A STUDY OF CO-EFFICIENT OF VARIATION ASSOCIATED WITH PLOTS AND BLOCKS OF DIFFERENT SIZES FOR SOME IMPORTANT FIELD CROPS

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1. INTRODUCTION

In experiments conducted on field crops, the recommended shape and size of plots and blocks is usually obtained from the data of uniformity trials conducted at the same site in the preceding years or at a different site having similar soil and agro-climatic characteristics. Several workers in India have conducted uniformity trials with various crops. Hutchinson and Panse (1935) worked with Cotton, Kulkarni *et al* (1936) worked with Jowar, Wynne, Vaidyanathan and Iyer (1936) and Wynne and Iyer (1936) with Sugarcane. Similar work with Paddy has been done by Bose *et al* (1936), Narsinga Rao (1937), Abraham and Vachhani (1964) and Agarwal and Deshpande (1967). One major limitation of making recommendations based on data of uniformity trials is that it is not practically possible to conduct sufficiently large number of such trials at different centres. Hence any recommended shape and size of plots and blocks for future recommendations is strictly applicable to those sites at which the uniformity trials had previously been conducted. An alternative approach is to study the plot to plot variability of a large number of field experiments conducted in the past and on the basis of this variability, to determine the best size of plot that will give maximum accuracy for comparison of treatment means for a given experimental area. Since different experiments will have different treatments, such as manurial or cultural treatments and since some crops are grown under both irrigated as well as un-irrigated conditions, the per plot variability associated with each experiment will be different under different conditions under which the experiment was conducted. It would, therefore, be interesting to study the variability associated with different sizes of plots and blocks for different experimental treatments and under irrigated or unirrigated conditions of the experiments.

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In the last two decades, a large number of experiments have been conducted on various important crops at different research stations all over the country. The present study is based on the data of experiments conducted during the period 1948-64 on six important crops, namely, Paddy, Wheat, Jowar, Cotton, Oilseeds and Sugarcane.

2. DESCRIPTION OF DATA

Since 1955, the Institute of Agricultural Research Statistics is conducting the project of National Index of Agricultural Field Experiments. Under this programme, the data of all the field experiments conducted at research stations all over the country have been collected. The results of experiments conducted during 1948-59 are presented in two series of the compendia published by the I.C.A.R. The results of experiments conducted during 1960-65 are in the process of publication. In all, the results of about 28,900 experiments conducted during this period were compiled and consolidated. Of these Paddy, Wheat, Jowar, Cotton, Oilseeds and Sugarcane account for about 68% of the experiments. It may be mentioned that the trials which were purely of a varietal nature have not been included in this project. Experiments in the cultivators' fields particularly on fertilizers have assumed considerable importance in recent years. However, since these experiments belong to a different category structually from the experiments at research stations and therefore, are not comparable, they have been kept outside the purview of the present study.

For each experiment included in the study, besides other items, information is available on the size of ultimate plot and the number of plots per block, the treatment details, the design adopted, whether the crop was irrigated or un-irrigated, the general mean of the experiment and the experimental error associated with each plot.

Precision of Experiments

It would be interesting to classify the total number of experiments studied according to the precision achieved for the comparison

TABLE 1

Percentage distribution of experiments according to % S.E. of 6 major crops

CROP

Percentage S.E.	*Paddy*	*Wheat*	*Jowar*	*Sugarcane*	*Cotton*	*Oilseeds*
<3	13·66	6·57	3·63	8·32	3·04	5·43
3 to 5	23·41	16·00	10·17	24·48	11·34	14·06
5 to 10	39·68	47·43	34·52	45·87	44·06	38·87
10 to 15	14·04	18·58	25·65	12·79	23·59	22·51
$\geqslant 15$	9·22	11·41	26·04	8·53	17·97	19·13
Number of experiments available	6326	3837	1544	2908	2170	1657

of the estimates of various treatment means. This could best be done through the percent S.E.'s of treatment means. Table 1 gives the frequency distribution of experiments in percentages according to level of the standard errors obtained.

The percentage of experiments having standard error less than 10% of the mean was 75 for Paddy and Sugarcane, 70 for Wheat, Cotton and Oilseeds and 48 for Jowar. The percentage of experiments having standard error less than 5% of the mean was 37 for Paddy, 33 for Sugarcane, 23 for Wheat, 14 for Cotton and Jowar and 20 for Oilseeds. The differences of the order of about 3 times the standard error are generally detected as significant by the usual tests of significance. On this basis, we find that only about 35% of the experiments on Paddy and Sugarcane were capable of detecting 15% or more difference between the treatment means while the corresponding percentage for other crops was much less. Since in many types of experiments we will be interested in detecting differences of even smaller order, it is necessary in the planning of the experiments to provide for either increased number of replications or other local control measures to effect reduction in the experimental error.

