Soil Heterogeneity to Determine Size and Shape of Plots: A Review

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ABSTRACT

Determination of optimum plot size has been regarded as important and useful area for agricultural field to measure soil heterogeneity in design of experiment. Adjacent plots, planted simultaneously to the same variety and treated alike as possible, will differ in as many characters as one would care to measure quantitatively. The causes for these differences are numerous but the most obvious and probably the most important, is soil heterogeneity. So, an adequate characterization of soil heterogeneity is very important to design any experiment in field trial. Uniformity trials are conducted to cope up with these problems and we can determine shape and size of plot to minimize the heterogeneity in field experiments. This paper reviewed deep and extensive trends in uniformity trials. This will help researchers for future experimentation of field trial.

Key words: Design of Experiments, Uniformity trials, Size and shape of Plot, Optimum plot size, coefficient of variation

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INTRODUCTION

In agricultural experimentation we are interested in ascertaining the relative worth of a set of treatments with reasonable confidence. The simple procedure of trying set of treatments each in a different field or plot does not seem to adequate to ascertain their relative worth with reasonable confidence. For even after discovering from a trial that some treatments have given a better performance than others we are left wondering whether the differences observed are due to treatments, to inherent fertility differences in the soil or some other experimental factors. Ideally we would like to try the treatments under identical conditions but even with the most uniform land that the inherent variation in the soil is quite considerable and the single plot side by side in the same field does not suffice for accessing the intrinsic worth of the treatments.

The plot is that part of the trial material to which a single treatment is applied and on which observations are made. Sufficient units are necessary for the planned treatments and replications. In practice, trial material is limited and compromises may often be necessary. The plots should be chosen to be representative of the population the trial is testing and to be as uniform as possible. Lack of uniformity can sometimes be mitigated with replicate blocks. In general, plots should be rectangular and of the same size in one trial and of similar size for a single trial series. Accuracy increases with plot size, but only up to a certain limit, for variability in soil and infestation conditions also tends to increase. Long thin rectangular plots are suitable for mechanical harvesting. Nearly square plots reduce the risk of interference between plots.

A good idea of the nature and extent of fertility variation in land can be obtained from the results of "Uniformity trials". In other words uniformity trial is planned to determine suitable size and shape of the plot and the number of plots in a block. Uniformity trial involves growing a particular crop on a field or piece of land with uniform conditions. All sources of variation except that due to native soil differences are kept constant. At the time of harvest the entire field is divided into smaller units of same size and shape of plot. The smallest the basic unit, the more detailed is the measurement of soil heterogeneity. In the past, large no. of research workers has attempted to study the soil fertility variation. It has been demonstrated that in field experiments the variation due to the soil is very important. There are other sources of variation confounded with the soil. Variation such as the spread of pests and diseases, winds, irrigation etc.

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. 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. They have revealed that for small sizes of plots the shape may have little effect whereas for large plots the effect of shape will be more. Some of researchers found that for fields with distinct fertility gradient, long and narrow plots best overcome the effects of soil heterogeneity.

Adjacent areas are correlated was 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. The review was taken on uniformity trials and size and shape of plot is as given below:

Christidis(1931) demonstrated number of uniformity trials and concluded that in no case square plots was more uniform than long narrow ones.

Cochran (1937) analyzed most of the uniformity trials performed before 1937 and was found that the yields of the same plot in successive years was positively correlated, whether the same crop followed or a different crop.

Smith (1938) developed an empirical model representing the relationship between plot size and variance of mean per plot. This model is given by the equation:

$$V_x = \frac{V_1}{x^b} \quad \text{or} \quad \log V_x = \log V_1 - b \log x$$

Where, x is the no. of basic units in a plot, V_x is the variance of mean per p[lot of x units, V_1 is the variance of mean per plot of one unit & b is the characteristics of soil and measure of correlation among contiguous units. For Given an estimate of the soil heterogeneity index b and the cost of conducting the experiment, he derived a equation for optimum plot size as:

$$x_{opt} = \frac{b(K_1 + K_g A)}{(1-b)(K_2 + K_g B)}$$

Where K_1 is the part of the cost associated with the number of plots only, K_2 is the cost per unit area, K_g is the cost associate with the borders, B is the ratio of the side borders to the test area, A is the area of the plotr end boreders, and b is the index of soil heterogeneity. If Non bordered plots are used, K_g is zero.

