COMPARISON OF METHODS FOR OPTIMUM PLOT SIZE AND SHAPE FOR FIELD EXPERIMENTS ON PADDY (*Oryza sativa*)

by

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(2017-19-001)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Comparison of methods for optimum plot size and shape for field experiments on paddy** (*Oryza sativa*)**"** 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 of any degree, diploma, associateship, fellowship or other similar title of any University or Society.

Place: Vellayani,

Date: 27.06.2019

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CERTIFICATE

Certified that this thesis entitled **"Comparison of methods for optimum plot size and shape for field experiments on paddy (*Oryza sativa*)"** is a record of research work done independently by Ms. Athulya C. K. (2017-19-001) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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ATHULYA C. K.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

AICARP	All India Co-ordinated Agronomic Research Project
CV	Coefficient of variation
Fig.	Figure
ha	Hectare
HI	Harvest index
IFSRS	Integrated Farming System Research Station
MAP	Month after planting
Ph	Plant height
SD	Standard deviation
Sy	Straw yield
T	Number of tillers
Ty	Total yield
V	Comparable variance
$V_{(x)}$	Among plot variance
V_x	Variance per unit area
X	Plot size
Y	Grain yield
b	Soil heterogeneity coefficient
cm	Centimeter
et al.,	Co-workers
g	Gram
i.e.,	that is
kg	Kilogram
m	Meter
Viz	Namely

Introduction

1. INTRODUCTION

It is important for the crop scientists to have a clear idea on field plot techniques so as to make use of the most effective shape, size of plots in a particular experiment to get consistent results. The accuracy of results in field experiments is largely controlled by size and shape of plots, and which are controlled by the size and shape of experimental area and nature of fertility variation or other variations of the field. To address these type of problems in agriculture research, it has become indispensable to standardize a suitable plot size and shape for the experimental plot for crops growing under different conditions, which may expected to reduce the standard error of the experiment. There are various elements which are concerned with the proper planning of field plot techniques. The use of inappropriate field plot technique influence the performance of the experiment and which may inflate experimental error and it may leads to improper inferences. Hence, to improve the quality as well as reliability of research results, there is a need to carry out research on optimum plot size based on field plot techniques (Masood *et al.*, 2012).

Determination of optimum plot size is not an end by itself. Its arrangement in suitable shape and number in a block is known to greatly influence the experimental error. Thus in nutshell, the choice of plot size and shape constitute an important landmark in planning field experiments (Kavitha, 2010). In general, the optimum plot size of an experimental unit cannot be given without considering nature of the experimental material, number of treatments per block, practical considerations, variability among experimental units, and cost of conducting the experiment.

The general problems in estimating optimum plot size are increased variability with decrease in plot size and increased cost for large plots. Large plots have less variability but the cost of experimentation will be higher, while smaller plots have high variability with less experimentation cost. Moreover, all plot sizes and shapes are not equally efficient in the point of view of cost considerations. In order to make a balance between cost and precision of the experiment, it is important to have a proper choice of optimum plot size.

The optimum plot size of a crop can be estimated by using the data on uniformity trails as well as using information on previous field experiments (Bharati *et al.*, 2017). The present work is an attempt to estimate optimum plot size of paddy based on uniformity trial data. Uniformity trial consists of planting an experimental area with a single crop, and applying cultural and management practices as uniformly as possible. All the sources of variation are kept constant throughout the experimental period. Then the experimental site is divided into small basic units of same size and shape and observations on yield and biometric characters are recorded separately from each basic unit. The size of the basic unit is mainly governed by the availability of resources. Smaller basic units provides a detailed study on soil heterogeneity.

Almost any experimental area may vary in fertility from one plot to the other and causing substantial change in yield. The most obvious reason for the change in yield even when the area is treated alike is soil heterogeneity.

Rice is India's pre-dominant crop having an area of 43993.4 thousand hectares with a production of 109698.4 thousand tons in India with a productivity of 2494 kg ha^{-1} (GOI, 2017). Today, rice occupies only the third position among Kerala's agricultural crops with respect to area under cultivation, and it is far behind coconut and rubber. Palakkad and Alappuzha are the two major rice producing districts in Kerala. Uma (MO-16) is a medium duration, high yielding variety of rice having duration of 115-120 days in mundakan and 120-135 days in virippu season. The crop is dwarf, medium tillering and non-lodging. The variety is suited to the three seasons and is especially good for the additional crop season of Kuttanad (KAU, 2016). In this context the objective of the present study is

- Estimation and comparison of methods for optimum plot size and shape for field experiments on high yielding variety of paddy.

Different statistical methods *viz.*, maximum curvature method, Fairfield Smith's variance law, modified maximum curvature method, comparable variance method, Hatheway's method, based on shape of the plot methods are being used for the estimation of optimum plot size. The basic units of uniformity trial are combined and the curve is plotted by taking plot size and coefficient of variation (CV) under maximum curvature method, whereas Smith variance law is used for fixing optimum plot size under Fair field method. Hatheway's method is one of the oldest methods of estimating optimum plot size. Cost ratio method takes the cost of field experimentation in to consideration whereas the comparable variance method consider the among plot variances for estimating optimum plot size. Generally all these methods do not provide a single value for optimum plot size. The optimum plot size estimated for a crop may varies across the treatments, locations, and the method of transplanting.

Optimum plot sizes were estimated for several crops. The main problem in estimating plot size with these methods is the necessity of grouping of contiguous basic units which complicates the use of these methods and affect the accuracy when the size of the uniformity trail is small (Schwertner *et al.*, 2015).

1.1 SCOPE OF THE STUDY

This is an important study to determine the optimum size and shape of plots for field experiments on high yielding variety of paddy (Uma) suited to Kerala conditions based on primary data collected from uniformity trial. The data consists of observations on growth attributes as well as yield and yield attributes of the crop. The findings obtained from the research work would enable us to identify the optimum plot size and shape for the selected paddy and it is useful for field experiments for researchers, so that it reduce the experimental error.

1.2 LIMITATIONS OF THE STUDY

As this is a post graduate research work there is a constraint of time, finance and accessibility of other resources, the present study is restricted to one variety for a single location. Even though the research is conducted with maximum accuracy, precision and sincerity, the primary data collected from field on both growth attributes and yield attributes manually may lead to manual errors. Since the research work was conducted in open field conditions, and also due to the extreme weather fluctuations which occurred in Kerala (Flood, 2018), it was tried to maintain a healthy crop stand throughout the cropping season. Sincere efforts have been made by the researcher to conduct the study as reliable as possible.

1.3 PRESENTATION OF THE THESIS

This thesis contains five chapters. The present chapter deals with the objectives, scope and limitations of the study. The second chapter *i.e.,* review of literature narrates the back ground of past work related to this research. Third chapter provides description about the experimental site and different methods to estimate the optimum plot size. Fourth chapter describes the results of the present analysis in association with the discussion of the inferences drawn. Fifth chapter represents the summary of the study.

Review of Literature

2. REVIEW OF LITERATURE

A careful and methodical literature review is essential to have an all-inclusive and systematic planning of study. It not only analyses what research has been done in the past, but it also evaluates, encapsulates, relates the disparities and connects relevant sources that are interrelated to the current research. Here efforts has been made to critically review the literature of the past research work pertinent to the present study. In general uniformity trials are conducted to determine the suitable size and shape of plots and the number of plots in a block of all most all the crops to understand the fertility variation of the field. In a uniformity trial, a particular crop is grown in a piece of land with uniform conditions. All sources of variations are kept constant except that due to native soil differences. At the time of harvest entire area is divided in to small basic units with same size and shape and produce from each basic unit is recorded separately. Optimum plot size and shape is required at the time of experimental layout to obtain accuracy and reliability in field experiments. In this context the objective of the study is to estimate and compare the methods for optimum plot size and shape for field experiments on high yielding variety of paddy, Uma. Uma (MO 16) is the medium duration and non-lodging variety of paddy suited to three seasons especially to additional virippu crop season of Kuttanad.

Keeping in view the objectives of study, the reviews are presented under the following headings;

2.1 Uniformity trial

2.2 Plot size

2.3 Plot shape

2.1 UNIFORMITY TRIAL

A single crop is planted in the experimental site and all the cultural and management practices are applied as uniformly as possible. All sources of variability excluding that due to native soil differences are kept constant. The planted area is then subdivided in to small units of same size and from which measurements of productivity are made (Gomez and Gomez, 1976).

Idrees and khan (2009) suggested that conducting a uniformity trial to study the field variability before doing any varietal contrast in a new field helps to make conclusions about the pattern of fertility in the experimental field. The generalize lattice designs on the average was found to be more efficient than complete block deigns in reducing the error mean square when various complete and incomplete block designs were used with dummy treatment structures on uniformity trial data.

Shukla *et al.* (2013) proposed a linear model with its deterministic component is proposed to relate the plot size represented by X and coefficient of variation (CV) represented by Y as

$$Y = a + b\ logX$$

The proposed model describes the relationship between the plot size and CV in a better way as compared to maximum curvature method and Smith's variance law method. The appropriateness of the model has been verified by examining the values of coefficient of determination (R^2), mean residual sum of squares (s^2), mean absolute error (*MAE*), Akaike information criteria (*AIC*) and standardized residuals. The point of maximum curvature was obtained for the proposed model as,

$$X = \sqrt{b^2/2}$$

It was observed that expression for obtaining point of maximum curvature was much simpler for the proposed model as compare to that of Fairfield Smith's model.

Estimation of optimum plot size was done for assessing the fruit mass of tomato, snap beans and zucchini using the uniformity trial size in Santa Maria. It was found that the size of uniformity trial s influenced the estimation of optimum plot size for evaluating the mass of fruits of tomato, snap-beans and zucchini. Resamples with relocation and estimation was tried for each uniformity trial. The optimum plot size was estimated using the formula

$$X_o = \frac{\sqrt[10^3]{2(1-p^2)s^2m}}{m}$$

Where p is the first order spatial autocorrelation coefficient, s^2 is the variance and m is the mean. It was found that an optimum plot size of 12 basic units (12 plants) for tomato and 21 basic units (42 plants) for snap-beans were enough for evaluating the fruit mass in plastic tunnel whereas 18 basic experimental units (36 plants) and zucchini with ten basic experimental units (10 plants) in plastic greenhouse were adequate for estimating the optimum plot size for evaluating the mass of fruits with two and three basic experimental units respectively (Schwertner *et al.*, 2015).

2.2 PLOT SIZE

Index of soil heterogeneity and experimental cost were used to determine the optimum plot size for unguarded plot and plot size was determined 9 m^2 (Awang and Mohdnor, 1984). It was noted that within the same size, plot shape did not affected plot variability and therefore the recommended plot sizes were 3 m × 3 m or 7.5 m × 1.2 m.

Al-Feel *et al.* (2013) analysed the consequence of different plot sizes on the estimation of wheat yield. It was found that large and medium sized plots had not shown a significant difference in yield estimation but a significant difference was found between large and small plot sizes and medium and small plot size for yield estimation.

Pal *et al.* (2015) used radius of curvature method for the determination of plot size in robust and showed that since squared plot sizes of 2 × 2, 3 × 3 and 4 × 4 had higher value for radii than the desired minimum values and they cannot be considered as optimum plot size. Though radii of 2 × 7 and 2 × 8 plot sizes had values less than the minimum values of radius of curvature, they were also still not recommended as optimum plot size. Plot sizes of 2 × 5, 2 × 6, 3 × 5 and 3 × 6 were recommended as the optimum plot sizes for robust.

Sausa *et al.* (2015) conducted an experiment to determine the plot size for field experiments, in randomised complete block design with 14 cultivars of sunflower and 10 replications. The appropriate plot size was estimated using the intra class correlation method. Intra class correlation coefficient was calculated using the variance analysis.

$$\hat{\rho} = \frac{V_1 - V_2}{V_1 + (K-1)V_2}$$

where V_1 is the residual mean square between plots, V_2 is the residual mean square between basic units in a plot and K is the number of basic units in the plot. The estimated optimum plot size in sunflower for grain yield was 2.52 m^2 with a boundary of one row on each side. The precision of experiment was found to be increased with plot size up to eight basic units (5.04 m^2) for seven replications. They reported that, the more efficient way for enhancing the precision of experiment is by increasing the number of replications and plot size than increasing the number of cultivars.

Bharati *et al.* (2017) estimated the efficiency of optimum plot size using the information on previous experiments conducted in split plot design. The process

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involved the accurate estimation of soil heterogeneity coefficient followed by optimum plot size and the expression for the determination of soil heterogeneity had been derived and illustrated through several artificial and real data. The result indicated a considerable gain in efficiency of 19 and 22 per cent. This procedure led to the saving of plot size from 20 per cent to 75 per cent. Optimum plot size under certain assumptions indicated the saving of the land to a considerable extent except the experiment on grain yield of oat in which the optimum plot size approaches to lesser than the actual plot size assumed. The result also indicated that Pusa farm soil was more heterogeneous and the bottom soil along with top soil was less heterogeneous.

2.2.1 Maximum curvature method

Abu-Zeid and Mansi (1971) estimated the optimum plot size for testing yield in irrigated sugarcane. The area under trial was 1.08 hectare block of 1482 ultimate units. Each ultimate unit was 2.4 m^2 (2 m x 1.4 m). Results of the analysis showed that the coefficient of variation decreased with an increase in plot size with rectangular shape plots as compared with square plots and longer plots as compared with wider plots. A minimum coefficient of variation was obtained with plots of the size 96 to 600 m^2. It was also reported that large numbers of replications were required for smaller plots.

Shin *et al.* (1973) estimated the optimum plot size and shape for soybean yield trials with the basic unit comprise of 2.5 m × 0.6 m plot. A sharp decline in coefficient of variation was noticed from the 4.5 m^2 plot for kumkang dairip variety and is 6 m^2 plot for clark variety. The results implied that 5-6 m^2 plot are sufficient for yield trials in hybrid progenies. The estimated coefficient of variation was about 16% in both the varieties with 7.5 m long plot and 15.3% in 10 m plot.

Bhatt (1993) conducted plot technique in potato at Anand using uniformity trial data of 1152 plots each having a dimension of 1 m × 0.90 m. Optimum plot size

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was obtained using maximum curvature method, Fair field variance law and spatial correlation method. The rate of decline in CV was more with rise in breadth of the plot than with increase in length of the plot. Eight unit sized plots (1 m × 7.20 m) were found to be optimum for field experiments on potato.

The experiments on variability in field experiments on maize crop variety planted at a spacing of 75 cm × 75 cm in Pakistan (Masood and Javed, 2003). The yield measurements were taken separately from basic units of 75 cm × 75 cm and the basic unit consisted of one row. The findings of this study showed the importance of plot variability in conducting field experiments. The estimated plot size for maize trials based on coefficient of variation was 3.75 m x 3.75 m (14.06 m^2) with square shape. The recorded plot size was small in size than the prevailing plot size of 15 m^2 in the study area. When the experimenter does not know the fertility pattern of the experimental area or when border effects are large, square shaped plots were found better.

Miyasaka *et al.* (2013) estimated the optimum size of taro using fresh and dry weights of individual corms collected from two field trials conducted under flooded culture as well as upland culture. Natural logarithm of variance of yield and the natural logarithm of plot size showed a strong linear relationship. The point of maximum curvature indicated a rapid decrease with larger plot sizes and was taken as optimum when expressed on the non-log transformed scale. The optimum plot size of 21 inner plants (5.7 m^2) for the second flooded trial and 18 inner plants (4.9 m^2) for the second upland trial was found best. Index of degree of correlation between neighbouring plots minimized the cost per unit of research. Both these methods of computing optimum plot size sometimes resulted in estimates that surpassed the maximum test of plot size for certain field trials. There was no evidence for the existence of spatial autocorrelation in the corm yield of taro, which indicated suitability of the two methods in computing optimum size of plot. It was also noticed that plot size did not considerably affected the power in detecting the differences between treatments.

Shitap and Darji (2014) determined the optimum plot size and shape of brinjal in Gujarat using maximum curvature method. The high yielding variety of the crop JBGR-1 was sown at a spacing of 90 cm × 60 cm. The average coefficient of variation over size of plot ranged from 52.39 per cent for one basic unit to 7.71 per cent for 60 basic units plot. The coefficient of variation decreased with increased plot size. The optimum size of plot estimated for brinjal was 6.48 m^2 (7.2 m × 0.9 m).

Lavezo *et al.* (2016) verified the plot variability among oat cultivars. Thirty two uniformity trials of 3 m × 3 m were performed and each uniformity trial was allocated in 36 basic experimental units of 0.5 m × 0.5 m. The plot size was estimated by maximum curvature method of the coefficient of variation model. Scott-Knott test was used for making mean comparisons among cultivars. The number of replications was determined by an iterative process, for experiments in completely randomized design and randomized block design. The plot size of 1.57 m^2 was found adequate to estimate the grain yield in the oat cultivars. Four replications were found sufficient to estimate grain yield in the experimental designs of completely randomized design (CRD) and randomized block design (RBD) with up to 50 treatments.

Ali shah *et al.* (2017) observed coefficient of variation for the most viable length to width ratio in the experimental plot as 23.95% for wheat yield trials in Pakistan. The long and narrow plots were found more effective as compared to short and wide plots of the same size. The most suitable number of replications for a plot size (3.05 m × 1.22 m) was estimated between 2 to 6. The observed direction of fertility was gradually from west to east as compared to north to east. The south west side also provided the high rate of fertility based on the study of plot size of (3.05 m × 1.22 m) which was found more appropriate for experimental purpose.

Chaves *et al.* (2017) estimated the optimum plot size for rye yield and investigated the variability of plot size between two cultivars and three sowing dates. The optimum plot size was determined by the method of maximum curvature of the coefficient of variation model. The optimal size of the plot to evaluate the grains yield of rye was observed as 6.08 m^2.

Facco *et al.* (2017) verified the influence of the basic experimental unit size in the estimate of optimum plot size obtained by the method of maximum curvature of the coefficient of variation model for the evaluation of fresh matter of sunhemp in Brazil. The sowing was performed in two sowing dates with a spacing of 0.5 m with a density of 20 plants per linear meter. In each evaluation period for each basic experimental unit plan, the first order spatial autocorrelation coefficient, variance, standard deviation, mean, coefficient of variation of the trial and the plot size were determined. For each basic experimental plan, the optimum plot size was determined by the method of maximum curvature of the coefficient of variation model. The optimum plot size increased linearly with increase of basic experimental unit and oscillated between 5.40 m^2 and 18.30 m^2 for the first sowing date and 16.34 m^2 and 4.60 m^2 for the second sowing date. The study concluded that the estimated optimum plot size depends on the size of basic unit.

Khan *et al.* (2017) estimated the optimum plot size and shape for mustard planted at a spacing of 30 cm between the rows and 10 cm within the plants in a row in Hisar. The uniformity trial yield data of 48 m × 48 m (2304 basic units) noted from each basic unit of 1 m × 1 m. The variability among plots of different sizes and shapes was determined by calculating coefficient of variation. It was detected that the coefficient of variation decreased with increased plot size when plots were elongated in north south direction (88 per cent decrease) and in east west direction (93 per cent decrease). Further it was observed that long and narrow plots elongated in east west direction were more useful than the compact and square plots in controlling the soil heterogeneity. The optimum plot size for yield trial was estimated to be 5 m^2 with rectangular shape based on maximum curvature method.

Lohmor *et al.* (2017) conducted a uniformity trial for evaluating the nature and extent of soil variability to decide the optimum size and shape of plots. The coefficient of variation calculated for yield of individual harvested units was observed to be as high as 13.92 per cent. The coefficient of variation was found to be decreased with increase in plot size in both the directions but was more when plots were elongated in north south direction (96.48 per cent reduction). The long and narrow plots extended in north south direction were found to be more convenient than the compact and square plots. It was detected that, the smallest plot shape had the highest efficiency and the optimum plot size was estimated to be 2 m^2.

Rojas and Flores (2017) conducted a study to determine the adequate size and shape of an experimental unit for corn yield trials. A uniformity trial was seeded and the method of maximum curvature was used. The point of maximum curvature was determined by visual inspection where the curve, product of the association between plot size and coefficient of variation stopped and fell abruptly and took an almost constant behaviour which located between 12 and 16 basic units. The soil heterogeneity index was obtained as 0.62, indicated soil as heterogeneous. There was no difference between the forms associated with the size of 12 basic units, however for practical reasons the form of 6×2 was considered the most suitable.

2.2.2 Modified maximum curvature method

Michels *et al.* (2015) estimated the optimum plot size in beans for reflectance measurements using modified maximum curvature method and the maximum distance method. The reflectance readings were recorded on beans with the help of the green seeker instrument. It obtained basic experimental units of 0.45 m^2 in an area with 6 m and 8 m in length carrying 46 combinations. By accepting the biggest obtained area, the study was concluded that an optimum plot size of 5.40 m^2 with 2 lines totalling 6 m long works better for reflectance measurements in beans.

Schmildt *et al.* (2016) estimated the optimal size of the plot and the number of replications for field experiments in four cultivars of papaya with different planting seasons. The methodologies of modified maximum curvature and maximum curvature of coefficient of variation were utilized for determining the optimum plot size. The number of replications was determined for a least significant difference in average of 20% and 30%. The optimum plot size substantiated the same size of plot by the two methods. The optimum size required differed with cultivars, variables and planting seasons. The study concluded that an optimum of six papaya plants planted in the field per plot using three replications was sufficient in providing reliable results.

The relationship between the size of the basic experimental units for empirical studies and the optimal plot size and the experiment precision with potato crop was investigated in Brazil. The model $CV(x) = A/X^B$ was adjusted, in which CV(x) indicates the coefficient of variation for different numbers of basic units, among the plots. Optimum plot size was estimated using modified maximum curvature method, by using the empirical relation of the function $CV(x) = A/X^B$, agreeing completely randomised design. Hatheway's method was used for estimating the experimental precision of different experimental arrangements. The modification in the maximum curvature method estimated that, the size of the experimental unit of potato initial experiments affected the optimum plot size determination with the same experimental precision and for variable number of treatments (Oliveira *et al.*, 2005).

2.2.3 Fairfield Smith variance law

Nair (1981) estimated the plot size for cashew in a 24 × 24 compact block arrangement. A single tree was considered as the ultimate stage unit. The trees were found to be highly heterogeneous. Fair field Smith's equation gave good fit for the data and the value of the heterogeneity index was estimated to be high in both arranged and un-arranged cases. It was observed that two plot bocks were most efficient for conducting field experiments on cashew.

Shallow and Wehner (1986) determined the optimum plot size for cucumber yield trials. For estimating regression coefficient, generalized least squares was recommended over Fairfield Smith's method. Optimum plot size estimated for once over harvest trials measuring yield of pickling and fresh market cucumbers was estimated to be 0.7 m^2 to 3.8 m^2 for conventional harvesting and 1.0 to 5.6 m^2 for simulated harvesting. The multiple harvest yield trials optimum plot sizes for determining yield of pickling or fresh market cucumbers were estimated to be 6.4 m^2 to 10.3 m^2.

Lakhera and Ali (1995) estimated the optimum plot size and shape for sunflower yield trials. The study observed a decreased coefficient of variation for bigger plot size. High efficiency was observed with smaller plots with more replications and less area than larger plots. Smith's coefficient of heterogeneity was 0.2133 and with 93.92% of variation. A plot size of 20 basic units (9 m^2) appeared as optimum with the shape of 10 rows each of 2 m long.

Kavitha (2010) conducted uniformity trial in soybean crop with rows were along east west direction and columns were in north south direction. The total area divided into 1470 units and each unit had a size of (1.2 m × 1.0 m). The observed relation between plot size and variance was in conformity with the Fairfield Smith variance law. At the larger plot sizes the regression line showed a tendency to curve down although Fairfield Smith method and maximum curvature also showed some difference and trend in decrease of coefficient of variation was found almost similar for the characters. From all these considerations a plot size of 3.6 m^2 (3.6 m × 1.0 m) was found advisable for conducting field experiments in soybean.