3. Accuracy of Experiments

The information obtained on a treatment contrast in an experiment depends on the magnitude of the experimental error and the number of replications for the contrast. The magnitude of the experimental error for comparative purposes is expressed as the percentage standard deviation divided by the mean and is generally known as co-efficient of variation (C.V.). The co-efficient of variation depends on a number of factors such as the size and shape of plots and blocks, the number of plots per block, their arrangement, the homogeneity or otherwise of the experimental material etc. The co-efficient of variation obtained in different experiments arranged according to the nature of crops, the size of plot and the number of plots per block are given in the Table 2. The ranges of sizes of plots used for classifying sugarcane experiments are different due to relatively larger plots adopted in experiments with this crop.

It may be mentioned that the figures given are not strictly comparable since they are based on experiments conducted at different locations and in different years. However, being based on a large number of experiments (10 and above), these figures would provide a fairly broad pattern of the magnitude of the co-efficient of variation in relation to factors under consideration. In order to further smoothen the data, a function of the form $y = ax_1^{b_1} x_2^{b_2}$ where x_1 and x_2 are the plot-size and number of plots per block respectively and y is the co-efficient of variation was fitted to the data, the fitting of the function being done on the basis of the actual plot sizes and the number of plots per block, using the number of experiments on which each observation is based as weights. The fitted functions for the various crops and the values of multiple correlation (R^2) are given below :—

Crop	*Fitted function*	*Value of R^2*
Paddy	$y=12{\cdot}51\ x_1^{-0{\cdot}0212}\ x_2^{\ 0{\cdot}0566}$	0·2688
Wheat	$y=12{\cdot}40\ x_1^{-0{\cdot}0478}\ x_2^{\ 0{\cdot}0808}$	0 4140
Jowar	$y=17{\cdot}41\ x_1^{-0{\cdot}0363}\ x_2^{\ 0{\cdot}0813}$	0·3890
Cotton	$y=15{\cdot}24\ x_1^{-0{\cdot}0486}\ x_2^{\ 0{\cdot}0367}$	0·4450
Oilseeds	$y=12{\cdot}76\ x_1^{-0{\cdot}0800}\ x_2^{\ 0{\cdot}0526}$	0·4344
Sugarcane	$y=\ 9{\cdot}99\ x_1^{-0{\cdot}0841}\ x_2^{\ 0{\cdot}0434}$	0·2433

The values of R^2 for Wheat, Cotton, Oilseeds and Sugarcane crops have been found to be significant. The estimated values from the fitted functions and the observed values are given in table 2.

TABLE 2.

Average Co-efficient of variation for 6 crops according to plot size and number of plots per block.

Number of Plots per Block

Plot Size in Acre	*≤7*		*8 to 12*		*13 to 16*		*>16*	
	Observed	*Estimated*	*Observed*	*Estimated*	*Observed*	*Estimated*	*Observed*	*Estimated*
				1. Paddy				
< 1/200	16·14 (925)	15·38	17·44 (444)	16·09	17·35 (167)	16·43	15·12 (114)	17·07
1/200-1/100	14·11 (1034)	15·12	15·17 (619)	15·82	15·77 (137)	16·16	16·13 (75)	16·80
1/100-1/50	14·64 (1092)	14·90	15.72 (544)	15·60	15·53 (55)	15·93	17·10 (34)	16·55
≥1/50	15·51 (730)	14·64	14·83 (286)	15·32	17·33 (16)	15·64	25·16 (23)	16·26
				2. Wheat				
<1/200	19·66 (233)	18·35	19·55 (138)	19·57	21·90 (60)	20·18	28·82 (59)	21·30
1/200 1/100	16·62 (450)	17·69	18·10 (383)	18·88	21 01 (71)	19·45	17·29 (45)	20·54
1/100-1/50	17·28 (864)	17·12	17·48 (526)	18·26	18·32 (80)	18·81	17·32 (20)	19·87

