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Optimum size and shape of plots based on data from a uniformity trial on Indian Mustard in Haryana

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सार – समरूपी परीक्षण आँकड़ों का सर्वाधिक प्रत्यक्ष उपयोग प्लाटों के अधिकतम अनुकूल माप और आकार के लिए सूचना उपलब्ध कराना है जिसके अन्तर्गत खेत में एकल किस्म की फसल बोई जाती है और छोटे प्लाटों में इनकी कटाई की जाती है। 1 मि. × 1 मि. के प्रत्येक बेसिक एकक से अलग-अलग रिकार्ड किए गए 48 मि. × 48 मि. (2304 बेसिक एकको) के फसल आँकड़ों का उपयोग करते हुए अनुकूल प्लाट माप और आकार का आकलन करने के लिए तिलहन अनुभाग के अनुसंधान फार्म, जेनेटिक और प्लांट ब्रीडिंग विभाग CCSHAU हिसार, हरियाणा राज्य, भारत में 2013-14 के रबी फसल के दौरान समरूपी फसल सुधारात्मक कार्यों का प्रयोग करते हुए भारतीय सरसों (*Brassica juncea* L.) कल्टीवर H-749 बोई गई। परिवर्तिताओं के गुणांक के आकलन द्वारा विभिन्न मापों और आकारों के प्लाटों की परिवर्तिता निर्धारित की गई। यह देखा गया है कि दोनों दिशाओं अर्थात प्लाटों के उत्तर दक्षिणी दिशा (88 प्रतिशत की कमी) में दीर्घीकरण में प्लाट के आकार में वृद्धि के रूप में परिवर्तिता के गुणांक कम हो जाते हैं। यह भी देखा गया है कि मृदा की विषमता के नियंत्रण में सघन और चौकोर प्लाटों की अपेक्षा पूर्व-पश्चिमी दिशा में दीर्घीकृत लम्बे और संकरे प्लाट अत्यधिक उपयोगी रहे हैं। अधिकतम वक्रता पद्धति पर आधारित फसल परीक्षण के लिए अनुकूलतम प्लाट आकार आयताकार आकार में 5 m^2 आकलित किया गया ।

ABSTRACT. The most obvious use of uniformity trial data is to provide information on the most suitable size and shape of plots, in which the field was planted to a single variety and harvested as small plots. Indian mustard (*Brassica juncea* L.) cultivar RH-749 was grown using uniform crop improvement practices during rabi season of 2013-14 at Research Farm of Oilseed section, Department of Genetics and Plant Breeding, CCSHAU, Hisar, Haryana state, India, to estimate optimum plot size and shape using yield data of the 48 m × 48 m (2304 basic units) recorded separately 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 observed that the coefficient of variation decreases as the plot size increases in case of both the directions *i.e.*, when plots were elongated in N-S direction (88 per cent decrease) or elongated in E-W direction (93 per cent decrease). Further it was observed that long and narrow plots elongated in E-W direction were more useful than the compact and square plots in controlling the soil heterogeneity. Based on the maximum curvature method the optimum plot size for yield trial was estimated to be 5 m^2 with rectangular shape.

Key words – Coefficient of variation, Heterogeneity, Optimum plot size and shape, Variability, Uniformity trial.

1. Introduction

In field experiments, the crop growth is largely controlled by genetic and environmental factors. Some of these factors can be separated by way of analysis of variance. Rest of the variations which are not attributed to any known factors is termed as experimental error. Among many factors that contribute to "error", heterogeneity produced by the soil itself is a chief source. So in field experiments and for the most crops, the heterogeneity of the soil is always the first factor to be given attention, to increase the efficiency of the experiment and reliability of the result. Soil variability is a familiar problem to agricultural scientists who must constantly deal with cumulative effects of micro variations which can easily mask treatment differences.