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.

C.E.Wasssom & R.R.Kalton(1953) estimated optimum plot size for bromegrass uniformity trials from three different fields. They studied efficiencies of the various plot sizes relative to the plot size having smallest variance & none was found to be more efficient than the basic plot in any field and observed that efficiency generally decreased rapidly as plot size was increased.

Federer (1955) suggested that there is need to obtain a weighted estimate of variance in which the weights were the degrees of freedom used to calculate the variance and the formula for calculating 'b' by weighted least square is:

$$b = \frac{\sum(Wi \log V_x \log X_i) - \frac{(\sum W_i \log V_x)(\sum W_i \log X_i)}{\sum W_i}}{\sum W_i (\log X_i)^2 - \frac{(\sum W_i \log X_i)^2}{\sum W_i}}$$

W.H.Hathway and E.J.Williams(1957) introduced a method of weighted variances of different sized plots which leads to an unbiased estimate b with asymptotically minimum variance. The suggested method was applicable to uniformity trial data as well as experimental data.

LeClerg et.al. (1962) introduced fertility maps for mapping soil heterogeneity in field experiments. The maps were constructed by assuming that the production (yield) of each plot is located at the center of the plot with a linear gradient of productivity from center to center of plots.

David Ernest Polson(1964) estimated optimum size, shape, and replicate number of safflower plots for yield trials. He compared three methods viz. comparable variance, Smith's regression method and Hathaway's convenient plot size method to determine optimum plot size. 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.

Romalito L. et.al. (1964) conducted a uniformity trial to determine the optimum plot size and shape and number of replications for sugarcane field experiments. The results revealed that 70 times the basic unit was estimated the optimum plot size related to soil heterogeneity and relatives cost.

Ignacio Mendez-Ramirez(1970)compared blocking models with model based on polynomials or selected orthogonal variables. A nested analysis (blocks and observations within blocks) was carried out for a variety of sizes and shapes of blocks for each of 34 uniformity trials. In six cases, blocks with size 20 or less had greater efficiency than the 5^{th} degree polynomial but the shapes of these blocks were very unusual for field experiments i.e. very narrow and long with the major dimension across the geographic trend patterns.

Lin And Binns(1984) proposed working rules to determine plot size and number of plots within a block in field experiments based on the value of the intrablock correlation (ρ), which was obtained from the analysis of variance of a randomized-block experiment.

William H. Swallow and Todd C. Wehner (1986) recommended generalized least square method over Smiths Index for estimating heterogeneity index b for multiple harvest yield trials. They estimated optimum plot size for pickling and it was found to be 6.4 to 10.3 m^2.

J.G.P.W. Clevers et.al(1986) used aerial photography for mapping the heterogeneity of a trial field with one barley variety and results were used to improve the experimental lay-out of field trials. Aerial photography was a good technique to map the heterogeneity of a field with respect to yield of barley.

Roger L. Vallejo and Humberto A. Mendoza(1992) determined optimum plot size and number of replications to evaluate yield of sweet potato clones. The optimum plot size was estimated using the methods of maximum curvature and comparison of variances. The adequate number of replications was determined using the Hatheway method. The estimated optimum plot size was 10, 15 basic units respectively and the adequate number of replications with a plot size of 15 basic units was four.

R. Zhang et.al.(1994) proposed an empirical equation to characterize the heterogeneity of non isotropic fields by introducing heterogeneity indices. They extended the formula of Fairfield Smith's empirical law describing heterogeneity in isotropic fields.

T S G Peiris et.al.(1997) proposed two methodologies to determine the most efficient plot size for tree crops using data from experiments based on randomized complete block design and discussed merits and demerits of methods. They showed that efficient plot size in field experiments for coconut for a wide range of agro ecological regions was four or six palms.

