Multiple Versus Single-Factor Experiments

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Whether comparisons are simple or complex largely depends on the factors being considered. In the chemical laboratory the relationship between an acid and a base does not fluctuate with time of day, intensity of light, or the method of adding one to the other. Titrations made during the summer are comparable with titrations made during the winter. In contrast to the standardization that is possible in the laboratory, agricultural crops are never grown in the field under a standardized set of conditions. In any one field many factors influence the growth and development of a crop. When several fields are considered, the variability of these factors is greatly increased. Under these conditions of variability the experimenter has to make the choice of how many factors should be considered in any given experiment. If' he chooses to make only one comparison, holding all other factors at a given level, he is then conducting single-factor experiments. The comparison may be between the presence or absence of a given fertilizer, or between different amounts of the same fertilizer, or between methods of application, or between dates of application. By adhering strictly to single-factor experiments only one of the above comparisons would be made in any one experiment.

In contrast to this procedure, multiple-factor experiments, or factorial experiments, as they are commonly termed, are those which include in one experimental set-up all combinations of several different sets of treatments or factors. Kind of fertilizer, amount of fertilizer, and date and method of application would all be considered simultaneously. By this procedure, information would be obtained on the response of each factor and also on the effects of changes in the level of each factor on the response of the others. More frequently than not the interaction relationships between related factors in a field experiment are more important than the primary effect of any one factor alone.

The data presented in this paper were selected from field experiments dealing with fertilizer and cultural practices in relation to sugar-beet seed production and from variety tests conducted in relation to variation in spacing and fertility level. In each case the source of the data is indicated by literature citation.

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Experimental Data Illustrating Multiple-Factor Relationships

Variety Tests. — Variety trials are generally standardized as much as possible, it has been shown, however, that sugar-beet varieties respond differentially to levels of fertility and variations in spacing (3, 4)[2]. This fact suggests that variety tests may profitably be conducted on varying levels of fertility and with variations in spacing. The data in table 1 give an example of practical significance, inasmuch as the three varieties shown have been widely used commercially. It is evident from the data in table 1 that all varieties decreased in percentage sucrose and coefficient of apparent purity as the manure increased. However, the variety S.L.C 5639 decreased proportionately more than did the other varieties. No one will question the value of knowing that variety S.L.C. 5639 decreased to as low as 12.62 percentage sucrose and 79.10 percentage purity with 20-inch spacing on high fertility. Varieties with this characteristic are unsatisfactory for commercial use.

Sugar-Beet Seed **Production Tests**

Early attempts at growing sugar-beet seed in southern Utah indicated that some serious soil deficiency or deficiencies interfered with plant growth. The most immediate need was to determine what elements were lacking. Early experiments showed that nitrogen and phosphate were the elements most concerned and that they must be applied to the growing crop before maximum or even economic yields could be obtained (2). As soon as the kind of fertilizer necessary to supply the needed elements had been decided upon, subsequent experiments dealt more extensively with quantities necessary and time of application (7). In the course of these experiments it was shown that a proper balance was necessary between nitrogen and phosphate if the most satisfactory results were to be obtained, in some cases applications of nitrogen without sufficient phosphate were actually detrimental. In addition to the weak, immature growth shown in figure 1, high-nitrogen fertilization was responsible for intensification of phosphate deficiency to the point where many plants turned brown and died.

The data in table 2 show that the combined response of nitrogen and phosphate is greater than the combined response of both fertilizers tested independently. The application of 600 pounds of ammonium sulfate without application of phosphate increased the yield of seed 246 pounds per acre. The application of 300 pounds of treble superphosphate alone increased the yield of cleaned seed 657 pounds per acre. When the 600 pounds of ammonium sulfate and 300 pounds of treble superphosphate were added in combination, the

-Figures in parentheses refer to Literature Cited.

Table 1,—Differential response of varieties of sugar beets to fertility level and spacing.