⩾1/50	16·97 (592)	16·44	17·92 (310)	17·54	22·64 (11)	18·07	—	19·36
			3. Jowar					
<1/200	24·95 (47)	24·16	33·10 (42)	25·78	—	26·58	28·78 (10)	28·07
1/200-1/100	23·43 (188)	23·51	24·70 (152)	25·08	26·73 (54)	25·84	24·20 (43)	27·31
1/100-1/50	21·40 (301)	22·92	25·49 (181)	24·45	23·17 (60)	25·19	24·93 (68)	26·63
⩾1/50	22·84 (219)	22·22	25·96 (143)	23·71	22·27 (37)	24·44	27·72 (14)	25·82
			4. Cotton					
<1/200	21·76 (144)	21·19	20·98 (83)	21·83	24·31 (12)	22·13	21·26 (20)	22·69
1/200-1/100	20·09 (508)	20·43	22·24 (232)	21·04	18·38 (44)	21·32	21·92 (59)	21·86
1/100-1/50	19·45 (422)	19·75	20·92 (186)	20·33	23·97 (30)	20·62	21·10 (31)	21·13
⩾1/50	19·64 (241)	18·95	18·10 (101)	19·52	17·73 (13)	19·79	20·04 (14)	20·29
			5. Oilseeds					
<1/200	21·78 (179)	21·21	23·44 (132)	22·65	39·05 (10)	23·10	29·66 (16)	23·93
1/200-1/100	20·16 (280)	20·43	21·46 (205)	21·30	20·41 (96)	21·73	20·12 (32)	22·32
1/100-1/50	18·68 (373)	19·32	19·40 (195)	20·16	24·27 (21)	20·55	23·10 (13)	21·30
⩾1/50	21·10 (118)	18·06	17·36 (55)	18·83	—	19·21	—	19·90
			6. Sugarcane					
<1/200	24·20 (42)	17·00	20·15 (22)	17·60	18·95 (11)	17·88	—	18·42
1/200-1/100	16·48 (129)	15·94	19·48 (55)	16·50	16·27 (13)	16·77	—	17·27
1/100-1/70	15·16 (201)	15·31	16·49 (115)	15·85	—	16·11	—	16·59
1/70-1/60	12·98 (208)	15·00	13·91 (95)	15·52	—	15·78	—	16·25
1/60-1/50	14·61 (271)	14·79	13·86 (160)	15·31	—	15·56	15·64 (12)	16·03
1/50-1/40	13·18 (272)	14·53	15·52 (155)	15·04	—	15·29	15·56 (10)	15·74
1/40-1/30	15·13 (463)	14·22	14·77 (352)	14·72	13·10 (44)	14·96	16·11 (37)	15·40
⩾1/30	14·63 (133)	13·26	16·89 (44)	13·73	—	13·95	—	14·36

Figures in brackets indicate the number of experiments on which the observed average Co-efficient of variation is based. Dashes (—) indicate that the number of trials for these classes were too few and hence deleted.

The fitted functions show that for all the crops, the co-efficients of variation decrease with the increase in plot size and increase with the increase in the number of plots per block. The rate at which the co-efficient of variation decreases with the increase in plot size is more marked for oilseeds and sugarcane than for other crops. Among the cereals, the rate of decrease has been maximum for wheat. These indicate that the advantage of using larger plots is not so much in the case of paddy and jowar as for wheat and the non-cereal crops like sugarcane. In the case of paddy the crop is grown under very uniform conditions which might explain partly for the smaller change in the co-efficient of variation with increase in plot size. With increase in number of plots per block, the maximum rate of increase in the co-efficient of variation has been for wheat and jowar indicating thereby that for these crops, there is greater advantage in the use of confounding and other incomplete block designs for reducing the block size. The coefficients of the functions fitted as well as the estimated values clearly show that the co-efficient of variation changes only at a very small rate both with the increase in plot size and increase in number of plots per block upto about 16 plots per block. It, therefore, appears that there is very little advantage in taking large plots of more than one cent for experiments on these crops. The effect of increase in the number of replications instead of an equivalent increase in plot sizes will correspond to an exponent of $-0{\cdot}5$ for x_1. This is much larger numerically than the exponents we have obtained for x_1 for all the crops, thus showing that increase in the number of replications is much more advantageous than increase in the plot size. Except for jowar crop, for other crops there does not appear to be any worth-while gain by using incomplete blocks when the number of treatments per block is less than 16. An important observation is that the co-efficient of variation for all crops is considerably higher than that generally reported on the basis of the data of uniformity trials. It may, therefore, be somewhat misleading to use co-efficient of variation observed in uniformity trials as the basis for determining the numbers of replications needed for experiments. On the other hand, these should be based on the results of actual field experiments with multiple treatments. Among the various crops, the co-efficient of variation is generally lowest for paddy which is grown in fields where the soil heterogeniety is reduced due to the puddling operations. Experiments on sugarcane also have shown comparatively smaller co-efficient of variation partly due to the larger sizes of plots generally used for experiments on this crop. For jowar crop which is grown under dry conditions and in fields which are somewhat lower in fertility, the co-efficient of variation is observed to be highest.

