Interrelation of Moisture, Spacing and Fertility to Sugar Beet Production

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MANY STUDIES have been made on the influence of soil moisture on yields of sugar beets (1)[2], (3), (5), (12), (13). Likewise, numerous investigations have been conducted on the effects of various fertilizers on the production of sugar beets (18), (14), (6), (9), (11), (16), (7), (8), (15). Similarly, experiments have been conducted to determine the most satisfactory between-row and within-row spacing (4), (10), (19), (17), (21).

Information obtained from these studies has aided in the economic production of sugar beets. However, it has been difficult to draw satisfactory conclusions on the basis of data from a study of single factors. This is pointed out by Tolman (20) in the statement:

> 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.

Coke (2) makes a similar observation:

> In one of our small, compact, beet-producing districts, the average yield of beets varied in a single year from 14 to 39 tons per acre. . . . If for these fields we had a measure of the factors of soil fertility, available soil moisture, soil atmosphere, and diseases and pests, it is very likely some explanation of the large variation in yield would be possible.
>
> Certainly we can learn little, for example, from fertilizer studies, if soil moisture or lack of oxygen in the soil atmosphere is the limiting factor. My plea is that in our research work we should recognize and attempt to measure to the limit of our ability all of the factors affecting plant response. Unless we do this, our progress will be limited.

This study was conducted to obtain information on some of the fundamental relationships among the three factors—fertility, moisture and spacing—as they affect yield of beets, yield of sugar, percentage sugar and juice purity of sugar beets. The conductance of this experiment was made possible through cooperative effort by the following organizations: Utah-Idaho Sugar Company, Amalgamated Sugar Company, Utah Agricultural Experiment Station, a research grant by the Kennecott Copper Company through the Utah State Agricultural College and the Bureau of Plant Industry, Soils and Agricultural Engineering of the United States Department of Agriculture.

Experimental Design and Procedure

This study was conducted in 1946 on Millville fine sandy loam soil type. The slope was about 1 percent to the south and 4/10 percent west.

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[2]Numbers in parentheses refer to literature cited.

The soil is calcareous throughout the profile and has a pH of 8.0, 270 parts per million soluble salts, less than 2 percent organic matter, and is low in available phosphate and nitrate. The area had been under dry-farm management, alternately in wheat and summer fallow, for 50 years. In 1945, the first year under irrigation, the area used in this experiment failed to produce a satisfactory pea crop. An adjoining piece of land similarly managed except that it was planted to sugar beets in 1945 produced 8 to 10 tons of beets per acre.

Plots were laid out in a randomized split-plot design. There were 24 main plots in each replication made up of 4 moisture, 3 spacing and 2 manure variables. Each plot was 100 feet long by 32 to 48 feet wide (depending upon row spacing). These variables may be described as follows:

1. Moisture—4
   W_1—Continuously moist (below 750 cm. water tension at 8-inch depth, 6 irrigations)
   W_2—Continuously moist until August 5. No irrigation thereafter, (3 irrigations)
   W_3—After July 15 allowed to reach wilting at 18-inch depth, (3 irrigations)
   W_4—After July 15 allowed to reach wilting at 30-inch depth, (3 irrigations)
2. Spacing—3
   S_1—Rows alternating 12 inches and 20 inches apart (equivalent to 16-inch spacing)
   S_2—Rows 20 inches apart
   S_3—Rows 24 inches apart
3. Manure—2
   M_1—No manure
   M_2—15 tons manure (50 percent dry matter)

Superimposed upon each of the 24 main plots, in each of the 3 replications, were 8 commercial fertilizer plots. Each of these plots were 4 rows wide and 50 feet long. These sub-plots were completely randomized within each large plot. These variables may be described as follows:

4. Commercial fertilizer—8
   F_1—100 pounds phosphoric acid
   F_2—80 pounds nitrogen, 100 pounds phosphoric acid
   F_3—80 pounds nitrogen, 200 pounds phosphoric acid
   F_4—80 pounds nitrogen, 200 pounds phosphoric acid, 150 pounds potash
   F_5—160 pounds nitrogen, 100 pounds phosphoric acid
   F_6—160 pounds nitrogen, 200 pounds phosphoric acid
   F_7—160 pounds nitrogen, 200 pounds phosphoric acid, 150 pounds potash
   F_8—80 pounds nitrogen, 200 pounds phosphoric acid, 150 pounds potash, 50 pounds copper sulfate

All fertilizer, except the second 80 pounds of nitrogen in the 160-pound nitrogen plots, was side-dressed 4 inches below the soil surface the first part of June, and immediately before thinning. The second 80 pounds of nitrogen, on the 3 high-nitrogen plots was applied on the surface of the irrigation furrow August 10. One hundred pounds of phosphoric acid was applied uniformly on all plots. This was done because the prevailing practice in the area was to apply phosphoric acid to sugar beets. In some respects this was unfortunate from an experimental point of view because in effect it eliminated the first phosphorus level as a variable.

Figure 1 is presented to clarify the field design and plot arrangement in this experiment. Replication 1, with the 24 separate main plots, is shown diagrammatically. Plots 1, 2 and 3 from replication 1 are given in greater detail, showing the random arrangement of the 8 commercial fertilizer sub-plots. It happens that these 3 main plots show the 3 spacing variables and 3 of the 4 moisture variables. There were 4 rows of sugar beets on the border of each main plot. These served to isolate the variable moisture, spacing and manurial treatments on each of these main plots.

Total rainfall for the months of June, July, August and September of 1946 was 2.26 inches. Over the past 20 years the average rainfall for this period in this area was 3.37 inches.

U.S. 22 whole seed was drilled April 22 and emerged May 1. Beets were thinned June 10. Two over-head sprinkler irrigations were applied to the entire field. The first over-head irrigation was applied June 26 and the second one July 15. Beginning July 15 the variable moisture treatments outlined above were initiated.

Soil-Moisture Data:—The soil-moisture stress in this experiment was followed by means of soil-moisture tensiometers and plaster-of-paris resistance blocks, hereafter referred to as resistance blocks.

Soil-moisture treatment 1 was kept at a low moisture tension throughout the experiment. This was true for all of the plots receiving this treatment. As was seen in the experimental design, the experiment was so arranged that plots having different spacing or different manure treatments could be irrigated differently for each moisture treatment. The soil-moisture tension in moisture treatment 1 was followed by means of tensiometers placed at the 8- and 18-inch depths. The tension at these depths did not exceed 750 centimeters of water at any time. Tensiometers were placed in all of the replications, in all spacings and both manure treatments of the larger plots, which were kept continuously moist throughout the season.

Consistency between moisture records on the three replications for the low moisture tension plots was good. The graph on the bottom of figure 2 is a record of one of the tensiometers on a low moisture-tension plot. A comparison of the curve with the scale on the right of figure 2 shows that the tension was less than 500 centimeters of water most of the season.

Soil-moisture tension in moisture treatments 2, 3, and 4 was followed by use of plaster-of-paris resistance blocks. It is well known that resistance blocks are somewhat limited in their ability to measure soil moisture adequately, as well as being limited in the range of soil moisture which they will measure. Their main limitations should be stated. They do not measure accurately soil-moisture stress below one atmosphere of tension and they are affected by variations in salts and temperature. Because of these facts there may be considerable error in interpreting moisture tension between 1 and 15 atmospheres. The blocks will, however, give useful information as to whether the tension is below one atmosphere or whether it is approaching a tension equivalent to that at the wilting percentage. The resistance blocks in this experiment were used to indicate when a particular depth of soil was approaching the wilting percentage, and to indicate soil depths from which moisture was being withdrawn. It is believed that the resistance blocks give rather reliable information on these points.