R. Poultney et.al.(1997) investigated and compared plot to plot yields of intercropped millet byb using two methods viz. combined plot analysis and integration of variograms. These two methods tackled the choice of plot size and shapes in different ways. They showed that if there is spatial correlation at the working scale then oblong plots were better than square one.

A.B. McBratney (2000) introduced the Opportunity Index for Site-Specific Crop Management (SSCM) and concluded that the CV is non-spatial and therefore potentially misleading when dealing with different sized areas.

Girma Taye et.al.(2000) investigated that broadcast sown trials were resulted in lower estimates of soil heterogeneity, higher coefficients of variation and higher value for adjacent plot correlation due to modified inter plant competition basal fertilizers within plots.

Faquir Mohhamad et.al.(2001) studied Lin and Binns method along with a method based on residuals from randomized complete block design and observed from RCBD correlation (p) that the Lin and Binns method was not much helpful; whereas, the method based on residuals works quite well. They indicated that the plot size using Lin and Binns method is usually higher than the plot size calculated by residual method.

Guangxlng Wang et.al. (2001) proposed a method to determine appropriate plot size and spatial resolution for mapping multiple vegetation types using remote sensing data for a large area and the range parameters of the within-support semivariograms implied the maximum range of the appropriate plot sizes.

Daryl T. Bowman(2001) determined the best plot size in uniformity trials to measure stability of phenotypes or measure variation in other individual or population attributes and concluded that there was no basis to use CV for crop performance trials.

Janusz Gołaszewski(2002) suggested some indicators for the application of spatial methods in field experimentation and the indicators were based on the data from two field-breeding experiments with pea and field bean. He suggested that the Smith's index of soil variability *b* was a convenient tool to assess the purposefulness of background variation analysis by applying spatial methods and recommended that application of kringing mtehod to the data produced the concomitant to reduce the experimental error effectively.

George E Boyhan et.al.(2003) estimated optimum plot size and optimum number of replications with short day onion and suggested that the size of the initial basic unit will have a strong influence on the appropriate plot size.

Rodrigo Machado Mello1 et.al.(2004) determined the proper plot size and shape for the culture of the Italian pumpkin in protected environments and estimates of best plots size and shape were obtained by the maximum curvature, variance comparison and Hathway methods. They concluded that plot size and shape was varied according to the season and according to the maximum curvature and Hatheway methods.

Bhatti A.U. and Rashid M.(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. They concluded that as the plot size increases variability decreases.

Sergio Jose Ribeiro de Oliveira et.al(2005) investigated the relationship between the size of the basic unit for exploratory experiments and the optimum plot size. The model

$$CV(x) = A/X^{B}$$

was adjusted, in which CV(x) was the coefficient of variation among plots with different numbers of basic units. Optimum plot size was estimated with the modified maximum curvature method of the function

$$CV(x) = A/X^{B}$$

Dilson Antonia Bisognin et.al.(2006) studied plot size variation among Potato clones to increase experimental precision of yield performance trials.

Sandra Feijo et.al.(2008) demonstrated that the heterogeneity index in plastic greenhouse was nearly zero and suggested that smaller plots combined with a large number of replications increased the experimental accuracy and plots with three plants per row plots, with six replications, was the most appropriate design.

M.P. Carvalho et.al. (2009) analyzed the characteristics and quality of the experimental plans of corn genotype evaluation trials, classified the heterogeneity index and determined the number of replications and plot size aimed at an adequate precision. They suggested that the number of replications must be limited to three and plot size must be increased from 5 m rows to three to improve trial precision.

Nadia Idrees and Muhammad Inayat Khan(2009) analyzed different complete and incomplete block designs superimposed with dummy treatment structure on uniformity trials data to make efficient design. They found that for all three sites under study, generalize lattice design was more efficient than complete block analysis to reduce the error mean square. They demonstrated that complete blocking system often performs poorly in their function of reducing experimental error.

L. Storck et.al.(2010) determined optimum plot size and the number of uniformity trials required to estimate optimum plot size in different corn hybrids and suggested that the number of uniformity trials required for estimating cob mass and optimal plot size is six, equivalent to 12.5% of the experimental area.