Lucas (2007) conducted uniformity trial on cotton and concluded that, plot shape had no significant effect on plant height but there were effects on bolls and seed cotton yield. Literature reports numerous evidences (Storck, 2010; Patil *et al*., 2010; Prajapati *et al.*, 2011; Masood and Raza, 2012) suggesting optimum plot size for different crops of the region. However, such information may be misleading, because optimum plot size depends upon individual soil conditions. This reflects that the knowledge of soil heterogeneity of the experimental site is a pre-requisite for determining optimum plot size for different crops of the region. With no previous assessment of the nature of the soil fertility, it is highly desirable to conduct a uniformity trial or blank test to obtain information on the direction and magnitude of soil variation.

In the conduct of uniformity trial, plot size and shape most suitable to the field can be estimated. Obviously, too large plots would require more time, money, labour and too small plots on the other hand are less expensive to maintain but tend to increase the size of the experimental error. The problem was therefore selected to see a scientific basis for using plot size and shape within optimum limits. To cope with the problem of the research workers, it has become necessary to standardize a suitable plot size and shape for the experimental plot of major crops grown under different conditions, which will reduce the standard error of the experiments.

The coefficient of variation and the plot size relationship has been investigated by several researchers including Mahalanobis (1940) and Panse (1941). Panse and Sukhatme (1954) gave detailed description of uniformity trial experiments. The determination of the optimum plot size is an important step in field experimentation as it takes into account variability, both due to crop species and soil heterogeneity. The two most widely used methods for selecting optimum plot sizes are those suggested by Smith (1938) and Hatheway (1961). Utilising these techniques, crop scientists have recommended optimal plot sizes and shapes for specific crop-soil combinations.

The objectives of the present study were to estimate the optimum plot size and shape for field research experiments on mustard yield trial; to determine the effect of plot size on variability in yield and to study the coefficients of variation of different plot sizes and shapes.

2. Materials and method

Source of data

The data were collected from the Research Farm of Oilseed section, Department of Genetics and Plant Breeding, CCSHAU, Hisar, Haryana state, India, where a uniform crop of Indian mustard (*Brassica juncea* L.) was raised during rabi season of 2013-14 over an area of 48 m × 48 m (2304 m^2). The field was divided into rows (East-West direction) and columns (North-South direction). The spacing between rows was 30 cm and plants within rows were about 10 cm apart. Border of 1.0 m each on both sides of the sown area was left out and harvesting of crop was done in small units each of size 1 m × 1 m (1 m^2). The units were arranged in 48 rows and 48 columns, each consisting of 48 units. The total number of experimental units thus obtained was 2304 in all. The grains from each of these basic units were harvested, bagged, threshed, cleaned, dried and weighted (in grams) separately. Yield differences between these basic units were taken as a measure of the area's soil heterogeneity.

Statistical analysis

The contiguous units were combined by taking 1, 2, 3, 4, 6, 8, 12, 24 and 48 units along rows (E-W direction) and 1, 2, 3, 4, 6, 8, 12, 24 and 48 units across columns to form plots of different shapes and sizes. Coefficient of variation (C.V.) for each size and shape of plot was calculated. To obtain C.V., the standard error was divided by mean of the corresponding plot size. The C.V. so obtained was utilized to determine optimum size and shape of plots.

2.1. *Relationship between C.V. and size of plots*

Smith (1938) gave an empirical relationship between plot size (X) and plot variance V_x. The law states that

$$V_x = V_1 / X^b \tag{1}$$

which on log transformation becomes

$$\log V_x = \log V_1 - b \log X \tag{2}$$

where,

V_x is the variance of yield per unit area among plots of size X units,

V_1 is the variance among plots of size unity,

b is the linear regression coefficient, indicating the relationship between adjacent individual experimental units or in other words it reflects soil heterogeneity and thus serve as an index of soil heterogeneity which can assume the values from 0 to 1, and

X is the number of basic units per plot.

