MODIFIED STATISTICAL METHODS ON ESTIMATION OF OPTIMUM PLOT SIZE IN CASSAVA (*Manihot esculenta* Crantz)

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Modified Statistical Methods on Estimation of Optimum Plot Size in Cassava** (*Manihot esculenta* Crantz)" is a bonafide record of research work done by me during the course of research and 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.

Place: Vellayani,
Date: 04-10-2017

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CERTIFICATE

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We, the undersigned members of the advisory committee of **Ms. Rakhi,T.,** for the degree of **Master of Science in Agricultural Statistics**, agree that the thesis entitled "**Modified Statistical Methods on Estimation of Optimum Plot Size in Cassava** (*Manihot esculenta* Crantz)" may be submitted by **Ms. Rakhi,T.,** in partial fulfillment of the requirement for the degree.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

GDP	Gross Domestic Product
CV	Coefficient of Variation
et al.,	Co workers
t ha^{-1}	Tons per Hectare
K	Potassium
m^2	Square metre
m	Metre
cm	Centimetre
R^2	Coefficient of Determination
ha	Hectare
MAP	Months After Planting
VH	Vellayani Hraswa
SP	Sree Pavithra
Kg	Kilogram
g	Gram
SD	Standard Deviation
df	Degrees of freedom
SS	Sum of squares
MS	Mean sum of squares
Min	Minimum
Max	Maximum

Introduction

1. INTRODUCTION

Agriculture is the single largest sector of India, contributing 16.5% of the gross domestic product (GDP) and providing employment to over 58% of the rural people (FIB, 2015). The agricultural field experiments have become important in research field for new innovations in variety improvement and technology development. For the conduct of field experiments, it is important for the research workers to have knowledge on field plot technique, mainly the plot size and shape best suited for the different situations. It is relevant to use the most efficient shape, size and arrangements of plots in every experiment for obtaining the most precise results with least variability. The main aim of most of the agricultural field experiments is the efficient estimation of treatment contrasts. To achieve this, it is necessary to control field variations or experimental error that may be due to fertility gradient and other uncontrollable factors like environmental factors.

In field experiments, soil variability is one of the important external sources of variation. This variability may be random or systematic. Usually researchers assume that the errors are independently and randomly distributed and they use block design experiments to minimize this source of variation. The experimental error depends on the block and plot (unit) size and their orientation. The precision of measurement frame of blocks lies in the control of heterogeneity within blocks. Generally, the greater the heterogeneity within blocks, the poorer the precision of variety effect estimates. Therefore incomplete block designs become more popular in varietal trials involving 10 or more treatments. The precision of significance tests in field trial is largely controlled by size and shape of plots, which are further controlled by the size and shape of area available for the particular experiment and the nature of fertility or inherent soil conditions. To cope with the problem of the research workers, it has become necessary to standardize a suitable plot size and shape for the experimental plot of major crops grown under different field conditions, which will reduce the standard error of the experiments. Field-plot techniques deal with the various elements of a properly planned agricultural field experiment, thus increasing the precision. The use of improper field-plot techniques may increase experimental error and lead to unsound inferences. Hence, to improve the quality as well as credibility of research results, there is a need to carry out research on field-plot techniques.

1.1 OPTIMUM PLOT SIZE

Size and shape of experimental units will affect the accuracy of the experiment. Selection of a plot with optimum plot size is essential for this purpose. Minimum size of experimental plot for a given degree of precision is known as **Optimum plot size** (Bueno and Gomes, 1983). Optimum plot size for an experiment depends on crop, available land area, number of treatments etc.

The selection of suitable size and shapes of the plots and blocks depends both on statistical considerations as well as practical feasibility. From statistical considerations the estimate of treatment on a given experimental area should be obtained with maximum accuracy and from practical point of view, the plots should be sufficiently large so that the various field operations can be done correctly. The shape of the plots and blocks is usually decided by the nature of the experiment and the area of the land available. However, rectangular and square plots are generally preferable for almost all crops.

The following factors need to be considered while determining the optimum plot size of an experimental unit:

- **Practical Consideration**: Certain practical aspects need to be considered while determining optimum plot size. Some constructions may already exist in the field, so it is not easy to change such constructions. If machines are used for harvesting or for intercultural practices, fairly large area is required. In case of green house, the experimental units have small area or number.

Experimental resources available also need to be considered in determining the plot size.

- **Nature of experimental material**: Plot size required for different crops varies according to varieties, spacing, etc.
- **Number of treatments per block**: Incomplete block designs may be used if there is large number of treatments to be tested.
- Variability among individuals or units within the experimental units (V_s) relative to the variability among experimental units (V_p) treated alike is another factor. The variance of treatment mean is proportional to $[V_p+V_s/k]$, where k is the replications or number of units that makes a particular plot. The relative size of V_p and V_s has considerable effects on optimum plot size.
- **Cost**: Let C_s be the cost of individual item within experimental unit which is independent of the cost of experimental unit and let C_p be the cost of experimental unit, independent of individuals in the unit. Then the cost per treatment with a single replication is $kC_s + C_p = C_t$ and the total cost of experiment is a random variable C_t ; the optimum size thus depends on the ratio of C_s and C_p (Krishan, 1995).

A uniformity trial is a trial conducted over an experimental material by selecting a particular variety of a crop and for the entire experimental unit uniform treatments are given. At harvest, the experimental unit is divided into small basic units (depending on the crop) and yield is recorded. Then to find the optimum plot size, the basic units are combined by adding the basic units in rows or columns. While combining rows or columns, no row or column should be left out. Then for the new units formed, we calculate coefficient of variation (C.V.) and based on the C.V. values the optimum plot size is determined. The size of the basic unit is governed mostly by available resources. The smaller the basic unit, the more detailed is the measurement of soil heterogeneity (Sardana *et al*., 1967).

There is not much information available regarding the optimum plot size and shape of various agricultural crops in India. Therefore, it is desirable to study the problem of uniformity trails for all major agricultural crops, cultivated under different conditions in different parts of the country. With the introduction of new high yielding disease resistant varieties of different crops and improved technology in agriculture, new investigations on optimum plot size and shape and different block arrangement for various crops are required.

Cassava (*Manihot esculenta* Crantz) which was believed to have originated from Brazil introduced into India by the Portuguese during the 17th century is now cultivated in about thirteen states of India with a major production in the South Indian states of Kerala (71100 ha) and Tamil Nadu (120600 ha) in 2013-14. In India 60 percent of production is used for the production of sago, starch and chips and we have a demand – supply gap of 1.5×10^6 tons of tapioca production (Sreenivas, 2007). However major production of cassava is used for household consumption in Kerala. Kerala state accounted for 45.5 per cent in area, 58.74 per cent in production to all India area and production in 2001- 02 (Edison *et al.*, 2006).

Realizing the importance of Cassava (*Manihot esculenta* Crantz) , one of the major tropical drought tolerant root crops grown in Kerala which is grown approximately in 102 countries of the world, with a major production from Africa, Asia and South America (FIB, 2012), the present study was to determine the optimum experimental plot size of Cassava. It is the second most important tuber crop after potato in India. It is the third largest source of food carbohydrates in the tropics after rice and maize. Cassava is not only a major staple food in the developing world but its use in industry is also on the increase for products like starch, sago, biodegradable plastic and biofuel. Cassava's advantage over other food crops includes its flexibility in planting time, harvesting time and its drought tolerance ability. Hence precise experimental techniques are required to have a better crop of cassava.

Keeping the above in view, Modified statistical methods on estimation of optimum plot size in cassava (*Manihot esculenta* Crantz) is conducted with the following objectives:

- To develop modified statistical methods for estimation of optimum plot size for field experiments.
- To identify the best experimental plot size for branching and non-branching type of cassava.
- Use a multivariate technique in discriminating branching and non-branching varieties of cassava.

1.2 PLAN OF STUDY

The outline of research work is divided into five chapters. In chapter 2, a brief account of previous works related to the study has been reviewed (review of literature). In chapter 3, a brief description of data as well as details of methodology used for the present study is described. The fourth chapter gives research results, its interpretations and the discussions are made. The fifth chapter summarizes the work carried out and conclusion drawn on the basis of the results obtained. At last a list of relevant references is included.

Review of Literature

2. REVIEW OF LITERATURE

Developing the framework for a study based on the ideas and concepts gathered from review work of existing literature of both theoretical and empirical nature will facilitate planning the study in a comprehensive and a systematic manner. It also helps us to know the previous work done in that area for different agricultural crops and acts as a pathway for the new research works. In this chapter efforts has been made to critically review the literature of the past research work relevant to the present study. In a uniformity trial, a particular crop variety is sown on the entire experimental plot and is uniformly managed throughout the growing season. At the time of harvest, border rows are removed from all sides of the field to reduce the interference from the neighbouring plots. Then the entire plot is divided into basic units (plots), with same size and shape. The produce from these basic units is harvested and yield is recorded separately for each basic unit. Then, the mean yield per basic unit is calculated. The advantage of a uniformity trail is that neighbouring units may be combined to form larger plots of various dimensions. The yield difference over the entire field is due to soil heterogeneity and other manual errors known as "Experimental Error". Hence all efforts in designing field experiments is to measure and control this error. Here, an attempt is made to compile the contributions made by different authors about the different methodologies adopted by them in determining the optimum plot size and shape of experimental plots. The determination of optimum plot size is an important factor in field experimentation as it is a fundamental step. Variation can be either due to crop species or due to soil heterogeneity. It is highly vulnerable to environmental, genetic and biotic factors. Soil heterogeneity is one of the consequential problems in agricultural field experimentation. So to cope up with the problem, attempts were first done to measure the degree of variation and then the methods to control it (Harris, 1920).

The objective of the present study is to develop modified statistical methods for estimation of optimum plot size for field experiments and use a multivariate technique in discriminating branching and non-branching varieties of cassava.

Low tuber yield of cassava in India has been associated with production constraints, such as unavailability of improved varieties and problems associated with climatic, soil, and biotic factors. Efforts are being made to develop new, improved genotypes that are high yielding with a stable yield across diverse agro-ecological zones (Rekha *et al.*, 1991).

Branching and non-branching types of cultivars are common in cassava with varying space requirements, plot size and duration. Discriminant function analysis is a multivariate statistical methodology used to classify genotypes with varying properties (Singh and Chaudhary, 2012). In breeding programmes, this function helps to construct an index to measure the advantage in selection based on measurements on a number of observable characters. This function can be used to classify the cultivars, and in turn useful in identifying optimum plot size depending on its type.

Vellayani Hraswa (released in 1998) is a short duration (155-180 days), high yielding (44 t ha^{-1}) variety recommended for southern districts of Kerala. Tubers of this variety have creamy white flesh with very good cooking quality (Pushpakumari *et al.*, 2015).

Sree Pavithra is the potassium efficient cassava variety which yields high (35-45 t ha^{-1}) and has excellent cooking quality, having low cynogenic glucoside (25.8 ppm) content and high K efficiency (243.65 kg tuber/kg K absorbed). It is suitable for cultivation in Kerala soils, which are inherently low to marginal in soil exchangeable K (Sheela *et al.*, 2016).

Keeping in view the objective of the study, the reviews are presented under the following headings:

2.1 Uniformity trials

2.2 Plot size and Shape

2.3 Discriminant function Analysis

2.1 UNIFORMITY TRIALS

Uniformity trial is one of the best methods to measure the soil heterogeneity. A uniformity trial is a trial conducted over an experimental material by selecting a particular variety of a crop and for the entire experimental unit, uniform treatments are given. At the time of harvest, the experimental unit is divided into small basic units (depending on the crop) and yield recorded separately (Gomez and Gomez, 1976).

2.1.1 Fertility/Productivity Contour Map

With the use of uniformity trial data fertility/productivity contour map can be prepared by studying the fertility gradient existing in a particular piece of land. Buckman and Brady (1960), stated that soil productivity means the ability of the soil to yield crops. Naturally, productivity of the soil is reflected by yield figures and hence the name "Productivity Contour Map". Adjacent areas are relatively more homogeneous while distant areas are heterogeneous, a point which facilitates the application of Fisher's principle of 'local control' in experimental design (Federer, 1967). The soil productivity contour map provides the information on the soil heterogeneity. Contour map describes graphically the productivity level of the experimental plot based on moving averages of adjacent units (Gomez and Gomez, 1976).

2.1.2 Intra Class Correlation As A Measure Of Soil Heterogeneity

Another approach is to calculate intraclass correlation from adjacent yield figures (Harris, 1920). Divide the entire field into N plots of unit size and P is the yield of an individual unit plot, Harris point outs that if heterogeneity in the experimental field are so large as to influence the yield of areas larger than single plot, these will bring similarity in adjoining plots, some tending to have higher yield than the average and others with lower yield. Thus, Harris stated that a composite index obtained from the m individual correlation coefficients computed between unit plots within each larger plot reflects the extent of soil heterogeneity. He proposed using the intraclass correlation coefficient of yields from adjacent areas as coefficient of heterogeneity.

2.1.3 Soil Heterogeneity Index by Smith

Smith (1938) introduced an empirical relationship between plot size and its variance as a measure of determining soil heterogeneity. The law states that

$$V_x = \frac{V_1}{x^b}$$

Where Vx is variance of yield (per unit area) among experimental plots of size x elements;

V_1 is the variance among plot of size unity and b is the regression coefficient which indicates relationship between adjacent individuals. If the experimental unit is composed of a random selection of x individuals, $b = 1$ and if the x individuals are identical, $b = 0$ and when there is correlation between adjacent elements, b will be less than unity. Smith computed b values for 39 different sets of uniformity trial data conducted on different crops. He found that mostly the values of b ranges between 0.2 and 0.8.

2.2 PLOT SIZE AND SHAPE

The selection of optimum plot size and shape depends on statistical consideration as well as practical feasibility. The choice of suitable plot's size and shape depends upon amount of experimental material available for the experiment as well as the facilities available for handling the plots. Based on the nature of treatment and nature of experimental material, different plot sizes are required for different crops. Plot size itself influence experimental error. It is important to distinguish between the effects of length of plot and the plot width.

2.2.1 Plot Size

Kulkarni *et al.*, (1936) conducted uniformity trial on the field crop Jowar and concluded that, as the size of the plot increases, the percentage of standard deviation decreases steadily. But for a given size of the experimental field, an increase in plot size also means a reduction in the number of replications. Thus the experiment error can be reduced by decreasing the percentage standard deviation due to increase of plot size.

Khurana *et al.*, (1992) conducted uniformity trial on soybean and he stated that, the coefficient of variation (%) decreases steadily as the size of the experimental field increases. Relative efficiency decreased with increase in plot size due to increase in variability of soil.

Zhang *et al.* (1993), conducted uniformity trial on wheat and concluded that variability decreases as plot size increases. As the plot size increases, variability decreases. Larger plot size results in higher cost of sampling.

Leilah and Al-Barrak (2005) conducted uniformity trial on sorghum and concluded that, with the increase in plot size, the variance among plots also increases. On the contrast, the variance per basic unit and coefficient of variability tends to decrease with each unit increase in plot size.

Lucas and Lori (2007), stated that based on the estimates of Smith's index of soil Heterogeneity (b) and experimental optimum plot sizes for bordered and unbordered plots for cotton were 22.3 m^2 and 9.6 m^2 for height; 72.2 m^2 and 39.2 m^2 for number of bolls; and 37.9 m^2 and 18.8 m^2 for yield, respectively.

Hatheway and Williams (1958) established the relation $E(\log V_x) = E(\log V_1) - b(\log V_x)$ where E is the expectation, b is the regression coefficient of V_x on log x, x is the number of units per plot, V_1 is the variance among the plots of size unity and V_x is the variance of mean per unit area for plots of size x units. This formula requires a finite population correction when the size of the block is small as compared with the size of the plot.

