Soil Fertility Studies in the Mountain States

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SOIL FERTILITY may be defined as the capacity or quality of the soil necessary to supply plant nutrients in sufficient amounts and in the correct balance for the growth of plants when factors such as temperature, moisture, soil reaction and the physical and biological conditions of the soil are favorable.

This definition of soil fertility recognizes not only the importance of an adequate supply of soil nutrients in a form readily available for plant use, but also the importance of having these nutrients in a proper balance one to another.

This definition recognizes that soil fertility is not just a question of nutrient supply but that it is also one of proper soil environment. To be fertile a soil must be in good tilth, permitting the free development of plant roots and allowing the free movement of soil, air and moisture, while at the same time the humus content should be at a level which will provide high moisture-holding capacity and active biological activity.

The building and maintaining of a high state of soil fertility requires a well-balanced soil-management program. This program must be one which will provide proper drainage, proper irrigation, maintenance of soil organic matter, prevention of soil erosion, and use of properly cared for manure, the utilization of green manures and crop residues from a sound crop-rotation practice, and the supplemental use of the proper kinds and amounts of commercial fertilizers.

The use of commercial fertilizer provides an immediate means of improving soil fertility but should not supplant a long-range program of soil improvement such as the one outlined above.

The economic importance of commercial fertilizer is readily apparent when one considers the fact that the farmers who grow sugar beets spend annually in excess of one million dollars for commercial fertilizers which are applied to the sugar beet crop. If these farmers are to get the most out of this phase of their soil-fertility program, they need an evaluation of their soil-fertility problems and advice as to the kind, quantity and quality of the fertilizer they use. A program to determine these factors may, and should, include such procedures as: plant analysis, soil tests, plot tests and field trials. All of these procedures can be used advantageously. Possibly the first three of these procedures are of most value when used as supplements to the field trials.

This paper deals largely with the results of field tests conducted in Utah, Idaho, Washington, Montana and South Dakota. These tests inves-

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tigated such problems as: kind, amount and ratio of fertilizer needed and the time of fertilizer application.

Experimental Methods and Procedures.—All fertilizer plots have been cooperative tests between sugar beet growers and the Utah-Idaho Sugar Company. The tests have included a comparison of nitrogen and phosphate fertilizers both when used alone and in combination. The complete set of treatments used is shown in the tables. In all cases the commercial fertilizers were side-dressed to either the planted or the growing crop. Plots were 8 to 12 rows wide and of sufficient length to provide approximately 6 to 8 tons of beets per plot. Figure 1 shows a general view of one of these cooperative plots. Beets from each plot were hauled by truck to the closest receiving point where the weight was obtained.

Figure 1.—General view of one of the commercial-fertilizer plots in South Dakota, September, 1947. Note alternating strip effects caused by the nitrogen fertilizer. The two strips in the center show a contrast of growth between 400 pounds of 16-20-0 left and check strip on the right. Yield difference of 3.17 tons per acre.

About 75 percent of the plots were sampled for sugar content. The sugar samples consisted of four 15-beet samples from each treatment.

Each treatment was run in duplicate on each farm and there were tests on from 8 to 12 farms in each factory district.

Experimental Results.—Tests in 1945: The complete results of the 55 field tests conducted in 1945 were reported in the proceedings of the 1946 meetings of the American Society of Sugar Beet Technologists (3).[2] A brief summary of these tests is shown in table 1.

One of the most interesting things brought out by these tests was the fact that in general the farmers were following a phosphate program that was adequately supplying their phosphate requirements, but that the

[2]Numbers in parentheses refer to literature cited.

nitrogen level had been so depleted that on most farms nitrogen was the limiting factor in plant growth.

In cases where the initial phosphate level was high, greatest yield increases resulted from the application of nitrogen fertilizer alone. In tests where the initial nitrogen level was high, greatest yield increases resulted from the application of phosphate fertilizers alone. In about 50 percent of the tests greatest yield increases resulted from the application of a combination of nitrogen and other commercial fertilizers. In a majority of tests the most profitable fertilizer treatment was 400 pounds of ammonium sulfate plus 200 pounds of treble-superphosphate.