Leandro Homrich Lorentz et.al. (2010) estimated the seed production heterogeneity index and the optimal experimental plot size to verify experimental precision in sunflower and the sunflower seed production heterogeneity index was high so they recommended that the plots should be large and the rows were used as blocks.

M. Asif Masood et.al.(2012) indicated that the Smith's index of soil heterogeneity (b = 0.491) had a degree of low similarity among the experimental plots and concluded that estimated plot size is larger than the plot size of 3m×5m generally used for paddy yield in the study area.

Christel Richter et. al. (2012) investigated that blocking and randomization were the basic principles of planning experiments and concluded that recommended layout of blocks and plots based on classical principles of block and plot construction accounted large scale heterogeneity.

M. Asif Masood et.al. (2012) examined that the results from comparable variance method were inappropriate for the estimation of the optimum plot size, where as maximum curvature technique revealed significant results and concluded that square shape seems better for large plot sizes in the study area.

Heike Knorzer(2013) stated that data collected from small plots of perennial crops, such as miscanthus or short rotation coppice plantations, a larger variability was expected than for cereals. They found that the variances for all traits in the experiments were rather high when the sampling area was smaller than 2 m^2 and concluded that an area of 3 m^2 is sufficient to eliminate approximately 90% of the variance and is therefore an adequate size of sampling area.

Michael D. Casler(2013) summarized 28 years of field based perennial forage grass research at a single location describing changes to experimental design methodology, illustrated both predicted and empirical results of those changes. He studied analysis of total forage yield for 114 genetic experiments of 11 forage grass species and concluded that a power of experiments resulted in a high level of predictability.

Mohamed Ahmed Al-Feel et.al.(2013) analyzed the effects of different plots sizes on the estimation of wheat yield and concluded that there were no significant differences between large and medium size plots in yield estimation but there were significant differences between large and small plot sizes and between medium and small plot sizes with respect yield estimation.

Jeffrey Willers et.al.(2014) investigated whether plot size affects incidence of white flower anther injury by tarnished plant bug in host plant resistance (HPR) evaluations and concluded that the white flower monitoring procedure was a consistent indicator of adult plant bug preferences and was not influenced by plot size or interspersions of cultivar lines among plots.

Diogo Vander lei Schwertner et.al. (2015) determined the uniformity trial size to estimate optimum plot size in order to evaluate fresh phytomass in lettuce plants and fruit weight in sweet peppers and concluded that uniformity trial using 27 basic experimental units to evaluate the fresh phytomass of lettuce plants, and with 29 basic experimental units to assess fruit weight in sweet pepper were sufficient to estimate optimum plot size.

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 and found that for square plots have radii of curvature much higher than the desired minimum values, thus square plots could not be taken as optimum plot sizes.

Comments:

Soil heterogeneity is one of the measure cause of experimental error in design of experiments. To minimize this error we have to choose appropriate plot size and shape to reduce variation in soil fertility. Smith's index of soil heterogeneity is a most useful technique in determining size and shape of plots and most of the researchers are recommended the use of smith's index of soil heterogeneity. Now a days, the variogram techniques are also effectively used for the spatial analysis of soil heterogeneity.

References:

[1] A.B. McBratney, B.M. Whelan, J.A. Taylor and M.J. Pringle. 2000. A Management Opportunity Index For Precision Agriculture: Paper presented at the 5th International Conference on Precision Agriculture and Other Resource Management.

[2] Bhatti, A. U. and Rashid, M. 2005. Shape and size of plots in field experiments and spatial variability. Sarhad J. Agric. 21(2),251-256.

[3]Christidis Basil G. 1931.The importance of plot shape in experiments. Jour. of Agr. Sci., 21,14-37.

[4]Cochran W. C. 1937. Catalogue of uniformity trial data. Suppl. Jour. Royal Stat. Soc., 4, 233-255.

[5] C. E. Wassom and R. R. Kalton.1953. Estimations of Optimum Plot Size Using Data from Bromegrass Uniformity Trials. Research Bulletin 396.

