Further Studies in Newer Designs for Large-Scale Variety Tests

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Agricultural field experimenters have often in the past been unable to secure valuable or pertinent information because they were handicapped in not having the proper designs available by which to lay out their tests. Probably the greatest source of error has been soil heterogeneity, and many attempts have been made to devise some scheme whereby the effect of this variation could be minimized.

Review of Literature

The randomized scheme of plot technique as devised by Fisher (4), where each replication includes all varieties or treatments in a complete block setup, has given very satisfactory results; and it was from these designs that Yates (12, 13, 14) evolved the quasi-factorial scheme whereby incomplete blocks are used as the basis for the removal of variations due to soil heterogeneity.[2] He reported (12) gains of from 26 to 57 percent in precision for the quasi-factorial over the randomized complete block arrangement. Bach incomplete block contains only a small number of the strains or treatments being tested, a complete replication being made up of a series of these incomplete blocks which are arranged so that variance can be removed for the strain or treatment which is free from block effects and thus an error variance is obtained for testing the strain or treatment means. Since all incomplete block designs have the property that the number of varieties or treatments included in each block is smaller than the total number to be tested, there is consequently a gain in precision due to the use of smaller blocks, at the expense of loss of information on those comparisons which are confounded with blocks. The total effect of soil heterogeneity determines whether or not this gain in precision due to using smaller blocks more than offsets the other loss of information.

Goulden (5, 6, 7) discusses the use of the several types of quasi-factorial designs and presents type problems to demonstrate the calculations involved. He (6) found gains of from 20 to 50 percent in precision for the quasi-factorials over the randomized complete blocks, and concludes that an increase of 50 percent in precision on the average might be expected by using these designs instead of the randomized complete block setup (5).

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[2] Figures in parentheses refer to Literature Cited.

Day and Austin (3) have made practical use of the 3 dimensional scheme in work on forest genetics and found their test, using 729 varieties of pines, to have a precision of 250 percent when compared with the randomized complete block design.

LeClerg (8) calculated the relative precision of the quasi-factorial and randomized complete block arrangements on sugar-beet seedling-stand data assuming 36, 25, 16, 9, and 4 hypothetical treatments. He found gains of 39 to 1 percent in precision for the quasi-factorial, when comparing the 2 designs for 36 treatments in 1937 and 1938, respectively. The fewer number of treatments resulted in only small gains or losses when using the quasi-factorial, so he concludes that with 25 or fewer treatments a slight gain in precision may result, but a loss is more likely.

Skuderna and Doxtator (10) in testing sugar-beet varieties under varied conditions conclude that the incomplete block designs are likely to be less efficient than the randomized complete block design for tests of 16 or less varieties, about equal in efficiency for 25 varieties, and with large gains in efficiency where 49 varieties are being tested.

Bush (1) reported precisions of 206 and 268 percent for weight of beets, and 228 and 296 percent for sugar percentage, using 343 strains of sugar beets when comparing the three dimensional design with the randomized complete block design. He further reported precisions of from 141 to 262 percent for weight of beets, and from 131 to 196 percent for sugar percentage when comparing various other types of quasi-factorial schemes with the randomized complete block design.

All of the above mentioned publications have dealt with the designs whereby inter-block information was not recovered. A newer method of calculation has been developed whereby both inter-block and intra-block information may be recovered. Cox, Eckhardt and Cochran (2), Yates (15, 16, 17), and Pope (9) have presented actual problems covering all quasi-factorial designs with their analysis, using this newer method of calculation. A substantial gain in precision is obtained by this new method over the older method.

Nomenclature

There has been considerable confusion in the nomenclature of these quasi-factorial designs, which are also known as pseudo-factorials, the following list being presented in order to clarify the different terminology.

Balanced lattice—two dimensional with all possible groups of sets.

Balanced incomplete block—incomplete randomized block.

Lattice square—quasi-Latin square.

Lattice design—two dimensional with two groups of sets.
Triple lattice—two dimensional with three groups of sets.
Cubic lattice—three dimensional with three groups of sets.

The nomenclature as first given will be used to designate the designs in this paper.

Precision and Efficiency of Designs

Quasi-factorial designs have been used quite extensively in the variety-testing program of the Great Western Sugar Company for the past 3 years and the precisions of these tests for 1939 and 1940 in percentage of the randomized complete block are presented in table 1.