1936 Test

Variety	Tons beets		Sucrose percentage		Purity	
	High fertility	Normal fertility	High fertility	Normal fertility	High fertility	Normal fertility
S. L. C. 833	22.37	21.23	15.79	17.69	85.47	88.78
S. L. C. 5639	23.38	20.56	13.45	16.88	79.90	87.78
Least sig. diff.	1.60	1.45	0.82	0.72	1.82	1.71

1937 Test

Variety	Tons beets				Sucrose percentage				Purity			
	High fertility		Normal fertility		High fertility		Normal fertility		High fertility		Normal fertility	
	10 in. Spacing	20 in. Spacing	10 in. Spacing	20 in. Spacing	10 in. Spacing	20 in. Spacing	10 in. Spacing	20 in. Spacing	10 in. Spacing	20 in. Spacing	10 in. Spacing	20 in. Spacing
S. L. C. 832	23.90	21.42	22.50	21.68	16.80	16.57	17.52	17.66	87.28	87.81	89.62	89.85
S. L. C. 022	25.57	27.72	25.83	26.01	16.56	15.82	16.92	16.74	90.57	87.19	88.49	88.27
S. L. C. 5630	26.03	24.87	25.38	22.98	13.13	12.62	15.88	15.40	79.21	79.10	87.82	87.27
Least sig. difference	2.12	2.52	1.85	1.67	1.45	1.45	0.97	0.99	4.08	3.90	3.40	3.24

Figure 1.—Interaction response of phosphate and nitrogen on sugar-beet seed in southern Utah. High nitrogen with no phosphate (left) causes weak succulent stems, uneven maturity of the seed, and late vegetative growth. None of these undesirable effects occurs when sufficient phosphate is added to balance the nitrogen.

increase in yield of seed as compared to the check was 1,194 pounds per acre. It is evident that this increase is almost 300 pounds greater than the total of the individual responses, and that it would be im-

Table 2.—Effect of nitrogen and phosphate on sugar-beet seed yields in southern Utah.

Pounds of ammonium sulfate applied	Treble superphosphate applied		
	None	300 pounds	600 pounds
None	1431	2088	2379
600 pounds	1677	2625	2760
1,000 pounds	1666	2657	2877

Least significant difference

possible to determine optimum amounts of either nitrogen or phosphate without studying their combined response.

Experiments in the Willamette Valley in Oregon (6) indicated that, under some conditions it may be impossible to determine what fertilizer elements are deficient without studying them both singly and in combination. Both nitrogen and sulfur are deficient and must be applied in sugar-beet seed production, yet either one applied alone gives a very unsatisfactory response (figure 2 and table 3).

When nitrogen was a limiting factor there was no response from the 94-pound application of sulfur ; when sulfur was a limiting factor, there was only a 250-pound increase in seed from 563 pounds of $NaNO_3$. However, when the additional 563 pounds of $NaX0_3$ were applied in combination with the 94 pounds of sulfur, the increase in seed was almost 1,000 pounds per acre. It is evident that the

Figure 2.—Interaction response of nitrogen and sulfur. General view of experimental plot near Jefferson, Oregon, showing nitrogen-deficient strips (B) and sulfur-deficient blocks (A), also the location where the three detail pictures A, B, and C were taken. A shows lack of nitrogen response when no sulfur was added. B shows lack of sulfur response when nitrogen was deficient. C shows the interaction response of adding nitrogen and sulfur in combination.

Table 3.– Nitrogen and sulfur responses on beets grown for seed in Oregon as shown by the pounds of clean seed per acre.

