UNIFORMITY TRIAL - SIZE AND SHAPE OF PLOT

Krishan Lal
I.A.S.R.I., Library Avenue, New Delhi - 11 0012

In agricultural experimentation every research worker is interested in ascertaining the relative worth of a set of treatments with reasonable confidence. The simple procedure of trying these 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 such a trail that some treatments have given a better performance than others the experimenter is left wondering whether the differences observed are due to treatments, to inherent fertility differences in the soil or some other accidental factors. Ideally the research worker would like to try the treatments under identical conditions but even with the most uniform land that he can select, he finds that the inherent variation in the soil is quite considerable and the simple procedure of trying out different treatments on single plots side by side in the same field does not suffice for assessing the intrinsic worth of the treatments. A good idea of the nature and extent of fertility variation in land can be obtained from the results of what are known as *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 a native soil differences, are kept constant. At the time of harvest the entire field is divided into smaller units of same size and shape and the produce from each such units is recorded separately. The smallest the basic units, the more detailed is the measurement of soil heterogeneity. In the past, large number of research workers has attempted to study the soil fertility variation through various methods. Some of the methods for soil fertility variation/plot size are given below:

1. Fertility Contour Map

An approach to describe the heterogeneity of land is to construct the fertility contour map. This is constructed by taking the moving averages of yields of unit plots and demarcating the regions of same fertility by considering those areas, which have yield of same magnitude. This approach of describing the variation in fertility has been adopted by large number of workers in India and abroad.

2. Maximum Curvature Method

In this method basic units of uniformity trials are combined to form new units. The new units are formed by combining columns, rows or both. Combination of columns and rows be done in such a way that no columns or rows is left out. For each set of units, the coefficient of variation (CV) is computed. A curve is plotted by taking the plot size (in terms of basic units) on X-axis and the CV values on the Y-axis of graph sheet. The point at which the curve takes a turn, *i.e.,* the point of maximum curvature is located by inspection. The value corresponding to the point of maximum curvature will be optimum plot size.

Harris (1915, 1920) has shown that adjacent areas are correlated, as such the hypothesis of no correlation is not tenable. He utilizes these criteria for subdividing the field into uniform areas. He suggested use of intra-class correlation as a measure of heterogeneity. If this correlation coefficient is in the neighbourhood of zero then field could be considered as homogenous field and whatever plot size is adopted, it will not lead to a large experimental error. These correlation coefficients do not give any idea of plot size.

3. Fairfield Smith's Variance Law

Keeping in view of drawbacks of various methods given above, Smith (1938) gave a empirical relations between variance and plot size. He developed an empirical model representing the relationship between plot size and variance of mean per plot. This model is given by the equation

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

where x is number of basic units in a plot, V_x is the variance of mean per plot of x units, V_1 is the variance of mean per plot of one unit, and b is the characteristics of soil and measure of correlation among contiguous units if $b=1$, $V_x = \frac{V_1}{x}$ and the units making up the plots of x unit are not correlated at all. On the other hand, if $b=0$, the x units are perfectly correlated and $V_x = V_1$ so there is no gain due to the larger size of plot. In general, b will be between 0 and 1 so that the larger plot gives more information with the same number of plots. In that case, larger area for the purpose of experiment will be used. The values of V_1 and b are determined by the principle of least squares.

Example:

Table-1 Grain yield (g/m^2) of Rice Variety IR8 from Uniformity Test covering an area 18x 36 m.

	Column							
Row	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	842	844	808	822	979	954	965	906
2	803	841	870	970	943	914	916	836
3	773	782	860	822	932	971	765	875
4	912	887	815	937	844	661	841	844
5	874	792	803	793	818	799	767	855
6	908	875	899	788	867	790	831	757
7	875	907	921	963	875	880	898	802
8	891	928	871	875	865	777	738	796
9	823	784	754	873	764	775	752	753
10	785	794	764	822	714	748	724	717
11	785	808	823	826	801	712	826	665
12	829	895	774	891	841	815	834	778
13	861	883	739	762	725	717	746	766
14	906	885	790	655	690	769	765	719
15	819	911	788	654	742	786	791	779
16	893	862	769	727	725	721	739	736
17	813	750	742	872	746	812	705	724
18	816	758	811	702	728	741	757	732
19	676	783	734	626	782	704	782	707
20	813	809	695	707	753	680	720	683

