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RESEARCH ARTICLE

ESTIMATION OF OPTIMUM PLOT SIZE AND SHAPE IN AGRICULTURAL EXPERIMENTS

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ABSTRACT

Determination of optimum plot size and shape has been regarded as an important and useful area to measure soil heterogeneity in field experiments. The smith's heterogeneity index method assumes the condition of independence of observations but often this condition of independence of observations does not satisfied. In this paper, we propose a method of determination of heterogeneity index using semivariances instead of variances used in smith's method. The main advantage of semivariogram technique is it considers magnitude and direction of heterogeneity in field experiments. The heterogeneity index calculated using semivariogram technique and Smith's technique is 0.17 sand 0.24 respectively and corresponding optimum plot size (x_{opt}) is 4.5 m^2 and 7.1m^2.

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INTRODUCTION

In agricultural experiments, soil variability is one of the important external sources of variation. Adjacent plots, planted simultaneously to the same variety and treated as alike as possible, will differ in as many characters as one could care to measure quantitatively. The causes for these differences are numerous but the most obvious, and probably the most important, is soil heterogeneity. The contribution of soil heterogeneity to experimental error stems from differences in soil fertility between plots within a block. The smaller this difference is, the smaller is the experimental error. The choice of suitable plot size and shape, therefore, should reduce the differences in soil productivity from plot to plot within a block and consequently reduce experimental error. The size and shape of the experimental units will affect the accuracy of the experimental results. In agricultural experiments comparative studies on plot size have been carried out& 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 & variability within the block may be increased. We have to strike a balance between these two opposing tendencies.

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We have to select a plot with optimum size for this purpose. This minimum size of an experimental plot for a given degree of precision is named as Optimum plot size. Once the optimum plot size has been determined, we have to decide the shape of the plots. The desirable shape of experimental plots is the one that will result in the smallest variation between plots within a block. In agricultural experiments many works on shape of plots have been done. Adjacent areas are correlated was first shown by Harris (1920) and he utilized this criteria for subdividing the field into uniform areas. The use of intra class correlation as a measure of heterogeneity was suggested by him and recommended that if correlation coefficient was in the neighborhood of zero then field could be considered as homogeneous field and whatever plot size is adopted, it will not lead to a large experimental error. After that as we explore scientific literature relating to this problem, we may a note a number of contributions, including Smith (1938) developed an empirical model representing the relationship between plot size and variance of mean per plot. Koch & Rigney (1951) demonstrated that the regression coefficient of the logarithm of variance on the logarithm of plot size can be estimated from experimental data in which treatment effects were present and from uniformity trials. They recommended that the variances of the different plot sizes should be weighted by their respective degrees of freedom. Bhatti and Rashid (2005) studied the effect of shape and size of plots on spatial variability in yields.

They studied the nature and magnitude of variability using various statistical procedures viz. frequency plot analysis and semivariogram analysis and showed that there was a considerable variation in yield data from different plot shapes and sizes. Satyabrata Pal *et al*. (2015) investigated a deep and extensive exploration of the effect of different plot sizes and shapes in discovering the minimum radius of curvature of the variogram and recommended expressions of the theoretical variograms for different plot sizes. Many other research workers conducted research to find optimum plot size, shape and orientation for field experiments.

MATERIALS AND METHODS

Previous Method

Serial Correlation Method

Serial correlation is useful in the characterization of the trend in soil fertility using uniformity trial data. The formula for computing a serial correlation coeffiucient of n observations is:

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

Where $X_{n+1} = X_1$.

A serial correlation can be viewed simply as a simple correlation between two variables, one at site I and other at site (i+1). A low correlation coefficient indicates that fertile areas occur in spots, and a high value indicates a fertility gradient. Two serial correlation coefficients – one for horizontal and another for the vertical arrangement- are computed from one set of uniformity trial data.The mathematical calculations of Serial correlation method are critical so, instead of use of serial correlation we can simply draw Box plots of yields for rows and columns separately. Which tells us the direction of trend in soil (in row or column) in simple and easily understandable manner.