Table 1.—Precision of quasi-factorial designs in percentage of the randomized complete block design—1939 and 1940 results.

Type of design	Year tested	No. of varieties	No. of replicates	Plot size	Precision of Quasi-factorial	
					Tons per A.	Percentage sugar
Balanced incomplete block	1939	31	6	4 rows x 30 feet	141	134
Lattice design	1939	169	6	2 rows x 30 feet	168	131
Lattice design	1939	169	6	2 rows x 30 feet	183	194
Cubic lattice	1939	343	3	2 rows x 30 feet	206	228
Cubic lattice	1939	343	6	2 rows x 30 feet	268	296
Triple lattice	1939	49	9	4 rows x 30 feet	262	196
Triple lattice	1939	49	9	4 rows x 30 feet	332	200
Triple lattice	1940	16	6	4 rows x 30 feet	187	121
Triple lattice	1940	16	6	4 rows x 30 feet	121	110
Triple lattice	1940	16	6	4 rows x 30 feet	124	134
Triple lattice	1940	25	9	4 rows x 30 feet	109	142
Triple lattice	1940	64	9	4 rows x 30 feet	156	244
Triple lattice	1940	16	6	4 rows x 60 feet	139	100
Triple lattice	1940	16	6	4 rows x 60 feet	111	108

These precision values were obtained by the older method of calculation whereby inter-block information was not recovered. In all cases there was a gain in precision by using this method, even in cases where only 16 varieties are involved and some very large gains are noted where a larger number of varieties are included in the test. There is, also, a tendency for a greater precision where the number of replicates is increased. Precision values are high according to the 1939 results for the triple lattice, and since this design is a very practical type for our tests, it has been the only quasi-factorial design used in 1940 and 1941, where it has given satisfactory results.

The newer method of calculation was used in 1941 where only the triple lattice was employed. These results are presented in table 2, the precision in percentage of the randomized block being presented where inter-block information was not recovered in comparison with the newer method whereby both inter- and intra-block information were recovered.

Table 2.—Precision of the triple-lattice design comparing intra-block with inter + intra-block recovery in percentage of the randomized complete block design —1941 results.

					Precision of triple lattice			
			w/w' (b)		Intra-block		Inter + intra-block	
No. of varieties	No. of replicates	Plot size	Tons per A.	Percentage sugar	Tons per A.	Percentage sugar	Tons per A.	Percentage sugar
16	6	4 rows x 60 feet	5	5	145	134	156	143
16	6	4 rows x 30 feet	4	7	164	157	128	106
16	6	4 rows x 30 feet	1	1	78	75	101	103
16	6	4 rows x 30 feet	3	5	98	132	111	142
16	6	4 rows x 30 feet	8	10	96	297	110	368
49	9	4 rows x 30 feet	5	5	97	120	137	126
49	9	4 rows x 30 feet	6	8	127	121	134	127

(b) Weighting factors.

It is very apparent that the newer method for calculation is more precise than the older method which is, of course, to be expected, but in order to analyze properly these data it might be well to refer to the literature where the question of efficiency and precision is adequately discussed.

Weiss and Cox (11) on page 304 of their bulletin describe efficiency. According to their discussion when w/w' is equal to 1, it means that the soil is homogeneous and the efficiency of the triple-lattice design is below that of the randomized complete block arrangement. In heterogeneous soil when w/w' is greater than 1, the reduction in block size by accounting for more soil variation usually more than compensates for the loss of information due to the arrangement.

Cox, Eckhardt, and Cochran (2) (table 25) give the percentage efficiency of triple-lattice designs with a given value of k (number of varieties per block) and w/w' (weighting factor). The gain in precision of the triple lattice in comparison with the randomized complete block will not be greater than the percentage efficiency, but this indication may be altered somewhat due to the local conditions, so that the precision may be greater or less than the indicated efficiency. However, this table does serve as a good check on the computations. Percentages less than the ones given cannot be expected where w/w' = 1. If we apply the rule that equal weights are used when B < B, B and E being the block and error mean squares, respectively, the lower limits are set by the efficiency of the design plus a loss of information due to inaccurate weights, which has a maximum of 4 to 5 percent.