The experimental errors are affected by the non-uniformity in the application of treatment in different replications. In order to study how far the co-efficient of variation is affected by the nature of treatments, the experiments were grouped according to whether the treatments were manurial or cultural. The results are given in Table 3.

It is clearly seen that the co-efficient of variation is larger for all crops in experiments with cultural treatments as compared to manurial experiments. The difference was, however, small for oil-seed crop. For other crops the co-efficient of variation was higher by 8 to 20 per cent.

TABLE 3

Average Co-efficient of variation for 6 crops under manurial (M) and cultural (C) conditions

Plot Size (in Acre)	*M*	*C*	*Plot Size (in Acre)*	*M*	*C*
	1. Paddy			**4. Sugarcane**	
<1/200	14 07 (849)	17·72 (374)	<1/200	18·77 (11)	32·85 (4)
1/200—1/100	13·80 (1070)	14·94 (205)	1/200—1/100	15·33 (95)	18·93 (22)
1/100—1/50	14·42 (1140)	16·96 (191)	1/100—1/50	13·39 (402)	14·95 (158)
⩾1/50	15·04 (643)	15·39 (139)	⩾1/50	14·84 (111)	14·55 (335)
	2. Wheat			**5. Cotton**	
<1/200	18 83 (204)	20·84 (81)	<1/200	20·82 (128)	15·79 (22)
1/200—1/100	17·18 (470)	17·60 (142)	1/200—1/100	20·08 (287)	22·65 (131)
1/100—1/50	16·87 (879)	18·39 (234)	1/100—1/50	19·27 (276)	23·51 (128)
⩾1/50	16·66 (674)	21·45 (156)	⩾1 50	16·87 (212)	24·13 (61)
	3. Jowar			**6. Oilseeds**	
<1/200	32·31 (43)	30·82 (4)	<1/200	22·87 (135)	24·39 (87)
1/200—1/100	22·73 (218)	25·54 (57)	1/200—1/100	18·18 (307)	21·55 (164)
1/100—1/50	21·40 (283)	24·60 (119)	1/100—1/50	18·99 (283)	19·23 (210)
⩾1/50	20·35 (176)	28·97 (105)	⩾1/50	21·95 (123)	17 45 (33)

Figures in brackets indicate the number of experiments on which average is based.

It is generally believed that the soil heterogeneity is higher when the crop is grown under un-irrigated conditions in which case we should expect experiments conducted on un-irrigated crops to show a larger co-efficient of variation than for irrigated crops. The co-efficients of variation obtained for different plot sizes on irrigated and un-irrigated crops are given in Table 4.

In most of the cases, the co-efficient of variation is higher with un-irrigated crop. The differences are however not consistent for different plot sizes but are generally larger for jowar and cotton crops.

TABLE 4

Average Co-efficient of Variation for 6 crops under irrigated and unirrigated conditions

Plot size in acre	*Irrigated*	*Un-irrigated*	*Plot size in acre*	*Irrigated*	*Un-irrigated*
	1. Paddy			**4. Sugarcane**	
<1/200	16·44 (862)	16·33 (539)	<1/200	19·02 (38)	—
1/200-1/100	13·53 (1078)	14·06 (547)	1/200-1/100	16·81 (178)	—
1/100-1/50	14·58 (1044)	15·02 (458)	1/100-1/50	14·36 (706)	—
⩾1/50	15·83 (750)	14·30 (200)	⩾1/50	14·69 (1461)	15·61 (150)
	2. Wheat			**5. Cotton**	
<1/200	18·87 (373)	17·04 (55)	<1/200	21·88 (142)	21·37 (106)
1/200-1/100	16·72 (648)	18·64 (192)	1/200-1/100	19·35 (437)	22·33 (325)
1/100-1/50	16·88 (964)	18·99 (381)	1/100-1/50	18·78 (322)	21·49 (309)
⩾1/50	14·89 (652)	21·78 (165)	⩾1/50	16·03 (158)	20·37 (154)
	3. Jowar			**6. Oilseeds**	
<1/200	25·59 (34)	30·12 (49)	<1/200	20·42 (105)	24·22 (192)
1/200-1/100	23·99 (113)	25·46 (259)	1/200-1/100	22·40 (171)	19·58 (322)
1/100-1/50	20·59 (146)	23·14 (374)	1/100-1/50	20·63 (101)	18·22 (440)
>1/50	24·49 (42)	26·26 (156)	⩾1/50	17·28 (281)	20·54 (131)