Nitrogen application	No sulfur	94 lb. sulfur in fall
	Pounds	Pounds
100 pounds $NaNO_3$ in fall; no nitrogen in spring	1,073	1,001
333 pounds $NaNO_3$ in fall + 330 pounds $NaNO_3$ in spring	1,823	2,061
Least significant difference	137	

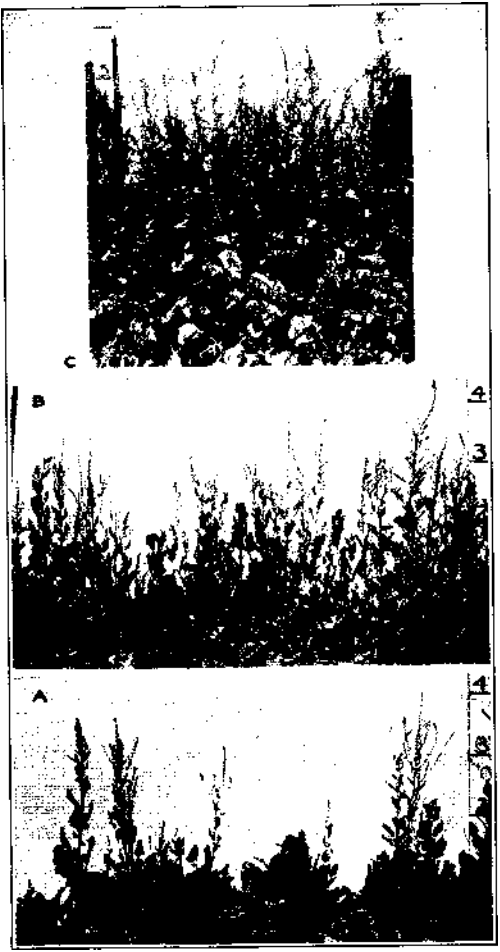
importance of either nitrogen or sulfur might have been overlooked if either one had been tested alone and the balanced comparisons had been omitted.

This experiment shows also that some care should be exercised in picking the form of commercial fertilizer to be used when the kind of fertilizer element is being determined. If ammonium sulfate had been used in place of sodium nitrate in the test just considered, the true relationship between nitrogen and sulfur would not have been evident. Existing literature on all previous fertilizer trials with established crops in any area is of course helpful in determining just what fertilizer elements should be tried on any new crop. Once the decision has been made as to what elements may be lacking, the possible interaction relationships should not be overlooked when the experiment is planned.

Very frequently cultural practices have an influence on fertilizer response. Previous crop, time, method of seedbed preparation, and planting date are all factors which may influence either the optimum amount of fertilizer or the optimum time of applying fertilizer (5). Again care must be exercised to pick those related factors which are applicable to the area and the crop under consideration. In southern Utah beets generally follow alfalfa. Because of this fact, in that area it is more important to know the effect of different methods of handling the alfalfa sod prior to the beet-seed crop than it is to know the relationship to seed production of other crops that are less likely ever to precede beets in the rotation.

Data from experimental plots in southern Utah (7) indicate that date of plowing the alfalfa sod prior to planting the beet-seed crop is not only an important factor in and of itself, but that it also has an important bearing on fertilizer practice and planting date. Each of these three factors may act separately or in combination, and the combined effect of any two factors may be additive or one may alter the effect of the other. The interaction relationships of these related factors is very evident from the data in table 4 and figure 3. It is evident that the mean difference in the acre yield of seed between the early and late-plowed plots was much greater on late-planted plots than on early planted plots. When the plots were planted September 1, the mean difference due to plowing date was 445 pounds of clean seed. When planting was delayed until September 22, the mean difference between plowing dates increased to 1,025 pounds of seed per acre.

On the other side of this relationship, the mean difference between the September 1 and September 22 plantings was very much greater on the plots plowed late than on the plots plowed early. Where the alfalfa sod had been plowed May 28, allowing for complete decomposition of the green manure, the mean difference be-



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tween the seed yield on the September 1 and September 22 planting was only 37 pounds of clean seed per acre. When the plots were not plowed until August 4, the difference in seed yield between the September 1 and September 22 planting was increased to 543 pounds per acre.

Both planting date and plowing date comparisons were greatly influenced by time of phosphate application. When fall fertilization, planting date, and plowing date were most favorably combined, the acre yield of seed was 3,262 pounds of clean seed per acre. When these same factors were all unfavorably combined, the yield was only 826 pounds. It is also evident that the percentage of plants entering into seed production was greatly influenced by each of the factors in the test and that interaction effects were much more important than the effect of any one factor alone. The proper evaluation of any one of the related factors in this test would have been impossible under any experimental set-up that did not give a measure of the interaction responses.