Tests in 1946: During the 1946 season, 50 fertilizer tests were conducted in the 5 mountain states in which the Company operates. A preliminary report of these tests was made at the Regional meetings of the American Society of Sugar Beet Technologists held in Salt Lake City in 1947 (4). These tests included applications of nitrogen, phosphorus and potash, and the effect of each of the elements tested was measured when they were applied alone as well as when applied in combination with the other elements tested. A complete set of the treatments, showing rates and combinations used, is shown in table 2.

It is evident from the data in table 2 that there was little or no indication of a yield response to potash but that there was a definite response from nitrogen and from nitrogen and phosphate used in combination. In many tests there was no response from phosphate used alone. In this regard, the general response pattern was similar to that of the 1945 tests. In almost every area, 300 pounds of 16-20-0 mixed fertilizer gave a greater response than did 300 pounds of either ammonium nitrate or treble-superphosphate used alone. The average yield increase from 300 pounds of 16-20-0 per acre was 2.11 tons.

The addition of minor elements to a 16-20-20 fertilizer did not have any significant effect on either yield or sucrose content.

Applications of 300 pounds of 16-20-0 mixed fertilizers depressed the sucrose content of beets an average of .30 percent. A 600-pound application of 16-20-0 depressed sucrose content an average of .74 percent.

Date of Fertilizer Application.—Tests in 1946: Some preliminary tests were conducted during the 1946 season to check on the comparative efficiency of applications made early or late in the growing season. Four dates of fertilizer application were compared. At planting time, at thinning time, at the last cultivation and on a fourth series the fertilizer was split—one-third of the total amount was applied at each of the other periods. The complete treatments and the results are shown in table 3.

It is evident from the data that in these tests, time of application had very little effect on yield response, although there was a general response from the fertilizer applied.

Table 1.—Fertilizer tests conducted in 1945 classified as to type of response as related to initial level of nitrogen and phosphorus and the importance of keeping a proper balance between N and P.

Classification of test as to limiting factor (P or N)	A. S.:	None	200	400	None	None	200	400	200	400
	T. S. P.	None	None	None	200	400	200	200	400	400
					(tons of beets)					
Nitrogen limiting factor (average of 18 tests)[1]		13.00	15.30	16.36	13.11	12.23	14.24	15.42	14.81	15.48
Phosphate limiting factor (average of 9 tests)[2]		18.87	17.11	17.00	19.49	21.16	20.94	20.84	19.69	20.30
Response to increased level of both N and P (average of 28 tests)[3]		19.53	21.17	22.13	20.62	20.67	22.34	23.60	20.98	22.63

[1]These farms all had the equivalent of 150 pounds of treble-superphosphate broadcast and worked into the seedbed before they were selected as test fields.

[2]These farms were all livestock farms and had been heavily manured, consequently initial nitrogen level was good.

[3]These were farms of better-than-average fertility where both the nitrogen and phosphate levels were being fairly well maintained, as evidenced by check yields.

Table 2.—Average yields (tons of beets) from commercial-fertilizer tests including various rates and combinations of such elements as: nitrogen, phosphorus, potash and a composite of minor elements. Tests conducted in 1946.

Amount and kind of fertilizer applied (per acre)	Salt Lake and Utah Co.	Gunnison	Box Elder County	Idaho	Montana	South Dakota	Washington	Average[1] response from all tests	Average sucrose content
1—Unfertilized check	13.98	15.75	14.15	13.46	13.97	10.83	19.89	14.52	15.81
2—150 lbs. treble-superphosphate	14.89	16.46	15.08	13.95	13.31	11.59	19.82	14.97	15.74
3—300 lbs. treble-superphosphate	16.53	16.84	15.64	13.98	13.96	12.42	20.11	15.60	15.80
4—150 lbs. ammonium nitrate	15.71	16.46	17.09	14.72	14.27	11.83	22.03	15.99	15.50
5—300 lbs. ammonium nitrate	16.03	16.45	17.47	15.05	14.89	12.16	22.99	16.43	15.46
6—200 lbs. potassium chloride	15.14	16.28	14.60	13.72	13.26	11.38	20.15	14.91	15.65
7—600 lbs. 16-20-0 mixed fertilizer	17.06	17.45	18.49	15.65	15.29	12.86	24.15	17.27	15.07
8—300 lbs. 16-20-0 mixed fertilizer	16.30	17.19	16.88	15.33	15.14	12.30	23.34	16.63	15.58
9—600 lbs. 16-20-20 complete fertilizer	16.42	16.41	17.43	15.55	16.00	13.00	24.94	17.15	15.09
10—600 lbs. 16-20-20 plus minor elements	17.33	17.17	17.18	15.19	15.89	12.60	25.32	17.26	15.11
Number of tests averaged in each area	8	5	6	9	6	8	8	50	18

[1]Weighted averages representative of the average response from all 50 tests.