The index of soil heterogeneity 'b' is the regression of the log of the plot variance (on a per unit basis) on the log of the number of basic units per plot. The bigger the estimated value of '*b*', the bigger the soil heterogeneity; in other words, values close to the unit indicate a larger soil heterogeneity and values close to nullity indicate that the adjacent portions are more correlated. It is worth noticing that '*b*' corresponds to all sources of environmental variation, not only to the soil variability. Smith (1938) computed the values of regression coefficients for thirty different sets of uniformity trial data and found that most of the regression coefficients fell within the range of 0.2 to 0.8. Generally, coefficient of variation is used as a relative measure for computing variability index of V_x.

In equation (2), the values of V_1 and b were computed by the principle of least squares. The normal equations so obtained were :

$$\sum_{i=1}^{n} \log V_{x_i} = n \log V_1 - b \sum_{i=1}^{n} \log X_i$$

$$\sum_{i=1}^{n} \log X_i \log V_{x_i} = \log V_1 \sum_{i=1}^{n} \log X_i - b \sum_{i=1}^{n} \log X_i^2$$

where,

$i = 1, 2, \ldots, n$ and

n denotes number of plot sizes.

On solving these equations we get :

$$\hat{b} = \frac{n \sum_{i=1}^{n} \log X_i \log V_{x_i} - \left(\sum_{i=1}^{n} \log V_{x_i}\right)\left(\sum_{i=1}^{n} \log X_i\right)}{n \sum_{i=1}^{n} \left(\log X_i\right)^2 - \left(\sum_{i=1}^{n} \log X_i\right)^2} \quad (3)$$

$$\log \hat{V}_1 = \frac{\sum_{i=1}^{n} \log V_{x_i} + b \sum_{i=1}^{n} \log X_i}{n} \quad (4)$$

The coefficient of determination (R^2) was computed for fitted equation to examine the suitability of the Smith's equation.

2.2. *Relative efficiency*

Agarwal and Deshpande (1967) suggested a method for obtaining relative efficiencies of different plot sizes. Two criteria, to reduce the experimental error for treatment comparisons, were suggested, *viz*., by taking larger plots and by increasing the number of replications. These were applicable for a fixed experimental area. Therefore, a plot size which satisfies both these criteria was the suitable plot size.

If V_1 and V_2 were the variances for two plot sizes X_1 and X_2, expressed on a unit basis, and r_1 and r_2 are the number of replications, then the relative efficiency (R.E.) of a plot size X_2 as compared to that of plot size X_1 can be taken as:

$$\text{R.E.} = \frac{\left(V_1 / r_1\right)}{\left(V_2 / r_2\right)}$$

As, for a fixed area, $X_1 r_1 = X_2 r_2$, then the relative efficiency in terms of coefficients of variations and plot sizes can be written as:

$$\text{R.E.} = \left(CV_1 / CV_2\right)^2 \times \left(X_1 / X_2\right)^2 \quad (5)$$

where,

CV_1 and CV_2 are the coefficients of variation corresponding for plot sizes X_1 and X_2 respectively.

Taking the efficiency of smallest plot as unity, the relative efficiencies of various plot sizes has been calculated.

2.3. *Optimum plot size*

The uniformity trials involve planting an experimental site with a single crop variety and applying all cultural and management practices as uniformly as possible. All sources of variability except those due to native soil difference are kept constant. Caldwell (1985) suggested that plot size will also depend on the nature of the treatments, the objective of the trial and the location and physical layout of the farm. The planted area is then sub-divided into small units of the same size (generally referred to as "basic units") from which separate measurements of productivity, such as grain yield, straw etc., are made. Yield differences between these basic units in terms of productivity are taken as measure of the area's soil heterogeneity. The smaller the basic unit, the more detailed is the measurement of soil heterogeneity; but naturally higher cost is involved. The production from these basic units is harvested and recorded separately for each basic unit. The usefulness of a uniformity trial lies in the fact that neighboring units may be amalgamated to form larger plots of various sizes and shapes. By combining the plots of adjoining area, different sizes and shapes of plots are obtained and C.V. for each shape and size is worked out. A suitable relation between the plot size and C.V. is fitted. The value of C.V. is obtained using the fitted equation. These C.V.'s are utilized for comparing the efficiency of different plot sizes by taking smallest plot as standard unit.