Discussion

The results obtained by use of multiple-factor experiments, such as illustrated in this paper, are of much greater practical value because of their wider basis of application than the results would have been if each factor had been tested separately under standardized conditions. In addition to the increased information obtained from multiple-factor experiments as compared to single-factor experiments, it has been shown that the cost per unit of information is actually less in multiple-factor than in single-factor experiments, and that contrary to the belief of many there need be no loss in precision of measurement if proper experimental designs are used (1, 8, 9). Experimental design should be given careful consideration in each planned experiment to make sure that the most efficient one is being used.

It may be felt by some that the above statements favor complication of experiments for complication's sake. That is to say, the more complicated an experiment or the more factors introduced, the better the experiment. This is not the thought implied. The number of treatments that can be introduced into any one experiment is limited rather severely by consideration of space and design, consequently the question is generally not what can be included but what should be included. The first step in making this decision is to list

Figure 3.—Interaction response of method of seedbed preparation, time of phosphate application and planting date. A shows the combined effect of late planting (September 22) and late seedbed preparation. B shows the increase in bolting brought about by early planting (September 2). C shows how late planting can be compensated for by proper seedbed preparation and phosphate fertilization.

Table 4 —Influence of planting date, plowing date, and time of phosphate application on the percentage of plants producing seed and the yield of clean seed per acre. (Averages of 4 replications)

Rate and time of application of treble superphosphate	September 1 planting			September 22 planting			Mean of May 28 plowing	Mean of Aug, 4 plowing
	Plowed			Plowed				
	May 28	Aug. 4	Mean	May 28	Aug, 4	Mean		
	76[1]	48	62	59	19	39	68	34
None	1,862	908	1,385	2,069	840	1,454	1,966	874
	86	80	S3	87	63	75	86	72
400 lb.—fall	2,922	2,667	2,795	3,104	2,663	2,884	3,013	2,665
	82	56	69	68	12	40	75	34
400 lb.—spring	2,565	2,345	2,455	2,724	826	1,775	2,644	1,586
	82	77	80	82	71	76	82	74
200 lb.—fall 200 lb.—spring	3,262	2,913	3,087	2,865	2,331	2,598	3,063	2,622
Mean of planting and	82	65	74	74	41	58	78	58
plowing dates	2,653	2,208	2,430	2,690	1,665	2,178	2,672	1,957

Least significant difference between seed-producer percentages—10 percent.

Least significant difference between yields of seed per acre—325 pounds.

[1] Percentage of plants entering into seed production.

all possible related factors. From this list are then selected those which are (1) most applicable to the area and crop under consideration; (2) of most immediate economic importance; (3) most closely related to the main purpose of the experiment, and (4) those fundamental to a long-range program.

Summary

In field experiments with agricultural crops many factors are encountered which affect growth. Attempts to measure each of these factors at a standardized level, disregarding the effect of related factors, has generally proved very disappointing- Multiple-factor, or factorial experiments measure simultaneously both the single and combined effect of the several related factors. In fertilizer trials it has been shown that a proper balance of deficient elements must be supplied if maximum responses are to be obtained. Experiments in southern Utah have shown that the interaction responses between nitrogen and phosphate are more important than the response of either element tested alone. A similar relationship exists between nitrogen and sulfur in southern Oregon- Experimental work in southern Utah also indicated that certain cultural practices, such as time and method of seedbed preparation and planting date, have a direct bearing on fertilizer practices, and that the proper evaluation of any one of the factors alone without due consideration of the related factors is impossible.

Variety trials have been standardized as much as possible. It has been shown, however, that sugar-beet varieties respond differentially to levels of fertility and spacing. This fact suggests that variety tests may profitably be conducted on varying levels of fertility and with variations in spacing.

In most cases information obtained from multiple-factor experiments is of greater practical value due to a wider basis of application than are results of experiments where single factors are tested under standardized conditions.

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