	$-164x10^{3}$	$833x10^{2}$	88^{**}

** Significant at 1%

* Significant at 5%

Table. 4.16

Different models fitted to CV along with the R^2 values for Method II after arranging with Canopy spread

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	0.819	-0.239		97**
$Y = a/x+b/\sqrt{x}+c$	0.117	0.435	0.323	99**
$Y^{-1} = a+b\log x$	1.175	0.939		98**
$Y^{-1} = ax+b\sqrt{x}+c$	-0.119	0.946	0.330	99**
5 plot block				
$Y = ax^{-b}$	1.206	-0.571		85**
$Y = a/x+b/\sqrt{x}+c$	-1.081	2.373	-0.309	85**
$Y^{-1}=a+b\log x$	0.244	2.986		76**
$Y^{-1}=ax+b\sqrt{x}+c$	0.358	-0.571	1.333	91**
10 plot block				
$Y = ax^{-b}$	1.042	-0.539		89**
$Y = a/x+b/\sqrt{x}+c$	-1.384	2.590	-0.378	93**
$Y^{-1}=a+b\log x$	0.488	2.913		85**
$Y^{-1}=ax+b\sqrt{x}+c$	-0.003	1.171	-0.297	90**
15 plot block				
$Y = ax^{-b}$	1.105	-0:541		80**
$Y = a/x+b/\sqrt{x}+c$	-0.291	1.146	0.011	86**
$Y^{-1}=a+b\log x$	1.056	1.875		69**
$Y^{-1}=ax+b\sqrt{x}+c$	-0.427	2.829	-1.645	78**

** Significant at 1%

* Significant at 5%

Table. 4.17

Different models fitted to /S/ along with the R^2 values for Method III after arranging with Trunk girth

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	$48x10^{-6}$	$-431x10^{-2}$		93**
$Y = a/x+b/\sqrt{x}+c$	$154x10^{-5}$	$-136x10^{-5}$	$273x10^{-6}$	95**
$Y^{-1}= a+b\log x$	$-397x10^{6}$	$958x10^{5}$		53*
$Y-1= ax+b\sqrt{x}+c$	$284x10^{6}$	$-101x10^{7}$	$827x10^{6}$	88**
5 plot block				
$Y = ax-b$	25x10-4	-514x10-2		97**
$Y = a/x+b/\sqrt{x}+c$	240x10-4	-212x10-4	427x10-5	95**
$Y-1=a+b\log x$	-173x106	362x106		27
$Y-1=ax+b\sqrt{x}+c$	$173x10^{6}$	$-704x10^{6}$	$635x10^{6}$	66*
10 plot block				
$Y = ax^{-b}$	$30x10^{-4}$	$-471x10^{-2}$		98**
$Y = a/x+b/\sqrt{x}+c$	$145x10^{-4}$	$-125x10^{-4}$	$247x10^{-5}$	97**
$Y^{-1}=a+b\log x$	$-246x10^{5}$	$551x10^{5}$		46*
$Y^{-1}=ax+b\sqrt{x}+c$	$211x10^{5}$	$-814x10^{5}$	$707x10^{5}$	92**
15 plot block				
$Y = ax-b$	388x10-5	$-471x10^{-2}$		99**
$Y = a/x+b/\sqrt{x}+c$	154x10-4	-135x10-4	269x10-5	96**
$Y-1=a+b\log x$	-204x105	460x105		48*
$Y-1=ax+b\sqrt{x}+c$	168x105	-641x105	550x105	92**

** Significant at 1%

* Significant at 5%

Table. 4.18

Different models fitted to CV along with the R^2 values for Method III after arranging with Trunk girth

	a	b	c	R^2
<u>Without blocking</u>				
$Y = ax^{-b}$	0.804	-0.493		98**
$Y = a/x+b/\sqrt{x}+c$	0.364	0.421	0.089	99**
$Y^{-1} = a+b\log x$	0.901	2.973		97**
$Y^{-1} = ax+b\sqrt{x}+c$	-0.153	1.913	-0.641	98**
<u>5 plot block</u>				
$Y = ax^{-b}$	1.694	-0.809		75**
$Y = a/x+b/\sqrt{x}+c$	-1.078	2.769	-0.466	77**
$Y^{-1}=a+b\log x$	-0.807	5.131		64**
$Y^{-1}=ax+b\sqrt{x}+c$	1.048	-3.088	3.283	88**
<u>10 plot block</u>				
$Y = ax^{-b}$	1.260	-0.680		92**
$Y = a/x+b/\sqrt{x}+c$	-0.822	2.350	-0.404	89**
$Y^{-1}=a+b\log x$	0.246	3.602		90**
$Y^{-1}=ax+b\sqrt{x}+c$	-0.235	2.577	-1.914	91**
<u>15 plot block</u>				
$Y = ax^{-b}$	1.214	-0.652		97**
$Y = a/x+b/\sqrt{x}+c$	0.473	0.836	-0.042	99**
$Y^{-1}=a+b\log x$	0.316	3.405		95**
$Y^{-1}=ax+b\sqrt{x}+c$	-0.150	2.074	-1.335	97**