The optimum plot size has been calculated using Maximum curvature method and Smith's variance law method.

2.3.1. *Maximum curvature method*

The maximum curvature method (Agarwal, 1973) has frequently been used to determine plot size for various field crops. With this method, yield data from 'basic units' of a uniformity trial were combined into plots of different sizes and shapes which were compared for degree of variability. An index of variability, *i.e*., coefficient of variation (C.V.) and plot sizes were plotted on the Y-axis and X-axis, respectively. The optimum plot size was read by inspection as the point on the curve where the rate of change for the variability index per increment of plot size was greatest. This method has two shortcomings: (*i*) the relative costs of various plot sizes were not considered and (*ii*) the point of maximum curvature was not independent of the basic unit.

Following the method of maximum curvature, optimum plot sizes (X_{opt}) was obtained by the procedure discussed below:

Consider Smith's equation (1)

$V_x = V_1 / X^b$

First two derivatives of V_x w. r. t. 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 by the formula as follows:

$$\rho = \frac{\left[1+\left(dV_x/dX\right)^2\right]^{3/2}}{d^2V_x/dX^2}$$

Now, by substituting the values of dV_x/dX and d^2V_x/dX^2 and on simplification, we get

$$\rho = \frac{1}{V_1 b(1+b)}\left[1+V_1^2 b^2 X^{-2(1+b)}\right]^{3/2} X^{(2+b)}$$

To maximize curvature, equate the first derivative $d\rho/dX$ to zero

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

Put the quantity equal to zero and on simplification, we get formula given by Agarwal (1973)

$$X_{\text{opt}}^{2(1+b)} = V_1^2 b^2 \left\{\left[3(1+b)/(2+b)\right]-1\right\} \qquad (6)$$

2.3.2. *Smith's variance law method*

The cost of field experimentation must also be reflected in optimum plot size. Smith (1938) worked out optimum plot size for different values of costs under assumption of linear cost structure. Consider the cost function as :

$C_x = C_1 + C_2X$

where,

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

C_1 is the fixed cost and

C_2 is the variable cost which depends on the size X of the experimental unit.

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

$C_0 = r\,(C_1 + C_2X)$

In order to determine the optimum plot size, we wish to maximize the amount of information per unit cost. The amount of information was defined to be the reciprocal of the variance. We can also minimize the relative cost per unit information, where the cost per unit information was given by

$$C' = \frac{C_1 + C_2X}{1/V_x} = \frac{(C_1 + C_2X)V_1}{X^b} \quad \text{(Using Smith's law)}$$

TABLE 1

Coefficient of variation for various plot sizes

No. of units in N-S direction	No. of units in E-W direction								
	1	2	3	4	6	8	12	24	48
1	20.07	14.12	11.81	10.22	8.24	7.42	5.44	3.28	1.44
2	14.78	10.50	8.82	7.93	6.31	5.95	4.34	2.67	-
3	12.68	9.11	7.93	6.92	5.52	5.25	4.09	-	-
4	11.00	7.89	6.82	6.24	4.83	4.64	3.52	-	-
6	9.05	6.79	5.84	5.47	4.31	3.99	-	-	-
8	7.71	5.67	4.95	4.77	3.78	-	-	-	-
12	6.10	4.80	4.03	4.11	-	-	-	-	-
24	4.08	3.47	-	-	-	-	-	-	-
48	2.34	-	-	-	-	-	-	-	-

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

$$-b\left(C_1 + C_2 X\right) X^{-1-b} + X^{-b} C_2 = 0$$

By solving, we get

$$X_{\text{opt}} = \frac{bC_1}{\left(1-b\right)C_2} \tag{7}$$

where,

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

C_1 is that part of total cost which is proportional to no. of plots per treatment and

C_2 is that part of total cost which is proportional to the total area per treatment.