	1	2	3	4	5	6	7	8
21	801	764	701	716	753	680	706	665
22	718	784	730	750	733	705	728	667
23	756	725	821	685	681	738	630	599
24	789	681	732	669	681	698	689	622
25	652	622	695	677	698	666	691	688
26	729	650	700	764	680	681	645	622
27	698	713	714	734	651	649	675	614
28	745	677	685	711	688	614	585	534
29	964	727	648	664	623	629	616	594
30	671	729	690	687	705	622	523	526
31	717	694	727	719	669	630	701	645
32	652	713	656	584	517	572	574	539
33	605	708	684	715	659	629	632	596
34	559	722	726	705	571	637	637	577
35	589	681	690	570	619	624	580	570
36	614	633	619	658	678	673	652	602

9	10	11	12	13	14	15	16	17	18
898	856	808	920	808	889	943	894	968	917
858	926	922	910	872	805	775	846	947	965
853	936	927	779	865	720	566	893	914	861
809	778	945	876	901	802	836	778	923	949
792	858	912	839	813	740	730	632	813	914
751	774	863	902	771	747	819	699	670	934
874	928	872	834	892	760	753	720	751	894
855	901	792	752	722	781	739	733	783	786
820	798	847	858	811	875	659	661	759	767
736	724	838	769	819	823	724	750	764	764
759	738	867	725	794	755	730	638	724	734
760	822	803	754	703	743	728	692	748	671
662	634	743	719	710	682	694	675	709	720
743	770	728	740	691	767	648	715	655	665
645	810	816	746	729	814	718	721	708	722
672	814	756	748	714	718	694	704	915	705
640	757	708	750	767	638	754	767	763	685
623	786	805	786	739	727	767	738	659	695
672	703	698	758	762	625	623	699	662	613
757	782	789	811	789	769	751	648	680	696
680	650	690	699	768	751	701	665	603	680
703	684	777	747	713	696	717	732	712	679
629	703	780	720	709	697	731	661	627	644
672	704	705	625	677	704	648	605	585	651
682	713	670	708	707	695	681	716	626	637
661	728	715	775	690	726	669	766	709	645
634	635	639	690	694	637	590	640	658	609
533	671	600	647	592	595	563	634	666	644
619	631	628	591	675	654	640	718	667	649
661	683	619	709	620	651	676	728	547	682
638	714	633	670	649	665	557	734	674	727
545	629	636	580	607	654	585	674	608	612
627	644	661	682	690	636	665	731	753	640
561	590	646	639	672	636	651	684	584	622
568	589	550	622	623	706	725	738	669	636
590	605	538	682	651	653	680	696	633	660

Smith's Index of Soil Heterogeneity

Step-1 Combine the *r x c* basic units to simulate plots of different sizes and shapes. Use only combinations that fit exactly into the whole area, i.e. the product of simulated plots and the number of basic units per plot must equal to the total number of basic units.

Step-2 For each of the simulated plots constructed in Step-1, compute the yield total *T* as the sum of basic units to construct that plot and compute $V_{(x)}$, V_x.

$$V_{(x)} = \frac{\sum_{i=1}^{w} T_i^2}{x} - \frac{G^2}{rc}, \text{ where } w = rc/x \text{ is the total number of plots simulated.}$$

The between plot variance for plot of size 2 x 1 m is

$$V_{(2)} = \frac{\sum_{i=1}^{324} T_i^2}{2} - \frac{G^2}{36x18} = 31{,}370 \text{ and}$$

$$V_x = \frac{V_{(x)}}{x^2}, \qquad V_2 = \frac{V_{(2)}}{2^2} = 7{,}842.$$

Step-3 For each plot size having more than one shape, test the homogeneity of between-plot variance $V_{(x)}$, to determine the significance of plot-orientation (plot shape) effect, by using F test or the Chi-square test. For each plot size whose plot shape effect is non-significant, compute the average of V_x values over all plot shapes. For others, use the lowest value.

For plot of size 2 m^2 there are two shapes only. So, F = 31,370/31,309 = 1.00 (NS).