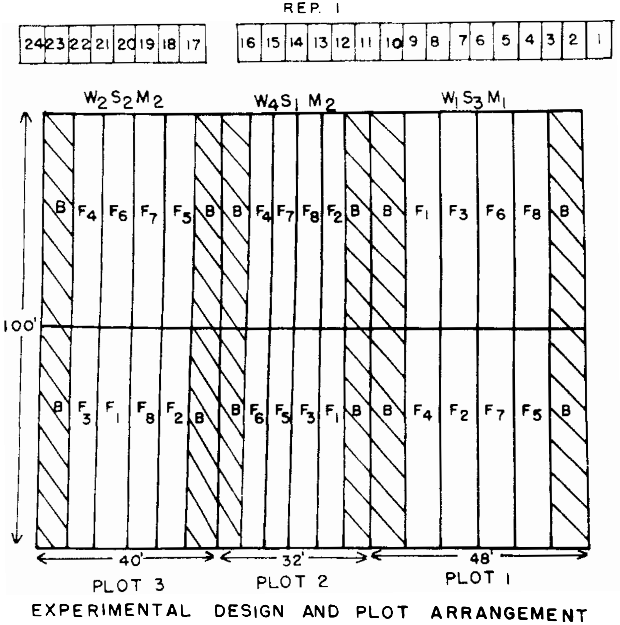


Figure 1.—Main plot arrangement in replication 1 and detail sub-plot arrangement in plots 1, 2 and 3. The letters in the plots indicate the plot treatments defined on pages 2 and 3.

Three sets of resistance blocks were placed in plots of moisture treatments 2, 3, and 4. Each set of resistance blocks consisted of five blocks placed at 8-, 18-, 30-, 48-, and 60-inch depths. Typical data for resistance block records for individual plots receiving moisture treatments 2, 3, and 4 are given in figure 2. It will be noted that the soil-moisture tension did not reach the wilting percentage at the depths indicated in the outline for these treatments until the latter part of the season. This was due to the fact that it was deemed necessary to keep the soil-moisture tension low until the young plants were well established, and also due to the fact, that the sugar beet plants did not dry the soil out as rapidly as had been anticipated. Moisture treatment 2 received two over-head irrigations, June 26 and July 15, and one furrow irrigation, August 5. Moisture treatment 3 approached the tension equivalent to the wilting percentage at the 18-inch depth late in August and was irrigated at that time. Moisture treatment 4 was irrigated about 10 days later even though all the plots on this treatment had not reached the wilting percentage at the 30-inch depth.

The plots receiving moisture treatments 1, 2, 3, and 4 received 6, 3, 3, and 3 irrigations, respectively. As previously noted the first two irrigations for each moisture treatment were light irrigations applied with a commercial over-head sprinkler system. The later irrigations were of the furrow type. No actual measure was made of the water applied but an attempt was made to apply sufficient water to wet the upper 2 feet of soil to field capacity.

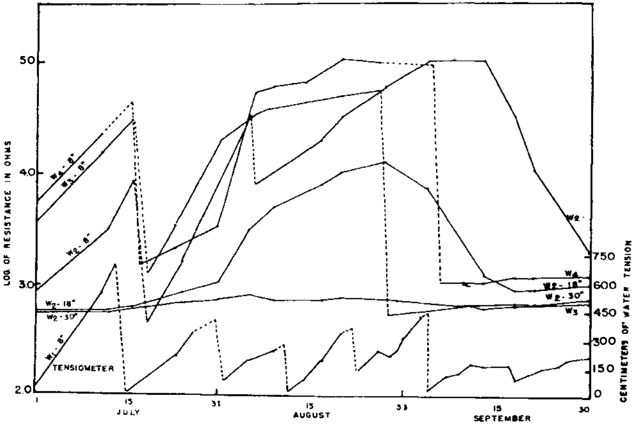


Figure 2.—Curves showing tensiometer record at 8-inch depth of moisture treatment 1 and resistance block records on moisture treatment 2 at 8-, 18- and 30-inch depth, moisture treatment 3 at 8-inch depth and moisture treatment 4 at 8-inch depth.

