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Studies on the Relative Efficiency of Different Experimental Designs for Sunflower (*Helianthus annuus* L.)

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Authors' contributions

This work was carried out in collaboration between all authors. Author NL designed and carried out the study and performed the statistical analysis. Author MK wrote the protocol and first draft of the manuscript. Author KK guided the other authors during whole research period. Author RKT managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The best experimental design to use in any given condition is the one which estimates the desired effects and contrasts with maximum precision or efficiency. In uniformity trial data, the treatments being considered as dummy, the relative efficiencies of various experimental designs were determined using the yield data taken from the uniformly raised sunflower crop during February 2014 to June 2014 at CCSHAU research farm, Hisar. Randomized Block Design (RBD) was found to be more effective in reducing error variation over Completely Randomized Design (CRD). Latin Square Design (LSD) was found to be more advantageous over CRD as well as RBD only when

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columns were considered as blocks. Split plot design was more efficient than RBD on comparison with sub plots (10.82% gain in precision) while less efficient with main plots in comparison to RBD. In case of factorial experiments, the gain in efficiency of the confounded design of order 2^5 increases upto 68 per cent for the 4-plots block.

Keywords: Experimental design; relative efficiency; uniformity trial; completely randomized design; randomized block design; Latin square design.

1. INTRODUCTION

Experimental designs have been widely used for the purpose of controlling experimental error. Some of the natural variation among the set of experimental units are physically handled in these designs so as to contribute minimum to differences among treatment means. There are various experimental designs available to meet the experimenters' requirements for different practical situations in order to control nature of variation. The best design to use in any given situation is the one which provides the estimate of desired effects and contrasts with maximum precision (efficiency), and has a simple layout and analysis. Thus the experimental design with adequate control of variability or which has minimum error variance is said to be more efficient than the one with relatively larger variance. The design which found more efficient is adopted for carrying out the experiments and for getting better results.

The same crop variety is grown in the experimental area under exactly uniform conditions throughout the duration in uniformity trials. At the time of harvest, the entire experimental area is divided into small units of same dimensions. Then the crops of each unit are separately harvested and the yield also recorded separately, to measure the heterogeneity present in the field which is only due to the soil because all other factors are uniform. Soil heterogeneity complicates the design and analysis of field experiments. In order to minimize the experimental error, suitable experimental design was selected from many available designs to meet experimenter's requirements under different circumstances. The prospects of increased accuracy by a proper choice of experimental plan have been widely explored (Khan [1]).

Completely Randomized Design (CRD) can be improved by providing error control measures by blocking and the improved design so obtained is called Randomized Block Design (RBD). This principle has been extended further to improve RBD by eliminating more sources of variation and Latin Square Design (LSD) is one such improved design with provision for the elimination of two sources of variation. Under the situations where different combinations of factors at different levels are tested, it is the factorial experiment alone which can furnish information regarding the interactions between various factors under study. It becomes extremely difficult to accommodate a large number of treatments in a block, because blocks of large sizes will not be sufficiently homogeneous and the precision of the treatments comparisons with heterogeneous blocks may suffer. One possible way of maintaining homogeneity would be to adopt the principle of confounding by sacrificing all or a part of information on certain treatment comparisons. The whole replicate is divided into desired number of small blocks.

Sunflower is one of the five popularly grown oilseeds crops in the world. India is the third largest oilseeds economy in world. Realizing the importance of sunflower (*Helianthus annuus* L.), being the third most important oilseeds crop in India after groundnut and mustard, the present study was undertaken to compare the relative efficiency of different designs leading to different arrangements of plots in sunflower.

2. MATERIALS AND METHODS

Uniform crop of sunflower (*Helianthus annuus* L.) was raised over gross area of 35 m × 40 m which after eliminating border effects reduces to net area of 32 m × 36 m. For conduction of field experiment, sunflower hybrid 66A507 Pioneer was selected and research was conducted during February 2014 to June 2014 at Department of Genetics and Plant Breeding research farm, CCS Haryana Agricultural University, Hisar, Haryana. The experimental field was divided into rows (E-W direction) and columns (N-S direction). The adjacent basic units (*i.e.* 1 m × 1 m) combined to form plots of different shapes and sizes.