Masood *et al.* (2012) estimated the optimum plot size and shape for field experiments on paddy yield trial by collecting data from rice research institute Kala shah, Lahore and Punjab. The Smith's index of soil heterogeneity was calculated to estimate optimum plot size and shape with yield data of the 12 m × 24 m noted separately from each basic unit of 1 m × 1 m (288 basic units). The Smith's index of soil heterogeneity (b = 0.491) indicated a degree of low association among the experimental units. It was found that, variance per unit area and coefficient of variation decreased rapidly with an increase in the plot size. The optimum plot size for paddy yield trial was estimated to be 6 m × 12 m with rectangle shape based on coefficient of variation for Lahore. The estimated plot size was higher than the plot size of 3 m × 5 m which is generally used for paddy yield trials in the study area.

2.2.4 Cost ratio method

In an experiment conducted with safflower plants planted at 114 feet wide and 189 feet long field in Utah where each basic unit had dimensions of 1.8 feet width and 5 feet length. Optimum plot size was estimated by taking the soil heterogeneity and relative costs in to consideration. Soil heterogeneity is derived with the equation

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

The parameter *b* is the regression coefficient indicating soil heterogeneity. The value of *b* is a constant for the given field and crop conditions, but its value varies with the crop from year to year. The estimated value of b for the 1188 basic plot sizes was 0.43. The two cost factors K_1 and K_2 were computed from information supplied by individuals experienced in working with safflower. The optimum plot size in basic units was then calculated by substituting the calculated values of b, K_1, K_2 in the formula derived by Smith. The proportions of cost calculated as $K_1 = 74.1$ and $K_2 = 25.9$ were then substituted in the formula to obtain plot size. The computed value was 2.2 times the basic unit (Wieldmann, 1962).

The plot size and shapes were determined (Basak, 2004) for jute and rice crop in Mohanpur, West Bengal. Using the cost considerations optimum plot sizes for jute and rice crops were 12.42 m^2 and 5.51 m^2 respectively. By relating coefficient of variation to the plot sizes, the maximum curvature method given the plot sizes of 6.5 m^2 (1.12 m × 5.76 m) and 15.86 m^2 (7.84 m × 2.02 m) for jute and rice crops respectively. By using Smith's cost concept optimum plot size was 15 m^2 (3 m × 5 m) for jute and 11 m^2 (11 m × 1 m) for rice.

2.2.5 Comparable variance method

Optimum plot size and shapes were estimated for corn and sorghum at International corn and sorghum research centre. Optimum plot size was estimated by the method of comparable variances. The plot size was estimated as 9m^2 with either square or rectangular shape for corn. Whereas for sorghum plot size was estimated at between 6-9 m^2 depended on soil type but no specific conclusion was made for plot shape (Vesurai *et al.*, 1980).

Vallejo and Mendoza (1992) conducted plot technique studies on sweet potato yield trials in Peru in 3 locations of La Molina, Tacna and San Ramon using uniformity trial data consisted of 24 rows 54 m long with 1m between the rows. Optimum plot size was determined using maximum curvature method and comparable variance by dividing the rows in to 1.2 m (6 hills) long sections. Using maximum curvature method, the optimum plot size was found to be 10 basic units (1 basic unit = 6 plants = 1.2 m^2) for La Molina and San Ramon where it was five basic units for Tacna. Comparison of variances method obtained a plot size of 15 basic units for all the three locations. The estimated number of replications was 4 for all the locations tested by Hatheway's method.

Viana *et al.* (2002) estimated the optimum plots size for field experiments with annatto. The uniformity trial comprised of 12 rows, with 12 plants in each row planted in 5 m × 4 m spacing and evaluated at 5 years of age. Maximum curvature method, modified maximum curvature method and the comparable variance method were used for the analysis. The plot size estimated varied according to the methodology used and the characteristic analysed. The optimum plot size was estimated to be 107.2 m^2 (5 plants) by the modified maximum curvature method, which ensued in more precise estimates.

Masood and Raza (2012) exercised maximum curvature method and comparable variance methods to determine the optimum plot size and shape for paddy in Lahore. The Smith's index of soil heterogeneity (b = 0.12) showed a degree of low association among the experimental units. The results of comparable variance method were inapt for the determination of the optimum plot size whereas maximum curvature method publicised significant results. The optimum plot size for paddy yield trial was estimated as 6 m x 3 m with rectangular shape based on the maximum curvature method for Lahore. The study results specified that the coefficients of variation (35.24, 23.80, 21.50, 19.49 and 17.86 per cent) declined with an increase in the plot size (1 m, 2 m, 3 m, 4 m, 6 m) respectively and the decrease was at maximum with the square shape plot of size (6 m x 6 m) basic units. Square shape appeared better for large plot sizes in the study area.

2.2.6 Hatheway's method

Polson (1964) estimated optimum size, shape, and replicate number of safflower plots for yield trials. The optimum plot size was estimated using three methods viz. comparable variance, Smith's regression method and Hathaway's convenient plot size method. The estimated plot size was 8, 5.5, 9.5 basic units respectively. From these results they concluded that all three methods were in fairly good agreement.

Boyhan *et al.* (2003) used five different statistical methods to estimate optimum plot size and three different methods to estimate optimum number of replications in short day onion with a basic plot size of 1.5 m × 1.8 m. Bartlett's test for homogeneity of variances, computed least significant difference (LSD) values, maximum curvature of coefficient of variation plotted against plot size and Hatheway's method for a true mean difference and Cochran and cox's method for detecting a per cent mean difference were adopted. Cochran and cox method for detecting the true difference as a percent of mean can be calculated as

$$\delta = \sqrt{(\frac{2}{r})\sigma(t_1 + t_2)}$$

Where t_1 is the significant value of t at 0.05 probability, t_2 is the value of t at 2(1-p) probability, r is the number of replications and σ is the true standard error per unit. Optimum plot size for the yield of five basic units and four replications as indicated using LSD values where the LSD was less than 5% for that plot size. Based on all the methods used for yield, a plot size of four to five basic units and three to five replications were appropriate. Visualisation of maximum curvature between coefficient of variation and plot size suggested a plot size of 7 to 8 basic units for yield, 10 basic units for seed stem, 5 basic units for purple blotch and botrytis leaf blight for 'southern belle' doubling and 10 basic units for sweet vidalia doubling. A number of plot size- replication combinations were optimum for the parameters tested with Hatheway's and Cochran and cox's method. Cochran and cox's method indicated a smaller plot size and replications than Hatheway's method regardless of the parameters under consideration. The study also noted that the size of the initial basic units had a strong influence on the appropriate plot size.

Fixation of proper plot size and shape for the culture of the Italian pumpkin was done in protected environments (Mello *et al.*, 2004). Two experiments were set in plastic greenhouse in summer fall and winter spring season. The experiment comprised of eight 23 m long lines with 20 plants per line. Estimates of best plots size and shape were obtained by the maximum curvature, variance comparison and Hatheway's methods. The plot size and shape varied according to the season and the

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ideal size and shape. According to the maximum curvature and Hatheway's methods, the optimum plot size to the summer fall and winter spring seasons were eight plants (4 × 2) plot and four plants (2 × 2) plot respectively.

Duran *et al.* (2012) estimated the coefficient of soil heterogeneity without performing tests of uniformity in common bean at Inter National Centre for Tropical Agriculture (CIAT). The coefficient of soil heterogeneity values were obtained as 0.59 and 0.66 using the law of variance of Smith and the equation proposed by Federer.

$$b = \frac{\sum(w_i Q_i P_i) - \sum(w_i Q_i)\frac{\sum(w_i P_i)}{\sum w_i}}{\sum w_i P_i{}^2 - \frac{\sum(w_i P_i)^2}{\sum w_i}}$$

where Q_i is the logarithm of yield of variance per unit area, P_i is the logarithm of the number of basic units in each plot size and W_i is the degree of freedom associated with a given variance. Hatheway's methodology was used to find the best combination of plot size. Soil heterogeneity coefficient by Federer´s method was more reliable because it was a weighted regression coefficient. The area studied had a soil heterogeneity coefficient of 0.66. They proposed that this methodology was effective in finding soil heterogeneity coefficient without performing uniformity trials.

Boyhan (2013) estimated the plot size and number of replications for watermelon over a 3 year period. Four different methods such as coefficient of variation, Hatheway's method with a 20% threshold, Bartlett's homogeneity of variance test and computed least significant differences were used. Plotting coefficient of variation against number of basic units using plots with different watermelon varieties suggested a plot size of 7 basic units (1 basic unit = 3.34 m^2). Bartlett's test suggested a larger basic unit plot sizes of 14 to 20 with multiple varieties. Results were unreliable with 2.23 m^2 plot sizes using Bartlett's test.

Computed LSDs obtained plot size of 10 basic units and five replications. Results with Hatheway's method were similar to plots of basic units against coefficient of variation. For fruit size, firmness, and soluble solids, the basic unit plot sizes ranged from 5 to 7. Plot size estimates were larger with 6.69 m^2 compared with 2.23 m^2 for fruit characteristics.

An experiment was conducted to determine the optimum plot size for evaluating the fresh matter of aerial part of dwarf pigeon pea cultivar IAPAR 43 formed by combinations of number of treatments, number of replications and precision levels. The fresh matter of aerial part was weighed on basic experimental unit of 1mx1m in 3 uniformity trials with size of 24 m x 12 m for each trial. Optimum plot size was determined by combinations formed by *i* treatments (i = 5, 10, 15 and 20), *r* replications (r = 3, 4, 5, 6, 7, 8, 9 and 10) and *d* precision levels (d = 5%, 10%, 15%, 20%, 25% and 30%). In this case d = 5% indicates more precision and d = 30% indicates smaller precision. In three uniformity trials optimum plot size in basic experimental units for a fixed number of treatments (*i*) and replications (*r*) increases with increased desired precision (*d*). With fixed number of *i* and *d* optimum plot size decreases with the increase in number of *r*. Meanwhile, with fixed values of *r* and *d*, there is reduction in optimum plot size with increased number of *i*. An optimum plot size of 9 m^2 was found to be sufficient to identify significant differences among treatments regarding the fresh matter of aerial part in dwarf pigeon pea at 5% probability of the 30% of the experiment overall mean in Southern Brazil (Filho *et al.*, 2017).

Schmilldt *et al.* (2017) determined a suitable plot size for field experiments with papaya genotypes. Two experiments were carried out using a randomized complete block design with 11 and 12 papaya genotypes respectively. In both experiments plots consisted of one row with 10 plants each. Spacing between rows was 3.5 m with 1.5 m within the rows. The results of these tests showed that the optimum plot size for the evaluation of yield in papaya was four plants by plot with four replications each assuming 30% of the precision for establishing differences among the means of two genotypes.

2.2.7 Variogram technique

Sethi (1985) used combined plot analysis and integration of variograms to compare plot to plot yield of maize and millet on terraced land. Combining plot diminished the residual variance of millet from 0.52 of 1 m × 1 m units to 0.08 for 4 m × 4 m plot whereas for maize it was from 4.91 to 0.61. The variogram for maize was isotropic and bounded with reduced experimental error for increased plot size. But in case of maize it was anisotropic and unbounded and also showed a greatest reduction in residual variance narrow pots. It was reported that both the method showed a consistent result.

Poultney *et al.* (1997) used combined plot analysis and integration of variograms to compare and estimate the plot to plot yield of intercropped millet and maize on terraces in Nepal. Combining plots reduced the residual of variance of millet from 0.52 $(t/ha)^2$ for 1 m × 1m to 0.08 $(t/ha)^2$ for 4 m × 4 m plots whereas the residual variance of maize declined from 4.91 of the original units to 0.61 for the combined plot. The variogram for millet was isotropic and bounded and within plot variance increased and experimental error decreased as the plot size increased to 4 m × 4 m and beyond which there was little gain. In case of maize the variogram was unbounded and gave no upper limit for the plot size. A reduction in residual variance resulted in narrow plots elongated in front to back of the terrace than along the contours. It was observed with consistent results from the two methods.

Saste and Sananse (2016) estimated the optimum plot size and shape in field experiments. A method called semi variogram technique which considered direction and magnitude of spatial dependence helped to reduce heterogeneity in field experiment. They calculated heterogeneity index using Smith's technique and semi variogram technique. Serial correlation and box plot techniques were used for finding

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trend in soil fertility. Box plots were drawn for both row and column observations. The graph for which there was much fluctuation in box plot was considered as the direction of soil fertility. The semi variance (γ(h)) was calculated with the equation

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(i) - Z(i+1)]^2, \text{ for } i=1,2,\ldots,N(h)$$

Where *N(h)* is the number of observation pairs with a distance *h*, and *Z* is the table value. The heterogeneity index by using Smith's method was 0.13 but this heterogeneity index was adjusted for further calculation of optimum plot size and the heterogeneity index by using semi variogram technique was 0.17. The optimum plot size calculated from Smith's index and semi variogram technique was 7.1 m^2 and 4.5 m^2 respectively.

2.3 PLOT SHAPE

In field experiments on rice with plots of a given size and shape, blocks efficiency gradually decreased with the size of the block. With blocks of the same size but different shapes formed from plots of same size, there was no apparent change in the efficiency of block within the range of block shapes (Abraham and Vanchini, 1964).

Field plot and sampling techniques (Sagisi and Ramos, 1978) on virginia tobacco variety MRS-3 planted at a distance 0.75 m between the rows and 0.75 m between the hills in a row in Laoag. There were 360 basic units composed of 5 plants or a plot of 3.75 m long and 0.75 m wide. The experiment showed that variability of the plot decreased with increased plot size. Unplanted border effects were found to have no significant influence. When plot shape was considered, narrow plots were found to be more desirable than multiple row ones. Three row plots (3 rows x 12 hills) served as the optimum plot size with both outside rows serving as side borders and one row on each end of the plot to serve as plot end borders and finally had the 10 sample hills from the centre row as the sample plants.

Shape of the plot doesn't 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 same dimension. The optimum plot size was calculated to be about 20 m^2 (Prabhakaran and Thomas, 1974). Some important aspects that determine optimum size of plot includes the presence or absence of border, crop type, number of treatments, level of technology employed in the area of cultivation and availability of financial resources (Bueno and Gomes, 1983).

The plot technique was conducted in lucern at Anand to find out the optimum size and shape of the plot and also for comparing the efficiency of different experimental designs. Coefficient of variation was used to find out the variability and which decreased with advancement of the crop age and was at maximum sixth cut. The rate of reduction in coefficient of variation was more with the increase in width of the plot. The plot size of 1 × 10 was found optimum for field experiments on lucern. The net shape for field experiments was taken as 10 m^2 covering 40 rows each of 1 m length and spaced at 25 cm apart (Ramani, 1990).

Efficiency of different size and shape of quadrats were determined for sampling standing crop. Three blocks each of size 1.2 m ×12 m were divided into 160 basic units using 30 cm × 30 cm quadrats. Variance was used to determine sample number for precise estimation of standing crop. It was noted that increased quadrat size accounted for 68% or more of the observed decrease in variance. Long, narrow rectangles were found more efficient for reducing variances but shape had little effect on variances. Larger quadrats were found more efficient in the experiment (Brummer *et al.*, 1994).

Zhang *et al.* (1994) reported that plot shape that minimized the sampling variation and cost dependents on the Smith's indices of soil heterogeneity (b_1 and b_2 in the X and Y directions respectively). When $b_1 > b_2$, plot sizes had their maximum dimensions in the X direction and gave more precise results than plots with other shapes. Plots having the same number of units in either direction gave more accurate results than plots with their greatest dimensions in the Y direction. When $b_2 > b_1$, plots had their greatest dimensions in the Y direction were more uniform than square plots. Square plots were more uniform than plots with greatest dimension in the X direction. When $b_1 = b_2$, the field was isotropic and squares were more uniform than other shapes.

The optimum plot sizes for maize yield trials were determined based on the coefficients of variation. The estimated plot size was 3.75 m x 3.75 m (14.06 m^2) with square shape for Tarnab, Peshawar and Pirsabak. The recorded plot size was lesser than the plot size of 15 m^2 which is usually used for yield trials of maize in the experimental area. Square shaped plots were also desirable either when the fertility variation of the area was not known to the experimenter or in conditions with large border effects (Masood and Javed, 2003).

Saste and Sananse (2015) reported that soil heterogeneity was the one of the measure cause of error in experimental design. Selection of proper plot size and shape reduced the soil fertility variation. Long and thin rectangular plots were found appropriate for mechanical harvesting whereas square shaped plots reduce the interference between plots. Smith's index of soil heterogeneity was the most appropriate measure which measured the plot size and shape accurately. They also reported the use of variogram technique for the spatial measure of soil heterogeneity.

Pal *et al.* (2016) estimated the optimum plot size on the basis of intra class correlation coefficient. Plots having unit size in any direction and long narrow plots were not taken into account. Square plots of sizes 2 x 2, 3 x 3, 4 x 4 possessed a higher values of radii of curvature than the chosen minimum values. Thus square plots were not considered as optimum. Though the radii of curvature analogous to plots of sizes 2 x 7 and 2 x 8 were smaller than the minimum values of radii of curvature, yet such plot sizes were not suggested as optimum, since these plots were of long and narrow shape. Plot sizes 5 x 5 and 6 x 6 were not considered since it had large sizes. For $\rho = 0.1$ to $\rho = 0.5$ the robust optimum plot sizes were 2 x 5, 2 x 6, 3 x 5 and 3 x 6 respectively.

Lohmor *et al.* (2017) conducted a uniformity trial for the estimation of optimum size and shape of blocks of sunflower at Haryana on a field of size 35 m × 40 m which reduced to 32 m × 36 m after eliminating border effects. The blocks extended in the north south direction were found more effective in decreasing error variation than those in the east west direction. The coefficient of variation reduced from 14.88 to 7.30 with increased block size from 4 to 16 for plot size 1 m^2 thus large blocks were found to be more effective than small plots. Block size of 16 was found more efficient with a block shape of 16 m × 1 m in the experimental area.

Materials and Methods

3. MATERIALS AND METHODS

The important methodologies used to undertake the present research are discussed in this chapter. It gives enough information about the work so that one can repeat the process. The present work is to estimate the optimum plot size and identify the shape for conducting field experiments of common high yielding variety of paddy suited to Kerala condition. The experiment was conducted at the Integrated Farming System Research Station, Karamana. Uma variety of paddy was used for cultivation and recommended package of practices were followed throughout the cultivation. The crop was raised in virippu season (July to November, 2018) with a spacing of 20 cm × 15 cm. The observations were recorded at monthly intervals. This chapter describes the various procedures adopted for the present research work in the following subheadings.

3.1 Description of the study area

3.2 Details of the experiment and the important characters

3.3 Statistical methods

3.1 DESCRIPTION OF THE STUDY AREA

The present research was conducted at Integrated Farming System Research Station (IFSRS), Karamana. Karamana is located in the heart of the city of Thiruvananthapuram, the capital city of Kerala. It is one of the most densely populated but green part of Thiruvananthapuram. IFSRS is located at Nedumcaud, Karamana, and 3.0 kilometer south east of Thiruvananthapuram central railway and bus station. The land of Karamana is made fertile by Karamana river. The research station has an area of 7.65 hectare of which 7.25 hectare was of double cropped wet land and 0.4 hectare of garden land. The center, formerly known as the Model Agronomic Research station, was established in 1955. From October 1983 onwards, the station was upgraded as the headquarters of the All India Coordinated Agronomic

Research Project (AICARP) in Kerala. The lead functions of IFSRS are to develop IFS models including rice based models and perform verification trials for agro techniques of rice.

3.2 DETAILS OF THE EXPERIMENT AND IMPORTANT CHARACTERS

A uniformity trial was conducted in an area of about 800 m^2 with 27.5 m breadth and 28 m length. The paddy seedlings were transplanted at a spacing of 20 cm × 15 cm. The field was divided in to 1.2 m × 1.2 m (1.44 m^2) plots, after leaving a border of one meter from all the sides of the plot to eliminate the border effects, thus give rise to 400 basic units. The crop was harvested separately from each of the basic units. Details of data on both growth parameters and yield parameters were taken for the study.

3.2.1 Growth parameters

Growth parameters such as plant height and tiller numbers were taken at monthly intervals. From each basic unit 7 plants were selected and the observations were average of seven recorded observation.

3.2.1.1 *Plant height (Ph)*

The plant height of paddy was taken at monthly intervals in centimeters (cm). The height is measured with a meter stick from the soil surface close to the hill to the tip of the plant. Ph_1, Ph_2, Ph_3 and Ph_4 are used to denote the plant height at one month after planting (MAP), 2 MAP, 3 MAP and 4 MAP.

3.2.1.2 *Tillers (T)*

Tillers are the stem produced by grass plants and denotes all shoots that grow after the initial parent shoot raises from a seed. The total number of tillers in each basic unit area is recorded by counting the total number of tillers from the sampled plants and its average. T_1, T_2, T_3 and T_4 are used to denote the number of tillers at 1 MAP, 2 MAP, 3 MAP and 4 MAP.

3.2.2 Yield parameters

Yield attributes on paddy was taken at the time of harvest from each basic unit separately.

3.2.2.1 *Productive tillers (T_p)*

The number of effective tillers was determined just before harvesting the crop for each basic unit from the sampled plants. The tillers having filled grains were recorded as productive tillers among the total number of tillers produced.

3.2.2.2 *Thousand grain weight (Gw)*

Thousand grains were selected randomly from each basic unit and the weight was recorded with the help of electronic weighing balance and are expressed in gram.

3.2.2.3 *Grain yield (Y)*

The weight of grain from each basic unit was recorded separately and expressed in gram.

3.2.2.4 *Straw yield (Sy)*

The straw obtained from each basic unit was collected separately and weighed.

3.2.2.5 *Harvest index (HI)*

Harvest index (*HI*) was calculated as the ratio of grain yield to the total above ground biomass. Higher the harvest index means, the plant is capable to deposit assimilates having economic importance from the source to the panicle. It is also a measurement of crop yield.

$$Harvest\ Index = \frac{Economic\ yield}{Biological\ yield}$$

$$HI = \frac{Grain\ yield}{Grain\ yield + Straw\ yield}$$

This formula was given by Amanullah and Imanullah in 2016.

3.3 STATISTICAL METHODS

A uniformity trial was conducted by selecting the Uma variety of paddy and uniform treatments are given for the entire experimental area. There were a total of 140 rows and 180 columns of plants in the experimental plot. Yield was recorded separately from each basic unit. Optimum plot size and shape are determined by several methods proposed by various researchers. Modified curvature method, Fair field Smith's variance law, Hatheway's method, cost ratio method and comparison of variances method were used for the determination of optimum plot size and shape. Maximum curvature method and Fairfield Smith variance law are the two important methods for estimating the optimum plot size. The basic units of uniformity trials are combined and curve is plotted by taking plot size and coefficient of variation (CV) under maximum curvature method, whereas Smith variance law was used for fixing optimum plot size under Fair field method. Hatheway's method is one of the oldest methods of estimating optimum plot size. Cost ratio method takes the cost of field experimentation in to consideration whereas the comparable variance method consider the among plot variances for estimating optimum plot size. Several types of analyses are available to evaluate the pattern of soil heterogeneity based on uniformity trials. The different methods for the determination of soil heterogeneity are discussed under the following subheadings.

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3.3.1 Descriptive Statistics

A descriptive statistics is a summary that quantitatively describes or summarizes the features of a collection of data. It provides simple summaries about the observations. It is a basis of the initial description of the data as a part of extensive statistical analysis. Descriptive measures such as mean, median, mode, standard deviation, minimum and maximum values were calculated for the data.

3.3.1.1 Mean

It provides a single number as a representative of the whole data. Average was calculated for both growth and yield characters for making inference about the observations. Let $Y_1, Y_2, \ldots, Y_n$ are the *n* observations, then mean of the data set is given by

$$\bar{Y} = \frac{\sum_{i=1}^{n} Y_i}{n}$$

3.3.1.2 Median

It is the middle most item of the data set that divides the distribution in to two equal parts when the items are arranged in the ascending or descending order.

3.3.1.3 Mode

Mode is the most frequent item in the data set. It helps to know the most common value in the data set.

3.3.1.4 Standard deviation

Standard deviation helps to know the dispersion of the data set in relation to the mean. When the data points are farther from the mean, it indicates a higher deviation within the data set which implies higher spread of the data set hence high standard deviation.