Step-4 Using the values of the variance per unit are V_x computed in Step 3, estimate the regression coefficient between V_x and plot size x. We fit the equation

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

where Y=log V_x - log V_1 , c=-b and X=log x

$$c = \frac{\sum_{i=1}^{m} w_i x_i Y_i}{\sum_{i=1}^{m} w_i x_i^2}, \quad \sum_{i=1}^{12} w_i x_i Y_i = -3.8503 \text{ and } \quad \sum_{i=1}^{12} w_i x_i^2 = 27.9743$$

c = -0.1376 or b=0.1376.

Here w_I is the number of plot shapes used in computing the average variance per unit area of the i^{th} plot and *m* is the total number of plots of different sizes.

Thus the Fairfield Smith's equation is $\hat{V}_x = \frac{9{,}041}{x^{0.1376}}$.

Table-2 Between-plot variance [$V_{(x)}$], variance per unit area (V_x) and coefficient of variability (CV) of plots of various sizes and shapes, calculated from Rice Uniformity Data in Table-1

Plot Size	and	Shape				
Size m^2	Width m	Length m	Plot numbers	$V_{(x)}$	V_x	CV %
1	1	1	648	9,041	9,041	13.0
2	2	1	324	31,370	7,842	12.1
3	3	1	216	66,396	7,377	11.7
6	6	1	108	235,112	6,531	11.0
9	9	1	72	494,497	6,105	10.7
2	1	2	324	31,301	7,827	12.1
4	2	2	162	114,515	7,157	11.5
6	3	2	108	247,140	6,865	11.3
12	6	2	54	908,174	6,307	10.8
18	9	2	36	1,928,177	5,951	10.5
3	1	3	216	66,330	7,370	11.7
6	2	3	108	247,657	6,879	11.3
9	3	3	72	537,201	6,632	11.1
18	6	3	36	1,981,408	6,115	10.7
27	9	3	24	4,231,622	5,805	10.4
4	1	4	162	113,272	7,080	11.5
8	2	4	81	427,709	6,683	11.1
12	3	4	54	943,047	6,549	11.0
24	6	4	27	3,526,179	6,121	10.7
36	9	4	18	7,586,647	5,854	10.4
6	1	6	108	238,384	6,622	11.1
12	2	6	54	913,966	6,347	10.9
18	3	6	36	2,021,308	6,239	10.8
36	6	6	18	7,757,823	5,986	10.5
9	1	9	72	514,710	6,354	10.9
18	2	9	36	2,017,537	6,227	10.8
27	3	9	24	4,513,900	6,192	10.7

This law can further be used for arriving at an optimum plot size. He has recommended the cost function $C = C_1+C_2 X$ where C_1 = overhead cost which is independent of plot size and C_2 is the consideration of cost by a unit increase in the plot size. Optimum value of plot size is one which minimises the cost per unit of information viz. $(C_1+C_2 X)$

Assuming that variance is given by

$$X_{opt} = \frac{b}{1-b}\frac{C_1}{C_2}$$

The optimum plot size had been worked out for different cost ratio and for values of b.

Optimum Plot Size

The optimum or recommended size of an experimental unit (plot) cannot be given without first considering several factors:

i) Practical Consideration: Certain practical aspects may dictate the size of experimental unit. In animal experiments the pen's or cages may be already constructed and not easily changed. The pasture or paddocks size may be determined by those already available and fenced. If grain combined and other power equipment are used, a fairly large plot may be essential. In green house studies, the experimental unit may have to be small. Experimental resources available would also determine the plot size.

ii) Nature of experimental material : The plot size is different for oat and for corn, pen or cages size for chicken and cattle are also different.

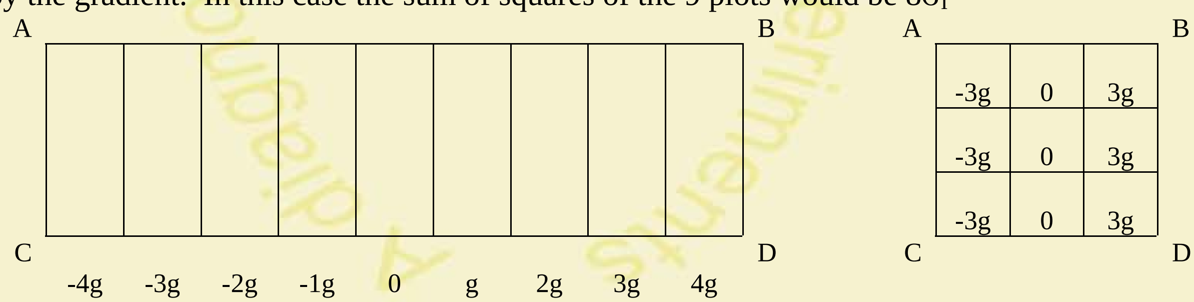
iii) Number of treatment per block or per incomplete block: For large number treatments to be tested, an incomplete blocks design may be used.