The efficiency of RBD relative to CRD can be estimated by the formula

$$\text{E (RB to CR)} = \frac{E_e\ (\text{CR})\ (n_1+1)\ (n_2+3)}{E_e\ (\text{RB})\ (n_1+3)\ (n_2+1)} \times 100 \quad (1)$$

Where;

E_e (RB) and E_e (CR) are the error mean squares of RBD and CRD, respectively and n_1 and n_2 are their respective degrees of freedom.

For the present study, the block sizes of 4, 8, 12 and 16 plots were taken to compare efficiencies. Further, the relative efficiency was calculated for the blocks both in N-S direction and E-W direction.

The relative efficiency of LSD to CRD is given as

$$\text{E (LS to CR)} = \frac{E_e\ (\text{CR})\ (n_1+1)\ (n_2+3)}{E_e\ (\text{LS})\ (n_1+3)\ (n_2+1)} \times 100 \quad (2)$$

Where;

E_e (LS) and E_e (CR) are error mean squares for LSD and CRD, respectively and n_1 and n_2 are their respective degrees of freedom.

If the relative efficiency E (LS to CR) > 1, design LSD is more efficient than CRD. If E (LS to CR) < 1, the converse is true.

The estimated relative precision of LSD over RBD using rows as blocks and columns as blocks, can be obtained as

$$\text{E (LS to RB)} = \frac{E_e\ (\text{RB})(n_1+1)(n_2+3)}{E_e\ (\text{LS})(n_1+3)(n_2+1)} \times 100 \quad (3)$$

Where,

E_e (LS) and E_e (RB) are error mean squares for LSD and RBD, respectively and n_1 and n_2 are their respective degrees of freedom.

For the given uniformity trial data, the Latin squares of order 5, 8 and 10 were to be studied for the plot sizes 1 m^2 and 2 m^2; and the relative efficiencies of these in relation to CRD and RBD were worked out.

The efficiency of the split plot design relative to the RBD on the sub plot comparison and main plot comparison is;

$$\text{E (Sub plot)} = \frac{n_a E_a + n_b E_b}{(n_a + n_b) E_b} \quad (4)$$

$$\text{E (Main plot)} = \frac{n_a E_a + n_b E_b}{(n_a + n_b) E_a} \quad (5)$$

Where,

E_b and E_a are error mean square for main plots and sub plots respectively and n_b and n_a are their respective degrees of freedom.

For present study, the split plot design with 5 main plots having 3 sub plots with 3 replications was considered.

The magnitude of increase in the precision due to confounding can be obtained by

$$E = \frac{n_b E_b + n_e E_e}{(n_b + n_e) E_e} \times 100 \quad (6)$$

Where;

E_b and E_e are mean squares for blocks within replication and error, respectively and n_b and n_e their respective degrees of freedom.

The comparison of different confounded designs (2^5, 2^4), (2^5, 2^3) and (2^5, 2^2) with RBD has been made with four replications in each case.

3. RESULTS AND DISCUSSION

The relative efficiencies of RBD over CRD were computed for 4, 8, 12 and 16 plots block of various plot sizes, elongated in N-S direction as well as in E-W direction. The results obtained from the comparisons of efficiencies for different block arrangements are presented in Tables 1 and 2. The results showed that when the plots were elongated in E-W direction, the increase in the block size results in the decrease in relative precision (from 114.042 for 4-plots block to 91.178 for 16-plots block in case of **1 m^2 plot size**), which indicates that the larger blocks were more heterogeneous. For a given plot size the gain in efficiency due to RBD was more for smaller blocks implying that smaller blocks were more effective in reducing the error variation. From the Table 1, it can also be noted that there was no appreciable gain in efficiency for the larger blocks (only 29.355 per cent for **18 m^2 plot size in 16-plots block)**. The relative efficiencies were relatively increased with the increase in plot size, for a given size of the block. The relative efficiency of RBD over CRD is maximum for plot of size 18 units, for a given block size (*i.e.* 189.431 for 4-plots block).