Sardana *et al.* (1967) found that optimum plot size for field experiments with potato was about 8.4 m^2. Pahuja and Mehra (1981) suggested a simple modification to the already known Smith's equation for determining the optimum plot size, as $V_x=V_1/x^b$ where $b=b^*/2$, b^* is the constant in Smiths equation, in field experiments with chick pea. The result of the experiments indicated that Coefficient of Variation (CV) showed no general trend with varying plot size. However, with 4 replications maximum precision could be obtained from a plot size 1.5 m x 50 cm. But with this CV, a difference of less than 17% of the mean could not be detected. Therefore larger plots were recommended so that difference of 10 to 15% was detectable. Iyer and Agarwal (1970) pointed out that in field experiments with sugarcane the CV decreased with an increase in plot size either in length or in breadth but the decrease was more rapid with increased length.

Prabhakaran and Thomas (1974) reported that the shape of plot do not have any consistent effect on the CV. However for a given plot size long and narrow plots generally yielded lower CV than square plots of the same dimension. The optimum plot size for cassava was computed to be about 20 m^2.

When fertility patterns of experimental area is unknown or when border effects are comparatively larger, it is advisable to go for square plots (Gomez and Gomez, 1976). One of the first methods used to determine the optimum plot size in field experiments for several crops is the maximum curvature method using CV. The Smith's variance law and its modifications are also used. In these methods, a uniformity trial conducted in a pre-determined area is harvested in basic units, which are combined to form experimental plots of various sizes. When the CV has been obtained, for each plot size, they are represented graphically against the size of each plot assessed. The optimum plot size is determined visually corresponding to the point of maximum curvature (Prabhakaran *et al.*, 1978).

Some important aspects that determine the optimal size of the plot includes the presence or absence of border, crop type, number of treatments, the level of technology employed in the area of cultivation and availability of financial sources (Bueno and Gomes,1983)

To determine the optimal size of plots, the comparison of variances is used. Viana *et al.* (2003) used modified maximum curvature method and Hatheway's method to determine the optimum plot size for experiments on cassava. More reliable results were obtained using the modified maximum curvature method. Using this method, the optimum experimental plot size for cassava was estimated to be 15.02 m^2 (26 plants).

Leandro *et al.* (2010) collected sunflower seed yield figures for plots of 1 m rows (0.4 m spacing). Plots of different sizes were made and the mean, variance and CV for each plot size and the production heterogeneity index were estimated, optimal plot size and experimental precision were measured. The sunflower seed production heterogeneity index was high, then the the plots were large and the rows were the blocks. The optimal plot size is two rows (0.4 m spacing) and 3 m long (2.4 m^2)

Patil *et al.* (2010) conducted studies on Bengal gram cultivar ICCC-37 and found 12 m^2 as optimum plot size for bengal gram under dry land situations. Rectangular plots were found to be more efficient in minimising the error variability compared to square plots.

The aim of the study by Storck *et al.* (2010) was to determine experimental optimal plot size in corn and they performed uniformity trials required to estimate optimum plot size. The optimum plot size for evaluating corn cob mass was a row 5m in length.

Prajapathi *et al.*, (2011) worked out optimum plot size for field experimentation in mustard crop. The optimum plot size was found to be 20 basic units (5m x 3.6m) with 6 replications using maximum curvature method.

A linear model has been constructed by Shukla *et al.* (2013) for uniformity trial experiments and it has shown better results as compared to existing models.

The modified maximum curvature method was developed to increase the precision of the maximum curvature method. In addition, other methods like comparison of variance, weighted regression, maximum distance method etc. are also attempted to work out the plot size and size and shape of blocks. These estimates vary even for the same crop or variety depending on date of planting and field conditions (Michel *et al.*, 2015).

Nair (2015) developed modified methods for determining optimum size and shape of plots for field experiments in rubber by ranking of the trees based on its yield.

Schmildt *et al.* (2016) studied the optimum plot size and number of replications in papaya field experiments. They concluded that optimum plot size required differs among varieties, between variables and between planting seasons, while the largest number of plants was required for the variables - number of fruits per plants and yield per plant. They found that optimum number of papaya plants planted in the field is six plants per plot using 3 replications.

Facco *et al.* (2017) estimated the plot size for the evaluation of fresh matter of sun hemp estimated by the method of maximum curvature method. It was inferred that optimum plot size depends on basic experimental unit's size.

2.2.2. Plot Shape

The combination of unit plots in different dimensions leads to different plot shapes. For example shape of 1 x 2 m^2 is different as that of 2 x 1 m^2. This leads to the soil heterogeneity among plots for particular shape. This can contributes to experimental error ultimately; therefore choice of suitable plot shape is vital in order to reduce the experimental error.

A study in this line by Christidis (1931) showed that (a) long and narrow plots are more uniform than square plots (b) Smaller the value of *W/L* (*W*= Width,

L=Length) the more uniform the experimental units. But Smith (1938) stated long narrow plots were more variable than square plots. Cochran (1940) showed that in case of fertility gradient being unidirectional, variance is least when plots are aligned along the fertility gradient and is less than that of square plots.

Reddy and Chetty (1982) conducted an experiment to study the effect of plot shape on variability. They used Smith's variance law. Here Fairfield Smith's variance law is extended to study simultaneously the effect of plot size and its rectangularity on variance. They generated yield data from uniformity trial for two seasons. The results showed that there is substantial reduction in variance due to rectangular plots. For a given gross plot area, the net area to be harvested in the case of a square plot is more than that from rectangular plot. So rectangular plot will only be efficient when the reduction in variance is more than that of square plots, it is due to an increase in the net plot size in the case of square plots of the same gross plot size.

Zhang *et al.* (1993) conducted uniformity trial in wheat and concluded that plot shape affect sample variance. The relationship between sample variance and plot shape is determined by the soil heterogeneity indices. Sample plots having their greatest dimension in the direction with the greatest index will give more precise results (less variation) than plots with other shapes.

Agnihotri *et al.* (1996) worked on the size and shape of plots and blocks for field experiment with eucalyptus in Shivalik hills and observed that block efficiency decreases with increase in block size. It is found that block shape had no consistent effect.

Mohammad *et al.* (2001) studied size and shape of plots for wheat trials in field experiments on 29 different data sets using the heterogeneity index. Finally, optimum plot sizes were estimated under different situations for plant height, grain yield and straw yield.

Bhatti and Rashid (2005) conducted a research work on the effect of shape and size of plots on spatial variability in cotton yield using statistical procedures such as frequency plot analysis and semivariogram analysis on nature and magnitude of variability in the yield data obtained from different plot shape and size. Results proved that there was a considerable variation in yield data from different plot sizes and shapes. As the plot size increases variability decreases. The optimum plot sizes were observed to be 2 m x 4 m and 8 m x 2 m units for field experiments on cotton.

Leilah and Al-Barrak (2005) conducted uniformity trial on sorghum and found out that, plot shape was found to be not important on plot to plot variability with the smaller plot sizes.

Lucas and Lori (2007) conducted uniformity trial on cotton and concluded that, plot shape had no significant effect on plant height but there were effects on bolls and seed cotton yield. This may be due to the presence of fertility gradient in the length of the experimental area. A plot shape of 4 rows x 64 hills was recommended for cotton.

Masood *et al.* (2012) conducted an experiment to study the optimum plot size and shape for field research experiments on paddy yield trials. They adopted maximum curvature method and compared variances using yield data on 12 m x 24 m (288 basic units) recorded separately from each basic unit of 1 m x 1 m. Soil heterogeneity *(b)* was found to be 0.122 which indicate a low degree of similarity among the plots. Based on maximum curvature method the optimum plot size for paddy yield trial was estimated to be 6 m x 3 m with rectangular shape for Rice

Research Institute, Lahore. The study results indicated that C.V. decreases (35.25, 23.8, 21.5) with an increase in the plot size (1 m, 2 m, 3 m) respectively and this decrease was maximum with the square shape of plot of size 6 m x 6 m basic units. As a result, square shape of the plot seems to be better for larger plot size of that area.

2.3 DISCRIMINANT FUNCTION ANALYSIS

Discriminant function analysis is a multivariate statistical technique for comparing and classifying composite samples into different groups based on a number of related variables.

Discriminant technique was used by Fairfield (1936) for selection in plants, and by Panse (1946) for selection in poultry. He obtained discriminant function by giving economic weightage to the genotypic characters under consideration.

The discriminant function techniques have been applied for classificatory problems by Murty *et al.* (1965) and they used D^2 statistics for genetic divergence in Brassica variety of brown sarson for the classification of the species and sub-species.

Minhajuddin *et al.* (2004) proposed a method to simulate the joint distributions which have equal positive pair-wise correlations and the method was illustrated for the *p*-dimensional families of beta (β) and gamma (Γ) distributions.

Sever *et al.* (2005) compared Fisher's discriminant analysis under normal and skewed curved normal distribution based on the apparent error rates, which were used as a measure of classification performance, and found that Fisher's discriminant analysis to be highly robust under skewed curved normal distribution.

Todorov and Pires (2007) studied the comparative performance of several robust linear discriminant analysis methods for classificatory purposes.

Materials and Methods

3. MATERIALS AND METHODS

The details of experimental material which served as database for the present study and the method of data treatment are discussed in this chapter.

3.1 DESCRIPTION OF THE EXPERIMENTAL SITE

3.1.1 Location and Climate

The experiment was carried out in an area of 400 m^2 at Instructional Farm, College of Agriculture, Vellayani. The Farm experiences a warm humid tropical climate. During the cropping season all the weather conditions were favourable for the crop except that there was high rainfall during later stages of crop growth but got a favourable climate during harvest.

3.1.2 Topography

The farm is situated at an altitude of 29 m above mean sea level (MSL) and is located at a latitude of $8^0 25'$ N and longitude $76^0 59'$ E

3.1.3 Soil Type

The soil of the experimental area was well drained laterite, gravelly and sandy loam.

3.2 MATERIALS

3.2.1. Crop Variety

As the part of research work, two varieties of cassava *viz.,* Vellayani Hraswa, a branching variety having duration of 6 months and Sree Pavithra, a non branching variety with duration of 8 to 10 months were planted in an area of 400 m^2 (ten cents). Two nodded setts were planted in the protray separately during the month of March 2016. After one month these were planted in the main field with spacing 75cm x

75cm for non-branching type and 90 cm x 90 cm for branching type. The cultural operations confirmed to the package of practices recommended by the Kerala Agricultural University. Fertilizers were applied at the rate of 75: 50: 100 N: P: K kg per hectare. The intercultural operations like weeding, removal of excess shoot about 30 days after planting, earthing up and pesticide spray were done. Gap filling was done after 20-25 days after planting in the main field.

3.2.2 Design and Layout

A total of 245 plants of branching type and 290 plants of non-branching types were numbered and observed for the study leaving the borders on all sides. Bimonthly biometric observations were taken. Date of completion of harvest was 8th October 2016 (Vellayani Hraswa) and 14th December 2016 (Sree Pavithra). Crop was harvested individually by taking both biometric as well as yield observations.

Data were collected for the following characters on each plant:

1. Growth parameters

1. Plant height(cm) (***Ht***)
2. Inter nodal length(cm) (***In***)
3. Number of primary branches (***Np***)
4. Height of first branching(cm) (***Hb***)
5. Number of functional leaves (***Nl***)

2. Yield parameters and yield

1. Number of tubers (***Nt***)
2. Tuber weight(g) (***Tw***)
3. Tuber length(cm) (***Tl***)

4. Tuber girth(cm) (***Tg***)
5. Tuber yield/plant (kg) (***Ty***)

The experimental unit or plot is defined as total amount of material to which one treatment is applied in a single replicate. The sampling unit is that fraction or part of the experimental unit selected for a single observation or sample (Federer, 1967). Our objective is mainly to find the soil heterogeneity, optimum plot size and plot shape. Experimental area selected for Vellayani Hraswa was having 15 rows and 16 columns (240 plants) and that of Sree Pavithra 16 rows and 18 columns (288 plants).The plot shape measurements have 2 aspects : the directions or orientation *i.e.*, along or across the rows and length: breadth ratio. A shape, 2x3 means 2 unit plots across the rows and 3 unit plots along the rows, thus making an experimental unit of 6 plots *i.e.*, plot size is 6 units. Similarly (3x2) can be defined. Length: breadth is measured in actual dimensions of the plot.

Based on the preliminary data, correlation and multiple regression analysis were performed. For growth parameter analysis, among the total number of plants, a sample of 50 plants was selected at random for each variety. For yield parameters, data on all of the plants for each variety is recorded at harvest.

3.3. OBSERVATIONS ON CROP

3.3.1. Biometric Characters

3.3.1.1. Plant Height: Height of the plant from bottom to top of the plant measured in cm, was recorded as plant height and observations were recorded at bimonthly interval. The plant height at second month, fourth and sixth months are denoted as Ht_2, Ht_4 and Ht_6 respectively.

3.3.1.2. Inter nodal Length: Distance between two nodes measured in cm was considered as inter nodal length. The inter nodal length at second, fourth and sixth months are denoted as In_2, In_4, and In_6 respectively.

3.3.1.3. Total Number of Leaves plant^{-1}: Total numbers of leaves in each plant was counted, every 2 months and they are denoted as Nl_2, Nl_4, and Nl_6 respectively.

3.3.1.4. Number of Primary Branches plant^{-1}: Number of primary branches was taken at bimonthly intervals and is denoted as *Np*.

3.3.1.5. Height of First Branching: Height of first branching was measured in cm from base of the stem, at soil level to the point where 1st branching took place and it was denoted as *Hb*.

3.3.2. Yield and Yield Parameters

The tuber yield and yield parameters were measured at harvest stage of each plant separately.

3.3.2.1. Number of Tubers plant^{-1} (Nt): Number of tubers was counted from each sample plant.

3.3.2.2. Average Tuber Weight (Tw): Weight of the tuber was measured in grams (g) from each plant and average worked out.

3.3.2.3. Average Tuber Length (Tl): Length was measured in cm for each tuber from each plant and average worked out.

3.3.2.4. Average Tuber Girth (Tg): Girth was measured in cm for each tuber from each plant and average worked out.

3.3.2.5. Tuber Yield (Ty): Tuber yield from each plant was weighed and recorded in kg.

3.4 STATISTICAL TOOLS AND TECHNIQUES EMPLOYED

3.4.1 Correlation Analysis

The knowledge regarding association of various characters among themselves is necessary to understand the nature and degree of relationship between quantitative variables. This is done by performing correlation analysis. The main result of a correlation is the correlation coefficient (*r*). It ranges from -1 to +1. The closer is to +1 or -1; the more closely the two variables are related. If *r* is close to 0, it means there is no linear relationship between the variables. If *r* is positive, it means that one variable is directly depend on the other variable. If *r* is negative, there is an inverse correlation between variables. The square of the correlation coefficient is equal to the percent of variation in one variable that is related to the variation in the other. Correlation coefficient was computed to study the association between tuber yield and biometric characters and yield and yield attributes. The analysis was done for each variety

$$r = \frac{covariance\ (X,Y)}{Standard\ deviation\ (X)\ standard\ deviation\ (Y)} = \frac{cov\ (X,Y)}{\sqrt{v(X)v\ (Y)}}$$

$$r = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2\ \Sigma(y_i - \bar{y})^2}}$$

Where, $cov\ (X,Y) = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})$

$$v(X) = \frac{1}{n-1}\Sigma(X_i - \bar{X})^2$$

$$v\ (Y) = \frac{1}{n-1}\Sigma(Y_i - \bar{Y})^2$$

$$r \in [-1,1]$$

The significance of correlation coefficients was tested using critical value (Fisher and Yates, 1963) of '*r*' for n-2 degrees of freedom (df) at the probability $p = 0.05$ and $p = 0.01$ level of significance, n is the sample size.

3.4.2 Multiple Regression Analysis

In agriculture, statistical models play a vital role in prediction of crop yield before harvests of the crops. An effort was made to develop the prediction models for the yield of the crop with biometrical observations for every bimonthly interval; one which was found to be significant was selected. In case, there is more than one model; the best models were selected based on values of R^2, adjusted R^2 and Mallow's C_P.

