4/ The symbol G (gelb) was used by Kajanus (5) to describe a yellow root character which may have been a similar genetic type for which Keller (6) used the symbol Y. Lindhard and Iverson (7) adopted Kajanus' symbols of R and G for red and yellow color types. Vilmorin (12) substituted the symbol J (jaune) for that of G. Owen in correspondence expresses the viewpoint that Y is a factor for extension of pigment rather than one which produces yellow pigment. Y causes much more pigment to be developed but does not determine whether the color is red or yellow.

THE THREE DIMENSIONAL QUASI-FACTORIAL EXPERIMENT WITH THREE GROUPS OF SETS FOR TESTING SUGAR BEET BREEDING STRAINS

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The recent trend toward breeding and production of "Home Grown" sugar beet seed has emphasized the problem as to how the breeding strains may be adequately tested in order to insure the maintenance or improvement in performance of the commercial varieties which evolve from these strains.

The ordinary commercial variety of sugar beets is extremely heterozygous, not unlike the commonly known varieties of corn (excluding present-day hybrids), or the human race. When a plant breeder is attempting improvement in resistance to disease, yielding ability, sugar content, shape of root and crown, and perhaps other characters, he is certain to be dealing with large numbers of strains regardless of whether the family or inbreeding mode of attack is followed.

The fact that our soils are very heterogeneous is generally recognized. When the number of strains being tested becomes quite large, the soil variations are necessarily increased due to the larger area covered by the test. It is obviously desirable to remove the effects of soil variations upon yield and other characters as nearly as possible.

Fisher 2/[b] introduced the randomized scheme of plot technique, basing his theory on the complete block setup i.e., where each replication includes all varieties. Yates 6/7/8/ has more recently evolved the scheme whereby incomplete blocks are used as the basis. These incomplete blocks are made up by arranging the strains in a series of blocks, each of which contains only a small number of the strains being tested. The arrangement is such that a variety variance can be calculated which is free from block effects and an error variance obtained for testing the significance of variety means.

There have been several types of designs evolved covering all phases of agronomic tests. Goulden 3/4/ has discussed the various types of designs and worked out examples to demonstrate the calculations involved for each type. He recommends the use of the Three Dimensional Quasi-Factorial method, designed by Yates, where the number of strains to be considered is 216 or more.

Day and Austin 1/ have applied this three dimensional scheme in testing the germination of 729 varieties of pines. Their experiment was planned so that the varieties were subjected to as many different block effects as possible, even to the point of introducing watering differences between blocks. The corrected average number of days from watering time to germination for each

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a) Statistician, Great Western Sugar Company

b) Figures in brackets refer to Literature Cited, Page 116 progeny was 4.6 days, while the actual average range was from 3.3 to 5.9 days. This is evidence that the design did eliminate the effects of plot differences upon the average values for the watering. They found their test to be 2½ times as precise as if the ordinary randomized block design had been used.

This scheme appears especially desirable for sugar beet breeding work because it provides for a large measure of local control as a result of the inclusion of a small number of plots within the block, between which variance is removed; at the same time providing for the testing of a large number of varieties or strains in one test.

The initial requirement of a Three Dimensional Quasi-Factorial test is that the number of strains to be tested shall be a perfect cube. In this case 343 strains of sugar beets or $(7)^3$ strains were tested. Therefore, 7 varieties made up one block and 49 blocks constituted one complete replication. The basic arrangement of the strains in sets in cubical form showing the position of the key numbers (uvw) of the strains in the cube is shown in Figure 1:

From this cube the three groups of sets may be written down. The groups result from slicing the cube in the directions indicated by the arrows in Figure 1. Each strain is indicated by the numbers uvw with vw constant in group X, uw constant in group Y, and uv constant in group Z. No attempt will be made here to demonstrate the manner in which the sets are written out since Goulden 3/4/ has already published a complete 3 x 3 x 3 scheme.

For this test there were two replications of each group. Thus, there were two blocks composed of the strains as designated in each set in the cube. Strains were randomized within each block with the blocks being randomized within the group. A different randomized arrangement was used by the second replication of the groups. The randomization was further completed by randomizing the groups over the field.

It is possible to distribute the blocks over the whole field without regard to group or replication but in order to facilitate handling of seed at planting time and enable one to make observations covering a complete replication at one time, it was deemed better in this case to keep one complete group together. The blocks were so arranged as to have each group or replication in as compact a form as possible. The distribution of the blocks within the groups over the field is shown in Figure 2.

The usual care and precautions for conducting an experiment were employed throughout the season using the block as the unit for standardization of cultural treatments.