When the plots were elongated in N-S direction, the RBD was superior to CRD and increase in the block size results in the decrease of the gain in precision. Also the relative efficiency was highest for the plot size 2 units for 4-plots block (*i.e.* 130.262). Thus, it was observed that when the plots were elongated in N-S direction, RBD was less effective in reducing the error variation but there was considerable gain in efficiency when the blocking was done in E-W direction. It can be concluded that blocks made perpendicular to the fertility gradient give efficient results. The similar results were also obtained by (Khan [1], Goswami [2], Sokhal [3], Khurana [4] and Kumar [5]).

A random sample of 4 sets of 5×5, 8×8 and 10×10 Latin squares were taken and the relative efficiencies of these over RBD and CRD were computed separately considering row and column blocking and results are presented in Table 3. The results from Table 3 revealed that in Latin square of the order 5×5, the gain in efficiency over CRD was 97.297 per cent *i.e.* 97 more replications would be required to get the same precision from CRD. Latin square of the order 8×8 was 72.618 per cent more efficient than CRD over the same experimental material and in case of 10×10 Latin square, the gain in efficiency over CRD was 81 per cent. However, the higher order Latin squares lead to decrease in efficiency as compared to the smaller order Latin squares, due to the introduction of more heterogeneity within rows and columns.

It is also obvious from Table 3 that the LSD was superior to the RBD. In case of 5×5 Latin square, the gain in efficiency was 63.576 per cent whereas it was 43.959 per cent for the Latin square of order 8×8. The Latin square of the order 10×10 was 64.343 per cent more efficient than RBD. Thus the gain in efficiency decreases with the increase in the order of Latin square. This was for the design when the columns were taken as blocks. But when the rows were considered as blocks (ignoring columns), the use of Latin square was not so beneficial and even may become relatively less efficient for the various order Latin squares. Hence, it can be concluded that only effectively designated Latin squares were preferred to CRD and RBD (with column blocking), for a given number of plots. It may also save some replications to achieve the required degree of precision.

Table 1. Efficiency of RBD over CRD when plots were elongated in E-W direction

Plot size (in units)	Block efficiency			
	4-plots block	**8-plots block**	**12-plots block**	**16-plots block**
1	114.042	101.651	98.845	91.178
2	121.312	102.776	86.719	52.212
3	128.915	91.215	85.134	57.982
4	135.136	88.693	77.862	75.639
6	150.465	143.782	121.053	116.518
8	155.893	85.659	62.615	-
12	161.557	149.312	128.351	119.422
16	168.676	-	119.422	-
18	189.431	158.434	-	129.355

Table 2. Efficiency of RBD over CRD when plots were elongated in N-S direction

Plot size (in units)	Block efficiency			
	4-plots block	**8-plots block**	**12-plots block**	**16-plots block**
1	114.041	101.552	98.849	91.178
2	130.262	115.116	103.810	97.300
3	118.849	111.265	95.604	77.996
4	115.136	98.693	87.762	75.639
6	125.865	113.282	101.083	95.338
8	121.893	85.639	72.815	-
12	119.537	109.272	100.334	94.412
16	118.560	-	91.412	-
18	120.371	95.334	-	89.655

The main plots as well as sub plots efficiencies for split plot design are given in Table 4. It was observed that a gain in precision at 10.82 per cent was obtained on comparison with sub plots while this design was less efficient with main plots in comparison to randomized block design. Here we conclude that the split plot design was more efficient than randomized block design where the experimenter was interested to have more precision in sub treatments and interaction comparisons than main treatments.