Proposed Method

Box plot technique

i) Draw Boxplots of Row observations of each row and observe it.
ii) Draw Boxplots of column observations of each column and observe it.
iii) For which graph there are much fluctuations in boxplots then trend of variability is along that direction.

Previous Method

Smith's index of soil variability

In 1938 Smith suggested a single measure to describe soil heterogeneity, known as index of soil variability or Smith's index of soil variability. Based on uniformity trials with a broad spectrum of species, Smith formulated the law referred to in literature as Smith's variance law. The law assumes that variance of the plots consisting of x basic units (V_x) is proportionally related to the variance of basic units (V_1) and inversely proportional to the number of basic units in the plot raised to a power of b.

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

The parameter b in the equation is the index of soil variability which can assume the values from 0 to 1. The larger the value, the more homogeneous the soil, and inversely. The parameter b is calculated as a coefficient of a logarithmic regression.

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

Proposed Methodology

Semivariogram Analysis

Kriging is a means of spatial prediction that can be used for soil and agricultural properties. It is a form of weighted local averaging. It is optimal in the sense that it provides estimates of values at unrecorded places without bias and with minimum and known variance. The first stage in kriging is the measurement of spatial variation in a property of interest. This measure is called a semivariance. Consider a transect along which observations have been made at regular intervals to give values $z(i)$, i = 1,2,..,N then the relation between pairs of points, h interval apart, can be expressed as the variance of the differences between all such pairs. So, the per-observation variance is half this value thus:

$$\gamma(h) = \frac{1}{2} Var[z(i) - z(i+h)] \qquad [1]$$

For example, the estimate of semivariance for a single transect with no missing observation when $h = 1$ is:

$$\gamma(1) = \frac{1}{2(N-1)} \sum_{i=1}^{N-1} [z(i) - z(i+1)]^2 \qquad [2]$$

A general form of this equation is given by:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(i) - z(i+1)]^2 \quad \text{for } i = 1,2,\dots.N(h) \qquad [3]$$

Where $N(h)$is the number of observation pairs $\{z(i), z(i+h)\}$ with a distance h. The expression $gamma(h)$ is known as the semivariance, and is a measure of similarity, on average, between points a given distance h, apart. The more alike are the points, the smaller is $gamma(h)$ and *vice versa*. As above, $gamma$depends on h, and the function relating the two is known as the semivariogram. The typical semivariogram model for the agricultural studies is mainly linear or spherical. These models have certain important characteristics: (i) it shows the nature of the geographic variation in the property of interest, and (ii) it is needed to provide kriged estimates at previously unrecorded points. In most instances $gamma(h)$ increases with increasing h to a maximum, approximately the variance of the data. The distance a is known as the range and it is assumed that points closer together than the range are spatially dependent; points further apart bear no relation to one another. A Semivariogram is one of the significant functions to indicate spatial correlation in observations measured at sample locations. It is commonly represented as a graph that shows the variance in measure with distance between all pairs of sampled locations. Such a graph is helpful to build a mathematical model that describes the variability of the measure with location. Modeling of relationship among sample locations to indicate the variability of the measure with distance of separation is called Semivariogram modeling. Semivariogram modeling is also referred as Variogram modeling. When spatial dependence present in experimental material then Semivariogram technique is effective which clearly indicates the direction and magnitude of trend in soil. Here we proposed methodology for calculation of heterogeneity index using semivariogram technique. The step by step procedure is:

i) Firstly check the data follows normal distribution or not.
ii) If it follows normal distribution then go to step (iv).
iii) If data does not follow normal distribution then normalize data using proper data transformation technique and use this transformed data for further calculation.
iv) Calculate semivariances for given lag distances.
v) Then take log of semivariances and their corresponding distances.
vi) Fit the regression model of log of semivariances and log of distances.
vii) The estimated coefficient b is the calculated heterogeneity index by using semivariance technique.
viii) By considering all the costs and this heterogeneity index we calculate the x_{opt} and this optimum plot size is used for further experiment.

Advantages of method

i) Variogram technique considers direction and magnitude of variation in experimental material.
ii) It is optimal in the sense that it provides estimates of values at unrecorded places without bias and with minimum and known variance.
iii) Plotting experimental material with calculated optimum plot size for experiment will minimize experimental error occurred due to soil heterogeneity.