3. Results and discussion

3.1. *Effect of plot size on error variability*

To have an idea about nature and magnitude of variability due to soil heterogeneity in plot yields, the coefficient of variation of yields of harvested units for various plot sizes of 1, 2, 3, 4, 6, 8, 12, 24 and 48 in different shapes were calculated and are presented in Table 1.

The coefficient of variation of yields of individual harvested units was observed to be as high as 20.07 per cent which indicates high degree of soil heterogeneity.

The coefficient of variation decreased with the increase in plot size in either direction. This decrease was rapid for the small plot sizes but lessens for larger plot sizes. It was also observed that the rate of decrease of C.V. was higher when the plots were elongated in E-W direction (93 per cent decrease) than those elongated in N-S direction (88 per cent decrease), thus indicating more homogeneity in E-W direction. Thus for a fixed size of plot, the plots elongated in E-W direction give less C.V. as compared to the plots in N-S direction, indicating thereby that the plots become more homogeneous when elongated along E-W direction.

3.2. *Effect of plot shape on error variability*

To study the effect of plot shape on error variability, C.V.'s for various plot shapes for a given plot size have been calculated and are presented in Table 2.

It was obvious from plot size 4 that C.V. was maximum when plots were elongated in N-S direction, *i.e.*, 4:1. The C.V. decreased from 11.00 per cent to 10.22 per cent when plots were elongated in E-W direction *i.e.*, 1:4. The C.V. in case of square plot 2:2 was 10.50 per cent which was more than 1:4 and less than 4:1. Thus for plot size of 4 units (4 m^2), plot shape 1:4 may be regarded as optimum since it has minimum C.V. for a given size of plot.

TABLE 2

Coefficient of variation for various plot sizes and plot shapes

Plot size (in units)	Plot shape	C.V. (%)	Minimum C.V. (%)
1	1:1	20.07	20.07
2	1:2	14.12	14.12
	2:1	14.78	
3	1:3	11.81	11.81
	3:1	12.68	
4	1:4	10.22	10.22
	2:2	10.50	
	4:1	11.00	
6	1:6	8.24	8.24
	2:3	8.82	
	3:2	9.11	
	6:1	9.05	
8	1:8	7.42	7.42
	2:4	7.93	
	4:2	7.89	
	8:1	7.71	
12	1:12	5.44	5.44
	2:6	6.31	
	3:4	6.92	
	4:3	6.82	
	6:2	6.79	
	12:1	6.10	
24	1:24	3.28	3.28
	2:12	4.34	
	3:8	5.25	
	4:6	4.83	
	6:4	5.47	
	8:3	4.95	
	12:2	4.80	
	24:1	4.08	
48	1:48	1.44	1.44
	2:24	2.67	
	4:12	3.52	
	6:8	3.99	
	8:6	3.78	
	12:4	4.11	
	24:2	3.47	
	48:1	2.34	

TABLE 3

Relative efficiencies of various plot sizes

Plot size (in units)	Plot shape	Coefficient of variation	Relative efficiency
1	1:1	20.07	1.0000
2	1:2	14.12	0.5051
3	1:3	11.81	0.3209
4	1:4	10.22	0.2410
6	1:6	8.24	0.1647
8	1:8	7.42	0.1142
12	1:12	5.44	0.0944
24	1:24	3.28	0.0649
48	1:48	1.44	0.0842

It was obvious from plot size 4 that C.V. was maximum when plots were elongated in N-S direction, *i.e.*, 4:1. The C.V. decreased from 11.00 per cent to 10.22 per cent when plots were elongated in E-W direction, *i.e.*, 1:4. The C.V. in case of square plot 2:2 was 10.50 per cent which was more than 1:4 and less than 4:1. Thus, for plot size of 4 units (4 m^2), plot shape 1:4 may be regarded as optimum since it has minimum C.V. for a given size of plot.