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \overline{Y})^2}$$

3.3.1.5 Quartiles

Quartiles split the data in to four quarters. There are three quartiles Q_1, Q_2 and Q_3. The first quartile indicates the mid number between smallest value and the median, Q_2 indicates the median and the third quartile gives the middle value between median and the highest value.

3.3.2 Box plot

Box plot graphically depicts the groups of numerical data through their quartiles. It shows how far the extreme values from most of the data. Box plots helps to compare distributions of values across groups. Box plots are depicted for both growth parameters as well as yield parameters and the outliers are also located for the study. Box plots were constructed using the software STATA 13 version.

3.3.3 Correlation analysis

It is necessary to understand the association, nature and degree of relationship between quantitative variables. The knowledge regarding this association is understand by performing correlation analysis. Correlation coefficient (r) provides information on association of various characters among themselves. Its value ranges from -1 to +1. When the value of r is close to -1 or +1, then the variables are related more closely and if r is close to zero, then there is no linear association between the two variables. A positive r value indicates that, one variable is directly depend on the other variable. If r is negative, then there is an inverse relation between the variables. In the present study correlation analysis was done to study the association between grain yield and yield parameters and yield and biometric characters. The character which is having high correlation with grain yield can be used as covariate for determining optimum plot size under covariate method.

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

$$r = \frac{\sum (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum (X_i - \overline{X})^2 (Y_i - \overline{Y})^2}}$$

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

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

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

$r \in [-1, 1]$

3.3.4 Methods to determine soil heterogeneity

The neighboring plots planted to the same variety simultaneously and treated as equally as possible will differ in many characters. The causes for these differences are numerous but the most apparent and perhaps the most important is soil heterogeneity. Experiences have revealed that it is impossible to get an experimental field that is wholly homogeneous. The methods used to determine the direction of fertility variation are discussed here.

3.3.4.1 Soil fertility contour map

Soil fertility contour map gives a useful demarcation about the fertility status of the experimental plot. It also helps to delineate the regions of same fertility. The

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fertility gradient is divided in to 6 number of classes based on the values and different shades were given to each group. Thus the basic units having the same fertility gradient have given the same demarcation. Soil fertility map is used to describe the heterogeneity of the land and also provide the direction of variation in fertility status. It can be developed by using the individual yield (Y_i) and by using moving average also.

3.3.4.1.1 Soil fertility contour map based on the yield of original basic units

Fertility gradient of the experimental plot can be calculated with the following equation.

$$Fertility\ gradient = \frac{Y_i - \bar{Y}}{\bar{Y}} \times 100$$

Where Y_i is the yield from each basic unit where $i=1,2,...,400$ and $\bar{Y}$ is the mean yield of the entire plot.

3.3.4.1.2 Soil fertility contour map based on moving average

Soil fertility contour map is a simpler but informative representation of soil heterogeneity where it explicitly defines the soil productivity level of experimental area based on moving averages of adjacent units. The number of contiguous units is decided for going in to the moving averages by combining several basic units to reduce large random variation expected on small plots. The area involved in each moving average should be as square as possible. The moving average for s x t combinations can be calculated by,

$$P_{s,t} = \frac{\sum_{i=s-1}^{s+1} \sum_{i=t-1}^{t+1} Y_{ij}}{s \times t}$$

Then shading pattern is assigned to each of the class which allows easier visualization of the fertility pattern (Gomez and Gomez, 1976). The moving average values are calculated for 3×3 and 5×5 combinations and the range of values are

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divided in to 6 different classes. Shading pattern was given same as that of fertility contour map based on yield of original basic units for each class.

3.3.4.2 Serial correlation

The randomness of the data set is tested with serial correlation. It besides helps in the depiction of trend in soil fertility using uniformity trial data. The formula for calculating serial correlation for *n* observations ($Y_1, Y_2, Y_3, \ldots, Y_n$) is

$$r_s = \frac{\sum_{i=1}^{n} Y_i Y_{i+1} - \frac{\left(\sum_{i=1}^{n} Y_i\right)^2}{n}}{\sum_{i=1}^{n} Y_i^2 - \frac{\left(\sum_{i=1}^{n} Y_i\right)^2}{n}}$$

The range of variation of serial correlation is from [-1, 1]. Horizontal and vertical serial correlation coefficients can be calculated from a single set of uniformity trail data. In this procedure, tabulate the entire data separately for horizontal and vertical arrangement and the total number of pairs for each arrangement equals the total number of observations. Serial correlation is computed with the above formula and the coefficient provides the direction of fertility gradient. A low value of serial correlation coefficient indicates that fertile areas occur in spots where as a higher value of coefficient indicates a fertility gradient (Gomez and Gomez, 1976).

3.3.4.3 Mean square between strips

Mean square between strips (group of units) method is analogous to that of serial correlation but it is easier to compute. In this method the basic units are combined to form horizontal strips and vertical strips. Then variability between strips in each direction is measured by the mean square between strips.

Vertical strip and horizontal strip sum of squares can be calculated by

$$\text{Vertical- strip SS} = \frac{\sum_{i=1}^{c} V_i^2}{r} - \frac{G^2}{rc}$$

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Similarly,

$$\text{Horizontal- strip SS} = \frac{\sum_{j=1}^{r} {H_j}^2}{c} - \frac{G^2}{rc}$$

Then the mean square can be calculated for both horizontal and vertical strips as

$$\text{Vertical- strip MS} = \frac{Vertical\ \ strip\ \ SS}{c-1}$$

$$\text{Horizontal strip MS} = \frac{Horizontal\ \ strip\ \ SS}{r-1}$$

Where r is the number of rows, c is the number of columns, V_i is the total of i^{th} vertical strip, H_j is the total of j^{th} horizontal strip and G is the grand total.

The relative value of horizontal and vertical mean squares specifies the probable direction of fertility gradient and the positioning for both plots and blocks.

3.3.4.4 Soil heterogeneity index

Smith's index of soil heterogeneity is used primarily to derive optimum plot size. The index gives a single value as a numerical measure of soil heterogeneity in an area. The value of the index indicates the degree of correlation between adjacent experimental plots. Its value varies between zero and unity. It is denoted by b and the model fitted by the following formula,

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

Where y is the variance of the plot and x is the plot size. The value of b lies between 0 and 1. 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 of b is near to '1' the field is heterogeneous i.e., the neighbouring plots are almost uncorrelated (Smith, 1938).

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Larger value of the index indicates a lower correlation between contiguous plots, signifying that the fertile spots are distributed randomly or in patches.

3.3.5 Methods to determine optimum plot size and shape

Several methods have been suggested by various researchers for finding the optimum plot size and shape.

3.3.5.1 Maximum curvature method

In this method, the basic units of uniformity trial are combined to form new units. Rows, columns or both the units are combined for forming new units in such a way that no rows or columns are left out. Coefficient of variation is calculated for each unit. A graph is plotted with plot size (in terms of basic units) on the X axis and CV on the Y axis. The point at which curve takes a turn *i.e.*, the point of maximum curvature will be taken as the optimum plot size (Prabhakaran *et al.*, 1978).

Coefficient of variation per unit area for all possible groupings of different plot size and shape combinations can be calculated with the formula;

$$CV = \frac{\sigma_x}{\overline{Y}_x} \times 100$$

Where σ_x is the standard deviation per unit area and $\overline{Y}_x$ is the general mean.

In order to calculate coefficient of variation per unit area in percent, the variance $V_{(x)}$ among all possible combination has to be estimated using the following formula,

$$V_{(X)} = \frac{Sum\ of squares\ of\ a\ given\ size}{Degrees\ of\ freedom}$$

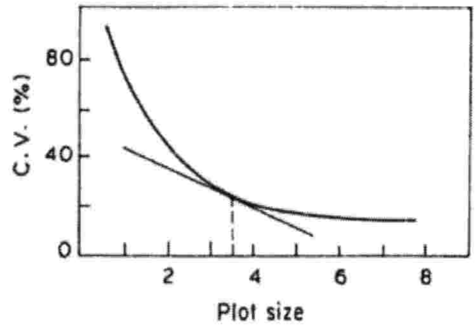
$$V_{(X)} = \frac{Sum\ of\ squares\ of\ a\ given\ size}{n-1}$$

To get variance per unit area V_x, the $V_{(X)}$ was divided with the square of plot sizes, *i.e.* the number of basic units involved in the formation of that plot size.

$$V_X = \frac{V_{(X)}}{X^2}$$

The plot size can be identified in this method for which rate of reduction in coefficient of variation is a minimum, and such plot would be just beyond the point of maximum curvature of the curve relating to the plot size and coefficient of variation (Federer, 1967).

The maximum curvature method has two important flaws. The relative costs of various plot sizes were not considered and the point of maximum curvature was not independent of the basic unit in the calculation. In the method of maximum curvature the optimum plot sizes (X_{opt}) was obtained graphically by the given procedure.



3.3.5.2 Fair field smith variance law

Smith (1938) gave the empirical relation between variance and plot size. For representing the empirical relation between plot size and variance of mean per plot Smith developed a model. The model is represented by,

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

$$logV_x = log\,V_1 - b\,log\,x$$

Where x is the number of basic units in a plot, V_x is the variance of mean per plot of x units, V_1 is the variance per plot of one unit and b is the soil heterogeneity index and is the characteristic of soil and measure of correlation among adjacent units.

When b = 1,

$V_x = \frac{V_1}{x}$, the units making up the plots of x units are not correlated at all.

When b=0

$V_x = V_1$, x units are perfectly correlated.

The values of V_1 and b are determined by the method of least squares.

Consider Smith's equation; $V_X = \frac{V_1}{X^b}$

The first two derivatives of V_X with respect to X were

$$\frac{dV_X}{dX} = V_1(-b)X^{-b-1}$$

$$\frac{d^2V_X}{dX^2} = V_1 b(b+1)X^{-(b+2)}$$

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

$$C = \frac{[1 + (dV_X/dX)]^2]^{\frac{3}{2}}}{d^2V_X/dX^2}$$

Now, by substituting the values of dV_X/dX and d^2V_X/dX^2 we get the simplified form of the equation as;

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

Equating the first derivative dC/dX to zero will maximize the curvature,

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

Equating this to zero and simplifying we get the formula given by Agarwal, 1973.

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

3.3.5.3 Modified curvature method

In case of modified maximum curvature method, the relationship between plot size x and C.V, y is given by the equation

$y = \frac{a}{x^b}$ where a and b are constants.

Taking log, equation becomes

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

When more than one C.V is there for same plot size, the minimum C.V is taken for fitting the curve. In case of modified maximum curvature method on simplification, optimum plot size can be obtained by the formula (Michel *et al.*, 2015)

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

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3.3.5.4 Covariate method

The experimental error caused by soil heterogeneity can be effectively controlled by covariance technique when the pattern of soil heterogeneity is spotty or unknown and variability between plots in the same block remains large despite blocking. In order to control experimental error arising due to soil heterogeneity uniformity trial data and crop performance data prior to treatment are being used as covariate. Two types of variables are involved in using uniformity trial data as the covariate. In this method first find out the variable having high correlation with 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 CV 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

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

Where ε is the error term identically and independently distributed as N $(0, \sigma^2)$. Though covariance analysis results in considerable gain in precision it has not been widely used in agricultural research. Because a uniformity trial is expensive to conduct and data from uniformity trial is effective only in the specific field conditions in which trial was conducted.

3.3.5.5 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

$$C_x = K_1 + K_2 X$$

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 upon the size x of the experimental unit. If r is the number of replications, then the cost for r replications is given by

$$C_0 = r(K_1 + K_2 X)$$

The main objective for determining optimum plot size is to maximize the amount of information per unit cost which is defined to be the reciprocal of variance.

Cost per information is given by

$$C = \frac{K_1 + K_2 X}{1/V_x} = \frac{(K_{1+}K_2 X)V_1}{X^b}$$

The minimum cost for the value of X can be obtained by equating the 1st derivative of C with respect to X to zero (Kavitha, 2010)

i.e., $$-b(K_1 + K_2 X)X^{1-b} + X^b K_2 = 0$$

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 cost

3.3.5.6 Hatheway' method

Hatheway's method is an estimate of true differences as a percent of the mean. It is estimated by the formula,

$$\mathrm{d}^2 = \frac{2(\mathrm{t}_1 + \mathrm{t}_2)^2(\mathrm{C.V})^2}{\mathrm{r}\,\mathrm{x}^\mathrm{b}}$$

Where d is the true difference between two treatments as a percent of the mean, t_1 is the significant value of t at 0.05 probability, t_2 is the value of t corresponding to 2(1-p) where p is the probability of obtaining a significant result, CV is the coefficient of variation, r is the number of replications, x is the plot size in basic units and b is the Smith's index for soil heterogeneity. Thus for each r replications the values of d_i was obtained that depending on the X_i the regression $d_i = AX_i^{-B}$ was estimated (Duran *et al.*, 2012). The optimum plot size can be estimated by fixing a range of values for d_i.

3.3.5.7 Comparison of variances method

In comparison of variances method, among plot variances ($V_{(X)}$) is calculated from the contiguous basic units of different combinations. The among plot variance were then divided by the number of basic units per plot to give the comparable variance, designated as V. The comparable variances were in turn divided by the number of basic units per plot (X) to give the variance of yield per unit area. This was designated as V_X. Combined with the previous method for finding the comparable variance, V_X can be directly computed with the following relationship

$$V_X = \frac{V_{(X)}}{X^2}$$

In order to obtain a measure of relative information, the comparable variances of all the plot sizes were compared with the plot size having the smallest comparable variance (Wiedemann, 1962).

3.3.5.8 Based on shape of the plot method

For determining the shape of the plot both length and breadth were used (Nishu, 2015).

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

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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.

Results and Discussion

4. RESULTS AND DISCUSSION

The study entitled "Comparison of methods for optimum plot size and shape for field experiments on paddy (*Oryza sativa*)" has been carried out at the Department of Agricultural Statistics, College of Agriculture, Vellayani, Thiruvananthapuram during the year 2017-2019. A uniformity trial was conducted and Uma variety of paddy was grown at Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram. Different statistical methods were included for describing the characteristic of the variation and various methods for estimating optimum plot size. Results based on the statistical analysis of the data during the course of research are presented in this chapter under the following headings.

4.1 Box plot and summary statistics of biometric and yield characters of the variety Uma
4.2 Correlation between biometric and yield characters of variety Uma
4.3 Soil heterogeneity
4.4 Estimation of optimum plot size
4.5 Yield estimation of variety Uma

4.1 BOX PLOT AND SUMMARY STATISTICS OF BIOMETRIC AND YIELD CHARACTERS

The entire cropping area was divided in to 400 basic units of same size (1.44 m^2). Each basic unit was 1.2 m in length and 1.2 m in width. Observations were taken on growth parameters and yield parameters at monthly intervals (1 Month after planting (MAP), 2 MAP, 3 MAP and at harvest) from sampled plants of each basic unit and averaged out. The mean, minimum, maximum, median, mode and standard deviations were worked out and are presented in the following tables. Descriptive statistics were also found out for growth attributes such as plant height, tillers and yield attributes such as grain yield, straw yield, productive tillers and harvest index.

4.1.1 Box plot and Summary statistics of biometric characters

4.1.1.1 Box plot and Summary statistics of plant height (*Ph*)

4.1.1.1.1 Box plot of plant height

Box plots were used to show the shape of the distribution, its central value and the variability. Box plots also helps to detect the presence of outliers in the data. Plant heights at various growth stages such as 1, 2, 3 and 4 MAP were taken for constructing box plots.

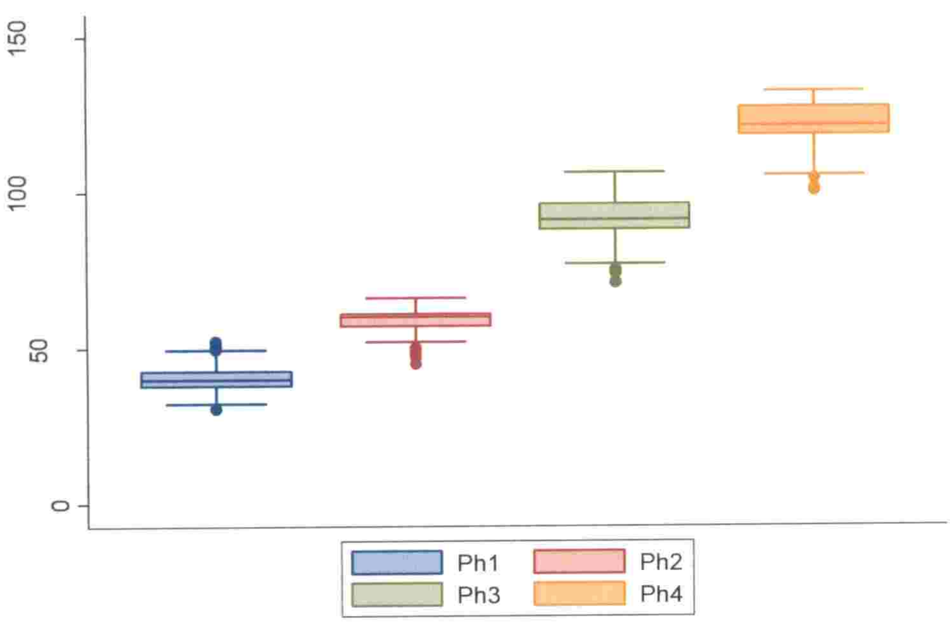

Fig. 1. Box plot of plant heights at 1 MAP, 2 MAP, 3 MAP and 4 MAP

The dots in the graph (Fig. 1) indicated the outliers present in plant height at various growth stages. From figure 1 it was clear that the presence of outliers in the plant height at various growth stages was very less. The outliers were reduced to very few from one month after planting to third and fourth month after planting.

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4.1.1.1.2 Summary statistics of plant height

Table 1. Summary statistics of plant height of paddy (Uma)

Period	Plant height Average (cm)	Standard deviation of mean	Minimum (cm)	Maximum (cm)	Median	Mode	C.V
1 MAP	40.55	0.196	30.5	52.4	39.8	39	9.65
2 MAP	58.53	0.194	45	66	60	60	6.63
3 MAP	91.35	0.333	71	106	91	90	7.23
4 MAP	121.37	0.314	100	132	121	120	5.17

From the table 1 it was clear that average height of Uma was increased from 40.55 cm to 58.53 cm at 2 MAP to 91.35 cm at 3 MAP and to 121.37 cm at the time of harvest with a minimum height of 52.4 cm at 1 MAP and to 132 cm at 4 MAP. The maximum height recorded was 52.4 cm at 1 MAP, 66 cm at 2 MAP, 106 cm at 3 MAP and 132 cm at the time of harvest. Coefficient of variation of plant heights at 1 MAP was high (9.65%) and was low at 4 MAP (5.17%). The plant showed a minimum height of 45 cm and a maximum height of 66 cm at 2 MAP with a coefficient of variation of 6.63%.

4.1.1.2 Box plot and Summary statistics of number of tillers (*T*)

4.1.1.2.1 Box plot of number of tillers

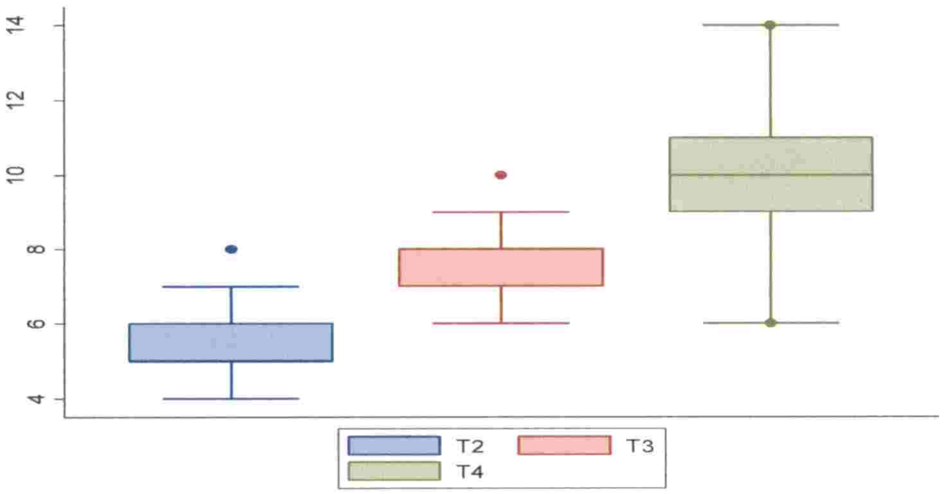

Fig 2. Box plots of number of tillers at 2 MAP, 3 MAP and 4 MAP.

It is evident from figure 2 that the number of outliers present in the data at various growth stages was very few. There were no outliers in the data of number of tillers at 3 MAP. The data on number of tillers at 2 MAP and 3 MAP had a single outlier which are above the maximum values whereas the number of tillers at 4 MAP had two outliers which was above (Q_3 + 1.5 IQR) and below (Q_1 - 1.5 IQR).

Table 2. Summary statistics of number of tillers of paddy (Uma)

Period	Number of tillers Average (No.)	Standard deviation of mean	Minimum	Maximum	Median	Mode	C.V
2 MAP	6	0.056	4	8	5	5	18.67
3 MAP	8	0.05	6	10	8	7	12.5
4 MAP	10	0.084	6	14	10	9	16.8

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From the table 2 it was evident that, as the plant grows the number of tillers reaches its maximum possible number. The average tiller number increased from 6 to 10 from 2 MAP to 4 MAP. The minimum number of tillers recorded at 2 MAP was 4, which increased to 6 at 4 MAP. The maximum tiller production of 14 numbers per hill was observed at 4 MAP. The most frequently occurring tiller number at 2 MAP was 5 which were increased to 7 at 3 MAP and 9 at 4 MAP. Coefficient of variation was found to be higher for number of tillers at 2 MAP (18.67%) and was less at 3 MAP (12.5%). The variety had an average tiller number of 10 with a standard deviation of 0.084 at 4 month after planting.

4.1.2 Box plot and Summary statistics of yield characters

4.1.2.1 Box plot of yield characters

4.1.2.1.1 Box plot of grain yield (Y)

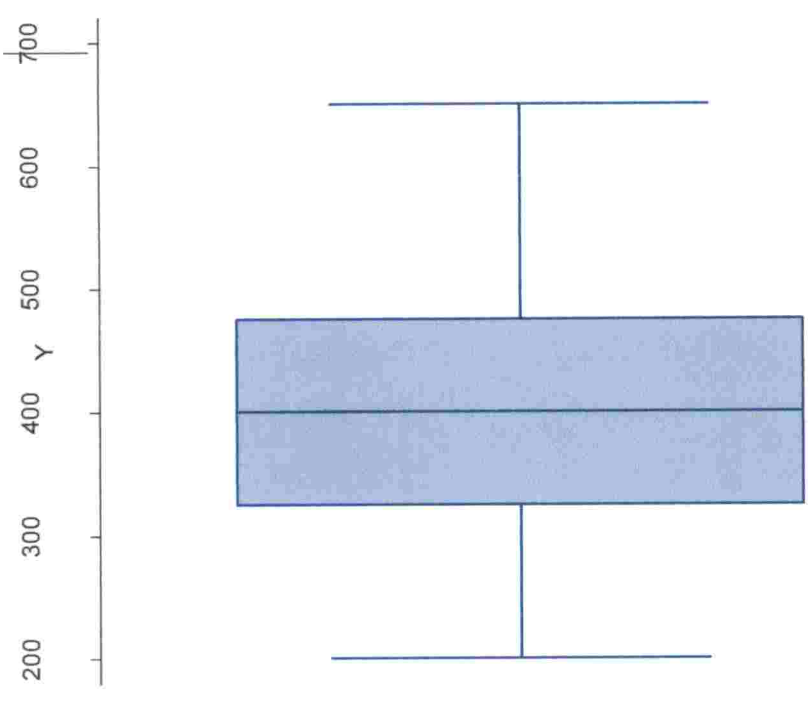

Fig 3. Box plot of grain yield

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From the figure 3, it was clearly evident that there were no outliers in the data set of grain yield. The median of the data set lies on a grain yield of 400 g and the minimum and maximum values are on 200 g and 650 g respectively. The range of the data set of grain yield was 450 g.