Since Goulden 3/4/ and Day and Austin 1/ have worked out complete problems using this scheme, it is not within the scope of this paper to show methods or steps in calculating the data. The results obtained, in comparison with those obtained in other tests, are shown in Table 1. The data are presented with the precision of the various Quasi-Factorial tests represented in percentage of the precision of the randomized block test taken as 100 per cent. The formulae for these precision calculations as used here were taken from Goulden 5/

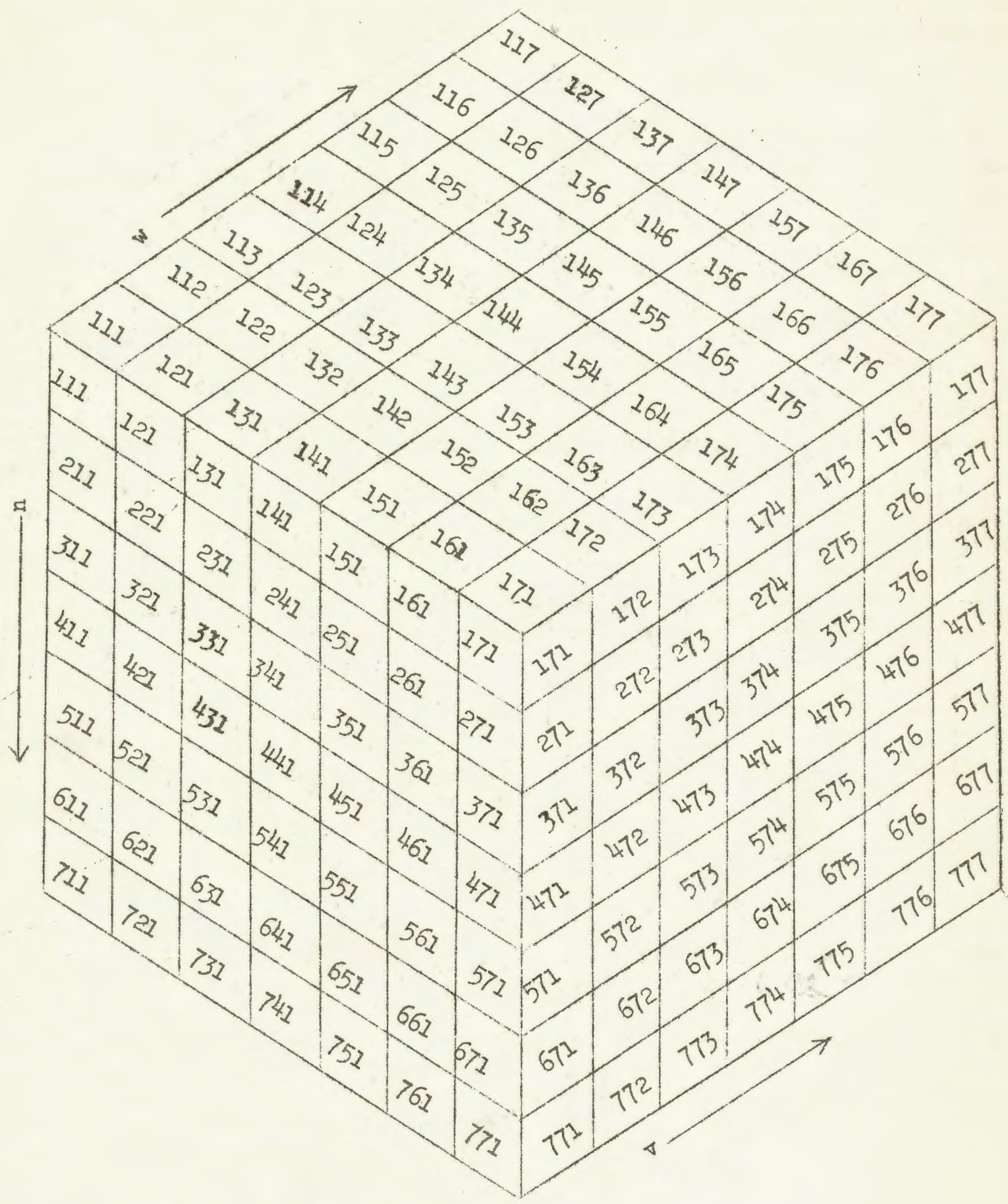

Figure 1 - 7 x 7 x 7 cube illustrating the principle involved in writing out the sets for a three dimensional Quasi-Factorial experiment