Similarly, for plot size of 6 units, the C.V. was minimum for the plot shape 1:6, *i.e.*, of the order of 8.24 per cent, hence it was the optimum plot shape for plot size 6. The same pattern exists for the plot of size 8 units where the minimum C.V. was of the order of 7.42 per cent for the plot shape 1:8 and for the plot of size 12 units where the minimum C.V. was of the order of 5.44 per cent for the plot shape 1:12 and for the plot of size 24 units where the minimum C.V. was of the order of 3.28 per cent for the plot shape 1:24. Thus, longer plots were more beneficial than the plots in compact and square shape.

3.3. *Relationship between coefficient of variation and plot size*

It has been observed that there exists a relationship between the plot size and the coefficient of variation as was established by Fairfield Smith in 1938. The suitability of the Smith's variance law was examined by fitting the equation (1) and (2).

For the present uniformity trial data, we obtain the Smith's law using equation (3) and (4) as

$$V_x = 23.878X^{-0.6487} \qquad \left(R^2 = 0.9625\right)$$

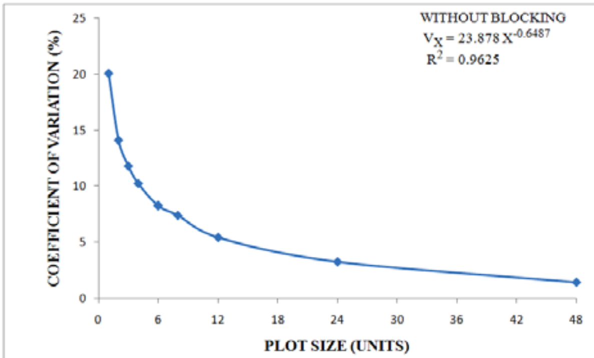

Fig. 1. Coefficient of variation in relation to size of plot

The equation was in conformity with Smith's law, where the soil variability index (b) was 0.6487. It indicates the positive correlation between the adjacent basic units. The fitted curve has been presented in Fig. 1.

3.4. *Relative efficiencies for different plot sizes*

To compare the efficiencies of plots of various sizes, the relative efficiencies were computed using the formula suggested by Agarwal and Deshpande (1967). For this purpose, efficiency of the smallest plot was taken as unity as the smallest plot was the most efficient of all the plot sizes. The relative efficiencies obtained by this procedure for the present experiment is presented in Table 3.

It was observed that the smallest plot has the maximum efficiency but as the plot size increases the efficiency goes on decreases due to the presence of soil variability.

3.5. *Optimum plot size*

By using equation (6), the optimum plot size has been worked out by maximum curvature method and was found to be approximately 5 units (*i.e.*, 5 m^2).

The optimum plot sizes were also computed by Smith's method from equation (7) considering the values of C_1/C_2 from 0.5 to 4 and the results are presented in Table 4. It was observed that for a given plot arrangement, the optimum plot size increases with the increase in the cost ratio, *i.e.*, when the fixed cost becomes larger than the variable cost.

The results from Smith's method were inappropriate for the estimation of optimum plot size, whereas maximum curvature technique revealed significant results. Accordingly plot size of 5 m^2 was found optimum for field experiment on Indian mustard using the maximum curvature technique.

TABLE 4

Optimum plot size under cost consideration

Value of b = 0.6487	
C_1/C_2	Optimum size of plot (m^2)
0.5	0.92
1.0	1.84
1.5	2.76
2.0	3.69
2.5	4.61
2.7	5.0
3.0	5.53
3.5	6.46
4.0	7.38

4. Conclusions

The study results reveal that there was a considerable variation in yield data gathered from different plot sizes. It was observed that long and narrow plots elongated in E-W direction were more useful than the compact and square plots. The relative efficiency of the smallest plot has found to be highest but it decreased with the increases in plot size due to the presence of soil variability. In accordance with the linear cost structure and Smith's variance law, optimum plot size was found out which increased with the increase in the ratio of fixed cost to the variable cost. Plot size of 5 m^2 with rectangle shape was found optimum for field experiment on Indian mustard using the maximum curvature technique. Researchers of the relevant area may use the estimated plot size in the study to have better control over the variability of the field experiment.

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