3.4.2.1 Coefficient of Determination (R^2) indicates proportion of variance in the dependent variable accounted by regression. It is computed using sum of squares.

$$R^2 = \frac{\beta' X'Y - n\bar{y}^2}{Y'Y - n\bar{y}^2}$$

$$R^2 = 1 - \frac{Y'Y - \beta' X'Y}{Y'Y - n\bar{y}^2}$$

Where Y is the column vector of observations of the dependent variable, X is the matrix representing predictor variables (including the first column of unity) and β is the vector of estimated partial regression coefficients.

The value of R^2 ranges from 0 to 1; indicate the extent to which the dependent variable can be predicted. An R^2 value of 0 indicates that the dependent variable cannot be predicted from the independent variables while value in between 0 to 1 indicates that the dependent variable can be predicted from the independent variable without an error.

3.4.2.2. Adjusted R^2 (R^2_{adj})

$$R^2_{adj} = 1 - (1 - R^2)\frac{n-1}{n-p-1}$$

R^2_{adj} should always be less than R^2 and it shows how the R^2_{adj} will increase if Student's '*t*' value of the added variable is greater than one (Draper and Smith, 1981). R^2_{adj} is a better measure than computed R^2 for comparative purposes. It is a modified version of R^2 which has been adjusted for the number of predictors in the model. Here, p is the number of regressor variables and n is the number of observations (Theil, 1971).

3.4.2.3. Mallow's C_p Criterion

Mallow's C_p criterion is used to find whether the model consisting of p regressors selected from k regressors is adequate or not or whether it suffers from lack of fit.

$$C_P = \frac{RSS_P}{\sigma^2} - (n-2p)$$

Where RSS_P is the residual sum of square of p regressors and n is the number of observations. Models with small C_P value have small total variance of prediction. If the C_P value is near to p it indicates that bias is small and if it is much greater than p indicate error is substantial and while it is below p it may due to sampling error and should be considered as no bias situation.

Multiple linear regression technique was used to find the linear effects of biometric characters at different stages for the two varieties. So regression models were fitted using explanatory variables. Prediction models for yield were developed with the help of biometrical observations. To know which of the predictor variables, among the ones included in the model, are most significantly contributing to the yield, the stepwise regression was carried out and the models obtained. SAS version 9.3 is used for the analysis. All multiple regression equations connecting yield (Y) with all possible combinations of predictor variables (X) were also tried. Eight parameters (X) were taken and therefore 255 models were tried for each of the varieties.

3.4.3 Soil Heterogeneity

The importance of soil heterogeneity as a source of experimental error was extensively studied during the first thirty years of 20^{th} century. Soil heterogeneity can be measured as the differences in performance of plants grown in a uniformly treated field. This study was mainly focused on characterizing soil heterogeneity in field. If crops are cultivated in uniform soil, it will produce a uniform yield. Several methods are available to measure soil heterogeneity based on uniformity trials such as construction of contour map, estimation of soil heterogeneity index etc. In this study, soil productivity contour maps were used to present soil heterogeneity.

3.4.3.1 Contour Map

Uniformity trial was conducted to know the nature of the soil fertility gradient. Under uniformity trail, a particular crop variety will be sown on the entire experiment field and uniformly managed throughout the growing period. During the harvest, border rows will be removed from all sides of the field. The remainder of the field will be divided into small plots which are known as basic units. The size of the basic unit is decided by judgment, depending on the crop and the variety. The produce from the each basic unit will be harvested and recorded separately. Then the mean yield per basic unit will be computed. The basic individual units giving yields above or below the specified percentage of the overall mean, for example 5%, 10%, 15% etc,. are marked on the plan of plots. Usually, the percentages are taken in such a way that we will get 5 to 8 groups of experimental units. The similar units are then joined by lines to produce the contour map. Such a map is called fertility contour map or fertility gradient map or soil fertility map. Using this map homogeneous experimental unit can be grouped as blocks. (Sundararaj, 1977).

A productivity contour map was prepared to know the pattern of heterogeneity existing in the field; the method was suggested by Gomez and Gomez (1976). The productivity is related to the ability of a soil to yield crops. Naturally yield values reflect the productivity of the soil and hence the name "Productivity contour map" (Buckman and Brady, 1960). Fertility Contour Map is constructed by taking the moving averages of yields of unit plots and demarcating the regions of same fertility by considering those areas, which have yield of same magnitude. For this, fertility gradient need to be calculated. This is computed by the formula,

$$\text{Fertility Gradient} = \frac{y_i - \bar{Y}}{\bar{Y}} x100$$

Where y_i is the yield of individual plot and $\bar{Y}$ is the average yield of the entire plot. Plots having similar fertility gradient will be given the same demarcation (colour).

3.4.3.2 Soil Heterogeneity Index

It gives a single value as a quantitative measure of soil heterogeneity in an area. The value of index indicates the degree of correlation between adjacent experimental plot. It is denoted by '*b*' and the model is fitted by the formula,

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

Where y is the variance of the plot and x is the plot size.

If the value of 'b' is close to zero, the area is homogeneous *i.e.,* the neighbouring plots are highly correlated and if the value is near to '1' the field is heterogeneous *i.e.,* the neighbouring plots are almost uncorrelated (Smith, 1938).

3.4.4 Methods For Optimum Plot Size Determination

The plot size that requires the minimum inputs to obtain higher degree of precision is termed as optimum plot size for a given experimental area. It depends on the extend of soil heterogeneity and the cost of experimental operations. As the relative importance of factors responsible for the variability in the yield data may vary with experiments, optimum plot size also varies for different field experiments.

Several methods for the determination of optimum plot size and shape are being suggested and attempted by various researchers from time to time as detailed below:

Conventional Methods

1. Maximum curvature method (Prabhakaran *et al.*, 1978)
2. Smith's variance law method (Sardana *et al.*, 1967)
3. Modified curvature method (Michel *et al.*, 2015)

Modified methods

1. Cost ratio method (Kavitha, 2010)
2. Based on the shape of the plot (Nishu, 2015)
3. Using covariates

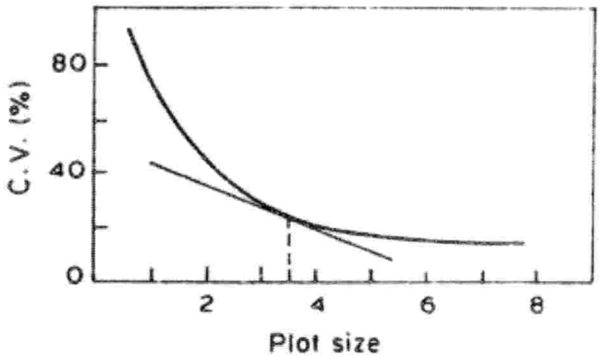
3.4.4.1 Conventional Methods

3.4.4.1.1 Maximum Curvature Method

In the maximum curvature method the basic units of uniformity trails are combined to form new units. Data on border rows were removed. The new units are formed either by combining columns or rows or both. For example, 2 unit plot can be formed either by combining 1 row and 2 column (1×2) or 2 rows and 1 column (2×1) Combination of columns and rows should be done in such a way that no column or row is left out. For each set of units, the CV is computed. To obtain CV, standard error was divided by the mean of corresponding plot size. The CV can be calculated by the formula:

$CV = \frac{\sigma}{\bar{x}} \times 100$, where σ is the standard deviation and $\bar{x}$ is the mean.

For a specific plot size, the average of CV for different combinations is taken. A curve is plotted by taking the plot size (in terms of basic units) on the X-axis and the CV values on the Y-axis of a graph sheet. The point at which the curve taken a turn, that is, the point of maximum curvature is located. The value corresponding to the point of maximum curvature will be the optimum plot size. (Sundararaj, 1977).



3.4.4.1.2 Smith's Variance Law Method

According to Smith's equation

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

Where Vx is the variance of plot size of x units, V_1 is the variance of plot size having unit size, x is the plot size and b is the soil heterogeneity index.

On log transformation it becomes

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

1st and 2nd derivative of V_x w.r.t x are

$$\frac{\partial V_x}{\partial x} = V_1(-b)x^{-b-1}$$

And

$$\frac{\partial^2 V_x}{\partial x^2} = V_1 b(b+1)x^{-(b+2)}$$

The curvature can be obtained by the formula given by Chopra and Kochhar (1967)

$$C = \frac{d^2V / dx^2}{[1 + (\frac{dV}{dx})^2]^{\frac{3}{2}}}$$

Substituting the values of 1st and 2nd derivative and on simplification we get,

$$C = \frac{1}{V_1 b(1+b)}[1 + V_1^2 b^2 x^{-2(1+b)}]^{3/2} x^{(2+b)}$$

To maximize curvature, equate the 1st derivative $\frac{\partial C}{\partial x} = 0$

$$\frac{1}{Vb\,(1+b)_1}\{3/2[1 + V_1^2 b^2 x^{-2(1+b)}]^{3/2} x^{(2+b)}\}$$
$$+ \{[1 + V_1^2 b^2 x^{-2(1+b)}]^{3/2}(2+b)x^{(1+b)}$$

Equating this to zero and on simplification we get

$$x_{opt}^{2(b+1)} = V_1^2 b^2 [\frac{3(1+b)}{2+b} - 1]$$

This formula was given by Agarwal and Deshpande (1967).

3.4.4.1.3 Modified Maximum Curvature Method

In case of Modified Maximum curvature method

The relationship between plot size, x and CV,y is given by the equation,

$$y = \frac{a}{x^b}$$

Where a and b are constants, x is the plot size and y is the CV

Taking log, equation becomes

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

When more than one CV is there for the same plot size, the minimum CV is taken for fitting the curve.

In case of Modified curvature method on simplification, optimum plot size can be obtained by the formula

$$x_{opt} = \left[\frac{(ab)^2 (2b+1)}{(b+2)} \right]^{\frac{1}{2(b+1)}}$$

3.4.4.2 Modified Methods

3.4.4.2.1 Cost Ratio Method

The cost of field experimentation is an important factor responsible for the optimum plot size determination. Smith (1938) worked out optimum plot size for different values of cost under assumption of linear cost structure and fitted an empirical relationship

$$C_x = K_1 + K_2X$$

Where C_x is the total cost including the cost of supervision and planning of experiment

K_1 is the fixed cost and

K_2 is the variable cost depends on the size X of the experimental unit

If r is the number of replications, then V_x/r is the variance of the mean of the r experimental units and cost of r replication is given by

$$C_0 = r\,(K_1 + K_2X)$$

Our objective is to maximize the amount of information per unit cost in order to determine the optimum size of the plot. The amount of information is defined to be the reciprocal of the variance.

Cost per information is given by

$$C' = \frac{K_1 + K_2 X}{1/V_x} = \frac{(K_1 + K_2 X)V_1}{X^b} \quad \text{(Smith's equation)}$$

Thus, the minimum cost for the value of X can be obtained by equating the 1st derivative of C' w.r.t. X to zero i.e.,

$$-b\,(K_1+K_2X)\,X^{-1-b} + X^{-b}\,K_2=0$$

On simplification,

$$X_{opt} = \frac{bK_1}{(1-b)K_2}$$

X_{opt} is the optimum plot size which provides the maximum information per unit of cost

K_1 is the part of the total cost which is proportional to the number of plots per treatment and

K_2 is the part of the total cost which is proportional to the total area per treatment.

3.4.4.2.2 Based on the shape of the plot

For determining the shape of the plot both length and breadth were used.

$$V_x = V_1 X_1^{-b_1} X_2^{-b_2}$$

Where X_1 and X_2 are the length and breadth to make a plot size of X units and b_1 and b_2 are the corresponding regression coefficients. By providing different values for X_1 and X_2, variance in each case is calculated and corresponding graph is drawn with plot size along x- axis and variance along y- axis. A constant and minimum variance is noted and its corresponding X_1 and X_2 values are regarded as the length and breadth of the optimum plot size.

3.4.4.2.3 Using Covariates

In this method first find out a variable having high correlation with the yield and the variables having maximum correlation with yield is replaced to determine the optimum plot size. For each plot size coefficient of variation is calculated separately. As the plot size increases C.V. decreases and attains almost minimum and then a constant value. The value corresponding to minimum coefficient of variation is considered as optimum plot size. Thus using different correlated covariates optimum plot size can be estimated. A model is fitted using regression analysis under covariate method

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

Where X_1 and X_2 are covariables. Here covariates used are yield and number of functional leaves which are highly correlated.

3.4.5 Discriminant Function Analysis

Discriminant function analysis is a statistical procedure to predict a categorical dependent variable (called a grouping variable) by one or more continuous or binary independent variables (called predictor variables). The orginal dichotomous discriminant analysis was developed by Fisher (1936). A discriminant function was fitted to understand the categorical difference between the two varieties. Discriminant analysis is used when groups are known a priori (unlike in cluster analysis). Each case must have a score on one or more quantitative predictor measures, and a score on a group measure. In simple terms, discriminant function analysis is classification - the act of distributing things into groups, classes or categories of the same type. The purpose of discriminant analysis is to investigate differences between or among groups and to access the relative importance of the independent variables in classifying the dependent variables. Mahalanobis distances are used in analysing cases in discriminant analysis, which is measured in terms of standard deviations from the centroid. By performing the discriminant function analysis, average, minimum and maximum score can be obtained. Based on this, we can decide to which group a new variety belongs to, based on a function. Discrimination is achieved by setting the variates weights for each variable to maximise the between groups variance relative to the within group variance. The linear function for a discriminant analysis also known as the discriminant function, is defined from an equation that takes the following form

$$Z = W_1 X_2 + W_2 X_2 + \dots\dots\dots + W_n X_n$$

where Z = Discriminant Score, Wi = Discriminant Weight, Xi = Independent Variable for $(i = 1, 2, \dots, n)$.

Results and Discussion

4. RESULTS AND DISCUSSION

A study entitled "Modified statistical methods on estimation of optimum plot size in cassava (*Manihot esculenta* Crantz)" has been carried out at Department of Agricultural Statistics, College of Agriculture, Vellayani, Thiruvananthapuram during the year 2015-2017. Two varieties of cassava namely Vellayani Hraswa and Sree Pavithra were planted and different methods for the determination of optimum plot size were used in the study. Results based on statistically analyzed data pertaining to the study conducted during the course of investigation are presented in this chapter under the following headings:

4.1 Summary Statistics of Biometric and Yield characters

4.2 Correlation Analysis

4.3 Multiple Regression Analysis

4.4 Soil Heterogeneity

4.5 Optimum Plot Size Determination

4.5.1 Conventional Methods

4.5.2 Modified Methods

4.6 Discriminant Function Analysis

4.1 SUMMARY STATISTICS OF BIOMETRIC AND YIELD CHARACTERS

Based on the observations of all growth and yield parameters of 50 samples from 2 cassava varieties taken at bimonthly interval (2 Months after planting (MAP), 4 MAP, 6 MAP, 8 MAP) , the mean, minimum, maximum and standard deviation (SD) were worked out and the following tables depicts the mean and SD of growth parameters such as plant height, inter nodal length, number of primary branches, height of first branching and number of functional leaves and yield characters like number of tubers, average tuber weight, tuber length, tuber girth and total yield per plant at different growth periods of cassava varieties.

4.1.1 Summary Statistics for the Biometric Observations

4.1.1.1 Summary Statistics of Plant Height (Ht)

Table 1. Summary statistics of plant height of Vellayani Hraswa (VH) and Sree Pavithra (SP)

Period	Plant Height Mean(cm)		Standard Deviation		Minimum (cm)		Maximum (cm)	
	VH	SP	VH	SP	VH	SP	VH	SP
2MAP	70.96	64.82	20.92	14.67	30	35	120	100
4MAP	124.12	139.50	24.63	25.59	76	80	190	200
6MAP	197.32	202.30	30.17	32.02	134	95	292	250
8MAP	--	309.83	--	44.92	--	140	--	400

It is evident from Table 1 that, the mean height of Vellayani Hraswa increased from 70.96 cm at 2 MAP to 197.32 cm at 6 MAP with a minimum height of 30 cm at 2 MAP to 134 cm at 6 MAP and that of Sree Pavithra is 64.82 cm at 2 MAP to 309.83 cm at 8 MAP with a minimum height of 35 cm at 2 MAP to 140 cm at 8 MAP The maximum height for Vellayani Hraswa recorded at 2 MAP and at 6 MAP were 120 cm and 292 cm, respectively and that of Sree Pavithra is 2 MAP and at 8 MAP were 100 cm and 400 cm, respectively.