Numerical Example

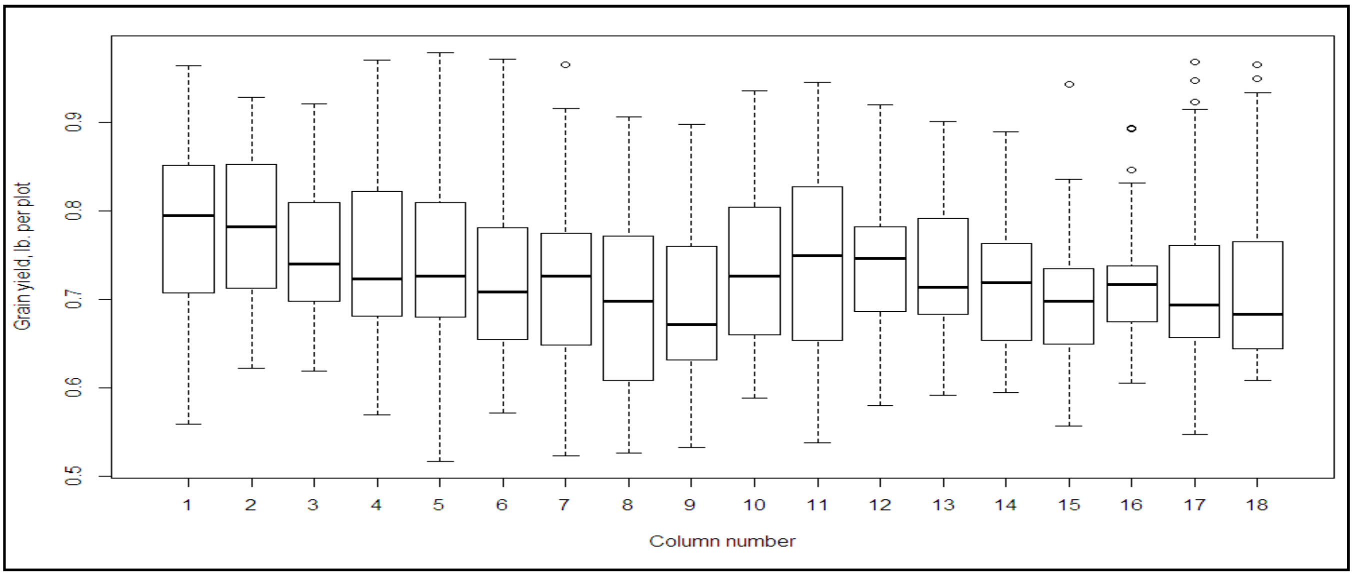
Here we analyzed one uniformity trial dataset for our study purpose which is taken from the book. The analysis by using semivariogram technique is as follows:

Firstly we have to check trend of direction of variability in yield i.e. whether variability is in row direction or in column direction.