The results obtained in these tests confirm the fundamental concepts of this design so that while there may be some question as to the necessity of using the design for 16 varieties, at least nothing is lost and by keeping the blocks together, by replicates which was done in these tests, it is possible to use the randomized complete block analysis where there is no apparent gain in precision.

General Considerations

There are several points which make the quasi-factorials appealing to the sugar-beet experimenter strictly from the agronomic viewpoint when testing a large number of varieties. It has seemed advisable to use relatively large plots in testing sugar-beet varieties, which are normally very heterozygous, in order that a fairly large sample might be taken without employing too great a number of replicates. Plot sizes as used in our work are 2 rows (20 inches apart) x 30 feet for some preliminary testing, 4 rows x 30 feet for some testing on the Experiment Station, and 4 rows x 60 feet in tests which are more or less cooperative with farmers. The smaller block of the quasi-factorial is desirable from the standpoint of soil variability on account of these relatively large plots. Irrigation control is much easier within a small block than over a large number of plots in a block or replication of the randomized complete blocks. It may be extremely difficult to complete one set of operations over one whole replication within a short enough time to consider it as uniform, especially if changes in weather occur. Also, general labor operations may be handled more efficiently with the smaller quasi-factorial block as a unit.

The general recommendation has been to use quasi-factorial designs where 25 or more varieties are involved, but from the results obtained here it would seem that we are safe in placing the limit at 16 or more varieties for sugar-beet variety testing. These are arbitrary limits and may be altered somewhat due to varying conditions. However, if tests designed as quasi-factorials are arranged in the field so that the blocks form complete replicates in as compact a form as possible the use of the randomized block analysis should be used where losses in precision are found to occur by the quasi-factorial analysis.

While the triple lattice has been found to be very practical and precise in our tests and can be highly recommended, no experimenter should use this or any other of the quasi-factorial designs until he determines which of these designs is the better adapted for each particular experiment.

The following list of characteristics should be an aid in determining which of the designs to use.

1. Balanced lattice:
   - (a) $V = k^2$ (where V = the number of varieties and k = the number of varieties per block).
   - (b) Number of replicates in units of $k + 1$.
   - (c) Block is unit.

2. Balanced incomplete block:
   (a) $V = k^2 - k + 1$.
   (b) Number of replicates in units of k but there is no complete replication except where Youden Squares are used.
   (c) Block is unit.

3. Lattice squares:
   (a) $V = k^2$.
   (b) Number of replicates in units of $(K+1)/2$ where k is odd and $k + 1$ where k is even.
   (c) Square is unit.

4. Lattice design:
   (a) $V = k^2$.
   (b) Number of replicates = 2, 4, 6, 8, etc.
   (c) Block is unit.

5. Triple lattice:
   (a) $V = k^2$.
   (b) Number of replicates = 3, 6, 9, etc.
   (c) Block is unit.

6. Cubic lattice:
   (a) $V = k^2$.
   (b) Number of replicates = 3, 6, 9, etc.
   (c) Block is unit.

Simunary

Since all of the tests using the quasi-factorial designs thus far conducted by the Great Western Sugar Company show a gain in precision over the randomized complete block, these precisions ranging from 101 to 358 percent, the additional effort necessary for planning the experiment and analyzing the data certainly is justified. There should be no hesitation as to the use of quasi-factorial designs in sugar-beet variety testing under the varied conditions of the Great Western territory.

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Selection of Sugar Beets for Size of Root Under Wide and Normal Spacings[1]

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The use of 40 x 40-inch spacing as an aid in testing sugar-beet varieties was suggested by Xnckols (3) in 1936. He pointed out that, with conventional 12 x 20-inch spacing, errors are introduced by variations in stand which cannot be avoided by the use of competitive beets and stated that the use of 40-inch spacing, as a method of eliminating the effects of irregular competition, had been tested with some promise.[3] In 1938 Nuckols (4) proposed the use of this spacing as an aid in selection of sugar-beet roots for breeding purposes, and discussed several advantages of the method.

[1]Contribution from the Division of Sugar Plant- Investigations, .Bureau of Plant Industry, U. S. Department or Agriculture.

[2]Assistanl Pathologist, located at Fort Collins, Colo. The writer is indebted to Dewey Stewart, Associate Pathologist, for advice in connection with the planning of this work, and to R. Ralph Wood. Agent, for assistance in carrying out the- details of the experiment.

[3]A competitive beet is one which is surrounded by normally spaced beets.