4.1.2.1.2 Box plot of straw yield (Sy)

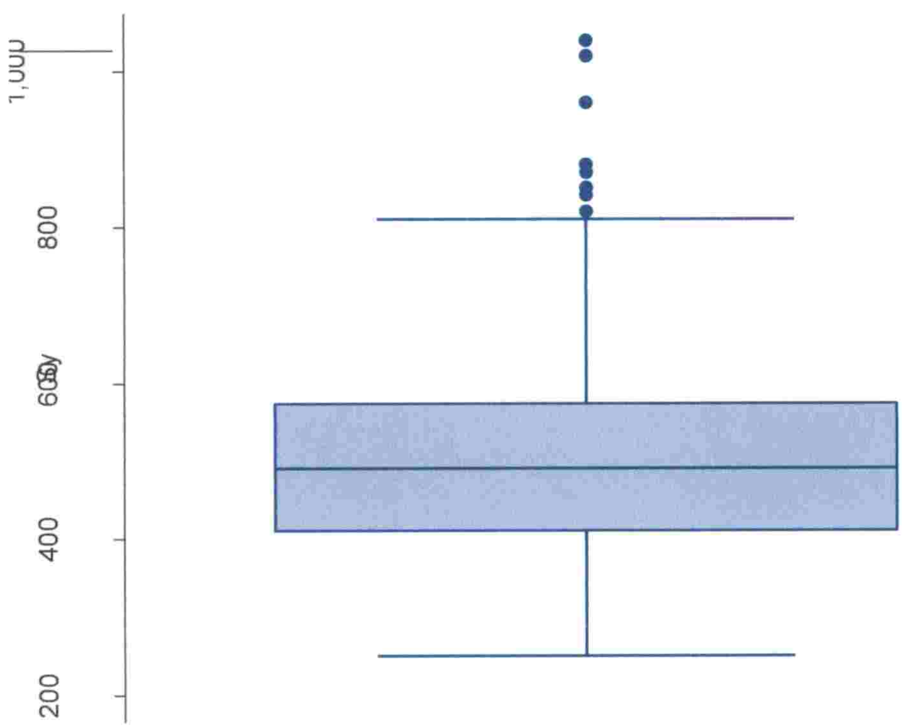

Fig 4. Box plot of straw yield

The figure 4 clearly shows the presence of outliers in straw yield. The box plot tells the presence of outliers which were above the maximum values. The middle most observation of straw yield lies on 0.501 kg. The first quartile (Q_1) was observed at 410 g and third quartile (Q_3) was at 572.5 g.

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4.1.2.1.3 Box plot of harvest index (HI)

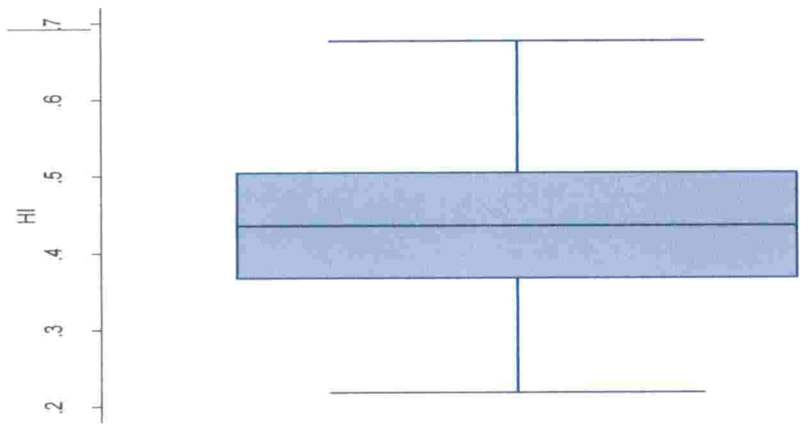

Fig 5. Box plot of harvest index

It is evident from fig. 5 that there were no outliers present on the data for harvest index. The harvest index values were found to be distributed from a minimum of 0.217 and to a maximum of 0.676. The first and third quartiles were estimated as 0.367 and 0.503 respectively. The inter quartile range for the data of harvest index was estimated as 0.136.

4.1.2.2. Summary statistics of yield characters

Table 3. Summary statistics of yield characters of paddy (Uma)

	Grain yield (g)	Straw yield (Kg)	Harvest index	Productive tillers (No.)
Mean	391.13	0.501	0.438	9
S. D of mean	5.13	0.0065	0.0046	0.549
Minimum	200	0.25	0.217	6
Maximum	650	1.04	0.676	10
Median	400	0.489	0.436	9
Mode	400	0.56	0.385	7
C.V	26.23	25.79	20.78	6.1

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The average grain yield obtained for Uma was 390 g per basic unit with a standard deviation of 5.13, whereas the crop obtained a mean straw yield of 0.501 kg per basic unit with a mean standard deviation of 0.0065. The paddy variety Uma yielded a minimum grain yield of 200 g and a maximum grain yield of 650 g per basic unit. The average harvest index of the crop per basic unit was noted as 0.438 with a standard deviation of 0.0046. The maximum and minimum harvest index recorded was 0.676 and 0.217 respectively. The paddy variety showed maximum productive tillers of 10 and a minimum of 6 per basic unit with an average productive tiller of 9 numbers. The coefficient of variation calculated for yield characters such as grain yield, straw yield and harvest index was below 27 per cent implied less variability in these variables. However the CV of 6.1 per cent for productive tillers indicated the stability of recorded observations.

4.2 CORRELATION BETWEEN BIOMETRIC CHARACTERS AND YIELD OF PADDY

Correlation can be found out among biometric characters and yield characters of Uma variety of paddy to assess the influencing factors of yield. The character which is accounted for maximum correlation with yield can be used for finding the optimum plot size of Uma by replacing the grain yield. The correlations worked out for plant height at different periods are presented in the following table 4.

4.2.1 Correlation between plant heights with yield

Table 4. Correlation of plant height of Uma with yield

	Y	1 MAP	2 MAP	3 MAP	4 MAP
Y	1				
1 MAP	-0.099	1			
2 MAP	0.098	0.003	1		
3 MAP	0.074	-0.043	-0.093	1	
4 MAP	-0.102*	-0.120*	0.0960	-0.022	1

From the table 4 it can be clearly seen that there was no significant correlation between plant heights at different times with grain yield. The plant height at 4 MAP showed a significant negative correlation of 0.102 with grain yield. The correlation between plant heights was found to be non-significant and showed negative values. Since the soil is heterogeneous the rate of increase of height in each plant may not be the same, when we consider individual plants that may show positive correlation with heights at different growth stages. But since we are considering the heights of a group of plants the overall effect may not give a positive correlation.

The results of correlation analysis conducted on 70 genotypes of rice and evaluated in kharif, 2012 was also in agreement with the above result. It observed significant genotypic and phenotypic correlation coefficients (Lakshmi *et al.*, 2012). The experiment was conducted in randomised complete block design with three replications under irrigated conditions. The genetic correlation coefficient (0.1878) was found to be higher than the phenotypic correlation (0.1693), indicated the masking effect of environment on these traits. Grain yield was negatively correlated with plant height for both at genotypic and phenotypic levels (Amirthadevarathinam, 1983).

4.2.2 Correlation between numbers of tillers and grain yield

Table 5. Correlation of tiller numbers with grain yield

	Y	2 MAP	3 MAP	4 MAP
Y	1			
2 MAP	0.097	1		
3 MAP	0.196*	0.226*	1	
4 MAP	0.206*	-0.159*	-0.234*	1

The table 5 shows that there was no significant correlation between grain yield and number of tillers at first month after planting but a 5 per cent significant correlation with number of tillers was obtained at 3 MAP and 4 MAP. Even though the number of tillers increases from 2 MAP to 4 MAP planting it showed a negative correlation between the number of tillers at 4 MAP to 2 MAP and 3 MAP. This result was in agreement with the correlation studies conducted in basmati rice (Zahid *et al.*, 2006). The correlation and path analysis study in Basmati rice in Pakistan reported a non-significant correlation (-0.0419) between number of tillers per plant and grain yield. Similarly a non-significant correlation was observed between plant height and grain yield (-0.328).

4.2.3 Correlation between yield characters

Table 6. Correlation for yield characters of Uma

	Y	Ty	HI	Sy	Tp	Gw
Y	1					
Ty	0.262^{**}	1				
HI	0.744^{**}	-0.405^{**}	1			
Sy	-0.041	0.952^{**}	-0.660^{**}	1		
Tp	0.128^{*}	0.088	0.084	-0.031	1	
Gw	-0.023	0.013	0.017	-0.001	0.013	1

The table 6 clearly reveals the significant correlation between the yield characters. Harvest index had a very high significant correlation of 0.744 with grain yield and a negative significant correlation of 0.405 with total yield (Ty). There was significant correlation between straw yield and total yield (0.952). But the correlation between straw yield and grain yield was insignificant. Based on correlation, harvest index and total yield can be used as a covariate for getting optimum plot size. The number of productive tillers per plant had a positive significant correlation with yield. The results were in conformity with Reddy *et al.* (1995), reported that grain yield can be increased whenever there is an increase in the number of productive tillers. Grain yield per plant showed a non-significant negative correlation with 1000 grain weight. The result was in agreement with Babu *et al.* (2012).

4.3 SOIL HETEROGENEITY

Soil heterogeneity of the given experimental site was studied with the help of fertility contour map, serial correlation and mean square between strips.

4.3.1 Fertility contour map

In order to find the nature and magnitude of soil heterogeneity of the experimental area, fertility contour map was prepared based on yield data of 400 basic units from the uniformity trial.

4.3.1.1 Fertility contour map based on the yield of original basic units

Fertility gradient was calculated separately for each basic unit and it varied from -48.82 to 66.35 per cent. It was then classified in to six groups having same range and then they have given different colour shades to identify the direction of fertility variation. Fertility gradient can be found out with the given equation.

$$Fertility\ gradient = \frac{Y_i - \bar{Y}}{\bar{Y}} \times 100$$

Where Y_i is the grain yield from each basic unit and $\bar{Y}$ is the mean yield of the entire plot. The basic units having the same fertility gradient were given the same demarcation. The estimated fertility gradient of each basic units are presented in table 7.

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Table 7. Fertility gradient based on yield of original basic units

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	8.77	27.96	40.75	8.77	-36.02	2.37	-36.02	-36.02	-36.02	-29.62	-42.42	-10.43	8.77	4.93	8.77	27.96	-4.03	-4.03	-10.43	-10.43
2	34.36	21.56	34.36	-36.02	-42.42	-23.22	-23.22	2.37	22.84	-48.82	-23.22	11.32	-36.02	-9.15	-16.83	-4.03	-10.43	-16.83	-23.22	11.32
3	53.55	53.55	27.96	-16.83	-36.02	53.55	2.37	-29.62	8.77	27.96	27.96	-42.42	-48.82	-10.43	2.37	8.77	2.37	15.16	2.37	-16.83
4	21.56	53.55	2.37	-16.83	-23.22	-48.82	-36.02	2.37	-4.03	-36.02	-4.03	27.96	-4.03	2.37	-48.82	-42.42	-42.42	-29.62	-16.83	27.96
5	2.37	2.37	34.36	-23.22	34.36	-36.02	49.71	2.37	-0.19	-29.62	-29.62	-36.02	-36.02	-42.42	8.77	15.16	15.16	-4.03	-16.83	-10.43
6	2.37	-10.43	21.56	31.80	22.84	-23.22	-33.46	-2.75	47.15	-42.42	59.95	34.36	27.96	40.75	22.84	27.96	25.40	27.96	21.56	8.77
7	-4.03	8.77	27.96	-42.42	8.77	-36.02	-36.02	-15.55	-16.83	-29.62	2.37	-28.34	27.96	-36.02	2.37	47.15	22.84	8.77	-4.03	-28.34
8	2.37	-4.03	-29.62	2.37	59.95	-10.43	-4.03	-7.87	-29.62	-33.46	-23.22	43.31	-28.34	40.75	-36.02	21.56	-7.87	2.37	-4.03	-33.46
9	-2.75	2.37	-48.82	34.36	34.36	-16.83	2.37	34.36	-12.99	-29.62	-4.03	8.77	22.84	-10.43	34.36	2.37	15.16	8.77	8.77	-29.62
10	-10.43	-23.22	-16.83	22.84	34.36	34.36	47.15	21.56	8.77	-4.03	47.15	34.36	40.75	15.16	-36.02	21.56	-4.03	-4.03	8.77	-4.03
11	21.56	15.16	8.77	59.95	22.84	15.16	33.08	47.15	47.15	15.16	-16.83	66.35	-10.43	15.16	40.75	21.56	27.96	21.56	21.56	15.16
12	27.96	-16.83	-2.75	15.16	-36.02	-42.42	-14.27	59.95	15.16	40.75	-36.02	-42.42	40.75	8.77	21.56	-10.43	2.37	2.37	8.77	40.75
13	27.96	40.75	34.36	8.77	15.16	21.56	27.96	-6.59	-10.43	2.37	-16.83	-48.82	-42.42	-23.22	-33.46	15.16	-10.43	-10.43	-16.83	2.37
14	2.37	-4.03	8.77	2.37	15.16	2.37	-23.22	-28.34	-36.02	-16.83	-2.75	8.77	-16.83	-42.42	-42.42	-23.22	-29.62	-36.02	-23.22	-36.02
15	-48.82	-42.42	47.15	2.37	40.75	8.77	-42.42	-25.78	21.56	-23.22	-48.82	-4.03	-10.43	-48.82	-48.82	-29.62	-36.02	-42.42	-36.02	2.37
16	-10.43	8.77	8.77	2.37	8.77	2.37	27.96	-10.43	2.37	47.15	27.96	8.77	27.96	-48.82	-36.02	-36.02	-36.02	-42.42	-10.43	-16.83
17	-16.83	-4.03	34.36	2.37	47.15	34.36	-23.22	-4.03	21.56	34.36	2.37	15.16	27.96	-4.03	2.37	-15.55	-6.59	-6.59	8.77	-23.22
18	21.56	-10.43	21.56	8.77	15.16	47.15	8.77	8.77	34.36	53.55	40.75	34.36	8.77	-10.43	-16.83	-23.22	-23.22	-16.83	2.37	-10.43
19	-7.87	-4.03	15.16	8.77	34.36	22.84	8.77	-7.87	21.56	27.96	8.77	12.60	8.77	-27.06	-23.22	-29.62	-29.62	-28.34	-10.43	-6.59
20	-2.75	-0.19	12.60	19.00	22.84	8.77	15.16	2.37	2.37	8.77	-2.75	11.32	2.37	-16.83	-10.43	-10.43	-10.43	-10.43	-4.03	-23.22

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The fertility gradient of each basic unit ranges from -48.82 to 66.35 per cent, and it was classified into six groups.

Table 8. Fertility gradient ranges and frequency (number of basic units and percentage) in the experimental area of paddy

Cass interval	Colour	Frequency	Percentage	Cumulative percentage
<-40		28	7	7
(-40 to -20)		72	18	25
(-20 to 0)		93	23.25	48.25
(0 to 20)		104	26	74.25
(20 to 40)		70	17.5	91.75
>40		33	8.25	100

From the table 8 it is very clear that highly fertile areas and very low fertile areas are very less which is accounted for 7 per cent and 8.25 per cent respectively. Almost 50 per cent of area is under average fertility gradient (-20 to 20). Fertility gradient between 0 to 20 per cent shows 26 per cent of area. The fertility gradients 0 to 20 per cent and -20 to 0 are distributed almost equally in area, which can be combined together to estimate the average fertility of the soil.

From the figure 6, we can conclude that the field was heterogeneous and the extreme fertile (red) and barren and low fertile (yellow) areas are scattered and more areas are under medium fertile range of 0 to 20 per cent. The contour map revealed that more area belongs under the fertility gradient ranged between -20 to 0 (23.25%) and 0 to 20 (26%) whereas the fertility gradient greater than 40 has a very small percentage (8.25%). A cumulative percentage of area up to 20 per cent fertility gradient was 74.25 per cent. The contour map reveals that more area of the experimental plot is under average fertility. Fertility contour map of yield of original basic units helps to study about the fertility gradient of each basic unit separately.

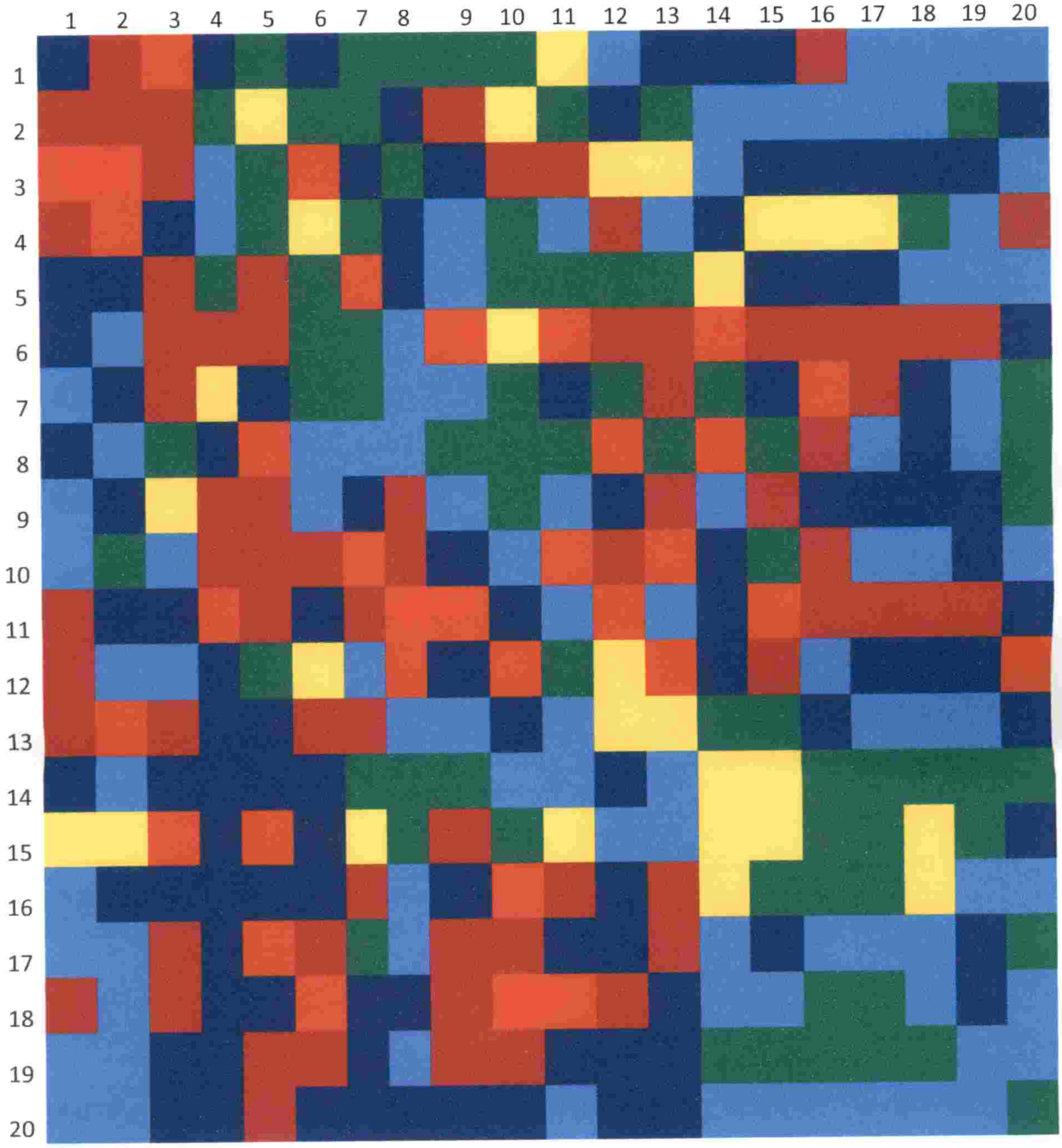

Fig 6. Fertility contour map of paddy based on yield of original basic units

4.3.1.2 Fertility contour map based on 3×3 moving average

Moving averages can be constructed by combining several basic units to reduce the large random variation expected on small plots (Gomez and Gomez, 1976). The moving averages are calculated using the following formula,

$$P_{s,t} = \frac{\sum_{i=s-1}^{s+1} \sum_{i=t-1}^{t+1} Y_{ij}}{s \times t}$$

Soil fertility status was determined for 3 × 3 moving averages and 5 × 5 moving averages. The fertility status varied from 236.11 to 522.22 in case of 3 × 3 moving average and 230 to 536 in case of 5 × 5 moving average. The moving average values were divided in to 6 different classes and different colour patterns are assigned to each of the class. Same colouring pattern is followed for lower to upper class soil fertility as that of fertility contour map based on yield of original basic units. The 3 × 3 moving average values are given in table 9.

The table 9 shows the fertility status based on 3 × 3 moving average. Here the fertility status ranges from 236.11 to 522.22. The moving average based fertility status obtained a more area under same fertility than based on fertility gradient. Here the number of rows and columns were reduced to 18 each. It provides the fertility status in its original units of grain yield. It was found that the adjacent units are little more homogeneous in fertility status than that based on fertility gradient.

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Table 9. Fertility status based on 3 × 3 moving average

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	522.22	461.11	366.67	336.11	330.56	352.78	336.67	339.44	350.56	334.44	323.33	333.33	348.89	396.11	397.22	397.22	369.44	367.78
2	522.22	444.44	344.44	308.33	313.89	347.22	367.22	367.22	378.33	365.00	351.11	343.33	317.22	339.44	325.00	338.89	338.89	370.56
3	500.00	441.67	383.33	341.67	373.33	373.33	388.89	365.56	373.89	350.00	327.78	308.33	313.89	344.44	355.56	363.89	358.33	369.44
4	447.22	432.22	427.22	355.00	350.00	336.11	401.67	363.33	373.89	366.67	408.33	397.22	378.33	383.89	382.78	387.78	382.22	394.44
5	427.78	412.78	441.11	363.33	369.44	333.89	388.33	352.78	373.89	347.78	400.56	370.00	397.78	428.33	472.22	471.67	432.78	392.22
6	397.22	393.33	435.56	396.67	368.33	317.22	347.78	333.89	362.22	383.33	441.11	443.89	417.78	447.78	445.56	467.22	431.11	390.56
7	370.00	369.44	411.11	405.56	391.67	351.67	353.33	329.44	313.89	350.00	400.00	408.33	398.33	419.44	435.00	443.33	412.78	360.00
8	333.89	364.44	431.11	475.56	469.44	434.44	416.67	367.78	355.56	407.78	452.22	463.33	409.44	413.89	395.56	415.00	401.11	370.56
9	367.22	414.44	456.67	495.56	480.56	485.56	490.00	446.11	412.78	441.67	472.78	470.00	439.44	436.11	444.44	438.89	436.11	411.11
10	392.22	417.78	437.78	445.56	431.67	478.33	506.11	500.00	441.67	436.11	444.44	463.89	450.00	433.33	427.78	425.00	427.78	438.89
11	458.89	461.67	445.56	425.56	409.44	452.22	477.22	482.22	408.33	375.00	344.44	375.00	398.33	415.00	423.33	416.67	411.11	427.78
12	442.22	428.33	417.22	391.67	376.11	389.44	383.89	399.44	364.44	342.22	322.78	322.22	334.44	334.44	342.78	347.22	341.67	361.11
13	419.44	433.33	466.67	441.67	419.44	362.22	337.22	337.22	333.89	325.56	311.67	291.67	256.67	270.56	287.22	302.78	286.11	305.56
14	377.78	405.56	450.00	427.78	408.33	352.22	341.11	360.56	378.33	389.44	386.67	336.11	275.00	236.11	252.78	255.56	263.89	286.11
15	380.56	416.67	475.00	455.56	436.11	376.67	376.67	418.33	427.78	416.67	411.11	375.00	330.56	275.56	285.56	281.67	300.56	318.33
16	413.89	422.22	455.56	463.89	463.89	430.56	419.44	472.22	505.56	505.56	475.00	416.67	369.44	308.89	307.78	301.11	333.89	340.56
17	412.22	422.22	472.22	486.67	475.56	432.22	420.56	473.33	497.22	490.56	460.00	419.44	376.11	326.67	318.89	312.78	342.78	351.11
18	410.56	421.67	459.44	472.22	470.56	440.56	431.67	456.67	475.56	475.56	445.00	401.11	353.89	317.78	313.89	311.67	333.89	343.89

Table 10. Soil fertility status and frequency (number of basic units and percentage) in the experimental area of paddy using 3 × 3 moving average

Cass interval	Colour	Frequency	Percentage	Cumulative percentage
<283.80		9	3.13	3.13
283.80-331.48		35	12.15	15.28
331.48- 379.17		97	33.68	48.96
379.17- 426.85		80	27.78	76.74
426.85- 474.54		44	15.28	92.02
>474.54		23	7.98	100.00

It is evident from table 10 that, the maximum area under the crop was having a medium productivity range. Least productive areas were accounted for only 3.13 per cent. Higher percent of area was under the fertility status between 331.48 g and 379.17 g and less area under the fertility less than 283.80 g. When we compare the fertility status of moving average with that based on yield of original basic units, we can see a gradual decrease in the area of very low and very high fertile areas whereas an increase in area for average fertile areas. The percentage of area under low fertility and high fertility has decreased from 7 to 3.13 and 8.25 to 7.98 as compared to fertility map based on yield of original basic units. The average fertile area was increased from 49.25 to 61.46 per cent.