F I E L D P L A N

With block numbers as they appear in Field

Z	27	36	19	47	3	24	6	43	9	2	35	23	17	22
	44	20	28	21	25	1	16	30	5	32	39	37	13	46
	14	45	31	12	41	33	10	49	29	7	4	8	26	38
X	19	41	33	24	28	32	23	48	40	18	15	11	42	34
	16	3	26	1	45	40	43	48	11	15	38	17	21	2
	20	35	29	46	7	39	42	37	27	34	13	18	4	44
	25	36	47	10	22	12	6	31	49	5	8	30	9	14
Y	17	1	20	39	11	48	49	26	25	28	34	16	36	18
	33	5	46	41	40	12	27	30	7	14	4	15	21	37
	42	45	13	43	35	23	19	32	31	10	47	6	38	44
X	48	22	3	24	29	19	25	9	22	8	29	24	3	2
	6	44	7	43	31	4	46	41	2	23	27	12	17	15
	26	18	36	14	35	8	13	45	42	30	1	28	34	9
	49	20	16	40	21	11	38	32	10	47	37	33	5	39
Z	13	14	31	6	9	29	26	44	48	34	7	42	45	2
	47	38	23	22	36	1	25	16	24	46	28	12	11	17
	18	8	41	10	3	19	21	15	4	49	30	35	39	20
Y	14	4	15	21	37	17	1	5	40	32	37	42	33	27
	44	33	34	5	46	41	49	40	12	7	27	18	39	11
	26	36	45	13	43	48	35	32	28	31	10	47	6	38
	25	3	22	20	23	9	2	30	8	29	19	16	42	24

Figure 2

Table 1 - Precision of other designs in per cent of the complete randomized block test used as standard

Test	Precision in per cent of Randomized Block Design
Quasi-Factorial - Examples, Yates	126 to 157
" " - " , Goulden	166 to 187
Incomplete Randomized Block, G.W.S. Co.	
Per cent sugar	134
Weight	141
Two dimensional, two groups of sets, G.W.S.Co.	
Per cent sugar	131 & 194
Weight	168 & 183
Two dimensional, three groups of sets, G.W.S.Co.	
Per cent sugar	196
Weight	262
Three dimensional, three groups of sets, G.W.S.Co.	
Three replications, Per cent sugar	228
" " Weight	206
Six replications, Per cent sugar	296
" " Weight	268

These results show the two dimensional with three groups of sets and the three dimensional with three groups of sets to be considerably more efficient than the other Quasi-Factorial schemes, all of which are highly efficient when compared with the complete randomized block. The two comparisons of the three dimensional plan show that the degree of efficiency is greater where the number of replications is increased.

The chief criticism of any of the Quasi-Factorial schemes is that the labor involved in planning and calculating is somewhat laborious, but the increased efficiency should be well worth the few days extra time necessary to apply the corrections. All results when presented are in the form of average plot values corrected in accordance with the relationship of the strain to the performance of other strains which occur in the same blocks with this strain. Thus, the effects of variation in soil and treatments are equalized for all strains. The amount of correction applied to the results for any strain may be readily seen by drawing off an average of the raw figures for the strain.

In addition to the high degree of efficiency obtained by this method, the three dimensional scheme with three groups of sets is especially desirable in testing sugar beet strains since the small number of plots within a block tends to make all agronomic work more efficient. Experience has shown that it is extremely difficult to complete one set of operations over one whole replication of a large number of strains within a short enough time to consider it as uniform, especially if some weather changes occur. It is much easier to control irrigations within a small block than over a large number of plots which would constitute a block or replication in the randomized block scheme. Also, from the standpoint of soil variability the smaller block is especially desirable in sugar beet testing work on account of the relatively large plot size necessary for an adequate test. The efficiency value obtained for three replications which is more than twice as large as for the randomized block indicates that we could test twice as many strains and obtain slightly greater accuracy with three replications under this scheme for approximately the same expenditure of land, time, and funds as is necessary where the complete randomized block is used with six replications. Thus, it would be possible to gain a broader view of the material in the preliminary phases of the breeding work.

The use of the three dimensional plan may be adapted to the degree of accuracy desired and apparently can be used with confidence.

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COMPARISON OF QUASI-FACTORIAL AND RANDOMIZED BLOCK DESIGNS FOR TESTING SUGAR BEET VARIETIES

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In order to obtain statistically significant differences between varieties or treatments, it is imperative that factors which influence error variance are adequately controlled. This can be accomplished in part through more critical selection of experimental fields, and in part through more efficient plot arrangement. However, experiments involving a large number of varieties or treatments, the size of the replications may become so large that plot variability of the test cannot be efficiently controlled.

In recent years there has been a growing tendency on the part of experimentalists to group classes of data into smaller and more homogeneous subclasses rather than using randomized blocks of larger size and possibly greater