4.1.1.2 Summary Statistics of Internodal Length (In)

Table 2. Summary statistics of internodal length of Vellayani Hraswa and Sree Pavithra

Period	In Mean(cm)		Standard Deviation		Minimum (cm)		Maximum (cm)	
	VH	SP	VH	SP	VH	SP	VH	SP
2MAP	3.03	3.04	0.383	0.678	2	2	3	4.50
4MAP	3.07	3.30	0.416	0.508	2.50	2.20	3.50	4.80
6MAP	3.50	3.30	0.054	0.628	3	2	4	5
8MAP	--	3.40	--	0.679	--	2.50	--	5.50

It is evident from Table 2 that, the average internodal length increased from 3.03 cm at 2 MAP to 3.5 cm at 6 MAP with a minimum intermodal length of 2 cm at 2 MAP to a maximum of 4 cm at 6 MAP. In case of Sree Pavithra the average intermodal length increased from 3.04 cm at 2 MAP to 3.40 cm at 8 MAP with a minimum intermodal length of 2 cm at 2 MAP to a maximum of 5.5 cm at 8 MAP.

4.1.1.3 Summary Statistics of Number of Primary Branches (Np)

Table 3. Summary statistics of number of primary branches of Vellayani Hraswa

Period	Np Mean	Standard Deviation	Minimum	Maximum
2MAP	1.09	0.426	1	3
4MAP	2.04	0.282	1	3
6MAP	2.04	0.282	1	3

It is evident from Table 3 that, the mean number of primary branches increased from 1.09 at 2 MAP to 2.04 at 6 MAP with a minimum number of primary branches of 1 at 2 MAP to a maximum of 3 at 6 MAP.

4.1.1.4 Summary Statistics of Height of Primary Branching (Hb)

Table 4. Summary statistics of height of primary branching of Vellayani Hraswa

Period	Hb Mean	Standard Deviation	Minimum	Maximum
2MAP	25.95	15.78	5	70
4MAP	53.16	31.51	9	140
6MAP	67.80	29.98	19	145

It is evident from Table 4 that, the mean height of 1st primary branching increased from 25.95 cm at 2 MAP to 67.8 cm at 6 MAP with a minimum height of 5 cm at 2 MAP to 19 cm at 6 MAP. The maximum height recorded at 2 MAP and at 6 MAP were 70 cm and 145 cm, respectively for this branching variety.

4.1.1.5 Summary Statistics of Number of Fuctional Leaves (Nl)

Table 5. Summary statistics of number of fuctional leaves of Vellayani Hraswa and Sree Pavithra

Period	*Nl* Mean(cm)		Standard Deviation		Minimum (cm)		Maximum (cm)	
	VH	SP	VH	SP	VH	SP	VH	SP
2MAP	35.10	25.38	13.91	6.67	12	12	72	40
4MAP	99.36	58.22	33.19	11.77	44	25	190	80
6MAP	174.8	75.52	51.94	18.21	70	34	303	95
8MAP	--	152.35	--	21.23	--	58	--	145

It is evident from Table 5 that, the mean of number of functional leaves of Vellayani Hraswa increased from 35.10 at 2 MAP to 174.8 at 6 MAP with a minimum of 12 at 2 MAP to 70 at 6 MAP. The maximum number recorded at 2 MAP and at 6 MAP were 72 and 303, respectively. In case of Sree Pavithra the mean of number of functional leaves increased from 25.38 at 2 MAP to 152.35 at 8 MAP with a minimum of 12 at 2 MAP to 58 at 8 MAP. The maximum number recorded at 2 MAP and at 8 MAP were 40 and 145, respectively

4.1.2 Summary Statistics for the Yield Observations

Table 6. Summary statistics of yield attributes of Vellayani Hraswa and Sree Pavithra

	Nt		*Ty*(kg)		*Tw*(kg)		*Tl*(cm)		*Tg* (cm)	
	VH	SP	VH	SP	VH	SP	VH	SP	VH	SP
Mean	4.97	5.57	2.14	2.55	0.38	0.45	22.77	24.37	16.67	18.49
SD	2.16	2.22	1.92	1.43	0.20	0.28	7.30	6.12	3.49	3.59
Min	1	1	0.50	0.60	0.15	0.10	8	1	4	6
Max	11	12	25	12	1.41	4.44	54	50	40	33

(*Nt*) - Number of tubers; (*Ty*) - Tuber yield/plant (kg); (*Tw*) -Tuber weight (kg); (*Tl*) -Tuber length (cm); (*Tg*) - Tuber girth(cm)

Average number of tubers obtained for Vellayani Hraswa was 5 per plant with a total tuber yield of 2.14 kg and average tuber weight of 0.388 kg. The average tuber length and tuber girth were 22.77 cm and 16.67 cm, respectively. The variety Vellayani Hraswa had a minimum yield of 0.5 kg and a maximum yield of 25 kg with a standard deviation of 1.92 kg. The minimum tuber weight was 0.15 kg and the maximum was 1.41kg with a standard deviation of 0.2 kg; which shows the high variations in yield of these varieties.

Average number of tubers obtained for Sree Pavithra was 5 per plant with an average total tuber yield of 2.55 kg and average tuber weight of 0.459 kg. The average tuber length and tuber girth were 24.37 cm and 18.49 cm, respectively. The variety had a minimum yield of 0.06 kg and a maximum yield of 12 kg with a standard deviation of 1.43 kg.

4.2. CORRELATION ANALYSIS

The knowledge regarding association of various characters among themselves is necessary to understand the nature and degree of relationship. The Pearson's product moment correlations between yield and biometrical characters at different plant growth stages (bimonthly) are calculated for branching and non-branching type and the results are presented as follows.

4.2.1 Correlation among Biometric Characters of Sree Pavithra

Table7. Correlation among biometric characters of Sree Pavithra

	Ht_2	Nl_2	In_2	Ht_4	Nl_4	In_4	Ht_6	Nl_6
Ht_2	1							
Nl_2	0.647**	1						
In_2	0.152	0.477**	1					
Ht_4	0.676**	0.396**	-0.118	1				
Nl_4	0.706**	0.561**	-0.023	0.805**	1			
In_2	0.195	0.330*	0.410**	0.028	0.154	1		
Ht_6	0.460**	0.383**	-0.135	0.779**	0.636**	-0.034	1	
Nl_6	0.394**	0.551**	0.151	0.531**	0.666**	0.183	0.644**	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

From the table 7 it is clear that height at 2 MAP is highly correlated with number of functional leaves at 2MAP and 4MAP and height at 4 MAP is highly correlated with number of functional leaves at 4 MAP and 6 MAP

4.2.2 Correlation among Biometric Characters of Vellayani Hraswa

Table8. Correlation among biometric characters of Vellayani Hraswa

	Ht_2	Nl_2	In_2	Ht_4	Nl_4	In_4	Ht_6	Nl_6	In_6
Ht_2	1								
Nl_2	0.603**	1							
In_2	0.064**	-0.015	1						
Ht_4	0.697**	0.321*	0.106	1					
Nl_4	0.592**	0.687**	-0.040	0.286	1				
In_2	-0.200	-0.265	-0.295	-0.032	-0.120	1			
Ht_6	0.419**	0.290*	0.095	0.591**	0.291*	-0.060	1		
Nl_6	0.166	0.283	0.014	0.082	0.361*	0.018	0.005	1	
In_6	0.482**	0.303*	-0.205	0.347*	0.254	-0.077	0.021	0.084	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

From the table 8 it is clear that height at 2 MAP is highly correlated with number of functional leaves at 2 MAP and 4 MAP.

4.2.3 Correlation Among Yield Characters of Sree Pavithra

Table 9. Correlation among yield characters of Sree Pavithra

	Ht	*Nl*	*Nt*	*Ty*	*Tw*	*Tl*	*Tg*
Ht	1						
Nl	0.463	1					
Nt	0.3114	0.479*	1				
Ty	0.318	0.517**	0.674	1			
Tw	0.223	0.179	0.116	0.315	1		
Tl	0.273	0.232	0.221	0.342	0.270	1	
Tg	0.381	0.304	0.235	0.350	0.186	0.353	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

From Table 9 it is clear that total yield and number of tubers is highly correlated with number of functional leaves (0.517, 0.479 respectively)

4.2.4 Correlation Among Yield Characters of Vellayani Hraswa

Table 10. Correlation among yield characters of Vellayani Hraswa

	Nt	*Tw*	*Tl*	*Tg*	*Ty*	*Ht*	*Np*	*Hb*	*Nl*
Nt	1								
Tw	0.091	1							
Tl	0.240	0.610**	1						
Tg	0.293*	0.429**	0.459**	1					
Ty	0.322*	0.346	0.335*	0.200	1				
Ht	0.210	0.300	0.276	0.300	0.130	1			
Np	0.007	0.335	0.136	0.130	0.260	0.207	1		
Hb	-0.053	-0.064	-0.126	-0.01	-0.110	0.193	0.184	1	
Nl	0.403**	0.591**	0.475**	0.44**	0.350	0.416	0.307	-0.090	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

The estimate of correlation coefficient between yield, plant height, inter nodal length and number of functional leaves are presented in the above table. All the estimated correlation coefficient between yield and biometric parameters were found to be non-significant. It is evident from the table that there is a high degree of association between average tuber weight with tuber length and tuber girth.

4.3 MULTIPLE REGRESSION ANALYSIS

In agriculture, statistical model plays a vital role in prediction of crop yield before harvests of the crops. An effort was made to develop the prediction models for the yield of the crop with biometrical observations for every bimonthly interval; one which is found to be the best was selected based on R^2 values, adjusted R^2 values and Mallow's C_P. Further the variables coming in the model for early prediction is another criterion to identify the best prediction models. Multiple linear regression technique was used to find the linear effects of biometric characters at different stages of the two varieties. To know which of the predictor variables included in the model are most significantly contributing to the yield, the stepwise regression was carried out and the models obtained.

SAS version 9.3 is used for the analysis of data and the salient results are presented below. All possible multiple regression equations connecting yield with all possible combinations were tried. Eight parameters were taken, therefore 255 models were tried and the best among them are presented below.

Sree Pavithra

For regression analysis, 8 variables were taken namely plant height (2 MAP, 4 MAP, 6 MAP), number of functional leaves (2 MAP, 4 MAP, 6 MAP), internodal length (2 MAP, 4 MAP). So a total of 255 combinations (models) were tried. Step up regression method was also used to identify the order of variables in regression model. Accordingly, the R^2, Adj R^2 and Cp values obtained for different number of variables for best estimation of yield, under different combinations were obtained and summarized in the Table 11.

Table11. Best yield prediction model parameters in Sree Pavithra

No. of variables in the model	R^2	Adj R^2	C_p	Variables used in the model
1	0.333	0.318	10.58	Ht_2
2	0.396	0.368	7.63	Ht_2, Nl_2
3	0.432	0.392	6.78	Ht_2, Ht_4, Nl_4
4	0.468	0.416	5.96	Ht_2, Nl_2, In_2, Ht_4
5	0.494	0.433	5.86	$Ht_2, Nl_2, In_2, Ht_4, Nl_4$
6	0.506	0.431	6.94	$Ht_2, Nl_2, In_2\ Ht_4, Nl_4, Nl_6$
7	0.525	0.430	7.43	$Ht_2, Nl_2, In_2, Ht_4, Nl_4, Ht_6, Nl_6$
8	0.531	0.429	9.00	$Ht_2, Nl_2, In_2, Ht_4, Nl_4, In_4, Ht_6, Nl_6$

From Table 11 it can be seen that adjusted R^2 reaches a steady stage with 7 variables and C_p obtained is 7.43. But for prediction purpose we can use the model with 2 variables with R^2 of 0.396. Here the variables used are height at 2 MAP and number of functional leaves at 2 MAP and details of the model are given below.

Table 12. ANOVA for Sree Pavithra for determining yield prediction model using two biometric characters.

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	10.42	5.21	14.12	<.0001
Error	43	15.87	0.36		
Corrected Total	45	26.29			

Variable	**Parameter Estimate**	**Standard Error**	**Type II SS**	**F Value**	**Pr > F**
Intercept	0.401	0.423	0.332	0.90	0.347
Ht_2	0.040	0.008	9.54	25.85	<.001
Nl_2	-0.037	0.017	1.65	4.47	0.040

Table 12 shows that height and number of functional leaves at 2 MAP are more influencing variable on yield with an R^2 of 0.396 and both the partial regression coefficients were significant at 5% level.

Model obtained is $Y = 0.401 + 0.040\ Ht_2 - 0.037\ Nl_2$

Vellayani Hraswa

Table 13 . R^2 of best yield prediction models and respective parameters in Vellayani Hraswa

No of variables in the model	R^2	Adj R^2	C_p	Variables used in the model
1	0.166	0.148	-1.70	Ht_2
2	0.191	0.156	-1.03	Ht_2, In_2
3	0.201	0.149	0.488	Ht_2, In_4, Nl_6
4	0.208	0.138	2.04	Ht_2 ,Nl_6, Ht_4, In_4
5	0.217	0.129	3.55	Ht_2, Nl_4, , In_4 , In_6
6	0.223	0.115	5.26	Ht_2, Nl_2 , Ht_4, In_4, In_6
7	0.228	0.099	7.00	Ht_2, Nl_2 , In_2 , Ht_4 , In_4, In_6
8	0.228	0.077	9.00	Ht_2, Nl_2 , In_2, Ht_4 , Nl_4, , In_4, Nl_6 , In_6 ,Ht_6

From Table 13 it is clear that all models for prediction gave R^2 value less than 20% only. So in this case yield cannot be predicted with better accuracy using biometric parameters only, (though many models were studied). Among these models details of one of the best models is described below:

Table14. ANOVA for Vellayani Hraswa for determining yield prediction model using three biometric characters

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	2.92	0.974	3.87	0.015
Error	46	11.59	0.251		
Corrected Total	49	14.51			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	0.092	0.663	0.004	0.02	0.889
Ht_2	0.010	0.003	2.40	9.55	0.003
In_4	0.203	0.175	0.337	1.34	0.253
Nl_6	0.001	0.001	0.146	0.58	0.449

Here height at 2 MAP, only have significant influence on yield.

The model obtained is $Y = 0.092 + 0.010\ Ht_2 + 0.203\ In_4 + 0.001\ Nl_6$

4.4 SOIL HETEROGENEITY

4.4.1 Contour Map

In order to find nature and magnitude of soil heterogeneity in the given area, fertility contour map was prepared. For this, uniformity trial was conducted to know the nature of the soil fertility. Fertility gradient of each plot were calculated separately for each variety and plots having similar fertility gradient were given the same demarcation (colour). This is presented in the Table 15. The map reveals the soil heterogeneity existed in the area which is not uniform.