** Significant at 1%

* Significant at 5%

Table. 4.19

Different models fitted to /S/ along with the R^2 values for Method III after arranging with Canopy spread

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	130×10^{-6}	-439×10^{-2}		96**
$Y = a/x+b/\sqrt{x}+c$	154×10^{-5}	-136×10^{-5}	271×10^{-6}	95**
$Y^{-1}= a+b\log x$	-237×10^{6}	546×10^{6}		41*
$Y^{-1}= ax+b\sqrt{x}+c$	196×10^{6}	-744×10^{6}	641×10^{6}	78**
5 plot block				
Y = ax-b	48x10-4	-561×10^{-2}		96**
$Y = a/x+b/\sqrt{x}+c$	180x10-4	-158x10-4	38x10-4	94**
Y^{-1}=a+blogx	-298x103	659x106		33
Y-1=ax+b$\sqrt{x}$+c	228x106	-853x106	711x106	62*
10 plot block				
$Y = ax^{-b}$	14×10^{-4}	-463×10^{-2}		99**
$Y = a/x+b/\sqrt{x}+c$	344×10^{-5}	-293×10^{-5}	575×10^{-6}	97**
Y^{-1}=a+blogx	-540x105	120x106		42*
Y-1=ax+b$\sqrt{x}$+c	464x105	-180x106	156x106	84**
15 plot block				
Y = ax-b	522x10-6	-438×10^{-2}		99**
$Y = a/x+b/\sqrt{x}+c$	307x10-5	-269x10-5	536x10-6	95**
Y-1=a+blogx	-598x105	137x106		52*
Y-1=ax+b$\sqrt{x}$+c	468x105	-174x106	147x106	95**

** Significant at 1%

* Significant at 5%

Table. 4.20

Different models fitted to CV along with the R^2 values for Method III after arranging with Canopy spread

	a	b	c	R^2
Without blocking				
$Y = ax^{-b}$	0.815	-0.517		96**
$Y = a/x+b/\sqrt{x}+c$	0.351	0.452	0.070	98**
$Y^{-1} = a+b\log x$	0.796	3.274		90**
$Y^{-1} = ax+b\sqrt{x}+c$	0.027	1.410	-0.167	92**
5 plot block				
$Y = ax^{-b}$	0.898	-0.656		67**
$Y = a/x+b/\sqrt{x}+c$	0.962	-0.127	0.159	91**
$Y-1=a+b\log x$	-0.086	5.775		32
$Y-1=ax+b\sqrt{x}+c$	0.260	1.017	-0.248	35
10 plot block				
$Y = ax-b$	0.916	-0.572		82**
$Y = a/x+b/\sqrt{x}+c$	-0.527	1.514	-0.174	85**
$Y-1=a+b\log x$	0.420	3.826		73**
$Y-1=ax+b\sqrt{x}+c$	0.335	-0.128	1.17	83**
15 plot block				
$Y = ax-b$	0.822	-0.535		92**
$Y = a/x+b/\sqrt{x}+c$	0.149	0.665	0.017	96**
$Y^{-1}=a+b\log x$	0.659	3.595		83**
$Y-1=ax+b\sqrt{x}+c$	0.160	0.629	0.584	90**

** Significant at 1%

* Significant at 5%

Discussion

DISCUSSION

Determinant of the scatter matrix had been used as a measure of variation in multivariate case by various workers. This measure of variation depends on the units of measurement and magnitudes of the observations. Hence it is not suitable for comparison of variation of plots of different sizes. Therefore the matrix of relative dispersion was defined. Each element of this matrix is unit free and hence the determinant. Thus /S/ facilitates comparison of plots of different sizes in the multivariate case just as coefficient of variation in the univariate case. Hence it was used as a measure of variation in the present investigation.