[6]Christel Richter and Barbel Kroschewski.2012. Geostatistical models in Agricultural field Experiments: Investigations based on Uniformity trials. Agronomy Journal,104,91-105.

[7] David Ernest Polson. 1964. Estimation of Optimum Size, Shape, and Replicate Number of Safflower Plots for Yield Trials; Thesis submitted to Utah State University.

[8] Daryl T. Bowman.2001.Common Use of the CV: A Statistical Aberration in Crop Performance Trials. The Journal of Cotton Science, 5 ,137-141.

[9] Dilson Antonio Bisgnin, Lindolfo Storck, Liege C da Costa, Mauricio G Bandinelli.2006.Plot Size variation to quantify yield of potato clones. Horticultura Brasileria,24,485-488.

[10] Diogo Vanderlei Schwertner, Alessandro Dal'Col Lúcio e Alberto Cargnelutti Filho.2015. Uniformity trial size in estimates of plot size in restrict areas; Revista Ciencia Agronomica, 46(3),597-606.

[11]Federer W.T. 1955. Experimental Design: Theory and Application.

[12] Faqir Mohammad, Tariq Mahmood Bajwa And Sohail Ahmad. Size and Shape of Plots for Wheat Yield Trials in Field Experiments. International Journal Of Agriculture & Biology, 4, 397-402.

[13]Girma Taye, Amsal Tarekegne, D.G.Tanner.2000.Estimation of Optimum plot dimensions and replication number for wheat experimentation in Ethiopia. African Crop Science Journal. 8, 11-23.

[14]Guangxlng Wang, George Gertner, Xlangyun Xlao, Steven Wente, AlanB.Anderson.2001. Appropriate Plot Size and Spatial Resolution for Mapping Multiple Vegetation Types. Photogrammetric Engineering & Remote Sensing;,67, 575-584.

[15]Golaszewski J. 2002.Geostastical approach to data from field experiments with check plots. Electronic Journal of Polish Agri. Universities, 5,1505-0297.

[16] George E Boyhan, David B Langston, Albert C.Purvis, C. Randell Hill. 2003. Optimum Plot size & number of replications with short day onions for yield, seedstem formation, No. of doubles & incidence of Foliar disease. J.Amer.Soc.Hort.Sci,.128(3),409-424.

[17]Hathway W.H., Williams E. J., 1958. Efficient estimation of the relationship between plot size and the variability of crop yields. Biometrics, 14, 207-222.

[18] Hatheway W.H. 1961.Convenient plot size. Agronomy Journal, 53, 279-280.

[19]Heike Kn Orzer, Karin Hartung , Hans-Peter Piepho, AndIrisLewandowski.2013.Assessment of variability in biomass yield and quality: what is an adequate size of sampling area for miscanthus? GCB Bioenergy.5, 572–579.

[20]Ignacio Mendez.1970. The study of uniformity trials and six proposals as alternatives to blocking for the design and analysis of field Experiments. Thesis submitted to North Carolina state University, Releigh.

[21]J.G.P.W. Clevers, G.W.A.M. v.d. Heijden, D.L.C. Brinkhorst-v.d. Swan. ;1985. Mapping the heterogeneity of agricultural fields by means of aerial photography.

[22]Jeffrey Willers, Tina Gray Teague, George Milliken and Fred Bourland.2014.Effects of Field Plot Size on Variation in White Flower Anther Injury by Tarnished Plant Bug for Host Plant Resistance Evaluations in Arkansas Cotton.Agronomy , 4, 144-164.

[23]Koch E.J., Rigney H.J. 1951. A method of estimating optimum plot size from experimental data. Agronomy Journal, 43, 17-21.

[24]Leclerc, E. L. , W. H. Leonard, And A. G. Clark. 1962. Field Plot Technique. Burgess, Minneapo lis. 2nd Ed. 373 .

[25]Lin C.S., M.R. Binns.1984.Working rules for determining the plot size and numbers of plots per block in field experiments. J. Agric. Sci., 103,11-15.