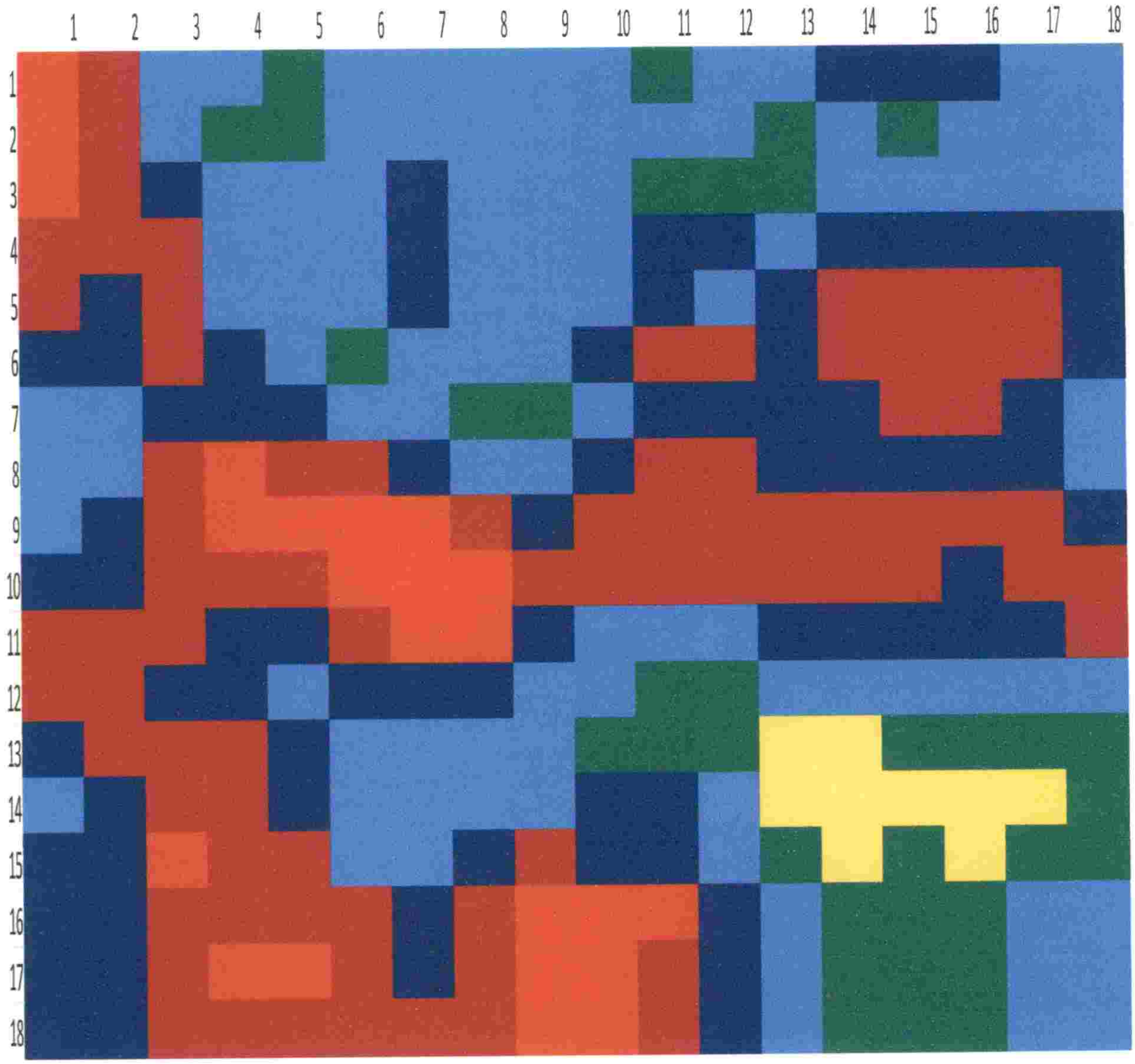

Fig 7. Soil fertility contour map based on 3 × 3 moving average

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From figure 7, it was evident that more area (60.46%) under soil having fertility range between 331.48 g - 379.17 g and also 379.17 g - 426.85 g. The upper portion of the field showed more fertility range of 331.48 g to 379.17 g and the lower portion was more pronounced with a fertility status greater than 426.85 g. The experimental plot having homogeneous fertility status when taken horizontally and becomes heterogeneous towards the centre and bottom portion. Greater than 20 per cent of area was under above average fertility and 15 per cent area was under below average fertility. Fertility status based on moving average provided more visible view of area under homogeneity. The fertility contour map based on 3 × 3 moving average showed more homogeneous plots (Masood *et al.*, 2012). The fertility status was divided in to 3 different classes (0.25-0.31, 0.31-0.36 and 0.36-0.42) in which more area under crop was with average fertility.

4.3.1.3 Fertility contour map based on 5×5 moving average

Soil fertility status was determined for 5 × 5 moving averages. The fertility status of 5 × 5 moving average varied from 230 g to 536 g. The moving average values were divided in to 6 different classes and different colour patterns are assigned to each of the class. Same colouring pattern was followed for lower to upper class soil fertility as that of fertility contour map based on yield of original basic units. The 5 × 5 moving average values are given in table 11.

Table 11. Fertility status based on 5 × 5 moving average

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	430	425	375	315	280	285	250	270	305	337	367	422	427	417	405	390
2	400	355	320	295	341	336	336	363	333	308	333	348	331	346	335	357
3	455	455	415	370	390	440	420	385	370	355	335	320	355	405	415	400
4	420	365	295	295	305	295	330	380	375	380	370	340	285	265	250	310
5	430	400	437	412	430	380	385	318	288	255	285	320	360	385	405	390
6	444	424	406	387	399	348	413	466	490	485	536	511	504	504	489	478
7	390	365	330	296	316	286	316	322	356	341	366	401	441	426	451	427
8	415	405	405	422	397	324	314	351	335	390	388	423	383	407	372	374
9	406	395	395	460	423	373	383	388	379	381	431	436	441	430	445	395
10	396	431	486	516	505	475	485	475	490	495	470	450	420	385	380	405
11	491	486	500	530	520	514	489	515	470	445	465	495	465	490	495	475
12	381	326	328	377	377	437	442	420	405	400	385	405	440	410	410	425
13	490	485	475	443	428	418	388	328	300	290	262	287	317	342	347	375
14	410	410	395	366	336	311	307	332	341	336	316	300	270	255	270	275
15	390	435	435	378	393	343	298	328	340	285	265	280	255	230	240	280
16	405	415	430	415	415	445	465	450	480	440	375	325	290	235	265	280

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The given table 11 shows the fertility status of the soil based on 5 × 5 moving average. The fertility status was varied from 230 g to 536 g. Here also the adjacent plot was found to more homogeneous than that based on fertility gradient. The moving average based fertility status divides more basic units under homogeneous groups the basic units in to more under homogeneous groups which simplifies the difficulty in selection of homogeneous plots for blocking. Here also the fertility status was divided in to 6 classes and similar colour shades were given as that of previous cases.

Table 12. Soil productivity ranges and frequency (number of basic units and percentage) in the experimental area of paddy using 5 × 5 moving average

Cass interval	Colour	Frequency	percentage	Cumulative percentage
<281		20	7.81	7.81
281-332		43	16.80	24.61
332-383		55	21.48	46.09
383-434		78	30.47	76.56
434-485		37	14.45	91.01
>485		23	8.99	100

The table 12 clearly reveals the percentage of area under each fertility range. Average fertility with fertility range greater than 383 g was present in more than 50 per cent of the total area. As the moving average value increases, the area under each fertility status increases gradually. The fertility range between 332 g and 434 g covered 51.95 per cent of total area and 24.61 per cent of total area was below 332 g.

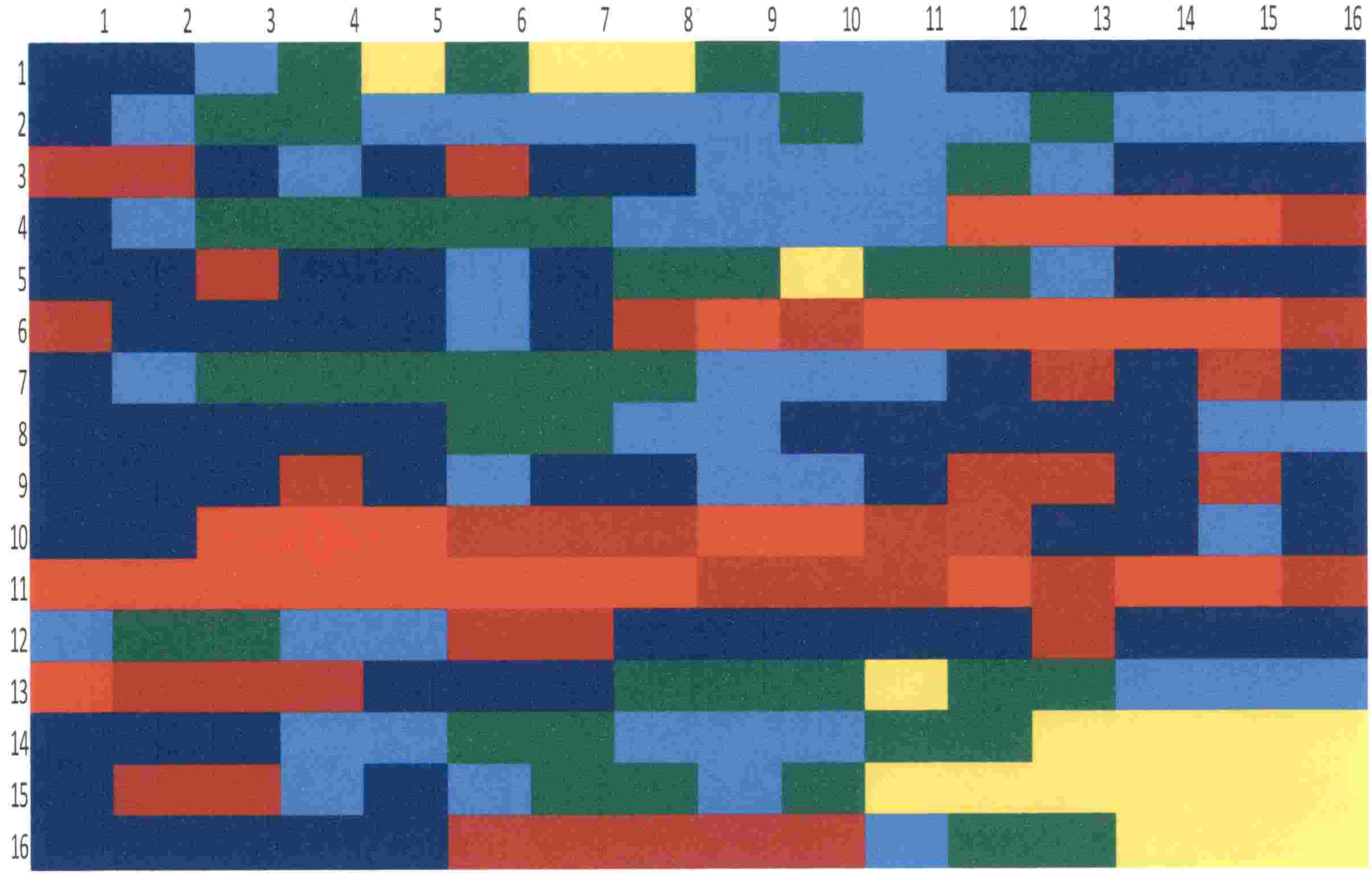

Fig 8. Soil productivity contour map of 5 × 5 moving average

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A gradual increase in the productivity status can be clearly seen from the figure 8. It can be clearly seen that as the moving average value increases, the soil productivity under each range also increases. Highly productive areas are concentrated towards the center of the field. More area of the field is under the fertility range between 383 g and 434 g which accounted for 30.47 per cent of the total area.

4.3.2 Serial correlation

In order to characterise the trend in soil fertility, serial correlation was calculated using uniformity trail data. The serial correlation values calculated for both vertical and horizontal arrangement and the estimated values are presented in table 13.

Table 13. Serial correlation coefficient for vertical and horizontal arrangement

Arrangement	Serial correlation coefficient
Vertical	0.189
Horizontal	0.327

From the table 13 it was evident that horizontal serial correlation coefficient was higher than the vertical serial correlation coefficient which indicates that the fertility gradient was more pronounced along horizontal direction than vertically. The vertical and horizontal serial correlation coefficient was estimated in rice in Pakistan was 0.314 and 0.341 (Masood *et al.*, 2012). Both coefficients were low indicating same fertility gradient and little more pronounced along the horizontal direction.

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4.3.3 Mean square between strips

The present data has 20 vertical strips and 20 horizontal strips. Mean square between strips can be calculated for both vertical and horizontal arrangement and the sum of squares are presented in table 14. The estimated mean square for vertical strip (187215) was less than that of horizontal strip (210250) indicates that soil fertility was more pronounced in horizontal direction rather than vertical direction.

Table 14. Mean square between strips values for vertical and horizontal arrangement

Arrangement	SS between strips	Mean SS between strips
Vertical	3557085	187215
Horizontal	3994750	210250

From the table 14 it can be clearly seen that horizontal arrangement showed a higher value of mean square than vertical arrangement. The higher value of mean square for the horizontal strips shows the fertility gradient in that direction. This result was in conformity with the conclusion of fertility contour map since the field was more or little homogeneous in the vertical direction. This result was in unison with the study by Masood *et al.* (2012) in rice in Pakistan. Mean square for horizontal strips (0.014) was relatively higher than mean square for vertical strips (0.006), which indicates that trend of soil fertility, was more pronounced along the length than along the width of the field.

4.4 ESTIMATION OF OPTIMUM PLOT SIZE

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

4.4.1 Maximum Curvature Method

Mean, standard deviation and coefficient of variation were calculated for different plot sizes and are given in the table 15. Maximum curvature graph was also plotted by taking plot size on X axis and coefficient of variation on Y axis.

Table 15. Coefficient of variation and its changes

Plot size (Basic units)	Plot size (m^2)	Shape	Mean	SD	CV	Min CV	Average	Percentage reduction
1	1.44	1×1	390.72	102.9	26.33	26.33	26.33	
2	2.88	1×2	781.45	167.02	21.37	20.29	20.83	20.89
		2×1	781.45	158.53	20.29			
3	4.32	1×3	1179.79	235.76	19.98	18.53	19.25	7.59
		3×1	1171.88	217.19	18.53			
4	5.76	1×4	1562.9	267.71	17.13	17.01	17.23	10.49
		4×1	1562.9	274.09	17.54			
		2×2	1562.9	265.89	17.01			
5	7.2	1×5	1953.62	314.68	16.11	15.3	15.71	8.82
		5×1	1953.63	298.83	15.3			
6	8.64	1×6	2359.58	380.42	16.12	14.14	15.53	1.15
		6×1	2343.75	331.45	14.14			
		2×3	2359.58	385.95	16.36			
		3×2	2343.75	362.9	15.48			
8	11.52	1×8	3178.38	402.5	12.66	12.56	13.58	**12.56**
		8×1	3093.5	388.65	12.56			

Plot size (Basic units)	Plot size (m^2)	Shape	Mean	SD	CV	Min CV	Average	Percentage reduction
		2×4	3125.8	445.86	14.26			
		4×2	3125.8	463.36	14.82			
9	12.96	1×9	3539.38	466.09	13.17	11.1	13.21	2.72
		9×1	3515.62	390.21	11.1			
		3×3	3536.11	543.28	15.36			
10	14.4	1×10	3907.25	530.98	13.6	10.8	12.63	4.39
		10×1	3907.25	421.99	10.8			
		2×5	3907.25	513.3	13.14			
		5×2	3907.25	507.3	12.98			
12	17.28	1×12	4874	541.87	11.12	11.12	12.35	2.22
		12×1	4777	538.17	11.26			
		2×6	4796.67	646.21	13.47			
		6×2	4687.5	558.32	11.91			
		3×4	4687.5	627.16	13.38			
		4×3	4720.83	612.02	12.96			
15	21.6	1×15	5969	639.38	10.71	10.71	11.85	4.05
		15×1	5810.75	623.65	10.73			
		3×5	5859.38	758.55	12.94			
		5×3	5898.96	767.32	13.01			
16	23.04	1×16	6356.75	654.71	10.3	10.3	10.98	**7.34**
		2×8	6356.75	713.19	11.22			
		4×4	6251.6	714.03	11.42			
18	25.92	1×18	7078.75	747.22	10.56	9.74	10.95	0.27
		18×1	7031.25	692.83	9.85			

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Plot size (Basic units)	Plot size (m^2)	Shape	Mean	SD	CV	Min CV	Average	Percentage reduction
		2×9	7053	732.93	10.39			
		9×2	7031.25	684.65	9.74			
		3×6	7072.22	824.2	11.65			
		6×3	7072.22	858.3	12.14			
20	28.8	1×20	7814.5	814.29	10.42	9.49	10.58	3.38
		20×1	7814.5	741.89	9.49			
		2×10	7983.5	888.8	11.13			
		10×2	7814.5	743.2	9.51			
		4×5	7812.75	964.29	12.34			
24	34.56	2×12	9748	897.38	9.2	9.2	9.72	**8.13**
		12×2	9654	888.47	9.2			
		3×8	9509.58	937.03	9.85			
		8×3	9429.58	880.71	9.34			
		4×6	9545	971.63	10.18			
		6×4	9375	989.22	10.55			
25	36	5×5	10068.12	967.05	9.6	9.6	9.6	1.23
27	38.88	3×9	10608.33	1018.19	9.59	9.23	9.32	2.92
		9×3	10608.33	978.78	9.23			
28	40.32	2×14	11236.5	971.3	8.64	8.47	8.69	6.76
		14×2	10982.5	930.49	8.47			
		4×7	11236.5	983.12	8.75			
		7×4	10972.5	975.38	8.89			
30	43.2	2×15	11938	1020.56	8.55	8.48	8.63	0.69
		15×2	11691.5	1004.51	8.59			

Plot size (Basic units)	Plot size (m^2)	Shape	Mean	SD	CV	Min CV	Average	Percentage reduction
		3×10	11718.75	1008.16	8.6			
		10×3	11797.92	1055.25	8.94			
		5×6	11797.92	1000.06	8.48			
		6×5	11718.75	1010.33	8.62			
32	46.08	2×16	12713.5	1007.43	7.92	7.42	7.72	**10.54**
		16×2	12374	969.44	7.83			
		4×8	12713.5	942.85	7.42			
		8×4	12374	953.01	7.7			
35	50.4	5×7	14045.62	1041.74	7.42	7.37	7.39	4.27
		7×5	13728.12	1011.48	7.37			
36	51.84	2×18	14157.5	1017.23	7.18	7.07	7.28	1.49
		18×2	14062.5	994.91	7.07			
		4×9	14157.5	1034.51	7.3			
		9×4	14062.5	1061.53	7.55			
		6×6	14144.44	1030.47	7.29			
38	54.72	2×19	14902.5	963.78	6.84	6.71	6.78	6.87
		19×2	14842	996.34	6.71			
40	57.6	2×20	15629	999.41	6.39	6.26	6.61	2.51
		20×2	15629	978.05	6.26			
		4×10	15629	1090.56	6.98			
		10×4	15629	1033.83	6.61			
		5×8	15891.88	1065.3	6.7			

Plot size (Basic units)	Plot size (m^2)	Shape	Mean	SD	CV	Min CV	Average	Percentage reduction
		8×5	15467.5	1042.85	6.74			
45	64.8	5×9	17696.88	1152.82	6.51	6.34	6.42	2.87
		9×5	17578.12	1115.33	6.34			
48	69.12	4×12	19496	1249.06	6.41	6.04	6.22	3.12
		12×4	19108	1153.44	6.04			
50	72	5×10	19536.25	1218.69	6.24	6.21	6.22	0
		10×5	19536.25	1212.56	6.21			

From table 15, it was clearly evident that as the plot size increases the value of coefficient of variation decreases and gradually it approaches a constant value. Since the coefficient of variation is the criteria for selecting optimum plot size under maximum curvature method, the plot size at which the CV becomes a constant can be selected as the optimum plot size. This process becomes difficult to understand about optimum plot size. Hence we consider the reduction in coefficient of variation. Analysing the value of percentage reduction in coefficient of variation, the plot size with 8 basic units showed maximum percentage reduction in CV (12.56%). A similar steep reduction in coefficient of variation was also visible for plot sizes which are the multiples of 8 basic units such as 16 basic units (7.34%), 24 basic units (8.13%) and for 32 basic units (10.54). The per cent reduction in coefficient of variation gradually reduces after a plot size of 24 basic units.

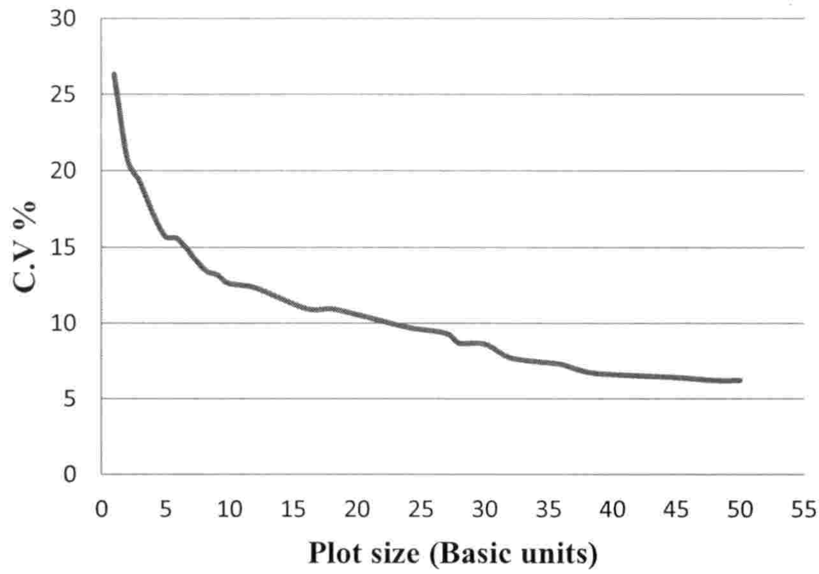

Fig 9. Curve depicting the reduction in coefficient of variation with plot size

From the graph (Fig. 9) it can be concluded that as the plot size increases, coefficient of variation decreases. After a certain point the graph takes a turn and then the value of coefficient of variation becomes a constant with increase in plot size. Hence the point at which the curve takes a turn was considered as the optimum plot size.

The plots of different sizes can be arranged in to different shapes such as vertical plots, horizontal plots, rectangular plots and square shaped plots. The changes in coefficient of variation was different for different plot shapes. To study the changes in CV with plot shapes, they are grouped into different shapes and CV was estimated. Different plot shapes with their coefficient of variation was given in the following table 16.