The relative efficiency of the confounded design was worked out by the ratio of variance obtained without confounding in 32 plot blocks, with respect to the confounding in 16-plots block, 8-plots block and 4-plots block and results are presented in Table 5. It is clear from the Table 5 that there was a gain in efficiency of 27 per cent in case of 16-plots block and when the block size was reduced to 8-plots block, this gain in efficiency increases to 43 per cent. Further, for 4-plots block, this gain in efficiency becomes 68 per cent. Hence it can be concluded that the gain in efficiency of the confounded design of order 2^5, increase with the decrease in the block size. And it was also obvious that the confounded designs were more efficient than the randomized block designs when the number of treatment combinations become large as the sub-blocks

Table 3. Efficiency of LSD over CRD and RBD using rows and columns as blocks

Plot size (in units)	Experiment	CRD	RBD (Columns as block)	RBD (Rows as block)
		5 × 5 Latin square		
1	1	177.245	112.134	178.524
	2	144.503	113.426	137.394
	3	140.652	104.850	145.348
	4	165.154	106.145	160.733
	Average	156.888	109.138	155.499
2	1	229.520	193.650	167.926
	2	150.117	152.372	115.708
	3	350.150	300.345	215.363
	4	221.035	225.694	114.225
	Average	237.705	218.014	153.305
Overall average		197.297	163.576	154.402
		8 × 8 Latin square		
1	1	154.258	124.259	142.624
	2	251.354	126.451	238.654
	3	198.315	211.675	106.325
	4	180.351	144.546	119.841
	Average	196.068	151.729	151.861
2	1	131.804	125.146	111.214
	2	135.421	129.251	105.346
	3	139.751	123.451	119.128
	4	189.692	166.912	113.247
	Average	149.167	136.197	112.234
Overall average		172.618	143.959	132.047
		10 × 10 Latin square		
1	1	151.264	127.583	135.965
	2	165.354	181.221	101.574
	3	147.215	131.022	117.241
	4	221.615	147.165	123.265
	Average	171.362	146.747	119.511
2	1	231.529	197.532	141.011
	2	198.302	178.015	134.812
	3	179.228	165.854	110.325
	4	154.212	186.354	119.657
	Average	190.818	181.938	126.451
Overall average		181.089	164.343	122.981

Table 4. Efficiency of split plot design (with 3 replications) in comparison to RBD

Plot size (in units)	Experiment no.	Main plot	Sub plot	Efficiency	
				Main plot	Sub plot
1	1	5	3	101.37	113.71
	2	5	3	118.54	87.92
	3	5	3	74.12	121.44
	4	5	3	96.73	100.85
Average				97.69	105.98
2	1	5	3	84.29	137.52
	2	5	3	107.48	90.15
	3	5	3	92.61	110.67
	4	5	3	115.07	124.33
Average				99.86	115.67
Overall average				98.78	110.82

Table 5. Efficiency of confounding

Plot size (in units)	Experiment no.	2^5 Factorial experiment		
		16 – plots block	8 – plots block	4 – plots block
1	1	119.215	135.267	159.452
	2	125.425	131.912	157.361
	3	117.251	124.245	167.124
	4	107.258	112.421	161.244
Average		117.287	125.961	161.295
2	1	135.365	157.215	171.548
	2	145.285	165.354	185.389
	3	125.361	167.248	175.481
	4	142.212	150.353	169.345
Average		137.056	160.042	175.441
Overall average		127.171	143.002	168.368

were able to remove more error variations from the experimental units, thus resulting in more precision. The results were in agreement with (Khan [1], Kumar [5], Kaushik [6], Kumar [7] and Idrees [8]).

4. CONCLUSIONS

A comparison among the efficiencies of various designs showed that RBD was more efficient than CRD for all block sizes, for the given plot sizes in both the directions. The increase in the block size results in the increase in relative precision when the plots were elongated in either direction, indicating that the larger blocks were more homogeneous. It was observed that when the plots were elongated in N-S direction, RBD was less effective in reducing the error variation but there was considerable gain in efficiency when the blocking was done in E-W direction. In LSD, the higher order Latin squares lead to decrease in efficiency as compared to the smaller order Latin squares due to the introduction of more heterogeneity within rows and columns. The gain in efficiency decreases with the increase in the order of Latin square over randomized block design when the columns were taken as blocks. But when the rows were considered as blocks (ignoring columns), the use of Latin square was not so beneficial. Split plot design was found to be more efficient than randomized block design where the experimenter was interested to have more precision in sub treatments and interactions; while this design was less efficient with main plots in comparison to randomized block design.The gain in efficiency of the confounded design increased with the decrease in the block size.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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