Three different methods of plot formation were considered in the present investigation. The third method was a slight modification of the second method proposed by Shrikande (1958). This modification was suggested in order to make maximum heterogeneity within plots so that maximum homogeneity is attained among plots. The optimum plot sizes arrived at for different block sizes by different methods and the comparison between the three methods of plot formation are discussed below.

Method I

Multivariate case

In the case of without blocking, single tree plots were found to be optimum on all the three considerations.

For blocks of size five, single tree plots were found to require minimum number of trees to achieve five percent error where as nine tree plots gave maximum efficiency and three tree plots were optimum by the method of maximum curvature.

Though nine tree plots had maximum efficiency(69.99), it required at least 18 trees to achieve five percent error while single tree plots needed only six trees to achieve five percent error and had efficiency (66.5) very nearer to that for nine tree plots. Similarly three tree plots had very low efficiency and required 18 trees to achieve five percent error. Hence single tree plots can be recommended for experiments with blocks of size five.

For blocks of size 10, two tree plots were found to require minimum number of trees to achieve five percent error and gave maximum efficiency. Optimum was found to be 18 using model II while single tree plots were found to be optimum using Smith's model by the method of maximum curvature. Two tree plots can be recommended on economic considerations.

For blocks of size 15, single tree plots were found to be optimum on all the three considerations.

<u>Univariate case</u>

In the case of without blocking, single tree plots were found to require minimum number of trees to achieve five percent SE and had maximum efficiency where as two tree plots were found to be optimum by the method of maximum curvature.

In the case of two tree plots 378 trees were required to achieve five percent standard error. But for single tree plots, 305 trees were needed to achieve five percent standard error. Hence single tree plots may be used for experiments when no blocking is adopted.

When blocking was adopted, 12 tree plots were found to requires minimum number of trees for blocks of size five, 12 tree plots for blocks of size ten and 10 tree plots for blocks of 15 plots. But single tree plots had maximum efficiency as well as optimum by the method of maximum curvature for all the three sizes of blocks.

Blocking was found to be effective in this method. single tree plots were found to be optimum in multivariate case while 10 tree plots were found to be optimum in univariate case with respect to the minimum experimental material for specified precision

Method II

Multivariate case

In the case of without blocking, single tree plots were found to require minimum number of trees to achieve five percent error and had maximum efficiency when the trees were arranged by trunk girth or by canopy spread. Three tree plots were optimum by the method of maximum curvature under both arrangements. Since single tree plots required far less number of trees compared to three tree plots, single tree plots can be used for experiments when this method is adopted.

For blocks of size five, two tree plots were found to require minimum number of trees to achieve five percent error and they had maximum efficiency under both arrangements. By the method of maximum curvature, single tree plots were optimum when arrangement was by girth while 13 tree plots were optimum when arrangement was by spread. Adoption of two tree plots in experiments will drastically reduce the number of trees compared to single tree plots or 13 tree plots and hence the cost. Therefore two tree plots can be recommended in this case.

For blocks of size ten, the minimum number of trees required to achieve five percent error was for 11 tree plots when arrangement was by girth and for single tree plots when the arrangement was by spread. Eleven tree plots were found to give maximum efficiency when arrangement was by girth whereas six tree plots gave maximum efficiency when arrangement was by spread.

Since the optimum plot sizes arrived at by different methods were not in agreement in either arrangements, a general recommendation could not be made here.

In the case of blocks of size 15, eleven tree plots required minimum number of trees to achieve five percent error and gave maximum efficiency whereas single tree plots were optimum by the method of maximum curvature when the arrangement was by girth. Eleven tree plots can be used in this case because of drastic reduction in total number of trees and hence in cost.

When the arrangement was by spread, six tree plots were found to require the minimum number of trees to achieve five percent error and gave maximum efficiency where as four tree plots gave optimum by the method of maximum curvature. Six tree plots may used for experiments with blocks of size fifteen in this case as consideration of reduced cost.

Univariate case

In the case of without blocking, single tree plots were optimum on all the three considerations under both arrangements.

For blocks of sizes five and ten a general recommendations could not be made because the optimum plot sizes arrived at by different methods were not in agreement with either arrangements.

In the case of blocks of size 15, six tree plots were found to require minimum number of trees to achieve five percent error under both arrangements. But single tree plots were optimum by the method of maximum curvature and gave maximum efficiency. Six tree plots may be used for experiments because of the reduction in the cost.

Blocking was found to be effectve in this method. Two tree plots were found to be optimum in multivariate case while six tree plots were found to be optimum in univariate case with respect to the minimum experimental material for specified precision.