Table 15. Fertility gradient ranges and frequency (number of plants and percentage) in the experimental area of Sree Pavtithra and Vellayani Hraswa

Class interval	Colour	Frequency / (%) (Sree Pavtithra)	Frequency/ (%) (Vellayani Hraswa)
< -50		24 (8)	58 (24)
(-50 to -10)		97 (33)	72 (29)
(-10 to 30)		99 (34)	48 (19)
(30 to 70)		48 (16)	49 (20)
> 70		28 (9)	19 (8)

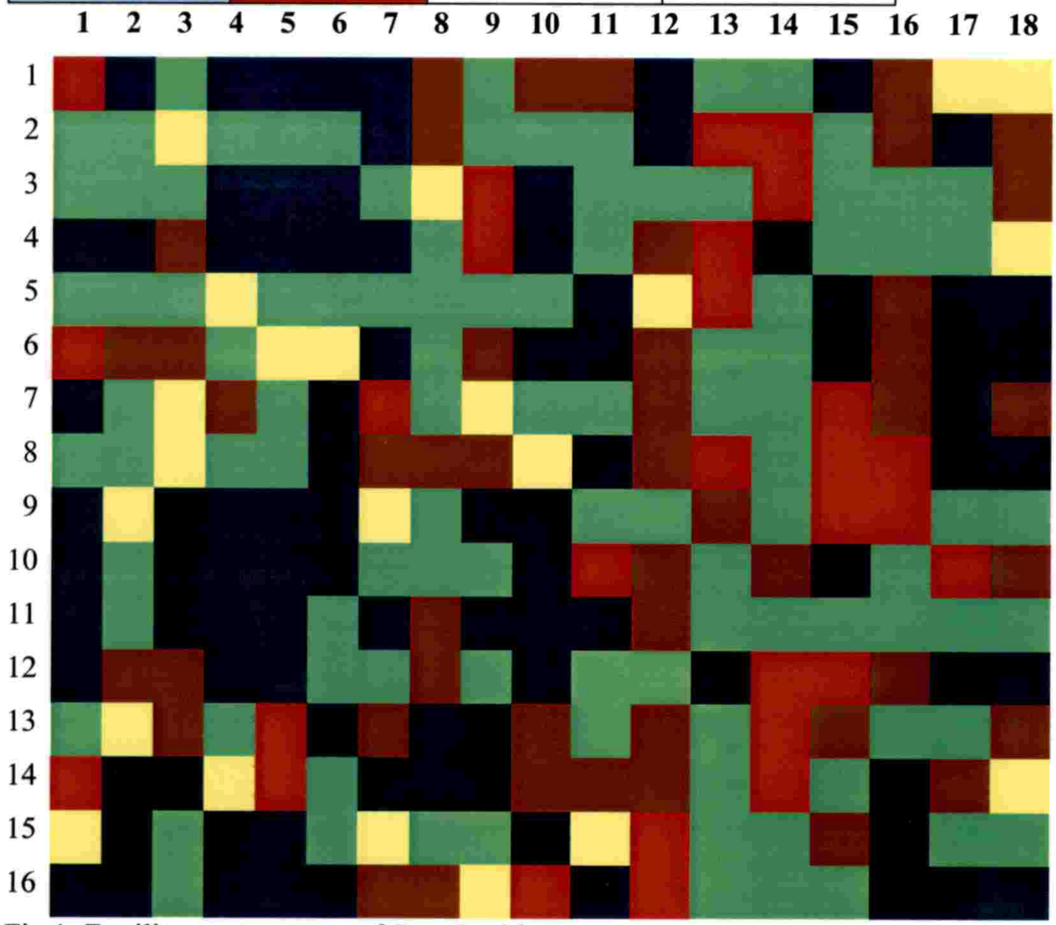


Fig.1. Fertility contour map of Sree Pavithra

From the above map it can be concluded that field is heterogeneous, extreme fertile area and barren (red and yellow) were scattered and more area is of average fertility gradient.

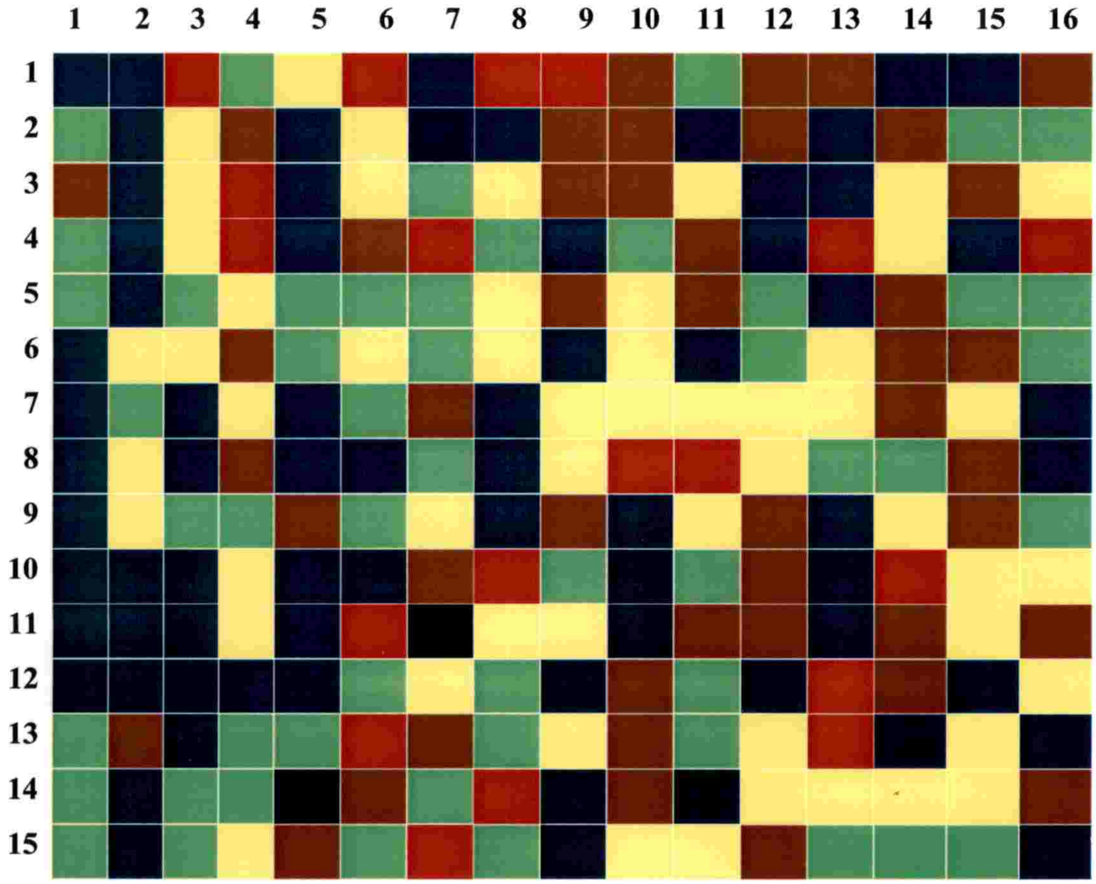


Fig. 2. Fertility contour map of Vellayani Hraswa

Highly heterogeneous land can be clearly seen here, right side of the field is almost homogeneous as compared to other parts.

In Contour map, it was observed that fertility gradient ranged from -50 to 70 and maximum frequency was in the range from -10 to 30 for Sree Pavithra (34%) and -50 to -10 for Vellayani Hraswa (29%) and a minimum of 8% (< -50) for Sree Pavithra and 8% (>70) for Vellayani Hraswa.

4.5 OPTIMUM PLOT SIZE DETERMINATION

The plot size that requires the minimum inputs to obtain higher degree of precision is termed as optimum plot size for a given experimental area.

NON-BRANCHING VARIETY- SREE PAVITHRA

4.5.1 Conventional Methods

4.5.1.1 Maximum Curvature Method

Based on the plot size mean, standard deviation and coefficient of variation of Sree Pavithra were estimated and given in the Table 16. Maximum curvature graph was also plotted and is given in the Fig. 3.

Table 16. Curvature measurement parameters of Sree Pavithra

Plot size	Shape	Mean	SD	CV	Min CV	Average
1		2.55	1.43	**56.28**	56.28	
2	**1x2**	2.56	0.994	**38.78**	38.78	39.78
	2x1	2.55	1.04	40.78		
3	**1x3**	2.58	0.806	**31.20**	31.20	31.94
	3x1	2.57	0.840	32.69		
4	**1x4**	2.59	0.704	**27.16**	27.16	27.89
	4x1	2.57	0.719	27.98		
	2x2	2.57	0.734	28.54		
5	**1x5**	2.60	0.643	**24.67**	24.67	24.69
	5x1	2.56	0.634	24.71		

Table 16. Curvature measurement parameters of Sree Pavithra (cont.)

Plot size	Shape	Mean	SD	CV	Min CV	Average
6	**1x6**	2.61	0.581	**22.26**	22.26	22.66
	6x1	2.56	0.571	22.26		
	2x3	2.59	0.597	23.05		
	3x2	2.58	0.596	23.07		
7	**1x7**	2.61	0.537	**20.54**	20.54	20.70
	7x1	2.56	0.532	20.85		
8	**1x8**	2.61	0.497	**19.04**	19.04	19.53
	8x1	2.55	0.501	19.58		
	2x4	2.60	0.517	19.89		
	4x2	2.59	0.508	19.62		
10	**1x10**	2.60	0.441	**16.94**	16.94	17.61
	10x1	2.56	0.453	17.67		
	2x5	2.61	0.470	17.98		
	5x2	2.58	0.462	17.87		
12	**1x12**	2.61	0.395	**15.13**	15.13	16.26
	12x1	2.57	0.437	17.00		
	4x3	2.61	0.414	15.87		
	3x4	2.61	0.426	16.31		
	6x2	2.57	0.438	16.99		
	2x6	2.61	0.425	16.25		
15	**1x15**	1.08	0.247	18.76	14.55	16.26
	15x1	2.55	0.432	16.90		
	3x5	2.62	0.381	**14.55**		
	5x3	2.60	0.385	14.81		

Table 16. Curvature measurement parameters of Sree Pavithra (cont.)

Plot size	Shape	Mean	SD	CV	Min CV	Average
18	**2x9**	2.60	0.323	12.39	11.61	13.55
	9x2	2.57	0.403	15.69		
	3x6	2.62	0.356	13.56		
	6x3	2.59	0.376	14.51		
	1x18	2.55	0.296	**11.61**		
20	**10x2**	2.57	0.393	15.26	11.48	13.26
	2x10	2.60	0.299	**11.48**		
	4x5	2.62	0.336	12.78		
	5x4	2.60	0.352	13.51		
24	**8x3**	2.58	0.376	14.55	9.23	12.3
	3x8	2.62	0.290	11.09		
	6x4	2.59	0.347	13.36		
	4x6	2.63	0.308	11.72		
	2x12	2.61	0.241	**9.23**		
	12x2	2.58	0.368	14.26		
25	**5x5**	2.61	0.326	**12.47**	12.47	12.47
26	**2x13**	2.59	0.356	13.74	8.55	11.15
	13x2	2.61	0.224	**8.55**		
28	**2x14**	2.61	0.212	**8.12**	8.12	11.55
	14x2	2.58	0.361	13.97		
	4x7	2.62	0.282	10.74		
	7x4	2.59	0.347	13.36		

Table 16. Curvature measurement parameters of Sree Pavithra (cont.)

Plot size	Shape	Mean	SD	CV	Min CV	Average
30	**3x10**	2.61	0.241	9.22	7.68	11.56
	10x3	2.59	0.354	13.66		
	6x5	2.61	0.308	11.80		
	5x6	2.60	0.322	12.38		
	15x2	2.57	0.375	14.59		
	2x15	2.60	0.199	**7.68**		
35	**7x5**	2.60	0.322	12.38	10.65	11.52
	5x7	2.61	0.279	**10.65**		
40	**8x5**	2.59	0.315	12.13	7.78	10.55
	5x8	2.61	0.248	9.51		
	10x4	2.59	0.332	12.80		
	4x10	2.61	0.203	**7.78**		

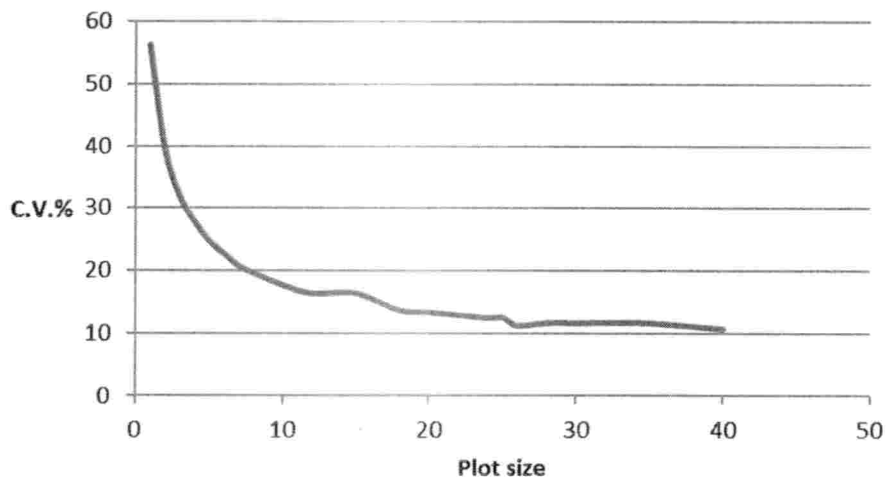


Fig. 3. Graph depicting the reduction in coefficient of variation and curvature of Sree Pavithra

Table 17. Summary table of plot size and shape along with coefficient of variation

Size	Shape	CV(%)	Min CV	Average CV
12	1x12	15.13	15.13	16.26
15	3x5	14.55	14.55	16.26
18	2x9	12.39	12.39	13.55
20	2x10	11.48	11.48	13.26
24	2x12	9.23	9.23	12.30

From Table 17, it can be concluded that as plot size increases, CV decreases and finally attains a constant value and then decreases at a decreasing rate. For non-branching type as the plot size increases from 1 unit to 40 units, a gradual decrease in CV can be observed upto 18 units (with an average of 13.55) and thereafter CV remains almost constant. So this plot can be considered as optimum plot size. For a plot size of 18 units, different combinations can be made i.e, 2x9 (2 unit length and 9 unit breadth), 9 x 2, 1 x 18, 6 x 3, 3 x 6. From this a minimum CV is obtained for the plot size 1 x 18 *ie.*, 11.61. So the shape of optimum plot size obtained in this method is 1 unit length and 18 unit breadth. Number of plants to be accommodated is 18 units and the area required is 10 m^2 (18 x 0.75 x 0.75).

4.5.1.2 Fairfield Smith's Variance Law

The relationship between plot size and C.V. was established by Fairfield Smith (1938). The suitability of the Smith variance law is examined by fitting the equation

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

Where V_x is the variance of yield per unit area among the plots of size X units, V_1 is the variance among the plots of one unit in size and b is the regression coefficient. Value of b obtained by performing regression analysis is given in table 18.

Table 18. Regression analysis under Fairfield Smith's law.

ANOVA					
	df	*SS*	*MS*	*F*	*Significance (F)*
Regression	1	4.16	4.16	1782.26	<0.01
Residual	18	0.042	0.002		
Total	19	4.202			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	3.95	0.027	142.75	<0.01
X	-0.452	0.01	-42.21	<0.01

Multiple R square = 0.99, Adj R^2 = 0.98

Under Fairfield Smith's law, equation obtained was

$$Y = 52.43X^{-0.453}$$

The $\mathbf{R^2}$ obtained is very high and the value of b is 0.453. It indicates a good positive relationship between adjacent plots.

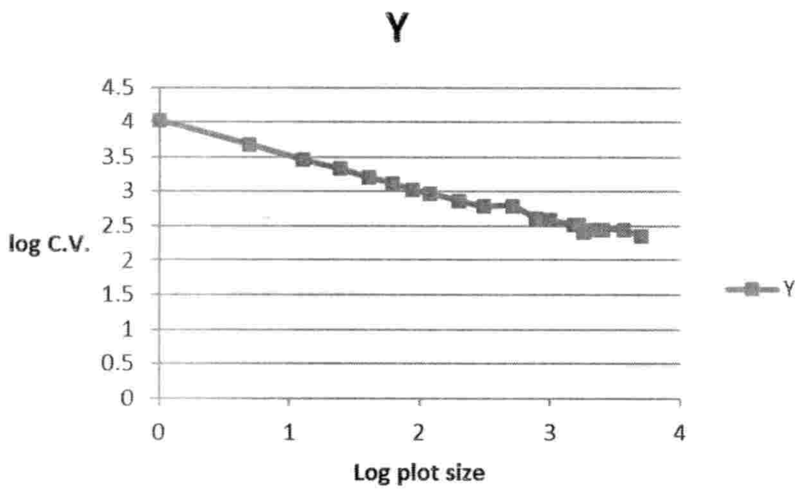


Fig. 4. The graph of coefficient of variation (on log scale) obtained under Fairfield Smith's law

Calculation of optimum plot size:

$$X_{opt}^{2(b+1)} = V_1^2 b^2[\frac{3(1+b)}{2+b} - 1]$$

X $_{opt}$ obtained by using this formula is 8.35. Number of plants to be accommodated is only 8 and the area required is 4 m^2. This is not a suitable method for the determination of optimum plot size since the graph is not attaining a perfect optimum position.