[26]L. Storck , A. Cargnelutti filho, S.J. Lopes, M. Toebe, T. Reis da Silveira.2010. Experimental plan for single,double and triple hybrid corn. Maydica, 55, 27-32.

[27]Leandro Homrich Lorentz, Alexandra Augusti Boligon, Lindolfo Storck ,Alessandro Dal'Col Lúcio.2010.Plot size and experimental precision for sunflower production. Sci. Agric.,67(4) ,408-413.

[28]Mello R.M., Lúcio A.D. Storc L.,Lorentz L.H., Carpes Hc., Boligon A.A. 2004. Size and form of plots for the culture of the Italian pumpkin in plastic greenhouse. Scientia Agricola, 61, 457-461.

[29]M.P. Carvalho, S.J. Lopes, A. Cargnelutti Filho, L. Storck. 2009. Variation In Heterogeneity of the Experimental Area And Experimental Plan For Corn Genotype Evaluation. Maydica 54 ,39-45.

[30]M. Asif Masood and Irum Raza.2012.Estimation of Optimum Field Plot Size and Shape in Paddy Yield Trial. American-Eurasian Journal of Scientific Research, 6, 264-269.

[31]M. Asif Masood and Irum Raza.2012.Estimation of Optimum Field Plot Size and Shape in Paddy Yield Trial. American-Eurasian Journal of Scientific Research, 6, 264-269.

[32] Michael D. Casler.2013. Finding Hidden Treasure: A 28-year case study for Optimizing Experimental design. Int. J. of the faculty of Agriculture and Biology,8(1),23-38.

[33] Mohamed Ahmed Al-Feel and Seram Kamal Mohamed Abdullah.2013.The Impact of Plot-Size on the Estimation of Wheat Yield in Sudan: The Case of New-Halfa Agricultural Scheme.Agricultural Economics Working Paper Series no. 2.

[34]Nadia Idrees and Muhammad Inayat Khan2009. Design Improvement Using Uniformity Trials Experimental Data. Pak. J. Agri. Sci., 46, 315-320.

[35]Romalito L. Lapiton, Andrea P.Dela Vifla, Elpidio L. Rosario.1964.Optimum size of Sampling units and number of replication for sugarcane field experiments. The Philippine Journal of Crop Science.

[36]Roger L. Vallejo and Humberto A. Mendoza.1992. Plot Technique Studies on Sweet potato Yield Trials. J. AMER. Soc. HORT. SCI., 117, 508-511.

[37]R. Poultney, J. Riley, R. Webster. 1997.Optimizing plot size and shape for field experiments on Terraces. Expl. Agric. ,33, 51-64.

[38]Smith H.F. 1938.An empirical law describing heterogeneity in the yields of agricultural crops. Journal of Agricultural Science, 28, 1-23.

[39]Swallow WH, Wehner T.C.1986.Optimum plot size determination and its application to cucumber yield trials. Euphytica, 35, 421–432.

[40]Sergio Jose Ribeiro de Oliveira,Lindolfo Storck, Sidinei Jose Lopes, Alessandro Dal'Col Lucio, Sandra Feijo, Henrique Perin Damo. 2005.Plot Size And Experimental Unit Relationship In Exploratory Experiments. Sci. Agric. 62(6), 585-589.

[41]Sandra Feijo, Lindolfo Storc ,Alessandro Dal Col Lucio, Sidinei Jose Lopes, Danton C Garcia, Ricardo H Carpes. 2008. Heterogeneity index of zucchini yield on a protected Environment and experimental planning. Hortic. Bras.,26,35-39.

[42]Satyabrata Pal, Goutam Mandal, Kajal Dihida .2015. Determination of robust optimum Plot Size and shape – a model-based approach. Biometrical Letters ,52, 13-22.

[43]T S G Peiris and R O Thattil .1997. Alternative methods to determine plot sizes for tree crops:a case study from coconut data. Cocos.,12,44-53.

[44]Zhang R, Warrick A.W., Myers D.E.1994.Heterogeneity, plot shape effect and optimum plot size. Geoderma, 62,183-197.