iv) Variability among individual or units within the experimental unit (V_s) relative to variability among experimental unit (V_p) treated alike. The variance of treatment mean is proportional to [$V_p + V_s/k$]. The relative size of the V_p and V_s has considerable effects on optimum size.

v) Cost: Let C_s be cost of an individual item within experimental unit which is independent of cost of experimental units. C_p be the cost of experimental unit, independent of individuals in the unit. Then the cost per treatment with a single replication is $kC_s + C_p = C_t$ and the total cost of experiment is a random variable C_t (v treatment, r replications) the optimum size thus depends on the ratio of C_s and C_p.

Shape of Plots

Cochran (1940) has also considered the problem of shape of plots for various types of fields. His results can very well understand by the following example. Suppose we have v=9 treatment to compare and we wish to select the plot shape with the smallest average experimental error variance when the direction of fertility gradient is unknown. The two extreme shapes selected are rectangular [plan (a)] and Square [plan(b)] as shown in Figure A. Let us consider the Case for which a linear fertility, gradient exists. Suppose it is parallel to AB (Fig. A) so that plots lie perpendicular to the gradient. The sum of squares among the 9 plots would be $8\sigma_i^2 + 60g^2$. If fertility to the gradient was parallel to AC, the plots would be parallel to the gradient and all the plots would be equally affected by the gradient. In this case the sum of squares of the 9 plots would be $8\sigma_I^2$



Plan (a) Plan (b)

Fig. A

If σ_I^2 is the random variance within blocks, independent of shape of plot, the mean squares as affected by the two plot shapes, rectangular and square as shown in Fig. A are given below:

Fertility Gradient	d f	Average value of Mean Square Plan (a)	Plan (b)
Parallel to AC	8	σ_I^2	$\sigma_I^2 + (54/8)g^2$
Parallel to AB	8	$\sigma_I^2 + (60/8)g^2$	$\sigma_I^2 + (54/8)g^2$
Average	8	$\sigma_I^2 + (30/8)g^2$	$\sigma_I^2 + (54/8)g^2$

If the plots were square as in plan (b) the sum of squares among plots would be the same for both cases. The average mean square for long narrow plots is smaller than that of the square plots.

As in the experimental design, the plots are generally arranged within blocks. Therefore, for the efficient planning the information on the efficiency of different block size is also of great importance. For working out the relative efficiency block sizes the ratio of error variance of a particular block arrangement to that without block arrangement can be worked out. This ratio is expressed as percentage and was taken as efficiency for that block arrangement.

In many a uniformity trials reported, it is observed that while the Fairfield Smith law explains the relationship between the plot size and average variation (or coefficient of variation) very well, the variation for different shapes of the same plot are not of the same order. In such situation, while the law can be used for arriving optimum plot size, the shape of the plot need to be arrived after examining the variation associated with the shapes. Studies have revealed that the relationship between the block size (for a fixed plot size and shape) and variation also follow a similar law viz. $Y=ax^b$ where Y is the variation (coefficient of variation) and x is the block size.

The repeated analysis of uniformity trial data by super imposing different sizes and shape of plots and blocks and studying the variances or coefficient of variation can be work out and studied with the help of the relationship to arrive the optimum plot/block size/shape. This data can also be used to study the relative efficiency of various experimental design like Completely Randomised Design, Randomised Block Design, Incomplete Block Design, Confounded Factorials, Latin Square.

References

Federer, W. T. (1967) *Experimental design: Theory and Application.* Oxford & IBH Publishing Co., New Delhi.

Gomez, K. A. and Gomez, A. A. (1984) *A statistical procedure for agricultural research.* John Wiley & Sons, New York.

Smith, M.F.C. 1938. An empirical law describing heterogeneity in the yields of agricultural crops. *J. Agril. Sci. Comb.*, **28**, 1-23.