Method III

Multivariate case

/S/ values for different plot sizes were very low when blocking was not adopted compared to those of blocks of different sizes. In other words blocking was ineffective under both arrangements. Arrangement with girth resulted in smaller /S/ values for all sizes of plots and blocks compared to that with spread. Therefore optimum plot sizes for no blocking only is discussed here.

Minimum number of trees required to achieve five percent error was for two tree plots (total six trees) when the arrangement was by girth and for four tree plots (total eight trees) when the arrangement was by spread. Optimum plot sizes arrived at with respect to maximum efficiency as well as by the method of maximum curvature was for larger plot sizes when arrangement was by girth and for smaller plot sizes when the arrangement was by spread. Adoption of larger plot sizes, although will achieve more precision, two tree plots will be quite sufficient for all practical purposes because of the minimum cost.

Univariate case

In the case of without blocking six tree plots were found to require minimum number of trees to achieve five percent standard error where as single tree plots were optimum by the method of maximum curvature and had maximum efficiency, when the arrangement was by girth. Six tree plots requiring least cost can be recommended for experiments in this case.

When the arrangement was by spread, 15 tree plots were found to require minimum number of trees to achieve five percent error where as single tree plots were found to have maximum efficiency. But six tree plots were optimum by the method of maximum curvature. Fifteen tree plots may be used for experiments in this case.

For blocks of size five, 12 tree plots were found to require minimum number of trees to achieve five percent error where as two tree plots gave maximum efficiency when the arrangement was by girth. But when the arrangement was by spread, twelve tree plots were found optimum with respect to the number of trees required to achieve five percent error and also gave maximum efficiency. But single tree plots were optimum by the method of method of maximum curvature. Twelve tree plots can be used as optimum under both arrangements because of the drastic reduction in cost.

In the case of blocks of sizes 10 and 15, a general recommendation was difficult because of the differences of the optimum plot sizes arrived at by different approaches.

Blocking was found to be ineffective in this method. Two tree plots were found to be optimum in multivariate case while 15 tree plots were found to optimum in univariate case with respect to the minimum experimental material for a specified precision.

Comparison of different methods

/S/ in multivariate case and coefficient of variation in univariate case were found to be low for all plot sizes when no blocking was adopted in method III compared to those in methods I and II. In other words, method III is a more efficient method of plot formation than methods I and II. Blocking was found to be effective in I and II methods of plot formation as the coefficient of variation or /S/ decreased for almost all the plot sizes when blocking was adopted.

When blocking was adopted in method III, there was no substantial reduction in the value of /S/. Hence blocking was ineffective in this method. In univariate case, for certain plot sizes, the coefficient of variation decreased and for many of the plot sizes, it increased. Therefore, one can not say on the effectiveness of blocking in general.

When the experiment is to be planned in an established garden, the third method can be adopted. The main aim of this method of plot formation is to increase variability within plots and thus achieve homogenity among plots . Experiments, forwhich fresh planting is to be done, methodI with blocking can be recommended.

As regards the different methods of determination of optimum sizes of plots, that requiring minimum number of trees for a specified precision is to be prefed over the others on economic consideration.

In the present investigation, blocking was done just to make the total number of trees in every block to be the same. If blocking is done judiciously, i.e., by proper stratification of the trees, blocking is likely to become more efficient. Pre-treatment yield would be a good covariate for experiment with Cocoa rather than the trunk girth or canopy spread since they had only very feable relationship with yield.

Summary

SUMMARY

Determination of optimum size of experimental unit based on simultaneous consideration of more than one character was attempted for the first time. The matrix of relative dispersion of 'p' characters, X_i, i=1.......p was defined as $S=(S_{ij})$ where

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

X_{ik} is the observation on i^{th} character of the k^{th} unit,
$\bar{X}_i$ is the mean per unit of the i^{th} character and
N is the total number of units.

/S/, the determinant of relative dispersion matrix was proposed as a measure of variation for comparison of plots of different sizes in the multivariate case.

The material consisted of 738 Forastero variety of cocoa trees grown in the Kerala Agricultural Development Project(KADP) farm, Vellanikkara of the Kerala Agricultural University. The following three methods of plot formation were used in the present investigation

Method I

The whole set of trees were divided into compact blocks of different sizes and plots of one to fifteen trees were formed by combining adjacent trees in the field.

Method II

All trees were arranged in descending order of magnitude of trunk girth and of the canopy spread separately and were divided into blocks of required size. Plots of one to fifteen trees were formed by combining adjacent trees in the list in each block for each arrangement.