Figures in brackets indicate the number of experiments on which average is based.

4. MINIMUM NUMBER OF REPLICATIONS

In the planning of agricultural experiments one of the main points on which decision has to be taken is the number of replications to be provided in the experiment. The number of replications needed depends on the precision desired of the estimates of the treatment effects, and the expected magnitude of the experimental error. Generally, an estimate of the experimental error is obtained from uniformity trials and the minimum number of replications are calculated based on such estimates of plot variability.

However, as we have already observed, the co-efficient of variation obtained in uniformity trials is generally much lower than what is obtained in actual experiments with multiple treatments.

It would, therefore, be desirable to utilize the co-efficient of variation observed in large number of experiments. We give below the minimum number of replications calculated on the basis of co-efficient of variation given in table 2. Generally, in agricultural experiments, the number of plots per block will vary from 8 to 12, confounding being adopted with large number of plots per block. The plot sizes adopted vary from experiment to experiment, but generally for all the cereal crops, it has been observed that a plot size beyond 1 cent is not of advantage. Keeping these considerations in view, the rounded values of the co-efficient of variations given in table 2 have been taken for the calculations. Generally a 10 to 15% difference between the treatments will be considered important enough to be detected although in some situations, such as comparison of different methods of application of a fertilizer, comparison of different forms of phosphatic fertilizers etc. even a smaller difference may be of interest. With estimate of coefficients of variation and the specified difference betweent treatments to be detected, the number of replications is given by

$$r = \frac{2(2{\cdot}1)^2 \, (C.V.)^2}{(\%\ \text{difference})^2} \qquad \ldots(1)$$

where we have taken 5% level of 't' as 2·1 which corresponds to an error degree of freedom around 18 to 20. The error degrees of freedom in actual experiments is generally of this order. The number of replications are given in table 5 below ;

TABLE 5

Minimum number of replications required for 6 major crops

Sl. no.	*Crop*	*Coeff. of variation (C.V.)*	*No. of replications to detect*	
			10% diff. by (1)	*15% diff. by (1)*
1.	Paddy	15	20	9
2.	Wheat	18	28	13
3.	Jowar	24	51	23
4.	Sugarcane	15	20	9
5.	Cotton	20·6	37	17
6.	Oilseeds	20·6	37	17

For detecting 15% difference between treatments, the minimum number of replications varies generally from 9 to 17 except for jowar where the number of replications needed are as many as 23. The study shows that the average number of replications kept in an experiment is about 5 indicating thereby that the majority of experiments carried out were not having adequate number of replications. For all the crops, an extensively large number of replications are needed if 10% difference between treatments are to be detected.

In practice due to limitations of resources, it will be seldom feasible to have so many replications at a particular location. Factorial experiments, which provide for an effective increase in the number of replications, repetition of experiments over different years and in some cases at different locations are some of the ways by which greater replication is obtained for estimating treatment effect.

Summary

This paper presents the results of a study conducted for determining the size of plots and blocks on the basis of plot to plot variability of a large number of field experiments conducted in the past for six major crops, namely, paddy, wheat, jowar, cotton, oilseeds and sugarcane. About 75% of the experiments on paddy and sugarcane, 70% on wheat, 59% on cotton and oilseeds and 48% on jowar reported for the period 1948-64, had standard error less than 10% of the mean. Further, only about 35% of the experiments on paddy and sugarcane were capable of detecting 15% or more differences between treatment means. It was found that, in general, a large number of replications was needed to detect differences between treatment means of this order. The average co-efficient of variation (C.V.) obtained for these crops revealed that the C.V. decreased with increase in plot size and increased with increase in number of plots per block. The co-efficients of variation obtained for the crops under study are found to be considerably higher than those reported from the uniformity trials data.

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