Table 3.—Summary of the yield of beets in tons per acre resulting from the application of commercial fertilizer at different periods of plant development. (Tests conducted in 1946.)

Amount of fertilizer applied and time of application	Location of test: Washington	Utah County	Salt Lake County	South Dakota	Combined averages
Planting time					
300 lbs. 16-20-0	27.95	16.74	15.01	12.86	18.84
600 lbs. 16-20-0	32.05	17.52	16.76	13.03	19.84
Average	29.99	17.13	15.89	12.95	18.99
Thinning time					
300 lbs. 16-20-0	30.08	16.92	14.74	12.16	18.47
600 lbs. 16-20-0	31.56	18.70	14.35	12.55	19.29
Average	30.82	17.81	14.55	12.35	18.88
Last cultivation					
300 lbs. 16-20-0	29.99	16.30	15.33	12.06	18.42
600 lbs. 16-20-0	30.75	17.66	15.44	12.52	19.09
Average	30.37	16.98	15.33	12.29	18.74
Split application					
300 lbs. 16-20-0	29.89	16.54	13.18	12.62	18.06
600 lbs. 16-20-0	29.10	18.45	14.38	13.56	18.87
Average	29.50	17.49	13.78	13.09	18.46
Combined average	30.17	17.35	14.90	12.67	18.77
Yield of check plots	25.80	13.81	13.78	11.95	16.34

Tests in 1947: The fertilizer tests conducted in 1947 included a study of the time and rate of application of nitrogen fertilizer. Each rate of nitrogen application was compared with and without the addition of phosphate fertilizer. All the phosphate treatments were applied at planting time, and one-half of the nitrogen treatments was applied at the same time. The other half of the nitrogen plots did not receive the nitrogen application until after thinning. Thus in each test there was a comparison of the time of applying nitrogen, but phosphate was in every case applied early. In this respect the 1947 tests varied from the time of application plots conducted in 1946, for in the 1946 tests both the nitrogen and phosphate were applied at different times.

It can be seen from the data in table 4 that the 1947 tests supported the results obtained in previous years. In many tests there was little or no yield increase from the application of phosphate fertilizer when it was applied alone, however, in two or three tests there was a very striking phosphate response, and one of these tests is reported separately in the Montana area (figure 2). The average yield increase from the 200-pound application of treble-superphosphate per acre in all 31 tests was .89 ton. There was a response to nitrogen fertilizer in 30 of the 31 test plots. The average yield increase from 200 pounds of ammonium nitrate was 1.72 tons per acre and there was further increase of 1 ton per acre from an additional 200-pound application of ammonium nitrate. The highest average yields resulted from a combination of 400 pounds of ammonium nitrate plus 200 pounds of treble-superphosphate per acre. This is equivalent to about 600 pounds of a 21-14-0 mixed fertilizer. A view of one of the plots which showed a marked nitrogen response is shown in figure 3. In a majority of tests, the most profitable yield increases resulted from the application of 200 pounds of ammonium nitrate and 200 pounds of treble-superphosphate. This is equivalent to 400 pounds of 16-20-0 per acre.

Table 4.—Summary of the tons per acre for 31 commercial-fertilizer tests which included varying rates of nitrogen at two different dates of application. Tests conducted in 1947.