Method III

The trees were first arranged as decribed in Method II. Plots of different sizes were formed by the following procedure. Let there be nk trees in a block. Divide the nk trees into 'n' groups of 'k' trees bearing continuous serial numbers each. When 'n' is even, the i^{th} plot was formed by combining i^{th} tree from each of the first 'n/2' groups and $(k-i+1)^{st}$ tree from each of the remaining 'n/2' groups. In other words the trees having serial number i, i+k, i+2k,.......i+((n/2)-1)k, ((n/2)+1)k-i+1,......nk-i+1 form i^{th} plot in each block, were i=1,2,3,.....n.

When 'n' is odd, i^{th} plot was formed by combining the i^{th} tree from each of the first((n+1)/2) groups and $(k-i+1)^{st}$ tree from each of the remaining ((n-1)/2) groups, where i=1,2,.....n. In other words the trees having serial number i, i+k, ...i+((n-1)/2)k, (((n+1)/2)+1)k-i+1, (((n+1)/2)+2)k-i+1,.....nk-i+1 form i^{th} plot in each block, where i=1,2,3,......n.

Of the three methods of plot formation, Method III, proposed in this investigation was found to be superior to Methods I and II for experiments in established gardens. Blocking was found to be ineffective in this method. Blocking was found to be effective in I and II.

Optimum sizes of plots were determined by following three different considerations for different block sizes under each of the three methods of plot formation.

(1) Optimum plot size is that which requires minumum experimental material for a specified precision. For the purpose, the number of replications to achieve P% error in multivariate case was proposed as

$$r = |S|^{1/p}/(P/100)^2$$

(2) Efficiency ~~per tree~~ for plot of x trees was taken as 1/xCV where CV is the coefficient of variation for plots of x trees in univariate case and $1/x \sqrt[p]{|S|}$ in multivariate case. That size which has maximum efficiency was considered as optimum.

(3) Optimum plot size also was obtained by the calculus method of maximum curvature, using best of four emperical models.

Of the three approaches, the first approach was recommended on economic considerations. The third method of plot formation without blocking was recommended for experiments in established gardens with two tree plots and the first method for those with fresh planting with single tree plots in small blocks.

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OPTIMUM SIZE OF PLOTS IN COCOA
(*Theobroma cacao* L.) - A MULTIVARIATE CASE

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A procedure to determine optimum size of experimental units in the multivariate case was proposed. For the purpose, the matrix of relative dispersion was defined and its determinant was used as the measure of variation for comparison of plots of different sizes. This procedure was illustrated with the help of observations on three characters of 738 trees of 'Forastero' variety of cocoa raised in the KADP farm of the Kerala Agricultural University, Vellanikkara. Optimum plot size also was obtained in the univariate case.

The following three different methods of plot formation were used in this investigation.

Method I

The whole set of trees were divided into compact blocks of different sizes and plots of one to fifteen trees were formed by combining adjacent trees in the field.

Method II

All trees were arranged in descending order of magnitude of trunk girth and of the canopy spread separately and were divided into blocks of required size. Plots of one to fifteen trees were formed by combining adjacent trees in the list in each block for each arrangement.

Method III

The trees were first arranged in descending order of magnitude of each character and they were divided into blocks of required size. Plots of different sizes were formed within each block by the following procedure. Let there be 'nk' trees in a block. The nk trees were divided into 'n' groups of 'k' trees each bearing continuous serial numbers. When 'n' is even, the i^{th} plot was formed by combining i^{th} tree from each of the first 'n/2' groups and $(k-i+1)^{st}$ tree from each of the remaining 'n/2' groups, where i=1,2,....n. When 'n' is odd, i^{th} plot was formed by combining the i^{th} tree from each of the first $((n+1)/2)$ groups and $(k-i+1)^{st}$ tree from each of the remaining $((n-1)/2)$ groups, where i=1,2,.....n.

Of the three methods of plot formation Method III, which was proposed in this study was found to be superior to Methods I and II for experiments in established gardens and Method I for experiments for which fresh planting is required

Optimum size of plots were also determined by three different methods viz.,

(a) that which requires mininmum experimental material for a specified precision
(b) that which has maximum efficiency and
(c) that for which the best fitting model has maximum curvature.

Of these three methods, the first one was found to be superior to the other two on economic considerations.

Two tree plots were found to be the optimum in multivariate case and 15 tree plots in univariate case when plots were formed by method III, without blocking, after arranging with trunk girth.