4.5.1.3 Modified curvature method

Here the model is $y = ax^{-b}$ where y is the variance of the plot and x is the plot size. Curvature (C) can be obtained by the formula

$$C = \frac{d^2y/dx^2}{[1 + (\frac{dy}{dx})^2]^{\frac{3}{2}}}$$

Point at which the curvature attains maximum value $\frac{\partial c}{\partial x} = 0$

On simplification, optimum plot size can be obtained by the formula

$$X_{opt} = \left[\frac{(ab)^2(2b+1)}{(b+2)}\right]^{\frac{1}{2(b+1)}}$$

a = 52.43

b = 0.452 X_{opt} = **8.11**

The optimum value is very close to that obtained by Fairfield Smith's method.

4.5.2 Modified Methods

4.5.2.1 Cost Ratio Method

Optimum plot size can be determined by the formula $X_{opt} = \frac{bK_1}{(1-b)K_2}$

When b is close to 0.5 then the optimum plot size is almost depend upon the relation of K_1 and K_2. The ratio of K_1 and K_2 determine the size of the plot where K_1 is the part of the total cost which is proportional to the number of plots per treatment and K_2 is the part of the total cost which is proportional to the total area per treatment. When the regression coefficient becomes larger the optimum plot size becomes larger and this is true for all values of K_2. When K_2 approaches unity the optimum plot size remains relatively small regardless of K_2 value (Table 19). Since the cost values are not known exactly, the optimum values were listed for a range of K_1 and K_2.

Table 19. Optimum plot size estimation under cost ratio method for different K_1 and K_2 values

K_1	K_2	*X opt*
1	1	0.827
2	1	1.65
3	1	2.48
4	1	3.31
5	1	4.13
6	1	4.96
7	1	5.79
8	1	6.62
9	**1**	**7.45**
10	**1**	**8.27**
1	2	0.413
2	2	0.827
3	2	1.24
4	2	1.65
5	2	2.06
6	2	2.48
7	2	2.89
8	2	3.31
9	2	3.72
10	2	4.13
1	3	0.275
2	3	0.551
3	3	0.827

K_1	K_2	*X opt*
4	3	1.10
5	3	1.37
6	3	1.65
7	3	1.93
8	3	2.20
9	3	2.48
10	3	2.75
1	4	0.206
2	4	0.413
3	4	0.620
4	4	0.827
5	4	1.034
6	4	1.24
7	4	1.44
8	4	1.65
9	4	1.86
10	4	2.06
1	5	0.165
2	5	0.331
3	5	0.496
4	5	0.662
5	5	0.827
6	5	0.993
7	5	1.15
8	5	1.32
9	5	1.490

From the table it can be observed that optimum plot size was found to be maximum at K_1=10 and K_2 =1. Here the CV remains almost constant (near to 8) for a wide range of plot size. As before the cost ratio method do not workout properly and is not giving a good result. Therefore, this method is not suitable for determination of optimum plot size in the present case.

4.5.2.2 Based on the Shape of the Plot

A relationship can be established between CV and the plot shape X_1 and X_2 (length and breadth). To study the effect of plot shape on soil variability (using Smith law), the equation is fitted as follows: $V_x = V_1 X_1^{-b_1} X_2^{-b_2}$

Where X_1 and X_2 are the length and breadth of the plot. The suitability is examined by computing the coefficient of determination. The equation can be expressed as

$$\text{Log } V_X = \log V_1 - b_1 \log X_1 - b_2 \log X_2$$

Where b_1 and b_2 are constants and V_1, and V_x are the coefficients of variation for various shapes of plots (Table 20).

Table 20. Regression analysis under model based on shape (length and breadth) of the plot.

Sree Pavithra

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.953
R^2	0.909
Adj R^2	0.906
Standard Error	0.121
Observations	68

ANOVA				
	df	SS	MS	F-value
Regression	2	9.71	4.8	326
Residual	65	0.96	0.1	
Total	67	10.68		
	Coefficients	Standard Error	t Stat	P-value
Intercept	3.9	0.04	81	<0.01
$Log(X_1)$	-0.41	0.02	-19	<0.01
$Log(X_2)$	-0.49	0.02	-23	<0.01

Obtained Equation is

$$V_x = 51.39 X_1^{-0.41} X_2^{-0.49}$$

Where $b_1 = 0.41$ and $b_2 = 0.49$ and $R^2 = 90\%$

By taking different values for X_1 and X_2 the CV obtained are shown below

Table 21. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) (under model based on shape of the plot)

X_1	X_2	CV		X_1	X_2	CV
1	1	51.39		1	7	19.78
2	1	38.71		2	7	14.90
3	1	32.80		3	7	12.63
4	1	29.17		4	7	11.23
5	1	26.62		5	7	10.25
6	1	24.71		6	7	9.51
7	1	23.20		7	7	8.93
8	1	21.97		8	7	8.46
9	1	20.94		9	7	8.06
10	1	20.06		10	7	7.72
11	1	19.29		11	7	7.42
12	1	18.62		12	7	7.17
13	1	18.02		13	7	6.93
1	2	36.57		1	8	18.53
2	2	27.55		2	8	13.96
3	2	23.35		3	8	11.83
4	2	20.76		4	8	10.51
5	2	18.95		5	8	9.60
6	2	17.59		6	8	8.91
7	2	16.52		7	8	8.36
8	2	15.64		8	8	7.92
9	2	14.90		9	8	7.55
10	2	14.28		10	8	7.23
11	2	13.73		11	8	6.95

Table 21. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) (under model based on shape of the plot)- cont.

X_1	X_2	CV		X_1	X_2	CV
12	2	13.25		12	8	6.71
13	2	12.82		13	8	6.49
1	3	29.98		1	9	17.49
2	3	22.58		**2**	**9**	**13.17**
3	3	19.14		3	9	11.16
4	3	17.01		4	9	9.92
5	3	15.53		5	9	9.06
6	3	14.42		6	9	8.41
7	3	13.54		7	9	7.90
8	3	12.82		8	9	7.48
9	3	12.21		9	9	7.12
10	3	11.70		10	9	6.82
11	3	11.25		11	9	6.56
12	3	10.86		12	9	6.33
13	3	10.51		13	9	6.13
1	4	26.03		1	10	16.61
2	4	19.61		2	10	12.51
3	4	16.62		3	10	10.60
4	4	14.77		4	10	9.42
5	4	13.49		5	10	8.60
6	4	12.52		6	10	7.98
7	4	11.75		7	10	7.52
8	4	11.13		8	10	7.10

Table 21. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) (under model based on shape of the plot)- cont.

X_1	X_2	CV		X_1	X_2	CV
9	4	10.61		9	10	6.77
10	4	10.16		10	10	6.48
11	4	9.77		11	10	6.23
12	4	9.43		12	10	6.01
13	4	9.13		13	10	5.82
1	5	23.33		1	11	15.85
2	5	17.58		2	11	11.94
3	5	14.89		3	11	10.12
4	5	13.24		4	11	8.99
5	5	12.09		5	11	8.21
6	5	11.22		6	11	7.62
7	5	10.53		7	11	7.15
8	5	9.98		8	11	6.77
9	5	9.51		9	11	6.46
10	5	9.11		10	11	6.18
11	5	8.76		11	11	5.95
12	5	8.45		12	11	5.74
13	5	8.18		13	11	5.55
1	6	21.34		1	12	15.19
2	6	16.07		2	12	11.44
3	6	13.62		3	12	9.69
4	6	12.11		4	12	8.62
5	6	11.05		5	12	7.87
6	6	10.26		6	12	7.30

Table 21. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) (under model based on shape of the plot)- cont.

X_1	X_2	CV		X_1	X_2	CV
7	6	9.63		7	12	6.86
8	6	9.12		8	12	6.49
9	6	8.69		9	12	6.19
10	6	8.33		10	12	5.93
11	6	8.01		11	12	5.70
12	6	7.73		12	12	5.50
13	6	7.48		13	12	5.32

By taking different values of X_1 and X_2 , the corresponding values of CV is plotted and minimum and constant variance was considered for finding optimum plot size. This is represented in the following graph.

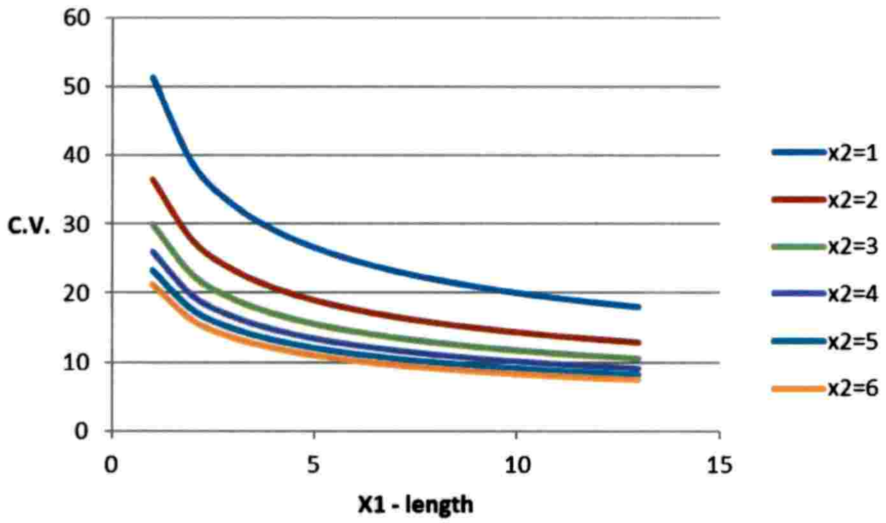


Fig. 5. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot.

(Here X_1=1,2,….,13 and X_2 takes the values 1,2…,6)

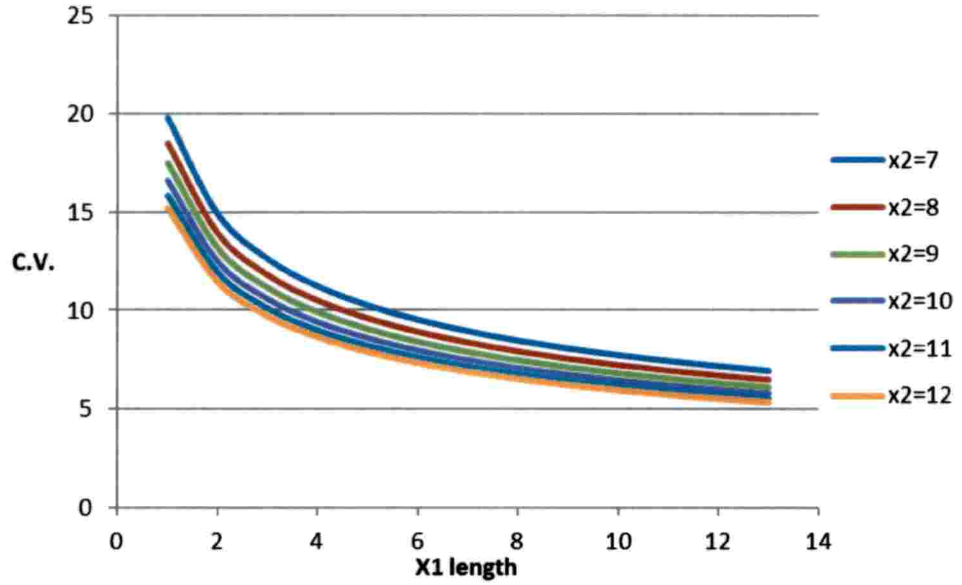


Fig. 5. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot. (continued).
(Here X_1 =1,2,….,13 and X_2 takes the values 7,8,….,12)

Under this method maximum curvature can be observed at X_1= 2 and X_2 =9 after that the line become straight line which was almost parallel to X axis. For high values of X_1, when X_2 is small like 1 or 2 units it can be seen that CV is not reducing considerably. Thus this method also gives an optimum plot size of 2×9 units (10.125m^2)

4.5.2.3 Covariate Method – Using number of Functional Leaves as Covariate

Here we used number of functional leaves as covariate for finding the optimum plot size. The plot size obtained in this case also is same as that obtained when yield alone was used as the main variable. This is shown in the following Table 22.

Table 22. Correlation between number of functional leaves and yield

	Plot size	CV(Yield)	CV(Leaves)
Plot size	1		
C.V.(Yield)	-0.755	1	
C.V.(Leaves)	-0.778	**0.967**	1

From Table it is clear that number of functional leaves and yield are highly correlated *i.e.,* about 97 percent.

Regression Analysis under Covariate Method

Table 23. Regression Analysis under Covariate Method

	Coefficients	Standard Error	t Stat	P value
Intercept	-8.66	4.27	-2.02	<0.01
Plot size (X_1)	-0.004	0.095	-0.05	>0.01
CV(leaves) (X_2)	0.98	0.099	9.85	<0.01

R^2 obtained was 94 %

Equation fitted as Y=-8.66 - 0.004 X_1 +0.98 X_2

Table 24. Coefficient of variation for yield and number of leaves for different plot sizes based on covariate method.

CV (Yield) (Y)	Plot Size (X_1)	CV(No. of leaves) (X_2)
56.28	1	59.39
39.78	2	46.81
31.94	3	51.55
27.89	4	37.01
24.69	5	33.81
22.66	6	32.44
20.70	7	29.63
19.53	8	29.20
17.61	10	26.95
16.26	12	26.01
16.26	15	24.16
13.55	18	**21.10**
13.26	20	23.35
12.37	24	21.87
12.47	25	23.75
11.15	26	18.59
11.55	28	20.20
11.56	30	20.38
11.52	35	21.24
10.55	40	19.57

As the plot size increases CV decreases and attains almost constant when it is near to 18. So it can be taken as optimum plot size. Number of plants to be accommodated in a single experimental plot is 18 and the area required is 10.125 m^2.

BRANCHING VARIETY - VELLAYANI HRASWA

4.5.1 Conventional Methods

4.5.1.1 Maximum Curvature Method

Based on the plot size, mean, standard deviation and coefficient of variation of Vellayani Hraswa were estimated and given in Table 26. Maximum curvature graph was also plotted and is given in the Fig. 6.

Table 25. Curvature measurement parameters of Vellayani Hraswa

	Plot	Mean	SD	CV	Min CV	Average
1	**1x1**	2.14	1.94	**90.42**	90.42	
2	**1x2**	2.15	1.41	65.54	58.98	62.26
	2x1	2.06	1.21	**58.98**		
3	**1x3**	2.19	1.15	52.72	44.52	48.62
	3x1	2.03	0.906	**44.52**		
4	**1x4**	2.21	1.01	45.89	42.46	44.72
	4x1	2.05	0.942	45.79		
	2x2	2.07	0.881	**42.46**		
5	**1x5**	2.23	0.925	41.376	32.84	37.10
	5x1	1.99	0.656	**32.84**		
6	**1x6**	2.25	0.871	38.67	34.67	37.83
	6x1	2.05	0.697	**34.67**		
	2x3	2.10	0.729	34.70		
	3x2	2.09	0.907	43.29		
7	**1x7**	2.27	0.841	37.05	28.09	32.57
	7x1	1.97	0.554	**28.09**		

Table 25. Curvature measurement parameters of Vellayani Hraswa (cont.)