Table 16. The changes in CV for horizontal plots and vertical plots

Horizontal plots			Vertical plots		
Plot size (basic units)	Plot shape	CV	Plot size (basic units)	Plot shape	CV
3	1 × 3	19.98	3	3 × 1	18.53
4	1 × 4	17.13	4	4 × 1	17.54
5	1 × 5	16.11	5	5 × 1	15.3
6	1 × 6	16.12	6	6 × 1	14.14
8	1 × 8	12.3	8	8 × 1	12.56
9	1 × 9	13.17	9	9 × 1	11.1
10	1 × 10	13.6	10	10 × 1	10.8
12	1 × 12	11.12	12	12 × 1	11.56
15	1 × 15	10.71	15	15 × 1	10.73
16	1 ×16	10.3	16	16 × 1	11.02
18	1 × 18	10.56	18	18 × 1	9.85
20	1 × 20	10.42	20	20 ×1	9.49

From table 16 it was evident that there was a considerable change in the coefficient of variation of horizontal plots and vertical plots for the same plot size. Horizontal plots showed a higher value of CV than vertical plots for the same plot size. For selecting long narrow plots, vertical plots seems better than horizontal plots since it showed a small value for CV.

Khan *et al.* (2017) observed that long and narrow plots elongated in east west direction were more useful than the compact and square plots in controlling the soil heterogeneity for mustard planted at a spacing of 30cm between the rows and 10cm within the plants in a row in Hisar.

Table 17. Change in coefficient of variation for square plots

Square shaped plots		
Plot size (basic units)	Plot shape	C.V
1	1 × 1	26.33
4	2 × 2	17.01
9	3 × 3	15.36
16	4 × 4	11.42
25	5 × 5	9.6
36	6 × 6	7.29

From table 17 it was evident that as the plot size increases, coefficient of variation decreases for the square shaped plots. Horizontal and vertical plots showed a lesser value for CV as compared to square shaped plots. For the plot sizes 4, 9 and 16 basic units, square shaped plots showed CV values such as 17.01, 15.36 and 11.42 whereas CV values were less than these for vertical and horizontal plots.

Table 18. Changes in coefficient of variation for rectangular plots

Rectangular plots			
Plot shape	CV	Plot shape	CV
1 × 2	21.37	2 × 1	20.29
2 × 3	16.36	3 × 2	15.48
2 × 4	14.26	4 × 2	14.82
2 × 5	13.14	5 × 2	12.98
2 × 6	13.47	6 × 2	11.91

Plot shape	CV	Plot shape	CV
3 × 4	13.38	4 × 3	12.96
3 × 5	12.94	5 × 3	13.01
2 × 8	11.22	8 × 2	11.14
2 × 9	10.39	9 × 2	9.74
3 × 6	13.07	6 × 3	12.14
2 × 10	11.13	10 × 2	9.51
4 × 5	12.34	5 × 4	12.04
2 × 12	9.2	12 × 2	9.2
3 × 8	9.85	8 × 3	9.34
4 × 6	10.18	6 × 4	10.55
3 × 9	9.59	9 × 3	9.23
2 × 14	8.64	14 × 2	8.47
4 × 7	8.75	7 × 4	8.89
2 × 15	8.55	15 × 2	8.59
3×10	8.6	10×3	8.94
5×6	8.48	6×5	8.62
4×8	7.42	8×4	7.7
5×7	7.42	7×5	7.37
2×18	7.18	9×4	7.55
4×9	7.3	18×2	7.07
4×10	6.98	10×4	6.61
5×8	6.7	8×5	6.74
5×9	6.51	9×5	6.34
4×12	6.41	12×4	6.04
5×10	6.24	10×5	6.21

Table 18 shows the changes in CV for rectangular plots. Vertical and horizontal plots showed lesser value for CV as compared to rectangular plots, but vertical and horizontal plots being not recommended widely for field experiments. In rectangular plots, the plot shape having high size for breadth than length showed lesser value CV as compared to the other.

Table 19. Summary table of plot size and shape along with coefficient of variation

Plot size	Shape	CV	Percentage reduction in CV
18	9 × 2	9.74	0.27
20	10 × 2	9.51	3.37
24	8 × 3	9.34	8.13
25	5 × 5	9.6	1.23

From the table 19 it can be seen that as the plot size increases, coefficient of variation decreases and then it attains a constant value. For Uma variety of paddy, coefficient of variation decreases from plot size 1 to 50 units. Gradual decrease in coefficient of variation can be seen up to the plot size 24 basic units and there after the CV remains constant. When we consider the percentage reduction in coefficient of variation the maximum percentage of reduction was seen for the plot size of 24 basic units and also the CV value remains a constant there after for the remaining plot sizes. The percentage reduction in CV also reduces after the plot size of 24 basic units. For the plot size of 24 basic units, different plot shape combinations can be made *i.e.,* 2 × 12 (2 unit breadth and 12 unit length) and 12 × 2 (12unit breadth and 2unit length), 8 × 3 (8 unit breadth and 3 unit length), 3 × 8 (3 unit breadth and 8 unit length), 4 × 6 (4 unit breadth and 6 unit length) and 6 × 4 (6 unit breadth and 4 unit length). Since long narrow plots were being not recommended for field experiments, rectangular shaped plots can be taken as the optimum plot size. From these different combinations, the plot shape 8 × 3with minimum CV is considered *i.e*, 9.34. So the shape of optimum plot size obtained by this method is 8 unit in breadth and 3 units in length. The area required was 34.56 m^2 (24×1.2 m $\times$ 1.2 m).

The reduction in coefficients of variation for plots of various sizes and shapes for rice in Pakistan indicate that as the plot size increases, coefficients of variation and variance per unit area decreases and this decrease was at maximum with the rectangle shape plot of 6 m $\times$ 12 m (Masood *et al.*, 2012). This decrease in the coefficient of variation and variance per unit area imply that the plot of rectangular shape of 6 m $\times$ 12 m basic unit was the most effective in reducing soil variation and was therefore considered the optimum plot size.

4.4.2 Fairfield Smith's Variance Law

The optimum plot size can be estimated by Fairfield Smith variance law by assuming the empirical relation

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

Where x is the number of basic units in a plot, V_x is the variance of mean per plot of x units, V_1 is the variance per plot of one unit and b is the regression coefficient. Ordinary least square regression was done to study about the suitability of the model. The results of regression analysis are presented in the following table.

Table 20. Goodness of fit of regression analysis

Regression Statistics	
Multiple R	0.98
R Square	0.97
Adjusted R Square	0.97
Standard Error	0.07
Observations	26

Table 21. ANOVA model for regression

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	3.94	3.94	730.22	<0.05
Residual	24	0.13	0.005		
Total	25	4.07			

Table 22. Estimated coefficients along with standard error

	Coefficients	Standard Error	t Stat	P-value
Intercept	3.37	0.04	84.31	<0.05
b	-0.373	0.01	-27.02	<0.05

The assumed relationship between plot size and coefficient of variation was estimated a multiple R square value of 0.98 and an adjusted R square of 0.97. The R^2 values indicated the best fit of the model. Analysis of variance table shows that regression sum of squares are significant at 5 per cent level of significance. The estimated intercept was 3.37 and *b* coefficient was 0.373. Hence, the soil heterogeneity coefficient was estimated as 0.373. So the equation obtained under Fairfield Smith's variance law was written as

$$Y = 29.08X^{-0.373}$$

The R^2 obtained under this method is very high and the value of b is 0.37. It indicates that the field was heterogeneous in fertility.

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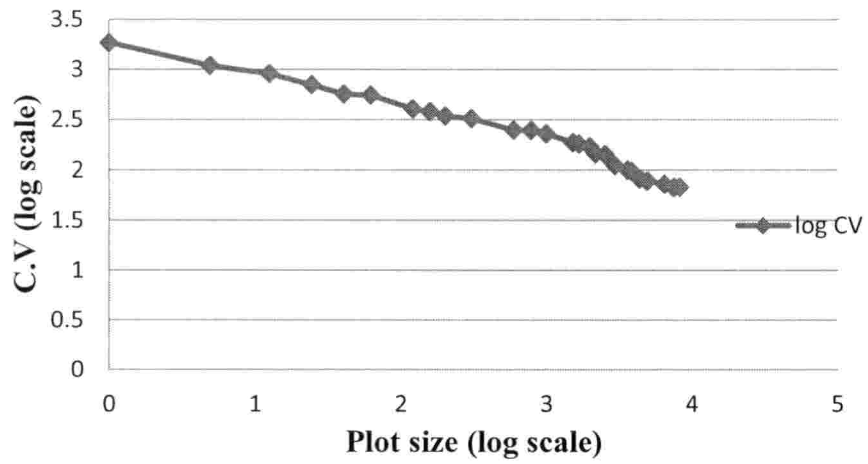

Fig 10. Graph of coefficient of variation (on log scale) obtained under Fairfield Smith's variance law.

The optimum plot size using Fairfield Smith variance law was given as

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

The optimum plot size obtained under this method was 6 basic units. So the area obtained under this method was 8.64 m^2. The plot size of 6 basic units didn't have a minimum value for coefficient of variation when compare the result with maximum curvature graph. Moreover the area obtained under this method was very less and hence it cannot be recommended as optimum plot size for field experiments on paddy.

Uniformity trial in soybean crop with rows were along east west direction and columns were in north south direction showed some difference in Fairfield Smith method and maximum curvature (Kavitha, 2010). At the larger plot sizes the regression line showed a tendency to curve down although and trend in decrease of coefficient of variation was found almost similar for the characters. From all these considerations a plot size of 3.6 m^2 (3.6 m × 1.0 m) was found advisable for conducting field experiments in soybean.

4.4.3 Modified Maximum Curvature Method

The optimum plot size under modified maximum curvature method can be estimated by assuming the relationship

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

Curvature can be obtained with the formula

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

Taking dC/ dx and equating to zero, the equation for optimum plot size can be obtained by the formula

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

The value of the constants were estimated by least square method were

a = 29.08

b = 0.373 and

$\mathbf{x}_{opt}$ = 5.076

The optimum plot size obtained by modified curvature method was 6 basic units with an area of 8.64 m^2. The result of modified maximum curvature method was in conformity with the Fairfield Smith's variance law. But this cannot be regarded as the optimum plot size for field experiments on paddy since the area was very less and CV was high.

Modified maximum curvature method was used for estimating optimal size of plots for reflectance measurements in beans (Michels *et al.,* 2015). The method obtained basic units of 0.45 m^2 in an area of lines 6 and 8 m in length performing 46 combinations of experimental area. By adopting the biggest obtained area, it was concluded that the optimum size of an experimental plot for work with reflectance in beans was 5.40 m^2 and the combination that presents the best distribution was 2 lines totalling 6 m long.

4.4.4 Comparable Variance Method

Comparable variances (V) were calculated for finding optimum plot size. Variance per unit area can be calculated with the given equation

$$V_X = \frac{V_{(X)}}{X^2}$$

Where V_X is the variance per unit area, $V_{(X)}$ is the among plot variance and X is the plot size.

Among plot variance, comparable variance and variance per unit area were calculated for finding optimum plot size and are given in the table.

Table 23. Variance measurements of paddy

Plot size	Plot Shape	SD	Among plot variance $V_{(X)}$	Comparable variance V	Average V	Variance per unit area Vx	Average Vx	% reduction in V_x
1	1 × 1	102.9	10588.41	10588.4	10588.41	10588.4	10588.4	
2	1 × 2	167.02	27895.68	13947.8	13256.86	6973.92	6628.43	37.40
	2 × 1	158.53	25131.76	12565.8		6282.94		
3	1 × 3	235.76	55582.78	18527.6	17125.71	6175.86	5708.57	13.88
	3 × 1	217.19	47171.5	15723.8		5241.28		
4	1 × 4	267.71	71668.64	17917.2	18124.29	4479.29	4531.07	20.63
	4 × 1	274.09	75125.33	18781.3		4695.33		

Plot size	Plot Shape	SD	Among plot variance $V_{(X)}$	Comparable variance V	Average V	Variance per unit area Vx	Average Vx	% reduction in V_x
	2 × 2	265.89	70697.49	17674.4		4418.59		
5	1 × 5	314.68	99023.5	19804.7	18832.29	3960.94	3766.46	16.87
	5 × 1	298.83	89299.37	17859.9		3571.975		
6	1 × 6	380.42	144719.4	24119.9	22301.35	4019.98	3716.89	1.32
	6 × 1	331.45	109859.1	18309.9		3051.64		
	2 × 3	385.95	148957.4	24826.2		4137.70		
	3 × 2	362.9	131696.4	21949.4		3658.23		
8	1 × 8	402.5	162006.3	20250.8	22704.65	2531.35	2838.08	**23.64**
	8 × 1	388.65	151048.8	18881.1		2360.14		
	2 × 4	445.86	198791.1	24848.8		3106.11		
	4 × 2	463.36	214702.5	26837.8		3354.73		
9	1 × 9	466.09	217239.9	24137.8	24616.92	2681.97	2735.21	3.62
	9 × 1	390.21	152263.8	16918.2		1879.80		
	3 × 3	543.28	295153.2	32794.8		3643.87		
10	1 × 10	530.98	281939.8	28193.9	24521.14	2819.39	2452.11	10.35
	10 × 1	421.99	178075.6	17807.6		1780.76		
	2 × 5	513.3	263476.9	26347.7		2634.77		
	5 × 2	507.3	257353.3	25735.3		2573.53		
12	1 × 12	541.87	293623.1	24468.6	28895.23	2039.05	2407.93	1.80
	12 × 1	538.17	289626.9	24135.5		2011.29		
	2 × 6	646.21	417587.4	34798.9		2899.91		
	6 × 2	558.32	311721.2	25976.8		2164.73		
	3 × 4	627.16	393329.7	32777.5		2731.46		
	4 × 3	612.02	374568.5	31214.0		2601.17		

Plot size	Plot Shape	SD	Among plot variance $V_{(X)}$	Comparable variance V	Average V	Variance per unit area Vx	Average Vx	% reduction in V_x
15	1 × 15	639.38	408806.8	27253.8	32698.74	1816.92	2179.92	9.47
	15 × 1	623.65	388939.3	25929.29		1728.62		
	3 × 5	758.55	575398.1	38359.87		2557.32		
	5 × 3	767.32	588780	39252		2616.8		
16	1 × 16	654.71	428645.2	26790.32	30148.42	1674.39	1884.28	**13.56**
	2 × 8	713.19	508640	31790		1986.88		
	4 × 4	714.03	509838.8	31864.93		1991.56		
18	1 × 18	747.22	558337.7	31018.76	33658.4	1723.27	1869.91	0.76
	18 × 1	692.83	480013.4	26667.41		1481.52		
	2 × 9	732.93	537186.4	29843.69		1657.98		
	9 × 2	684.65	468745.6	26041.42		1446.75		
	3 × 6	924.2	854145.6	47452.54		2636.25		
	6 × 3	858.3	736678.9	40926.61		2273.7		
20	1 × 20	814.29	663068.2	33153.41	34856.36	1657.67	1742.82	6.80
	20 × 1	741.89	550400.8	27520.04		1376.00		
	2 × 10	888.8	789965.4	39498.27		1974.91		
	10 × 2	743.2	552346.2	27617.31		1380.87		
	4 × 5	964.29	929855.2	46492.76		2324.64		
24	2 × 12	897.38	805290.9	33553.79	35909.49	1398.07	1496.23	**14.15**
	12 × 2	888.47	789378.9	32890.79		1370.45		
	3 × 8	937.03	878025.2	36584.38		1524.35		
	8 × 3	880.71	775650.1	32318.75		1346.61		
	4 × 6	971.63	944064.9	39336.04		1639.00		
	6 × 4	989.22	978556.2	40773.18		1698.88		

Plot size	Plot Shape	SD	Among plot variance $V_{(X)}$	Comparable variance V	Average V	Variance per unit area Vx	Average Vx	% reduction in V_x
25	5 × 5	967.05	935185.7	37407.43	37407.43	1496.30	1496.30	0.00
27	3 × 9	998.19	996383.3	36903.08	36192.47	1366.78	1340.47	10.41
	9 × 3	978.78	958010.3	35481.86		1314.14		
28	2 × 14	971.3	943423.7	33693.7	33277.91	1203.35	1188.50	11.34
	14 × 2	930.49	865811.6	30921.84		1104.35		
	4 × 7	983.12	966524.9	34518.75		1232.81		
	7 × 4	975.38	951366.1	33977.36		1213.48		
30	2 × 15	1020.5	1041543	34718.09	34452.27	1157.27	1148.41	3.37
	15 × 2	1004.	1009040	33634.68		1121.16		
	3 × 10	1008.1	1016387	33879.55		1129.32		
	10 × 3	1055.2	1113553	37118.42		1237.28		
	5 × 6	1000.1	1000120	33337.33		1111.24		
	6 × 5	1010.3	1020767	34025.56		1134.19		
32	2 × 16	1007.4	1014915	31716.1	29311.9	991.13	915.70	20.24
	16 × 2	969.44	939813.9	29369.18		917.79		
	4 × 8	942.85	888966.1	27780.19		868.13		
	8 × 4	953.01	908228.1	28382.13		886.94		
35	5 × 7	1041.7	1085222	31006.35	30118.77	885.90	860.54	6.05
	7 × 5	1011.5	1023092	29231.19		835.18		
36	2 × 18	1017.2	1034757	28743.25	29352.93	798.42	815.36	5.25
	18 × 2	994.91	989845.9	27495.72		763.77		
	4 × 9	1034.5	1070211	29728.08		825.78		
	9 × 4	1061.5	1126846	31301.28		869.48		
	6 × 6	1030.5	1061868	29496.35		819.34		

Plot size	Plot Shape	SD	Among plot variance $V_{(X)}$	Comparable variance V	Average V	Variance per unit area Vx	Average Vx	% reduction in V_x
38	2 × 19	963.78	928871.9	24444	25283.75	643.26	665.36	18.40
	19 × 2	996.34	992693.4	26123.51		687.46		
40	2 × 20	999.41	998820.3	24970.51	26816.37	624.26	670.41	-0.76
	20 × 2	978.05	956581.8	23914.55		597.86		
	4 × 10	1090.5	1189321	29733.03		743.32		
	10 × 4	1033.8	1068804	26720.11		668.00		
	5 × 8	1065.3	1134864	28371.6		709.29		
	8 × 5	1042.8	1087536	27188.4		679.71		
45	5 × 9	1152.8	1328994	29533.2	28588.39	656.29	635.30	5.24
	9 × 5	1115.3	1243961	27643.58		614.30		
48	4 × 12	1249.1	1560151	32503.14	30110.15	677.15	627.29	1.26
	12 × 4	1153.4	1330424	27717.16		577.44		
50	5 × 10	1218.7	1485205	29704.11	29555.07	594.08	591.10	5.77
	10 × 5	1212.6	1470302	29406.04		588.12		

Table 23 clearly reveals the relationship of plot size with comparable variance (V) and variance per unit area (V_x). Comparable variance increased with increase in plot size up to a certain point and then after it decreases. The average value of comparable variance increases up to a plot size 24 basic units and attains its maximum value of comparable variance and thereafter it shows an irregular trend. When we consider the variance per unit area for estimating optimum plot size, there was a gradual reduction in variance per unit area with increasing plot size. Maximum reduction in variance per unit area was seen for the plot sizes which are the multiples of 8. The plot size having 8, 16 and 24 basic units showed a maximum reduction of

23.64, 13.56 and 14.15 per cent in variance per unit area. For better understanding on estimation of optimum plot size a graph was plotted with plot size on X axis and variance per unit area on Y axis and was given in figure.

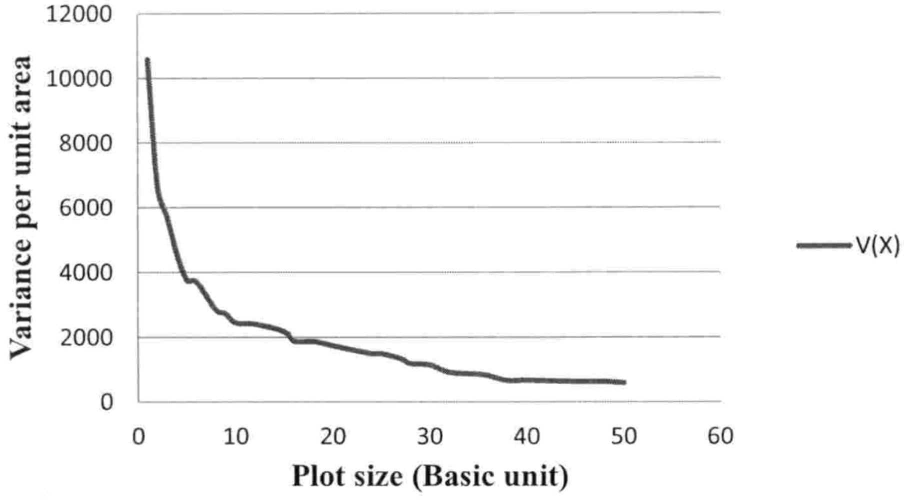

Fig. 11. Graph depicting the reduction in variance per unit area with plot size of paddy

A gradual reduction in the variance per unit area with plot size was depicted in the figure 11. As the plot size increases, variance per unit area also decreases. A steep decline in variance can be seen for plot sizes up to 8 basic units and then the curve attains its maximum curvature. After a certain point the curve becomes almost parallel to the X axis indicating a constant rate of reduction in variance per unit area. Here the optimum plot size was estimated as 24 basic units which accounted for an area of 34.56 m^2 (24 × 1.2 m × 1.2 m).

In order to obtain a measure of relative information, comparable variances for all the plot sizes were compared with the plot size having the smallest comparable variance and it is given in the table 24.

Table 24. Relative information values

Plot size	Average V	Relative Information
1	10588.41	100
2	13256.86	79.87
3	17125.71	61.83
4	18124.29	58.4
5	18832.29	56.22
6	22301.35	47.48
8	22704.65	46.63
9	24616.92	43.01
10	24521.14	43.18
12	28299.9	37.41
15	29207.74	36.25
16	30568.58	34.63
18	32467.98	32.61
20	38521.6	27.49
24	39051.43	27.11
25	37407.43	28.3
27	38494.49	27.5
28	32719.13	32.36
30	35278.84	30.01
32	29853.81	35.46
35	33238.03	31.85
36	33867.18	31.26
38	30663.92	34.53
40	30129.12	35.14
45	31178.01	33.96

Plot size	Average V	Relative Information
48	35731.24	29.63
50	33583.52	31.52

From the table 24 it is evident that as the plot size increases the relative information decreases. A gradual reduction in relative information can be seen up to the plot size of 24 basic units. There after an irregular change in the relative information pattern was seen. After a plot size of 24 basic units, the relative information value changes become irregular and does not followed a specific decreasing pattern.

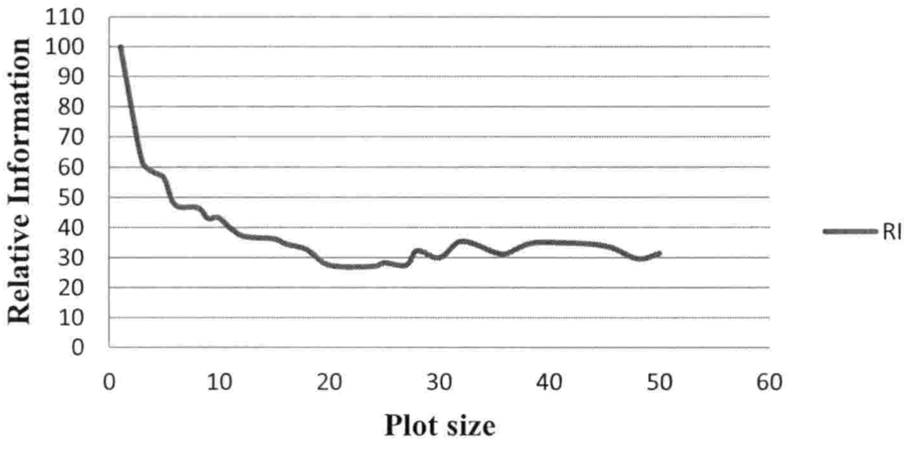

Fig 12. Graph depicting the gradual decrease in relative information with plot size

A rapid initial decrease in relative information can be seen up to a plot size of 24 basic units there after it showed an irregular trend in relative information values.