				A N at planting time					A N after thinning				
Location of tests	Number of tests	Check	200 lbs. TSP[1]	200 lbs. A N[2]	200 lbs. A N plus 200 lbs. TSP	400 lbs. A N	400 lbs. A N plus 200 lbs. TSP	Average	200 lbs. A N	200 lbs. A N plus 200 lbs. TSP	400 lbs. A N	400 lbs. A N plus 200 lbs. TSP	Average
Montana	1	5.98	8.22	5.95	8.18	5.42	9.23		5.31	8.87	6.79	9.16	
Montana	4	11.02	11.66	11.70	12.69	12.09	12.57	12.26	12.42	12.46	11.99	12.84	12.43
South Dakota	4	9.11	9.59	11.22	11.32	12.18	12.72	11.86	11.65	11.59	12.37	11.93	11.88
Washington—													
Toppenish	4	21.78	23.28	24.64	24.66	25.09	25.50	24.97	25.43	25.79	26.19	26.03	25.86
Walla Walla	2	26.13	26.17	—	—	—	—	—	29.22	30.17	31.02	32.10	
Idaho	3	13.83	14.00	16.22	16.75	16.61	17.10	16.67	16.79	16.78	16.89	17.06	16.88
Utah—													
Gunnison	2	19.67	19.69	21.33	19.98	21.38	20.52	20.80	21.68	21.26	20.03	20.23	20.80
Garland	4	19.20	20.89	21.63	22.64	23.03	24.48	22.95	22.28	23.20	21.84	23.16	22.62
Salt Lake and Utah Co.	7	17.23	18.31	19.63	20.02	20.14	20.40	20.05	19.33	19.83	20.05	20.06	19.82
Average of 29 tests	31	15.76	16.65	17.48	18.18	18.46	18.94	18.26	18.11	18.48	18.37	18.65	18.40
Average sucrose percentage	20	15.65	15.75	15.48	15.41	15.07	15.03	15.25	15.47	15.45	15.12	14.95	15.25

[1]TSP=treble-superphosphate

[2]A N=ammonium nitrate

There was little or no difference in the yields from plots receiving the nitrogen at planting time as compared to those which were side-dressed after thinning. In the Yakima Valley, the area with the longest growing season, the tests seemed to indicate some advantage from the later nitrogen application. From the averages of all the tests there is some indication that the most profitable time of nitrogen application may depend on the amount to be applied. When only 200 pounds of ammonium nitrate were applied, there was some advantage to side-dressing it after thinning. When 400 pounds of ammonium nitrate were applied, greatest average yields resulted from side-dressing the nitrogen immediately following planting. However, these differences were small as compared to the general fertilizer response resulting from the application of the fertilizer at either one of the dates. Thus the tests indicate that, within the limits of the time tested, it was much more important to get the fertilizer applied than it was to give too much consideration as to just when it should be applied.

Figure 2.—Commercial-fertilizer plot typical of the few where phosphate was so limiting that nitrogen alone gave no response. Plot on left with 400 pounds of ammonium nitrate per acre yielded 5.42 tons per acre as compared to 9.23 tons per acre from plot on the right which had 600 pounds of 16-20-0. Check plot yielded 5.98 tons per acre. Plot near Great Falls, Montana. Very few fields were found this deficient in phosphate.

Application of 400 pounds of 16-20-0 decreased the sucrose content an average of .24 percent. This corresponds rather closely with the .23 percent decrease resulting from the application of 300 pounds of 16-20-0 in the 1946 tests. Application of 600 pounds of 21-14-0 per acre decreased sucrose percentage an average of .60 percent. It is apparent that the second 200 pounds of fertilizer decreased sugar percentage more than did the first 200 pounds applied. The production of gross sugar per acre from the check plots was 2.4664 tons per acre. The 400-pound application of 16-20-0 produced 2.820 tons of gross sugar per acre and the 600-pound application of 21-14-0 per acre produced 2.818 pounds of gross sugar per acre. These figures again emphasize the fact that the most profitable fertilizer application was the 400 pounds of 16-20-0 per acre.

General Observations.—During the 3 years of these tests, which involved work with a total of about 150 cooperating farmers, several significant observations have been made which do not properly fall under the heading of experimental results. However, some of them do have a bearing on practical fertilizer practice and for that reason these observations are recorded here.

Figure 3.—Commercial-fertilizer plot typical of those where the major response came from nitrogen fertilizer. Check on right yielded 14.53 tons per acre. Plot on left with 600 pounds of 16-20-0 per acre yielded 21.36 tons per acre. Plots receiving 400 pounds of ammonium nitrate alone yielded 20.67 tons per acre. This test located near Garland, Utah.