	Plot	Mean	SD	CV	Min CV	Average
8	**1x8**	2.28	0.825	36.17	25.86	29.90
	8x1	1.97	0.510	**25.86**		
	2x4	2.12	0.646	30.39		
	4x2	2.02	0.551	27.19		
10	**1x10**	2.27	0.711	31.35	22.61	26.13
	10x1	1.98	0.448	**22.61**		
	2x5	2.14	0.582	27.21		
	5x2	2.00	0.469	23.35		
12	**1x12**	2.23	0.619	27.68	20.34	23.23
	12x1	2.01	0.410	**20.34**		
	4x3	2.05	0.447	21.73		
	3x4	2.09	0.473	22.63		
	6x2	1.99	0.437	21.90		
	2x6	2.15	0.540	25.12		
15	**1x15**	2.15	0.533	24.73	18.51	21.24
	15x1	2.14	0.465	21.66		
	3x5	2.10	0.422	20.07		
	5x3	2.03	0.377	**18.51**		
18	**2x9**	2.16	0.465	21.48	17.46	18.90
	9x2	1.98	0.348	17.53		
	3x6	2.11	0.404	19.11		
	6x3	2.02	0.353	**17.46**		
20	**10x2**	1.99	0.329	16.50	16.11	17.33
	2x10	2.16	0.427	19.75		
	4x5	2.09	0.354	16.95		

Table 25. Curvature measurement parameters of Vellayani Hraswa (cont.)

24	**8x3**	2.01	0.299	**14.87**	14.87	15.90
	3x8	2.11	0.368	17.42		
	6x4	2.04	0.307	15.05		
	4x6	2.09	0.330	15.74		
	2x12	2.14	0.360	16.81		
	12x2	2.02	0.314	15.49		
25	**5x5**	2.06	0.291	**14.10**	14.10	14.10
26	**2x13**	2.12	0.339	15.98	14.27	15.13
	13x2	2.04	0.291	**14.27**		
28	**2x14**	2.10	0.319	15.19	14.09	14.77
	14x2	2.07	0.292	14.09		
	4x7	2.09	0.322	15.33		
	7x4	2.03	0.273	14.46		
30	3x10	2.11	0.318	15.02	12.97	14.22
	10x3	2.02	0.269	13.31		
	6x5	2.05	0.268	13.08		
	5x6	2.07	0.269	12.97		
	15x2	2.15	0.352	16.32		
	2x15	2.07	0.303	14.62		
35	**7x5**	2.04	0.236	**11.54**	11.54	12.10
	5x7	2.07	0.262	12.66		
40	**8x5**	2.04	0.216	**10.57**	10.57	11.91
	5x8	2.07	0.260	12.58		
	10x4	2.04	0.226	11.06		
	4x10	2.09	0.281	13.42		

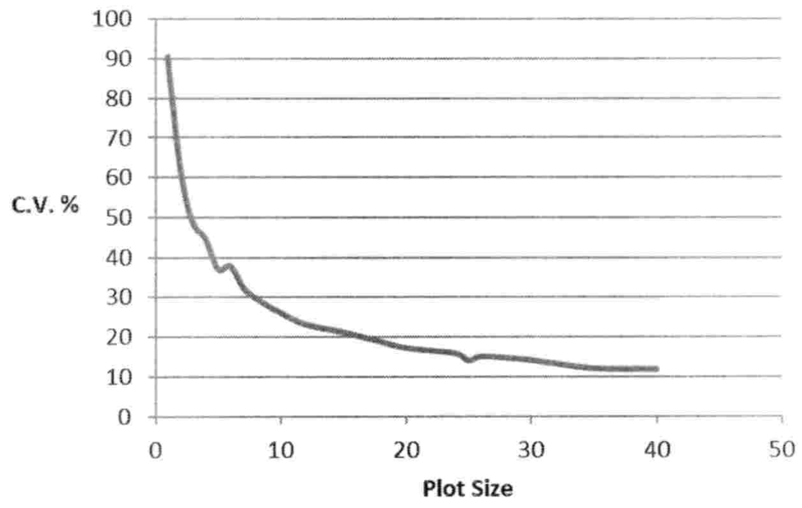


Fig. 6. Graph depicting the reduction in coefficient of variation and curvature of Vellayani Hraswa.

Table 26. Summary table of plot size and shape along with Coefficient of variation

Size	Shape	Mean	SD	CV(%)	Min CV	Average
20	10x2	1.99	0.329	16.50	16.11	17.33
	2x10	2.16	0.427	19.75		
	4x5	2.09	0.354	16.95		
	5x4	2.05	0.331	16.11		
24	**8x3**	**2.01**	**0.299**	**14.87**	**14.87**	**15.90**
	3x8	2.11	0.368	17.42		
	6x4	2.04	0.307	15.05		
	4x6	2.09	0.330	15.74		
	2x12	2.14	0.360	16.81		
	12x2	2.02	0.314	15.49		
26	2x13	2.12	0.339	15.98	14.27	15.13
	13x2	2.04	0.291	14.27		

From the table it can be concluded that optimum plot size of branching variety was 24 units with a minimum CV of 15.90. For a 24 unit plot size, a combination of 8 x 3 with a minimum CV of 14.87 is found to be the best shape. Number of plants to be accommodated per plot is 24. Area required for the same is 19.44 m^2. Prabhakaran and Thomas (1974) reported almost the same result. The optimum plot size for cassava was computed to be about 20 m^2. They reported that shape of plot do not have any consistent effect on the CV. However for a given plot size long and narrow plots generally yielded lower CV than square plots of the same dimension.

4.5.1.2 Fairfield Smith's Variance Law

Table 27. Regression analysis under Fairfiield Smith's law

Regression Statistics	
Multiple R	0.997
R^2	**0.995**
Adj R^2	0.995
Standard Error	0.040
Observations	20

ANOVA

	df	SS	MS	F value
Regression	1	6.36	6.3	3814
Residual	18	0.030	0.01	
Total	19	6.39		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	**4.541**	0.023	193	<0.01
X	**-0.56**	0.009	61	<0.01

$$Y = 4.54 + (-0.560)X$$

Under Fairfield Smith's law, equation obtained was

$$V_x = 93.86\ X^{-0.560}$$

The R^2 obtained is very high and b value is 0.560. It indicates a positive relationship between adjacent plots.

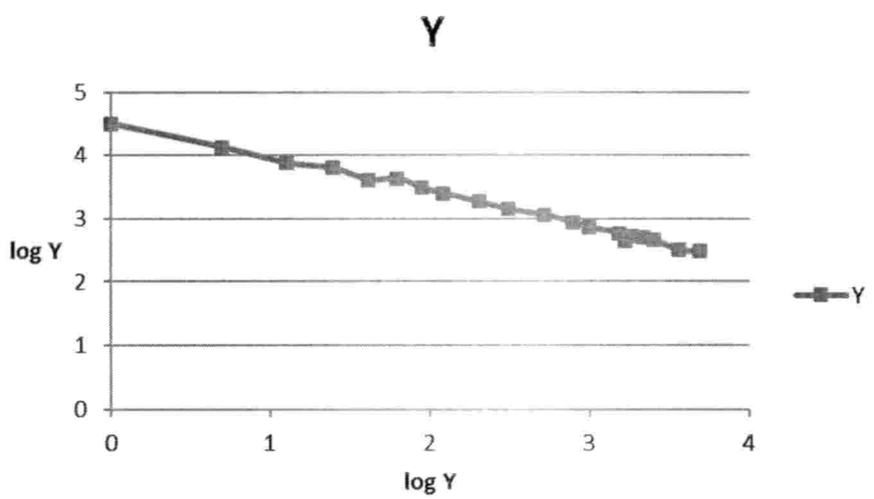


Fig. 7. The graph of coefficient of variation (on log scale) obtained under Fairfield Smith's law

Calculation of optimum plot size:

$$X_{opt}^{2(b+1)} = V_1^2 b^2 [\frac{3(1+b)}{2+b} - 1]$$

X $_{opt}$ obtained by using this formula is 24.3923

4.5.1.3 Modified curvature method

Here the model is $y = ax^{-b}$ where y is the variance of the plot and x is the plot size.

Curvature (C) can be obtained by the formula

$$C = \frac{d^2y/dx^2}{[1 + (\frac{dy}{dx})^2]^{\frac{3}{2}}}$$

Point at which the curvature attains maximum value $\frac{\partial C}{\partial x} = 0$

On simplification, optimum plot size can be obtained by the formula

$$X_{opt} = \left[\frac{(ab)^2(2b+1)}{(b+2)}\right]^{\frac{1}{2(b+1)}}$$

$a = 93.784$

$b = 0.561$

$X_{opt} = 11.92$

For this variety also optimum plot size is almost similar to that of Farirfield Smith's method.

4.5.2 Modified Methods

4.5.2.1 Cost Ratio Method

Optimum plot size can be determined by the formula $X_{opt} = \frac{bK_1}{(1-b)K_2}$

As in the case of Sree Pavithra the optimum plot size is attempted for different values of K_1 and K_2. Here also the value of b is close to 0.5. Since the cost values are not known exactly, the optimum values were listed for a range of K_1 and K_2 and are listed in Table 28.

Table 28. Optimum plot size estimation under cost ratio method for different K_1 and K_2 values

K_1	K_2	X opt
1	1	1.27
2	1	2.54
3	1	3.82
4	1	5.09
5	1	6.36
6	1	7.64
7	1	8.91
8	1	10.19
9	**1**	**11.46**
10	**1**	**12.73**
1	2	0.636
2	2	1.27
3	2	1.91
4	2	2.54
5	2	3.18
6	2	3.82
7	2	4.45
8	2	5.09
9	2	5.73
10	2	6.36
1	3	0.424
2	3	0.849
3	3	1.27
4	3	1.69

Table 28. Optimum plot size estimation under cost ratio method for different K_1 and K_2 values (cont.)

K_1	K_2	X opt
5	3	2.12
6	3	2.54
7	3	2.97
8	3	3.39
9	3	3.82
10	3	4.24
1	4	0.318
2	4	0.636
3	4	0.955
4	4	1.27
5	4	1.59
6	4	1.91
7	4	2.22
8	4	2.54
9	4	2.86
10	4	3.18
1	5	0.254
2	5	0.509
3	5	0.764
4	5	1.01
5	5	1.27
6	5	1.52
7	5	1.78
8	5	2.03
9	5	2.29

From the table it can be observed that optimum plot size was found to be maximum at K_1=10 and K_2 =1. Here the CV remains almost constant (near to 11) for a wide range of plot sizes. As before the cost ratio method do not workout properly and is not giving a good result. Therefore, this method is not suitable for determination of optimum plot size in the present case.

4.5.2.2 Based on the Shape of the Plot

A relationship can be established between C.V. and the plot shape X_1 and X_2 (length and breadth). To study the effect of plot shape on soil variability (using Smith law), the equation is fitted as follows: $V_x = V_1 X_1^{-b_1} X_2^{-b_2}$

Where X_1 and X_2 are the length and breadth of the plot. The suitability is examined by computing the coefficient of determination. The equation can be expressed as

$$\text{Log } V_X = \log V_1 - b_1 \log X_1 - b_2 \log X_2$$

Where b_1 and b_2 are constants and V_1, and V_x are the coefficients of variation for various shapes of plots (Table 29).

Table 29. Regression analysis under model based on shape (length and breadth) of the plot.

Regression Statistics	
Multiple R	0.989
R^2	0.978
Adj R^2	0.977
Standard Error	0.071
Observations	67

ANOVA

	Df	SS	MS	F value
Regression	2	15.06	7.534	1462
Residual	64	0.329	0.005	
Total	66	15.39		

	Coefficients	Standard Error	t Stat	P-value
Intercept	4.55	0.028	159.57	<0.01
Log (X_1)	-0.609	0.012	-49.57	<0.01
Log (X_2)	-0.516	0.012	-42.04	<0.01

Obtained Equation is

$$V_x = 94.95 X_1^{-0.61} X_2^{-0.52}$$

Where b_1=0.61 and b_2=0.52 and R^2=98%

By taking different values for X_1 and X_2 the CV obtained are shown below

Table 30. Coefficient of Variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot

X_1	X_2	CV		X_1	X_2	CV
1	1	94.95		1	7	34.76
2	1	62.25		2	7	22.79
3	1	48.63		3	7	17.80
4	1	40.81		4	7	14.94
5	1	35.63		5	7	13.04
6	1	31.88		6	7	11.67
7	1	29.02		7	7	10.62
8	1	26.76		8	7	9.79
9	1	24.90		9	7	9.12

Table 30. C.V. corresponding to different values of X_1 and X_2 (under model based on shape of the plot) - cont.

X_1	X_2	CV		X_1	X_2	CV
10	1	23.36		10	7	8.55
11	1	22.04		11	7	8.07
12	1	20.90		12	7	7.65
13	1	19.91		13	7	7.29
1	2	66.39		1	8	32.45
2	2	43.52		2	8	21.27
3	2	34.00		3	8	16.62
4	2	28.53		4	8	13.94
5	2	24.91		5	8	12.17
6	2	22.29		6	8	10.89
7	2	20.29		7	8	9.92
8	2	18.71		8	8	9.14
9	2	17.41		9	8	8.51
10	2	16.33		10	8	7.98
11	2	15.41		11	8	7.53
12	2	14.61		12	8	7.14
13	2	13.92		13	8	6.80
1	3	53.84		1	9	30.53
2	3	35.30		2	9	20.02
3	3	27.58		3	9	15.64
4	3	23.14		4	9	13.12
5	3	20.20		5	9	11.45
6	3	18.08		6	9	10.25
7	3	16.46		7	9	9.33

Table 30. C.V. corresponding to different values of X_1 and X_2 (under model based on shape of the plot)- cont.

X_1	X_2	CV		X_1	X_2	CV
8	**3**	**15.17**		8	9	8.60
9	3	14.12		9	9	8.01
10	3	13.24		10	9	7.51
11	3	12.50		11	9	7.08
12	3	11.85		12	9	6.72
13	3	11.29		13	9	6.40
1	4	46.41		1	10	28.92
2	4	30.43		2	10	18.96
3	4	23.77		3	10	14.81
4	4	19.95		4	10	12.43
5	4	17.41		5	10	10.85
6	4	15.58		6	10	9.71
7	4	14.18		7	10	8.84
8	4	13.08		8	10	8.15
9	4	12.17		9	10	7.58
11	4	10.77		11	10	6.71
12	4	10.21		12	10	6.36
13	4	9.73		13	10	6.06
1	5	41.36		1	11	27.53
2	5	27.12		2	11	18.05
3	5	21.18		3	11	14.10
4	5	17.78		4	11	11.83
5	5	15.52		5	11	10.33
6	5	13.89		6	11	9.24

Table 30. C.V. corresponding to different values of X_1 and X_2 (under model based on shape of the plot)- cont.

X_1	X_2	CV		X_1	X_2	CV
7	5	12.64		7	11	8.41
8	5	11.65		8	11	7.75
9	5	10.85		9	11	7.22
10	5	10.17		10	11	6.77
11	5	9.60		11	11	6.39
12	5	9.10		12	11	6.06
13	5	8.67		13	11	5.77
1	6	37.64		1	12	26.32
2	6	24.68		2	12	17.25
3	6	19.28		3	12	13.48
4	6	16.18		4	12	11.31
5	6	14.12		5	12	9.87
6	6	12.64		6	12	8.83
7	6	11.50		7	12	8.04
8	6	10.61		8	12	7.41
9	6	9.87		9	12	6.90

By taking different values of X_1 and X_2, the corresponding values of C.V. is plotted and minimum and constant variance was considered for finding optimum plot size. This is represented in the following graph.