Table 25. Summary table of plot size shape along with variance per unit area

Plot size	Shape	V_x	Percentage reduction in V_x
18	9 × 2	1446.75	0.76
20	10 × 2	1380.87	6.80
24	8 × 3	1346.615	14.15
25	20 × 1	1496.30	0.00

From the table 24 it can be clearly seen that as the plot size increases, the variance per unit area decreases. A rapid decrease in percentage reduction of variance per unit area can be seen up to a plot size of 24 basic units and there after the decrease in variance was very low and it becomes a constant. So a plot size of 24 units can be considered as the optimum plot size. For the plot size of 24 basic units, a plot shape of 8 × 3 combination was found to be best shape since it showed a minimum variance among other plot shapes for the same plot size. Hence the optimum plot size for paddy under this method was 8 units in breadth and 3 units in length. The area required was 34.56 m^2.

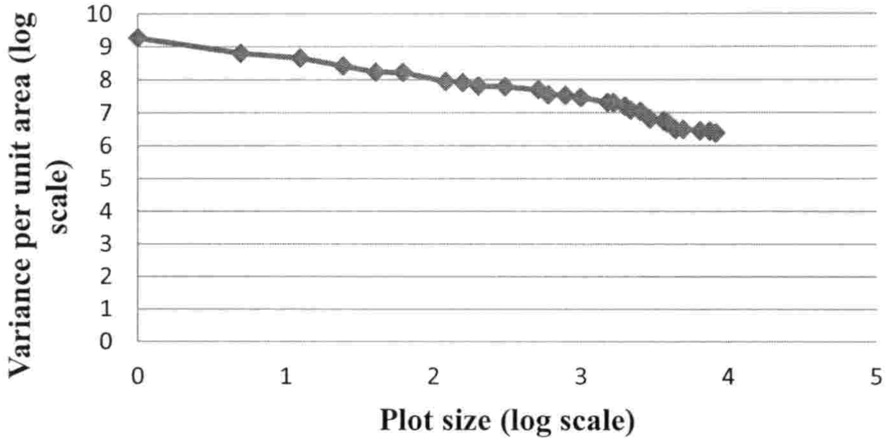

Fig.13. Graph depicting the decrease in variance per unit area (on log scale) with increase in plot size.

The figure 12 shows the changes in variance per unit area on log scale with plot size in basic units on log scale. When they are plotted on a log scale basis, it showed a linear trend.

Estimation of optimum plot size in safflower utilized comparable variance method and the relative information values (Wiedman, 1962). Comparable variance of the basic plots was found to be contributed to largest relative information. As the plot size increased, relative information decreased. The relative information decreased rapidly, which was very high for the basic plots and decreased up to a plot size of about 8 to 10 basic units. After that point the reduction was found to be very less.

4.4.5 Based on shape of the plot

Optimum plot size can be estimated based on shape of the plot by taking the equation

$$V_x = V_0 X_1^{-b_1} X_2^{-b_2}$$

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Where X_1 and X_2 are length and breadth of the plot, b_1 and b_2 are constants and V_0 and V_x are the coefficient of variation for different shapes of the plot. Regression equation was fitted for determining the suitability of the model. The given equation can be re written as

$$\log V_x = \log V_0 - b_1 \log X_1 - b_2 \log X_2$$

Regression analysis under this method is given as following

Table 26. Goodness of fit of regression analysis under model based on shape of the plot

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.90
R Square	0.81
Adjusted R Square	0.80
Standard Error	0.15
Observations	93

Table 27. ANOVA model for regression under model based on shape of the plot

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	8.99	4.49	188.8045	<0.05
Residual	90	2.14	0.0231		
Total	92	11.13			

Table 28. Estimated coefficients along with standard error under model based on shape of the plot

	Coefficients	Standard Error	t Stat	P-value
Intercept	3.35	0.0566	59.27	<0.05
b_1	-0.411	0.0219	-18.77	<0.05
b_2	-0.311	0.0219	-14.24	<0.05

The coefficients estimated by least square method are

$V_0 = 28.50$

$b_1 = 0.411$ and

$b_2 = 0.311$

The regression estimates showed that the model was appropriate in estimating the optimum plot size of paddy with a R^2 value 0.81 which implies the best fit of the model. Coefficient of variation was estimated for different length-breadth plot combinations.

Table 29. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) of the plot.

		X_2																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
X_1	1	28.63	23.07	20.33	16.18	14.76	13.70	12.85	12.17	11.59	11.09	10.67	10.30	9.96	9.66	9.39	9.15	8.92	8.71
	2	21.52	17.34	15.29	12.17	11.10	10.30	9.66	9.15	8.71	8.34	8.02	7.74	7.49	4.26	7.06	6.88	6.71	6.55
	3	18.22	14.68	12.94	10.30	9.39	8.71	18.18	7.74	7.38	7.06	6.79	6.55	6.34	6.15	5.98	5.82	5.68	5.54
	4	16.18	13.04	11.49	19.15	8.34	7.74	7.27	6.88	6.55	6.27	6.03	5.82	5.63	5.42	5.31	5.17	5.04	4.93
	5	14.76	11.90	10.48	8.34	7.61	7.06	6.63	6.27	5.98	5.72	5.50	5.31	5.13	4.98	4.84	4.72	4.60	4.49
	6	13.70	11.04	9.73	7.74	7.06	6.55	6.15	5.82	5.55	5.31	5.10	4.93	4.77	4.62	4.49	4.38	4.27	4.17
	7	12.85	10.36	9.13	7.27	6.63	6.15	5.77	5.46	5.20	4.98	4.79	4.62	4.47	4.34	4.22	4.11	4.00	3.91
	8	12.17	9.80	8.64	6.88	6.27	5.82	5.46	5.17	4.93	4.72	4.53	4.38	4.23	4.11	3.99	3.89	3.79	3.70
	9	11.59	9.34	8.23	6.55	5.98	5.55	5.20	4.93	4.69	4.49	4.32	4.17	4.03	3.91	3.80	3.70	3.61	3.53
	10	11.10	8.94	7.06	6.27	5.72	5.31	4.98	4.72	4.49	4.30	4.14	3.99	3.86	3.75	3.64	3.55	3.46	3.38
	11	10.67	8.60	6.79	6.03	5.50	5.11	4.79	4.54	4.32	4.14	3.98	3.84	3.71	3.60	3.50	3.41	3.33	3.25
	12	10.30	8.30	6.55	5.82	5.31	4.93	4.62	4.38	4.17	3.99	3.84	3.70	3.58	3.47	3.38	3.29	3.21	3.13
	13	9.96	8.03	6.34	5.63	5.14	4.77	4.47	4.23	4.03	3.86	3.71	3.58	3.47	3.36	3.27	3.18	3.10	3.03
	14	9.66	7.79	6.15	5.46	4.98	4.62	4.34	4.11	3.91	3.75	3.60	3.47	3.36	3.26	3.17	3.09	3.01	2.94
	15	9.39	7.57	5.98	5.31	4.84	4.49	4.22	3.99	3.80	3.64	3.50	3.38	3.23	3.17	3.08	3.00	2.93	2.86
	16	9.15	7.37	5.82	5.17	4.72	4.38	4.11	3.89	3.70	3.55	3.41	3.29	3.18	3.09	3.00	2.92	2.85	2.78
	17	8.92	7.19	5.68	5.04	4.60	4.27	4.01	3.79	3.61	3.46	3.33	3.21	3.10	3.01	2.93	2.85	2.78	2.71
	18	8.71	7.02	5.55	14.93	4.49	4.17	3.91	3.70	3.53	3.38	3.25	3.13	3.03	2.94	2.86	2.78	2.71	2.65
	19	8.52	6.87	5.42	4.82	4.39	4.08	3.83	3.62	3.45	3.30	3.18	3.06	2.97	2.88	2.79	2.72	2.66	2.59
	20	8.34	6.72	5.31	4.72	4.30	3.99	3.75	3.55	3.38	3.23	3.11	3.00	2.90	2.82	2.74	2.66	2.60	2.54

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It is difficult to make a clear conclusion on optimum plot size from the table 29. Hence optimum plot size was found out by plotting a graph with CV for different values of X_1 and X_2.

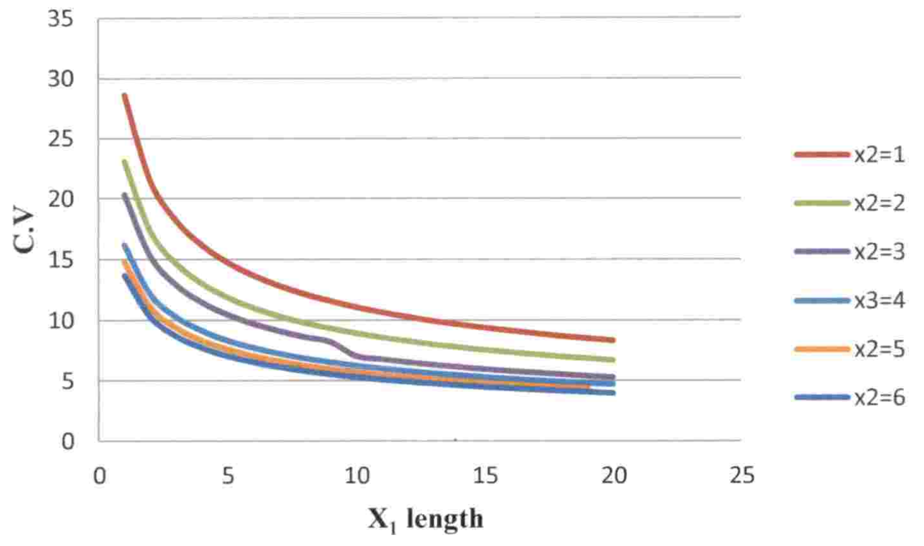

Fig 14. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot.

(Here $X_1 = 1,2,\ldots,20$ and $X_2 = 1,2,\ldots,6$)

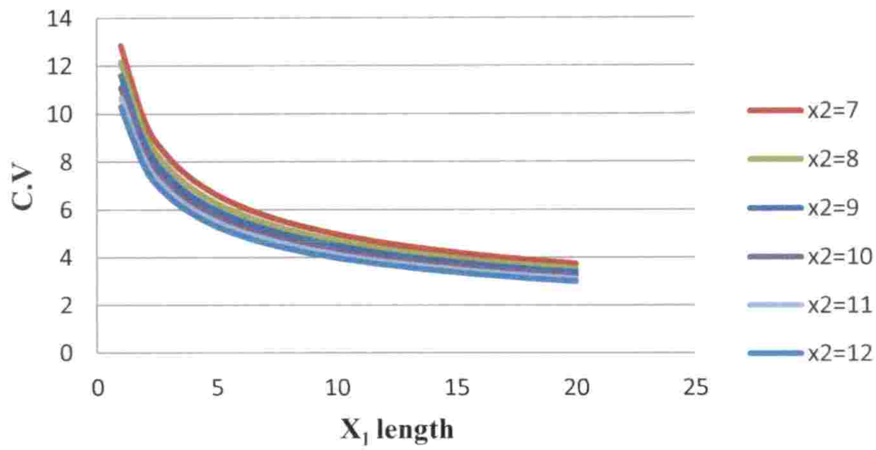

Fig 15. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot (continued).

(Here $X_1 = 1,2,\ldots,20$ and $X_2 = 7,8,\ldots,12$)

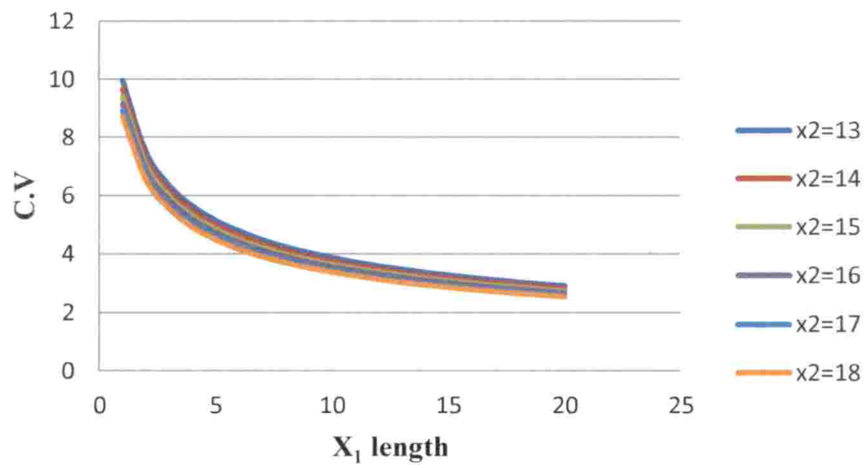

Fig 16. Coefficient of variation corresponding to different values of X_1 (length) and X_2 (breadth) under model based on shape of the plot (continued).

(Here $X_1 = 1,2,\ldots,20$ and $X_2 = 13,14,\ldots,18$)

The figures 14, 15 and 16 show the C.V values for different values of X_1 and X_2. The figure 14 shows the reduction in C.V when $X_1 = 1,2,\ldots,20$ and $X_2=1,2,\ldots,6$. Here the reduction in coefficient of variation with X_1 are very steep for the values of $X_2 = 1,2,\ldots,6$. The figure 14 shows the gradual reduction in CV for the different values of X_1 and X_2. A similar trend can also be seen up to $X_2 = 8$. Thereafter for the remaining values of X_2 there was not much steep in the curvature and the curves become overlapped each other. The overlapping of curves shows a constant CV for the values of X_1 and X_2. The values of X_1 and X_2 after which the CV becomes a constant can be taken as the optimum plot size. Here, when $X_1 = 3$ and $X_2 = 8$ was considered as the optimum plot size under the model based on shape of the plot method. The estimated optimum plot size was 24 basic units, which was accounted for an area of 34.56 square meters. This method was also inconformity with the maximum curvature method in estimating optimum plot size of paddy (Uma).

4.4.6 Cost ratio method

Optimum plot size under cost ratio method can be estimated with the given formula

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

The plot sizes were determined for different range of values of costs K_1 and K_2, since the costs were not known exactly. Here the plot size X depended upon the fixed cost K_1 and variable cost K_2. The optimum plot size values were listed for a range of values of K_1 and K_2 are given in the following table 30.

Table 30. Optimum plot size in basic units under cost ratio method for different values of K_1 and K_2

		K_2									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
K_1	**1**	0.59	0.30	0.20	0.15	0.12	0.10	0.08	0.07	0.07	0.06
	2	1.19	0.59	0.40	0.30	0.24	0.20	0.17	0.15	0.29	0.12
	3	1.78	0.89	0.59	0.45	0.36	0.30	0.25	0.22	0.20	0.18
	4	2.38	1.19	0.79	0.59	0.48	0.40	0.34	0.30	0.26	0.24
	5	2.97	1.49	0.99	0.74	0.59	0.50	0.42	0.37	0.33	0.30
	6	3.57	1.78	1.19	0.89	0.71	0.59	0.51	0.45	0.40	0.36
	7	4.16	2.08	1.39	1.04	0.83	0.69	0.59	0.52	0.46	0.42
	8	4.76	2.38	1.59	1.19	0.95	0.79	0.68	0.59	0.53	0.48
	9	5.35	2.68	1.78	1.34	1.07	0.89	0.76	0.67	0.59	0.54
	10	5.95	2.97	1.98	1.49	1..19	0.99	0.85	0.74	0.66	0.59

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From the table 30 it was concluded that, plot size was found to be maximum when the value of fixed cost $K_1=10$ and variable cost $K_2=1$. The optimum plot size obtained under this method was 5.95 basic units. This method was not considered as a suitable method for estimating optimum plot size, since a correct estimate on fixed cost and variable costs were not worked out properly. Moreover the estimation of cost ratios for each basic unit was not done properly during the course of the experiment.

Optimum plot size was estimated for sunflower (*Helianthus annuus)* in soil of Hisar using cost ratio method. Optimum plot size was worked out for different values of cost under the assumption of linear cost structure. The study found that, the optimum plot size increased with increase in the cost ratio for given plot arrangement (Lohmor *et al.*, 2017).

4.4.7 Covariate method

Correlation analysis was done on both biometric characters and yield characters. The character which is having high correlation with yield was estimated and used as the covariate. All the observed growth parameters of the variety Uma didn't show a significant correlation with grain yield but harvest index showed a high significant correlation (0.744) with yield. Then in order to estimate optimum plot size under covariate method harvest index was taken as covariate and the yield was replaced with the covariate for finding optimum plot size. Coefficient of variation is calculated separately for each plot size under covariate method. Coefficient of variation decreases with increase in plot size. The plot size which is in conformity with minimum CV was considered as the optimum plot size. The coefficient of variation obtained for different plot sizes using harvest index as the covariate is depicted in the following table 31.

Table 31. Coefficient of variation for different plot sizes using harvest index as the covariate.

Plot size (basic units)	Plot size (m^2)	Shape	Mean	S.D	C.V	Average C.V
1	1.44	1×1	24.32	6.93	28.51	28.51
2	2.88	1×2	48.64	11.50	23.64	22.96
		2×1	48.64	10.83	22.27	
3	4.32	1×3	73.05	15.74	21.55	21.05
		3×1	72.55	14.91	20.55	
4	5.76	1×4	97.28	19.14	19.68	19.32
		4×1	97.28	19.02	19.55	
		2×2	97.28	18.22	18.73	
5	7.2	1×5	121.60	22.88	18.82	18.32
		5×1	121.60	21.67	17.82	
6	8.64	1×6	146.11	27.34	18.71	17.05
		6×1	145.09	21.80	15.03	
		2×3	146.11	24.74	16.93	
		3×2	145.09	25.41	17.51	
8	11.52	1×8	197.44	32.49	16.46	15.36
		8×1	189.79	23.93	12.61	
		2×4	194.55	30.28	15.56	
		4×2	194.55	32.67	16.79	

Plot size (basic units)	Plot size (m^2)	Shape	Mean	S.D	C.V	Average C.V
9	12.96	1×9	219.16	36.07	16.46	15.36
		9×1	217.64	29.25	13.44	
		3×3	217.85	35.25	16.18	
10	14.4	1×10	243.19	39.89	16.40	14.83
		10×1	243.19	30.14	12.39	
		2×5	243.19	36.78	15.12	
		5×2	243.19	37.45	15.40	
12	17.28	1×12	301.51	48.68	16.15	13.81
		12×1	288.26	24.41	8.47	
		2×6	295.79	43.75	14.79	
		6×2	290.18	36.60	12.61	
		3×4	290.18	43.77	15.08	
		4×3	292.56	46.15	15.77	
15	21.6	1×15	372.75	56.93	15.27	13.25
		15×1	355.12	28.82	8.11	
		3×5	362.73	55.05	15.18	
		5×3	365.27	52.73	14.44	
16	23.04	1×16	394.88	50.03	12.67	13.06
		2×8	394.88	52.67	13.34	
		4×4	389.11	51.27	13.18	

Plot size (basic units)	Plot size (m^{2})	Shape	Mean	S.D	C.V	Average C.V
18	25.92	1×18	438.33	66.70	15.22	12.54
		2×9	435.37	57.88	13.29	
		9×2	435.27	51.34	11.80	
		3×6	435.69	64.27	14.75	
		6×3	435.69	51.53	11.83	
20	28.8	1×20	486.39	72.72	14.95	12.27
		20×1	486.39	44.37	9.12	
		10×2	486.39	51.78	10.65	
		4×5	485.95	69.70	14.34	
24	34.56	2×12	603.01	79.32	13.15	12.26
		3×8	587.95	78.21	13.30	
		8×3	575.60	58.96	10.24	
		4×6	582.68	80.15	13.76	
		6×4	580.36	62.95	10.85	
25	36	5×5	607.98	73.33	12.06	12.06
27	38.88	3×9	653.54	86.42	13.22	11.97
		9×3	653.54	70.02	10.71	
28	40.32	2×14	701.69	92.24	13.15	11.99
		4×7	701.69	94.72	13.50	
		7×4	667.50	62.30	9.33	

Plot size (basic units)	Plot size (m^2)	Shape	Mean	S.D	C.V	Average C.V
30	43.2	2×15	745.50	98.83	13.26	11.90
		3×10	725.45	97.32	13.41	
		10×3	730.54	67.53	9.24	
		5×6	730.54	96.12	13.16	
		6×5	725.45	75.70	10.44	
32	46.08	2×16	789.75	101.70	12.88	11.82
		4×8	789.75	100.22	12.69	
		8×4	759.15	75.20	9.91	
35	50.4	5×7	877.11	111.97	12.77	11.63
		7×5	833.37	87.44	10.49	
36	51.84	2×18	876.65	101.40	11.57	11.36
		18×2	870.55	95.70	10.99	
		4×9	876.65	114.29	13.04	
		9×4	870.55	87.49	10.05	
		6×6	871.39	97.23	11.16	
38	54.72	2×19	923.12	109.23	11.83	11.09
		19×2	922.02	95.36	10.34	
40	57.6	2×20	972.77	121.15	12.45	10.30
		20×2	972.77	70.24	7.22	
		4×10	972.77	127.04	13.06	

Plot size (basic units)	Plot size (m^2)	Shape	Mean	S.D	C.V	Average C.V
		10×4	972.77	80.41	8.27	
		5×8	987.19	116.56	11.81	
		8×5	948.93	85.06	8.96	
45	64.8	5×9	1095.82	105.19	9.60	10.10
		9×5	1088.18	115.30	10.60	
48	69.12	4×12	1206.02	124.75	10.34	9.91
		12×4	1211.06	114.87	9.49	
50	72	5×10	1215.97	141.47	11.63	9.91
		10×5	1215.97	99.56	8.19	

From table 31 it was evident that using harvest index as covariate in estimating plot size also follows the same pattern as that of with main variate grain yield. Increase in plot size resulted in the reduction of coefficient of variation and at a certain point the reduction in CV became a constant. The pattern of reduction in CV is plotted against plot size and was given in the following graph.

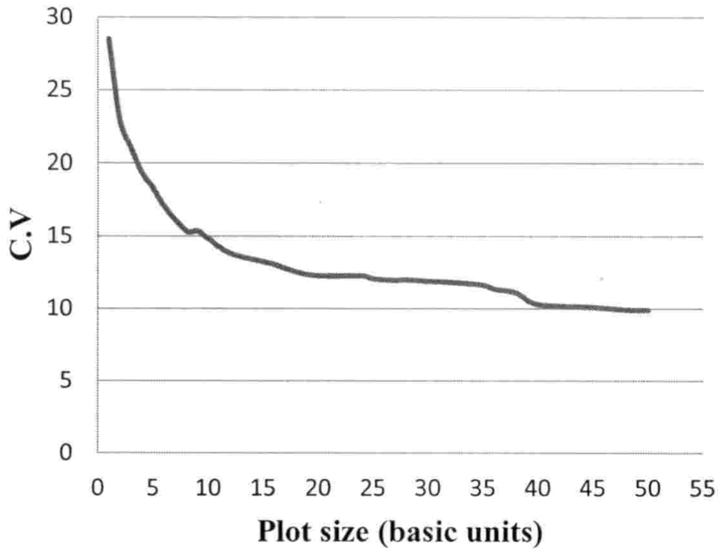

Fig 17. Graph showing changes in C. V with plot size under covariate method

The figure 17 shows the reduction in CV with plot size under covariate method. There is drastic reduction in CV with plot size when plot size is increased from 1 basic unit onwards. A gradual reduction in coefficient of variation was observed from 1 to 24 basic units and after that the reduction in CV becomes a constant indicated by the parallel nature of the curve with the X axis. Hence the curvature measurements indicated an optimum plot size of 24 basic units under covariate method of paddy.

The optimum plot size of branching and non-branching variety of cassava was estimated using covariate method (Rakhi, 2017) at college of agriculture, Vellayani. The estimated optimum plot size for branching variety of cassava (Vellayani Hraswa) was 19.44 m^2 and 10.125 m^2 for non-branching variety (Sree Pavithra) of cassava.

A comparison can be made between plot size under maximum curvature method and covariate method.