Many farmers entertain the misconception that nitrogen fertilizers are extremely transitory and that nitrogen must be applied in small frequent amounts just as it is needed by the plant. This idea is carried to the extreme by some who claim that nitrogen only holds in the soil for a period of 12 to 14 days and that it frequently volitalizes as a vapor and is lost into the atmosphere. These tests and many others which might be cited prove that applications of nitrogen remain effective throughout the growing season.

It is well established that nutrient elements must be in solution before they can be utilized to any great extent by growing plants. Commercial fertilizers should, therefore, be applied at sufficient depth in the soil to assure that they will at all times be in contact with adequate soil moisture. Fertilizers are easily side-dressed 3 to 5 inches deep prior to thinning, but when the side-dressing is delayed until after thinning, the soil in many cases is so dry and hard that side-dressing is difficult and the fertilizer in many cases is placed near the surface where the soil soon dries out after each irrigation until the beets become large enough to shade the ground. One other disadvantage has been encountered when application of the fertilizer has been delayed until after thinning. Generally by the time thinning has been completed, the first crop of alfalfa hay needs to be cut and beans and potatoes need to be planted. By the time these jobs have been taken care of, the beets are suffering for water and the irrigation must be further delayed until the fertilizing can be taken care of. As a result of these difficulties, the authors have seen many cases where the fertilizer has lain in the shed all season instead of being applied to the beet crop. Early application of fertilizer avoids almost all these difficulties.

One other difficulty encountered was the failure of the farmer to increase his irrigation to take care of his increased level of fertility. In several cases the authors observed plots where the check strip showed no signs of moisture shortage but where the foliage of beets on the heavily fertilized strips were badly wilted and in some cases were starting to burn. In some other cases definite bands of fertilizer were in evidence in the soil at harvest time. Irrigation practice should be geared to the fertilizer practice. Fertilizing in each row and then irrigating in every other row does not make for efficient fertilizer use. Neither can maximum fertilizer response be obtained without adequate moisture to support the increased growth.

Discussion and Summary

The results of fertilizer tests conducted in the mountain states during the past 3 years indicate that sufficient attention has not been paid toward the maintenance of soil nitrogen. In many cases farmers have been applying phosphate fertilizers over a period of years but during the same period little or nothing has been done to maintain the nitrogen level in their soils. As a result, nitrogen was shown to be a limiting factor in crop production on a majority of the farms on which tests were located.

These tests have further pointed out the importance of establishing and maintaining a balanced level of fertility. Phosphate applications on fields where nitrogen was limiting gave no yield response and in several cases seemed to depress yields. Also where phosphate was limiting, nitrogen applications were ineffective in increasing yields but did cause a decrease in sucrose content so that the end result was a definite drop in sugar per acre.

The importance of maintaining a balance in soil fertility has been recognized for more than a century, and many research workers have reported that an increase of one element in the soil, generally results in an increase of this element in the plant, and that an increase of any one element in the plant is generally offset by a decrease of other elements in the plant. A rather complete review of this literature has been given by C. A. Browne (1).

In view of the fact that one element cannot be substituted for another and that an excess of one nutrient element actually interferes with the proper utilization of others, it becomes of increasing importance that fertilizer usage be based on actual need. Schreiner (2) has summarized this phase of the program as follows: "Evaluation of the fertility of a soil and of the quantity and quality of a fertilizer required for profitable yield and quality of crop is indispensible to economic fertilizer usage and essential to efficient crop production."

One encouraging factor indicated by these tests is the similarity of response over the five mountain states in which the tests were located. The following facts seem to apply pretty generally to each and all of the areas tested:

1. There was a general nitrogen deficiency.

2. There was a general phosphate response.

3. Greatest yield increases resulted from applying both nitrogen and phosphate.

4. Little or no evidence was found to indicate a potash deficiency, or that any great general benefits would result from the additional minor elements.

5. Date of nitrogen application proved to be relatively unimportant as compared to the importance of at least getting it applied.

6. An application of 300 to 400 pounds of 16-20-0 or its equivalent per acre seemed to be the most profitable application.

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