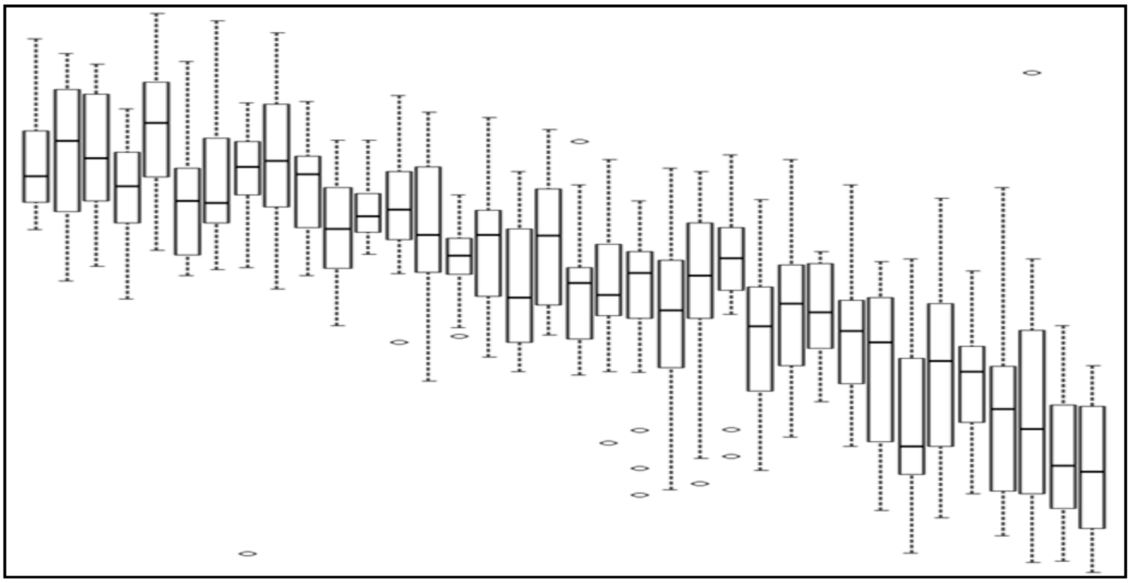
It is clearly seen from the graph that there is no considerable variation in yield across columns. It is clearly seen from the graph that there is highly considerable variation in yield across rows i.e. from E to W direction. So, we have to block the experimental material along N to S direction and blocking along N to S direction is first step of reducing soil heterogeneity. After that we have to choose Optimum plot size which reduces variation within plots. This plot shows that there is considerable autocorrelation along E to W direction.

Heterogeneity Index

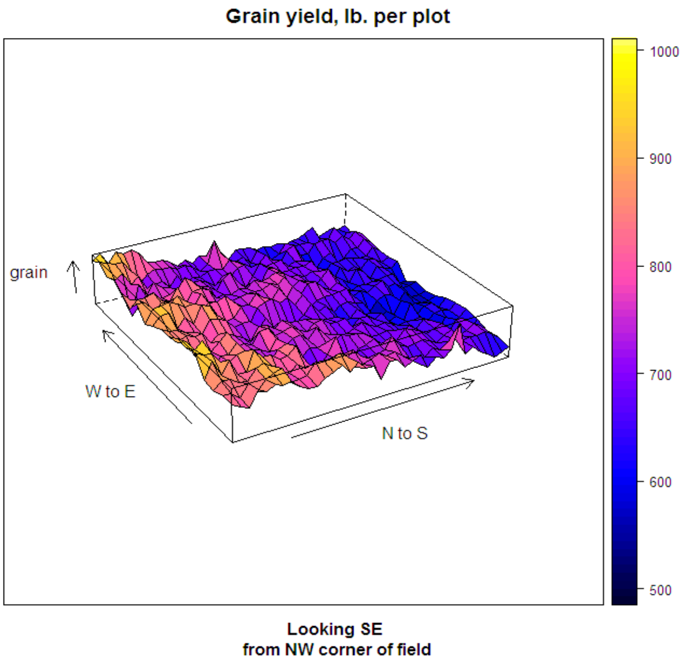
By using proposed method and Smith's method we calculate heterogeneity index. For given example data does not follow assumptions of semivariogram technique so, we transform the data using log transformation technique. The heterogeneity index by using Smith's method is 0.13 but this heterogeneity index is adjusted for further calculation of optimum plot size and it is 0.24 after adjustment. The heterogeneity index by using semivariogram technique it is 0.17. The optimum plot size calculated from Smith's index and semivariogram technique is 7.1m^2 and 4.5 m^2 respectively.



Graph 1. Box plot for trend analysis for columns



Graph 2. Box plot for trend analysis for rows



Graph 3. Plot of Autocorrelation surface of Grain yields

Conclusion

Spatial dependence in adjacent plots is one of the cause of heterogeneity in field experiments. So, here we propose a method called semivariogram technique which considers direction and magnitude of spatial dependence which helps us to reduce heterogeneity in field experiment. We calculate heterogeneity index using Smith's technique and Semivariogram technique. The heterogeneity index by using Smith's method is 0.13 but this heterogeneity index is adjusted for further calculation of optimum plot size and the heterogeneity index by using semivariogram technique it is 0.17. The optimum plot size calculated from Smith's index and semivariogram technique is 7.1m^2 and 4.5 m^2 respectively.

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