Table 32. Coefficient of variation values under maximum curvature method and covariate method

Plot size (basic units)	Plot size (m^2)	CV (Maximum curvature method)	CV (Covariate method)
1	1.44	26.33	28.51
2	2.88	20.83	22.96
3	4.32	19.25	21.05
4	5.76	17.23	19.32
5	7.2	15.71	18.32
6	8.64	15.53	17.05
8	11.52	13.58	15.36
9	12.96	13.21	15.36
10	14.4	12.63	14.83
12	17.28	12.35	13.81
16	23.04	10.98	13.06
18	25.92	10.95	12.54
20	28.8	10.58	12.27
24	**34.56**	**9.72**	**12.26**
25	36	9.6	12.06
27	38.88	9.32	11.97
28	40.32	8.69	11.99

Plot size (basic units)	Plot size (m^2)	C.V(Maximum curvature method)	C.V (Covariate method)
30	43.2	8.63	11.90
32	46.08	7.72	11.82
35	50.4	7.39	11.63
36	51.84	7.28	11.361
38	54.72	6.78	11.09
40	57.6	6.61	10.29
45	64.8	6.42	10.10
48	69.12	6.22	9.91
50	72	6.22	9.91

The optimum plot size estimated under covariate method and maximum curvature method was 24 basic units which accounted for an area of 34.56 m^2. Hence the covariate method was in conformity with the maximum curvature method. Both the methods showed a constant trend in coefficient of variation values after 24 basic units. Hence covariate method can be adopted for estimating optimum plot size of crops.

4.4.8 Hatheway's method

The difference between treatments means are estimated by

$$d^2 = \frac{2(t_1 + t_2)^2 (CV)^2}{r\, x^b}$$

Here the values of t_1 and t_2 depend on the probability levels and degrees of freedom of the experimental error which are chosen by the researcher for a particular experiment. Normally a significant level of 5 per cent is assumed for estimating experimental error with the hope of getting a significant differences in eight of ten experiments (p = 0.8) and tries degrees of freedom which are more than 14. Under these assumptions the $(t_1 + t_2)^2$ value is close to 9, hence the equation can be reformed as

$$d^2 = \frac{18 \times CV^2}{r \times x^b}$$ (Duran *et al.*, 2012)

For the estimation of optimum plot size under Hatheway's method, d_i values are estimated for different values of r (r = 2,3,4,5,6) and the x, b and CV are previously determined.

Here x = 24 basic units, b = 0.373 and the d was estimated for a range of values of CV which were determined previously for different plot size combinations. Regression analysis was done to know the goodness of fit of the model and the coefficients were estimated by least square method. The estimated coefficients were then used for estimating the optimum plot size in basic units with the given equation

$$d_i = AX_i^{-B}$$

Where the constants A and B are estimated by the method of least square for each set of replications and are given in the following tables. Goodness of fit of the model and coefficient estimates are presented in the following tables.

Table 33. Goodness of fit of regression analysis for Hatheway's method

Regression statistics	r = 2	r =3	r =4	r =5	r =6
Multiple R	0.984	0.984	0.984	0.984	0.984
R Square	0.968	0.968	0.968	0.968	0.968
Adjusted R Square	0.967	0.967	0.967	0.967	0.967
Standard Error	0.073	0.073	0.073	0.073	0.073
Observations	26	26	26	26	26

Table 34. Estimated coefficients along with standard error for Hatheway's method

	Coefficients				
	r = 2	r = 3	r = 4	r = 5	r = 6
Intercept	3.876 (96.97) [0.040]	3.673 (88.29) [0.040]	3.529 (88.29) [0.040]	3.418 (88.29) [0.040]	3.327 (88.29) [0.040]
B	-0.373 (-27.02) [0.014]	-0.373 (-27.02) [0.014]	-0.373 (-27.02) [0.014]	-0.373 (-27.02) [0.014]	-0.373 (-27.02) [0.014]

( ) - t stat and [ ] – standard error

The models for different number of replications can be represented as,

Table 35. Estimated models under Hatheway's method

Replication (r)	Model
2	$d_i = 48.23\ X^{-0.373}$
3	$d_i = 39.37\ X^{-0.373}$
4	$d_i = 34.09\ X^{-0.373}$

Replication (r)	Model
5	$d_i = 30.51\ X^{-0.373}$
6	$d_i = 27.85\ X^{-0.373}$

Optimum plot sizes were estimated for a range of values of d_i. For the present work the range of values of d_i are fixed between 5,10,15,20,25 and 30. The plot sizes which are in agreement with the already estimated plot size were taken as the optimum plot size. The plot size values for the models with different values of *r* and *d* are given in the following table 36.

Table 36. Estimated values of optimum plot size for d_i = 5,10,15,20,25,30 and r = 2,3,4,5,6.

	Optimum plot size (x)				
d_i	r =2	r =3	r =4	r =5	r =6
5	435.5	252.7	171.8	127.6	99.9
10	67.9	39.4	**26.0**	19.9	15.6
15	22.9	13.3	9.0	6.7	5.3
20	10.6	6.1	4.2	3.1	2.4
25	5.8	3.4	2.3	1.7	1.3
30	3.6	2.1	1.4	1.0	0.8

Estimation of optimum plot size under Hatheway's method is based on arbitrarily choosing the number of replications and difference between treatment means. Optimum plot sizes were estimated for different number of replications and different levels of percentage difference between treatment means. Optimum plot size of 26 basic units was obtained for 10 per cent difference between the treatment means and 4 replications. An optimum plot size of 23 basic units was obtained for a mean difference of 15 per cent and with two replications, but which cannot be recommended. Hence the optimum plot size of 26 basic units can be considered as optimum for field experiments on Uma variety of paddy which accounted for an area of 37.44 m^2 (26 × 1.2 × 1.2). The estimated plot size is also in agreement with the plot size estimated by maximum curvature method.

The plot size and number of replications were estimated for watermelon over a 3 year period (Boyhan, 2013). Four different methods such as coefficient of variation, Hatheway's method with a 20 per cent threshold, Bartlett's homogeneity of variance test and computed least significant differences were used. Results with Hatheway's method were similar to plots of basic units against coefficient of variation. For fruit size, firmness, and soluble solids, the basic unit plot sizes ranged from 5 to 7. Plot size estimates were larger with 6.69 m^2 compared with 2.23 m^2 for fruit characteristics.

4.5 YIELD ESTIMATION OF UMA VARIETY OF PADDY

A yield estimation can be made for the given experimental conditions using the harvest data of Uma variety of paddy. The grain yield of each basic was used for estimating the per hectare yield of the variety Uma. The projected per hectare yield also helps us to obtain a conclusion about the optimum plot size. The maximum projected yield can be found out for 1 hectare area of the crop which will help to make a conclusion on optimum plot size. The projected yield for Uma under the given experimental conditions for the given experimental area is depicted in the following table 37.

Table 37. Yield estimation of Uma

Plot size (basic units)	Plot size (m^2)	Shape	Mean yield per plot (g)	Estimated yield per hectare (kg)
1	1.44	1×1	390.72	2713.333
2	2.88	1×2	781.45	2713.368
		2×1	781.45	
3	4.32	1×3	1179.79	2730.995
		3×1	1171.88	
4	5.76	1×4	1562.9	2713.368
		4×1	1562.9	
		2×2	1562.9	
5	7.2	1×5	1953.62	2713.361
		5×1	1953.63	
6	8.64	1×6	2359.58	2730.995
		6×1	2343.75	
		2×3	2359.58	
		3×2	2343.75	
8	11.52	1×8	3178.38	2759.01
		8×1	3093.5	
		2×4	3125.8	
		4×2	3125.8	
9	12.96	1×9	3539.38	2731.003
		9×1	3515.62	
		3×3	3536.11	
10	14.4	1×10	3907.25	2713.368
		10×1	3907.25	
		2×5	3907.25	

Plot size (basic units)	Plot size (m^2)	Shape	Mean yield per plot (g)	Estimated yield per hectare (kg)
		5×2	3907.25	
12	17.28	1×12	4874	2820.602
		12×1	4777	
		2×6	4796.67	
		6×2	4687.5	
		3×4	4687.5	
		4×3	4720.83	
15	21.6	1×15	5969	2763.426
		15×1	5810.75	
		3×5	5859.38	
		5×3	5898.96	
16	23.04	1×16	6356.75	2759.006
		2×8	6356.75	
		4×4	6251.6	
18	25.92	1×18	7078.75	2730.999
		18×1	7031.25	
		2×9	7053	
		9×2	7031.25	
		3×6	7072.22	
		6×3	7072.22	
20	28.8	1×20	7814.5	2713.368
		20×1	7814.5	
		2×10	7983.5	
		10×2	7814.5	
		4×5	7812.75	

Plot size (basic units)	Plot size (m^2)	Shape	Mean yield per plot (g)	Estimated yield per hectare (kg)
24	34.56	2×12	9748	2820.602
		12×2	9654	
		3×8	9509.58	
		8×3	9429.58	
		4×6	9545	
		6×4	9375	
25	36	5×5	10068.12	2796.7
27	38.88	3×9	10608.33	2728.48
		9×3	10608.33	
28	40.32	2×14	11236.5	2786.83
		14×2	10982.5	
		4×7	11236.5	
		7×4	10972.5	
30	43.2	2×15	11938	2763.426
		15×2	11691.5	
		3×10	11718.75	
		10×3	11797.92	
		5×6	11797.92	
		6×5	11718.75	
32	46.08	2×16	12713.5	2759.006
		16×2	12374	
		4×8	12713.5	
		8×4	12374	
35	50.4	5×7	14045.62	2786.829
		7×5	13728.12	

Plot size (basic units)	Plot size (m^2)	Shape	Mean yield per plot (g)	Estimated yield per hectare (kg)
36	51.84	2×18	14157.5	
		18×2	14062.5	
		4×9	14157.5	
		9×4	14062.5	
		6×6	14144.44	
38	54.72	2×19	14902.5	2723.41
		19×2	14842	
40	57.6	2×20	15629	2713.368
		20×2	15629	
		4×10	15629	
		10×4	15629	
		8×5	15467.5	
		5×8	15891.88	
45	64.8	5×9	17696.88	2731
		9×5	17578.12	
48	69.12	4×12	19496	2820.602
		12×4	19108	
50	72	5×10	19536.25	2713.368
		10×5	19536.25	

From the table 37 it can be clearly seen that maximum estimated yield was obtained for a plot size of 24 basic units which accounted for an area of 34.56 square meters. The maximum estimated per hectare yield of Uma under the given experimental conditions was 2820.602 kg (2.82 tons), whereas the expected yield of Uma is 6-7 tons per hectare. The maximum estimated per hectare yield was observed at a plot size 24 basic units (optimum plot size).

Summary

5. SUMMARY

Optimum plot size and shape of crops are vital for the efficient planning of field experiments. Moreover the size and shape of the experimental units will affect the accuracy of the experimental results. The use of improper field plot techniques may inflate experimental error and lead to spurious inferences. Hence, to improve the quality as well as integrity of research results, there is a need to carry out research on field plot techniques. In agricultural experiments comparative studies on plot size have been carried out and found that an increase in plot size increases the precision of single plot yield. However, an increase in the plot size results in an enlarged block and variability within the block may be increased. In order to strike a balance between these two opposing tendencies we have to select a plot with optimum size.

In this context the present research work entitled "Comparison of methods for optimum plot size and shape for field experiments on paddy (*Oryza sativa*)" was formulated with the following objectives.

- Estimation and comparison of methods for optimum plot size and shape for field experiments on high yielding variety of paddy.

The study was based on primary data. Uma (MO-16) is a medium duration variety of rice having duration of 115-120 days in mundakan and 120-135 days in virippu season. The crop is a dwarf, medium tillering and non-lodging variety of rice. A uniformity trial experiment was conducted at Integrated Farming System Research Station (IFSRS), Karamana in an area about 800 m^2. Uma variety of paddy was used for cultivation and recommended package of practices were followed for cultivation. The crop was raised for virippu season, 2018. The crop was transplanted at a spacing of 20 cm × 15 cm in the month of July, 2018. The field was divided in to 1.2 m × 1.2 m (1.44 m^2) plots, after leaving a border of one meter from all the sides of the plot to eliminate the border effects, thus give rise to 400 basic units. The observations were recorded separately from sampled plants of each basic unit at monthly intervals. The crop was harvested separately from each basic unit.

Details of data on growth parameters and yield parameters were taken separately for the study from sampled plants of each basic unit and average was taken. Initial data analysis includes box plot and descriptive statistics were carried out to study about the distribution of the data and to detect outliers. The average height of Uma was increased from 40.55 cm to 58.53 cm at 2 MAP (months after planting) to 91.35 cm at 3 MAP and to 121.37 cm at the time of harvest with a minimum height of 52.4 cm at 1 MAP and to 132 cm at 4 MAP. The average tiller number increased from 6 to 8 to 10 from 2 MAP, 3 MAP to 4 MAP. The minimum number of tillers recorded at 2 MAP was 4, which increased to 6 at 4 MAP. The maximum tiller production of 14 numbers per hill was observed at 4 MAP.

The estimated average of grain yield was 400g with a minimum of 200 g and a maximum of 650 g respectively. The range of the data set of grain yield was 450g. The average straw yield was 0.501 kg. The first quartile (Q_1) was observed at 0.410 kg and third quartile (Q_3) was at 0.572 kg. The estimated harvest index was found to be distributed from a minimum of 0.217 and to a maximum of 0.676. The first and third quartiles were estimated as 0.367 and 0.503 respectively.

Correlation can be found out among biometric characters and yield characters of Uma variety of paddy to assess the influencing factors on yield. The plant height at 4 MAP showed a significant negative correlation of 0.102 with grain yield. The correlation between plant heights was found to be non-significant and negative. There was no significant correlation between grain yield and number of tillers at first month after planting but a 5 per cent significant correlation was obtained at 3 MAP and 4 MAP. Even though the number of tillers increased from 2 MAP to 4 MAP planting, it showed a negative correlation between the number of tillers at 4 MAP and 3 MAP. Harvest index had a very high significant correlation of 0.744 with grain yield and a negative significant correlation of 0.405 with total yield. There was significant correlation between straw yield and total yield (0.952). But the correlation between straw yield and grain yield was insignificant. Based on correlation, harvest index and total yield can be used as a covariate for getting optimum plot size.

Soil heterogeneity of the given experimental site was studied with the help of fertility contour map, serial correlation and mean square between strips. Fertility gradient was calculated separately for each basic unit and it varied from -48.82 to 66.35 per cent. Highly fertile areas and very low fertile areas are very less which was accounted for 7 per cent and 8.25 per cent respectively. Almost 50 per cent of area of the experimental field was under average fertility gradient (-20 to 20). It was observed that 26 per cent area had a fertility gradient between 0 to 20 per cent. Soil fertility status was determined for 3×3 moving averages and 5×5 moving averages also. The fertility status varied from 236.11 to 522.22 in case of 3×3 moving average and 230 to 536 in case of 5×5 moving average. The percentage of area under low fertility and high fertility has decreased from 7 to 3.13 and 8.25 to 7.98 as compared to fertility map based on yield of original basic units. The average fertile area was increased from 49.25 to 61.46 per cent and fertility contour map based on 3×3 moving average accounted for variation in the original values and it provides a clear understanding on fertility variation.

Horizontal serial correlation (0.327) coefficient was higher than the vertical serial correlation coefficient (0.189) which indicates that the fertility gradient was more pronounced along horizontal direction than vertically. Mean square between strips was calculated for both vertical and horizontal arrangement and the estimated mean square for vertical strip (187215) was less than that of horizontal strip (210250) indicates that soil fertility was more pronounced in horizontal direction rather than vertical direction.

Maximum curvature method, Fair field Smith's variance law method, modified maximum curvature method, comparable variance method, based on shape of the plot method, cost ratio method, covariate method and Hatheway's method were used for estimating optimum plot size. In maximum curvature method, as the plot size increases the value of coefficient of variation (CV) decreases and gradually it approaches a constant value. The plot size with 8 basic units showed maximum percentage reduction in CV (12.56%). A similar steep reduction in coefficient of variation was also visible for plot sizes which are the multiples of 8 basic units such as 16 basic units (7.34%), 24 basic units (8.13%) and for 32 basic units (10.54). The per cent reduction in coefficient of variation gradually reduces after a plot size of 24 basic units.

There was a considerable change in the coefficient of variation with respect to shape of plots. The plot shape was renamed as horizontal strip, vertical strip, square plots and rectangular plots. Horizontal strips showed a higher value of CV than vertical strip plots for the same plot size. Horizontal and vertical strip shaped plots showed a lesser value for CV as compared to square shaped plots. For the plot sizes 4, 9 and 16 basic units, square shaped plots showed CV values such as 17.01, 15.36 and 11.42 whereas CV values were less than these for vertical strip and horizontal strip plots. Vertical and horizontal plots showed lesser value for CV as compared to rectangular shaped plots, but vertical and horizontal plots being same as that of row planting or column planting which is not recommended widely for field experiments. In case of rectangular shaped plots, the plot shape having high breadth than length showed lesser value CV as compared to the other.

From these different combinations of 24 basic unit plot size, the plot shape 8 $\times$ 3 with minimum CV (9.34) was considered as optimum plot size with rectangular shape. So the shape of optimum plot size obtained by maximum curvature method was 8 unit in breadth and 3 units in length. The required area was estimated as 34.56 m^2 (24×1.2 m $\times 1.2$ m).

The optimum plot size obtained under Fairfield Smith's variance law and modified maximum curvature method was 6 basic units. So the area obtained under both method was 8.64 m^2. The plot size of 6 basic units didn't have a minimum value for coefficient of variation when compared the result with maximum curvature graph. Moreover, the area obtained under this method was very less and hence it was not recommend as optimum plot size for field experiments on paddy.

As the plot size increases, variance per unit area decreased under comparable variance method. A steep decline in variance was seen for plot sizes up to 24 basic units and then the curve attains its maximum curvature. After 24 basic units the curve becomes almost parallel to the X axis indicating a constant rate of reduction in variance per unit area. Here, the optimum plot size was estimated as 24 basic units which accounted for an area of 34.56 m^2 (24×1.2 m $\times 1.2$ m).

The values of X_1 (length) and X_2 (breadth) after which the CV becomes a constant was taken as the optimum plot size under shape of the plot method. Here, when $X_1 = 3$ and $X_2 = 8$ was considered as the optimum plot size. The estimated optimum plot size was 24 basic units, which was accounted for an area of 34.56 square meters. This result was also in conformity with the result of maximum curvature method in estimating optimum plot size of paddy (Uma).

Cost ratio method estimated an optimum plot size of 5.95 units when the value of fixed cost $K_1 = 10$ and variable cost $K_2 = 1$. This method was not considered as a suitable method for estimating optimum plot size, since a correct estimate on fixed cost and variable costs were not worked out properly. Moreover the estimation of cost ratios for each basic unit was not done properly during the course of the experiment.

Optimum plot size was estimated using covariate method by substituting harvest index as covariate. In this method the increase in plot size resulted in the reduction of coefficient of variation and at a certain point the reduction in CV became

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a constant. A gradual reduction in coefficient of variation was observed from 1 to 24 basic units and after that the reduction in CV becomes a constant indicated that the curve becomes parallel to the X axis. Hence, the curvature measurement indicated an optimum plot size of 24 basic units under this method for paddy.

Estimation of optimum plot size under Hatheway's method is usually based on arbitrarily choosing the number of replications and difference between treatment means. The difference between treatment means (d_i) values were estimated for different values of r (r = 2, 3, 4, 5, 6) and the values of x, b and CV are chosen from this experiment. Optimum plot size of 26 basic units (37.44 m^2) was obtained for 10 per cent difference between the treatment means and four replications under this method.

Yield estimation was made for the given experimental conditions using the harvest data of Uma variety of paddy. The grain yield of each basic was used for estimating the per hectare yield of the variety Uma. The maximum estimated yield of 2.82 tons was obtained for a plot size of 24 basic units (34.56 m^2).

Comparison of methods for optimum plot size was done based on coefficient of variation. Generally all these methods do not provide a unique estimate on optimum plot size. But in this research work, maximum curvature method, comparable variance method, covariate method and based on shape of the plot method provided a unique estimate for optimum plot size. Hence, these methods can be used for estimating optimum plot size and shape for field experiments on paddy and the estimated plot size was 34.56 m^2 with rectangular in shape.

5.1. SUGGESTIONS

- Optimum plot size estimation can be extended to different crops, different varieties and to different locations.

- More observations can be taken during the crop growth period which would extend the applications of covariate method.
- Comparison of optimum plot size for manual transplanting and machine transplanting.

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Abstract

Comparison of methods for optimum plot size and shape for field experiments on paddy (*Oryza sativa*)

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ABSTRACT

The research work entitled "Comparison of methods for optimum plot size and shape for field experiments on paddy (*Oryza sativa*)" was conducted with the objective of estimation and comparison of methods for optimum plot size and shape for field experiments on high yielding variety of paddy. The study was based on primary data collected from a uniformity trial conducted in an area of 800m^2 with Uma variety of paddy in virippu season 2018 at Integrated Farming System Research Station (IFSRS), Karamana. The crop was transplanted at a spacing of 20 cm × 15 cm. The field was divided in to 1.2 m × 1.2 m (1.44 m^2) plots, after leaving a border of one meter from all the sides of the plot to eliminate the border effects, thus give rise to 400 basic units. Observations on plant height and number of tillers were recorded separately from each basic unit at monthly intervals and number of productive tillers, thousand grain weight, grain yield and straw yield were recorded separately from each basic unit at the time of harvest.

The average height of the plant increased from 40.55 cm at one month after planting (MAP) to 121.37 cm at four MAP. The number of tillers per plant varied from 4 at two MAP to 14 at four MAP. The grain yield per basic unit varied from a minimum of 200 g to a maximum of 650 g with an average yield of 391.13 g per plot. The average straw yield was 0.501 kg. The first quartile (Q_1) was observed at 0.410 kg and third quartile (Q_3) was at 0.572 kg. The estimated average harvest index was 0.438 with a coefficient of variation (CV) of 20.78 per cent. The mean productive tillers estimated was 9 per plant. The correlation between productive tillers and grain yield was significant (0.128). Harvest index showed a very high significant correlation of 0.744 with grain yield.

Soil fertility contour map was constructed based on yield data of all original basic units and by taking 3 × 3 and 5 × 5 moving average and the results of the analysis have shown that 3 × 3 moving average provided a more prominent picture of

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fertility status of the field and thus concluded that fertility gradient was more in horizontal direction. Serial correlation of horizontal and vertical strip and mean squares between vertical and horizontal strips also revealed that fertility gradient was more pronounced in horizontal direction.

The optimum plot size estimated by combining the basic units of 1.44 m^2 into plots of different sizes along with CV for each plot size. The different methods used for the estimation of optimum plot size are maximum curvature method, Fairfield Smith's variance law method, modified maximum curvature method, comparable variance method, cost ratio method, covariate method, based on shape of the plot method and Hatheway's method. Generally these methods need not provide a unique estimate. The optimum plot size estimated under maximum curvature method and comparable variance method was 34.56 m^2 (24 basic units) with rectangular shape and it was same for both methods. The optimum plot size estimated under covariate method by taking harvest index as covariate was also 34.56 m^2. The optimum plot size estimated by considering length (X_1) and breadth (X_2) also provided same plot size (34.56 m^2) with X_1 =3 units and X_2 =8.

Optimum plot size under Hatheway's method was estimated by choosing varying number of replications and difference between treatment means. A plot size of 37.44 m^2 (26 basic units) for four replications and 10 per cent difference between the treatment means was found to be optimum under this method. The optimum plot size estimated under Fairfield Smith's variance law method and modified maximum curvature method was 8.64 m^2 and it was not considered as optimum because it was smaller in size. Optimum plot size under cost ratio method was obtained by considering different cost ratios of fixed cost K_1 and variable cost K_2. The estimated plot size under cost ratio method was 5.95 units with $K_1 = 10$ and $K_2 = 1$.

The comparison of methods for optimum plot size was done based on CV. The maximum percentage reduction in CV was found to be with a plot size of 24 basic units and percentage reduction was very low thereafter. Hence maximum curvature method, comparable variance method, covariate method and shape of the plot methods can be recommended for estimating optimum plot size for Uma variety of paddy for field experiments and the estimated optimum plot size was 34.56 m^2 and the recommended shape was rectangular.

Plate 1. Nursery view

Plate 2. Transplanted field

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Plate 3. Observation recording (separately from each basic unit)

Plate 4. Crop harvesting (separately from each basic unit)