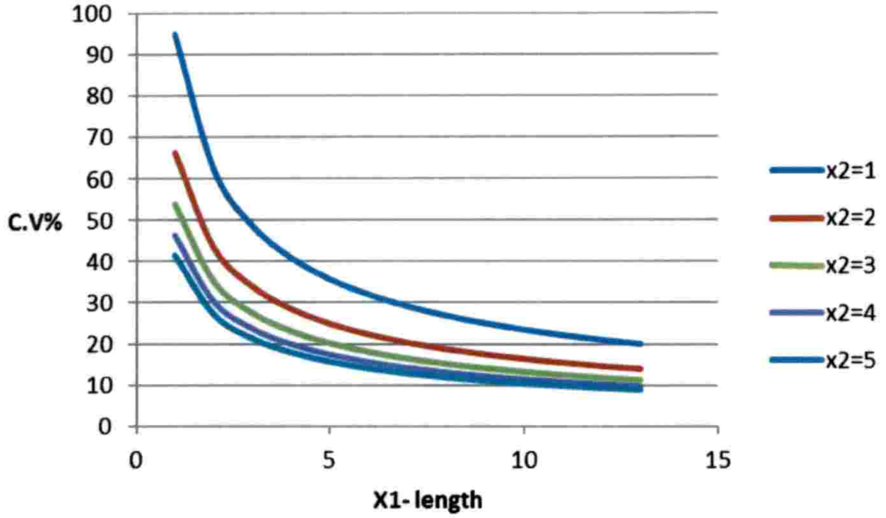


Fig. 8. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot.

Here X_1=1,2,….,13 and X_2 takes the values 1,2…,6

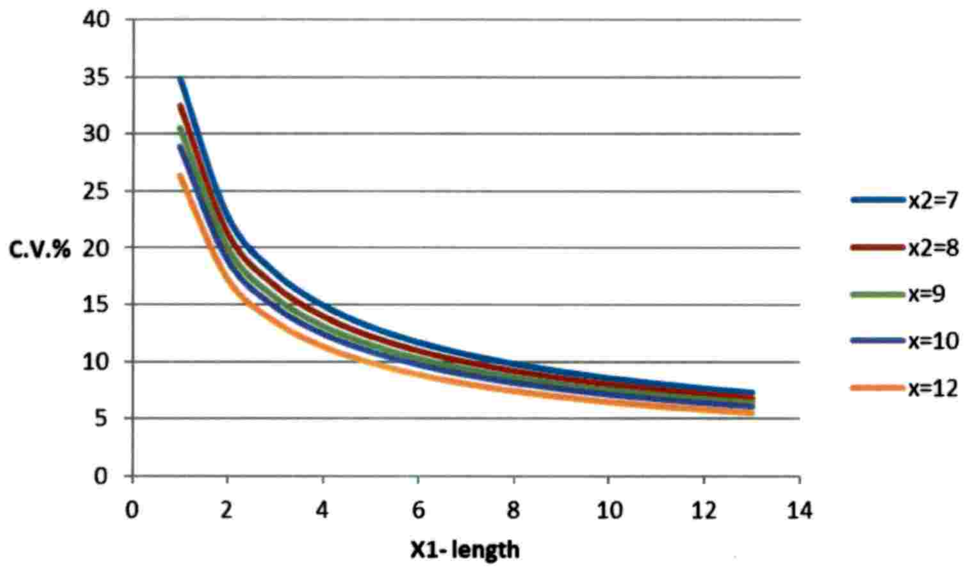


Fig. 8. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot. - continued)

Here X_1=1,2,….,13 and X_2 takes the values 7,8,….,12

Under this method maximum curvature can be observed at $X_1 = 8$ and $X_2 = 3$ after that the line become straight line which was almost parallel to X axis. For high values of X_1, when X_2 is small like 1 or 2 units it can be seen that CV is not reducing considerably. Thus this method also gives an optimum plot size of 8x3 units ($19.44m^2$).

4.5.2.3 Covariate Method – Using Number of Functional Leaves as Covariate

Here we used number of functional leaves as covariate for finding the optimum plot size. The plot size obtained in this case also is same as that obtained when yield alone was used as the main variable. This is shown in Table 31.

Table 31. Correlation between yield and number of functional leaves

	Plot Size	CV(yield)	CV(leaves)
Plot Size	1		
CV(yield)	-0.785	1	
CV(leaves)	-0.800	**0.997**	1

From the table it is clear that number of functional leaves and yield are highly correlated about i.e., 99 percent.

Regression Analysis under Covariate Method

Table 32. Regression Analysis under Covariate Method

	Coefficients	Standard Error	t Stat
Intercept	-3.53	1.35	-2.61
plot size(X_1)	0.061	0.040	1.52
CV(leaves)(X_2)	1.65	0.038	42.70

R^2 obtained was 99 percent.

Equation fitted as $Y = -3.53+0.06X_1 + 1.65\ X_2$

Table 33. Coefficient of variation for yield and number of leaves for different plot sizes based on covariate method.

CV (Yield) (Y)	Plot Size (X_1)	CV(No. of leaves) (X_2)
90.42	1	56.95
62.26	2	39.40
48.62	3	31.92
44.72	4	27.68
37.10	5	25.58
37.83	6	23.10
32.57	7	22.21
29.90	8	20.10
26.13	10	18.20
23.23	12	16.16
18.90	18	12.80
17.33	20	11.98
15.90	**24**	**10.69**
14.10	25	10.83
15.13	26	10.45
14.77	28	9.38
14.22	30	9.08
12.10	35	8.48

As the plot size increases CV decreases and attains almost constant when it is near to 24. So it can be taken as optimum plot size. Number of plants to be accommodated in a single experimental plot is 24 and the area required is 19.44 m^2.

4.6 DISCRIMINANT FUNCTION ANALYSIS

Discriminant function analysis is used to develop a function that can discriminate the varieties studied based on their biometric measurements. The purpose of discriminant analysis is to investigate differences between or among groups and to access the relative importance of the independent variables in classifying the dependent variables. Mahalanobis distances are used in analyzing cases in discriminant analysis, which is measured in terms of standard deviations from the centroid.

The function obtained was $Z = 1.084\,X_1 - 0.686\,X_2 + 0.109X_3 + 0.017\,X_4$

Where X_1= plant height, X_3= number of tubers

X_2= tuber length, X_4= total yield, X_5= tuber yield

Table 34. Discriminant Function scoress in case of Sree Pavithra and Vellayani Hraswa

	SP	VH
Average	236.37	84.09
SD	71.79	79.90
Max	401.10	263.10
Min	-229.9	-208.28

Combined average was obtained as 166.64. Average of Sree Pavithra was more as compared to Vellayani Hraswa. Sree Pavithra got a score ranging from -229 to 401 while the score of Vellayani Hraswa ranged from 263 to -208. The average score of 166 was obtained for both the varieties from which it can be concluded that when the score is less than 166, the variety is generally Sree Pavithra and if more, the variety is Vellayani Hraswa.

By maximum curvature method optimum plot size of branching variety – Vellayani Hraswa was 24 plants with plot size 19.44 m^2 with 8 unit length and 3 unit width with a minimum C.V. of 14.87 is found to be the best shape. Prabhakaran and Thomas (1974) reported almost the same result. The optimum plot size for cassava was computed to be about 20 m^2. They reported that shape of plot do not have any consistent effect on the C.V. However for a given plot size long and narrow plots generally yielded lower C.V. than square plots of the same dimension.

FUTURE LINE OF RESEARCH

- Estimation of optimum plot size based on covariates which are highly correlated with yield give results similar to that of analysis based on yield data itself. Hence, optimum plot size estimation based on covariates can be attempted for other crops also.
- Studies on estimation of block shape and number of replications can be further attempted and block efficiency based on different experimental designs can be obtained.

Summary

5. SUMMARY

Agriculture is the single largest sector of India, contributing 17.9% of Gross Domestic Product to the Indian Economy (FIB, 2015). So the agricultural field experiment becomes a vital part of research for new innovations for conducting field trials. It is important for the agricultural scientists to have knowledge on field plot techniques, optimum size, shape and arrangements of plot for a particular type of experiment for obtaining the appropriate results. The precision of significance tests in field trial is largely controlled by the size and shape of area available for the particular field trial and the nature of fertility variations. The present problem was therefore to examine the scientific basis for using plot size and shape within optimum limits for proper conduct of field experiments.

The present research work entitled with "Modified statistical methods on estimation of optimum plot size in cassava (*Manihot esculenta* Crantz)" was formulated with the following objectives.

- To develop modified statistical methods for estimation of optimum plot size for field experiments
- Use a multivariate technique in discriminating branching and non-branching varieties of cassava.

The study was based on the primary data. Two varieties namely Vellayani Hraswa (branching type) with a spacing of 90 cm x 90 cm and Sree Pavithra (non-branching type) with 75 cm X 75 cm were grown in an area of 400 m^2. Bi-monthly observations were recorded for both varieties on growth parameters along with final yield parameters. Inter correlations among the growth parameters showed that the height and number of leaves were highly correlated with yield. Multiple linear regression analysis were carried out for both varieties using yield as dependent variable and biometric measurements as independent variables.

The salient findings of the study are summarized below:

- In case of Sree Pavithra, all the estimated correlation coefficients between yield and biometric parameters were found to be less correlated. There is a high degree of association between yield and number of functional leaves (0.658 for 2 MAP, 0.786 for 4 MAP and 0.648 for 6 MAP).
- In case of Vellayani Hraswa, all the estimated correlation coefficients between yield and biometric parameters were found to be less correlated. During 2 MAP height is highly correlated with internodal length as well as number of functional leaves (0.482 and 0.603 respectively).
- In case of Sree Pavithra, adjusted R^2 reaches a steady stage with 7 variables and C_p obtained is 7.43. But for prediction purpose we can use the model with 2 variables with R^2 of 0.396. Here the variables used are height at 2 MAP and number of functional leaves at 2 MAP with variables height at 2 MAP and number of leaves at 2 MAP. Model obtained is Y = 0.401+ 0.040 Ht_2 - 0.037 Nl_2. Among the various regression equations, the best model obtained for prediction of yield in Vellayani Hraswa was using height at 2 months after planting (MAP), internodal length at 4 MAP and number of leaves at 6MAP with an adjusted R^2 of 20%. Here height at 2 MAP, only have significant influence on yield. The model obtained is Y= 0.092 + 0.010 Ht_2 + 0.203 In_4 + 0.001 Nl_6.
- In Contour map, it was observed that fertility gradient ranged from -50 to 70 and maximum frequency was in the range from -10 to 30 for Sree Pavithra (34%) and -50 to -10 for Vellayani Hraswa (29%) and a minimum of 8% (< -50) for Sree Pavithra and 8% (>70) for Vellayani Hraswa.
- For non-branching type (Sree Pavithra) the optimum plot size obtained was with 18 units (10.12 $m^{2)}$ in case of maximum curvature method as well as by the use of length and breadth of the plot method.

- In case of modified curvature method and Fairfield smith's cost ratio method optimum plot size obtained were 8 units.
- By considering the shape of the plots minimum variance was obtained when length was taken as 9 units and breadth as 2 units. The R^2 values were worked out in all cases and along with practical considerations maximum curvature method was found to be better with a plot size of 9x2 units.

- For branching type (Vellayani Hraswa) the optimum plot size obtained was with 24 (19.44 m^2) units by using maximum curvature method.
  - In case of modified curvature method and Fairfield Smith cost ratio method, optimum plot size obtained was 12 units.
  - Minimum variance was obtained when length was taken as 8 units and breadth as 3 units. High R^2values indicates that maximum curvature method was found to be better method with a plot size of 8x3 units.
- A discriminant function was fitted to understand the categorical difference between the two varieties based on five variables and obtained a score ranging from -229 to 401 and an average score of 166 for both the varieties from which it can be concluded that when the score is less than 166, the variety is Sree Pavithra and if more the variety is Vellayani Hraswa.

To cope with the problem of the research workers, it is essential to standardize a optimum plot size and shape for the experimental plot of major crops grown under different conditions, which will increase the precision of the experiments. Hence, to improve the quality and credibility of research results, there is a need to carry out research on field-plot techniques.

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Abstract

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MODIFIED STATISTICAL METHODS ON ESTIMATION OF OPTIMUM PLOT SIZE IN CASSAVA (*Manihot esculenta* Crantz)

by

RAKHI, T.

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Abstract of the thesis

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KERALA, INDIA

2017

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ABSTRACT

A study entitled "Modified statistical methods on estimation of optimum plot size in cassava (*Manihot esculenta* Crantz)" has been carried out at Department of Agricultural Statistics, College of Agriculture, Vellayani, Thiruvananthapuram during 2015-2017. Modified statistical methods for estimation of optimum plot size for field experiments were attempted for branching (Vellayani Hraswa- 6 months duration) and non-branching (Sree Pavithra 8-10 months duration) varieties of cassava. A multivariate discriminant function is also developed for characterizing the above two varieties.

The study was based on the primary data. The variety Vellayani Hraswa was grown with a spacing of 90cm x 90cm and Sree Pavithra with 75cm X 75cm in an area of 400 m^2. Bimonthly observations were recorded for both varieties on growth parameters along with final yield parameters. Inter correlations among the growth parameters showed that the height and number of leaves were highly correlated with yield. Multiple linear regression analysis was carried out for both varieties using yield as dependent variable and biometric measurements as independent variables. Among the various regression equations the best model obtained for prediction of yield in Vellayani Hraswa was using height at 2 months after planting (MAP), internodal length at 4MAP and number of leaves at 6MAP with an adjusted $R^2$of 20% and Sree Pavithra with variables height at 2MAP and number of leaves at 2 MAP with an adjusted R^2 of 40%.

In Contour map, it was observed that fertility gradient ranged from -50 to 70 and maximum frequency was in the range from -10 to 30 for Sree Pavithra (34%) and -50 to -10 for Vellayani Hraswa (29%) and a minimum of 8% (< -50) for Sree Pavithra and 8% (>70) for Vellayani Hraswa.

For determining optimum plot sizes the conventional methods (maximum curvature method, Fairfield Smith variance method) and modified methods (length and breadth of plots, cost of cultivation ratios and covariate method) were attempted.

For non-branching type the optimum plot size obtained was with 18 units in case of maximum curvature method as well as by the use of length and breadth of the plot method. In case of modified curvature method optimum plot size obtained was 8 units. By Fairfield Smith's cost ratio method, the result obtained was about 8.5 units. By considering the shape of the plots minimum variance was obtained when length was taken as 9 units and breadth as 2 units. The R^2 values were worked out in all cases and along with practical considerations maximum curvature method was found to be better with a plot size of 9x2 (10.12 m^2) units.

For branching type the optimum plot size obtained was with 24 units by using maximum curvature method. In case of modified curvature method, optimum plot size obtained was 12 units. By Fairfield Smith cost ratio method the result obtained was also about 12 units. Minimum variance was obtained when length was taken as 8 units and breadth as 3 units. High R^2 values indicated that maximum curvature method was found to be better with a plot size of 8x3 (19.44 m^2) units.

A discriminant function was fitted to understand the categorical difference between the two varieties based on five variables and obtained a score ranging from -229 to 401 and an average score of 166 for both the varieties from which it can be concluded that when the score is less than 166, the variety is Sree Pavithra and if more the variety is Vellayani Hraswa.

By studying different methods for the determination of optimum plot size for cassava, Maximum Curvature Method as well as Method using Covariate are found to be the most appropriate ones. Optimum plot size for Vellayani Hraswa was 19 m^2 accommodating 24 plants. In case of Sree Pavithra, it was 10m^2 accommodating 18 plants.

Plate 1: Field view

Plate 2. Sree Pavithra

Plate 3. Vellayani Hraswa

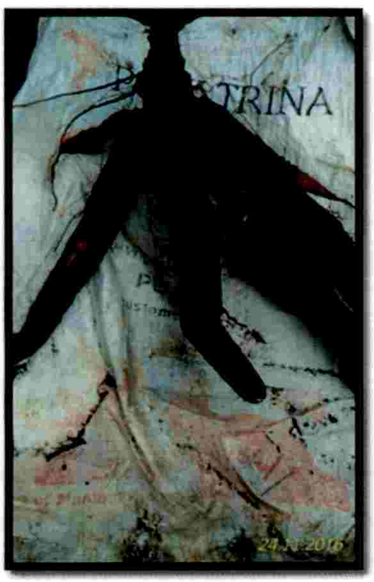

Plate 4. Tuber-Sree Pavithra

Plate 5. Tuber- Vellayani Hraswa