Experimental Results

Plant Data.—Large variations in yields were obtained on this experiment from individual plots receiving different treatments. The poorest treatment gave a yield of 13 tons per acre while the best treatment gave a yield of 26 tons per acre. The factory average for beets in this area for 1946 was 12 tons per acre.

There were significant differences in yield of beets and tons of sugar for the three main factors: moisture, spacing and manure treatments, on moisture treatment 1. Likewise, on moisture treatment 1 there were significant differences in percentage sugar and purity for variations in applied nitrogen, but no significant differences in percentage sugar or purity for variations in moisture, spacing, or manure. The only significant differences on yield of beets or sugar on moisture treatments 2, 3, and 4 were those between nitrogen fertilizers. There were no significant differences for differentials in phosphorus, potassium, or copper treatments under any of the moisture treatments. This may not be surprising in the instance of phosphorus fertilization since it will be remembered that one level of phosphoric acid was applied uniformily over the entire field.

Effect of Spacing Variables.—Figure 3 shows the effect of rate of nitrogen (0, 80, and 160 pounds per acre) on the yield of beets at three spacings. Beets within the row were spaced 1 foot apart in this experiment. Differences required for significance at the 5-percent level for the treatments being compared are indicated by verticle bars on the graph. The shorter bar is a measure of significant differences between any two fertilizer treatments and the longer bar is a measure of significant differences at the 5-percent point between any two spacing treatments. Both bars should be used in a verticle position. It is readily seen that there are significant differences for the three fertilizer treatments at the 12- by 20-inch spacing. Eighty pounds of nitrogen were significantly better than no nitrogen on the 20- and 24-inch spacings, but the 160 pounds of nitrogen did not produce any more beets than the 80 pounds of nitrogen on the 20- and-24-inch spacing. There were significant differences between 24-inch and 20-inch spacing treatments for only the 160-pound level of nitrogen. The 12- by 20-inch spacing was not significantly better than the 20-inch spacing for any of the levels of nitrogen.

Figure 4 gives the tons of sugar produced per acre for the same treatment as was indicated in figure 3. When one compares the 12- by 20-inch spacing with the 24-inch spacing at all nitrogen levels, significant increases in tons of sugar per acre with closer spacing of beets will be noted. The 20-inch spacing produced more sugar than the 24-inch spacing for the no added nitrogen, but there was no significant difference between the 20- and the 12- by 20-inch spacing on any of the nitrogen levels.

Figures 3 and 4 indicate clearly that if one is to obtain a maximum return from high amounts of nitrogen it is necessary to have a sufficient number of plants to utilize it fully. This is evident when one compares the yield of beets from plots having no nitrogen with those from plots which received 160 pounds of nitrogen at each of the three spacing treatments. There is no significant difference in yield of beets or sugar between 20-inch and 12- by 20-inch rows. Apparently, there was not a sufficient number of plants on the 20 or 24-inch row spacings to benefit from the extra 80 pounds of nitrogen in the 160-pound treatment versus the 80-pound treatment.

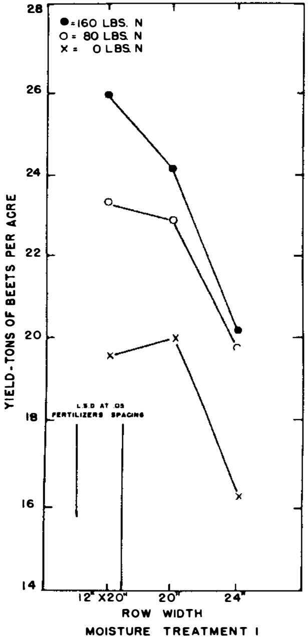


Figure 3.—Yield of sugar beets under various row-width spacing and at three nitrogen-fertilizer levels.

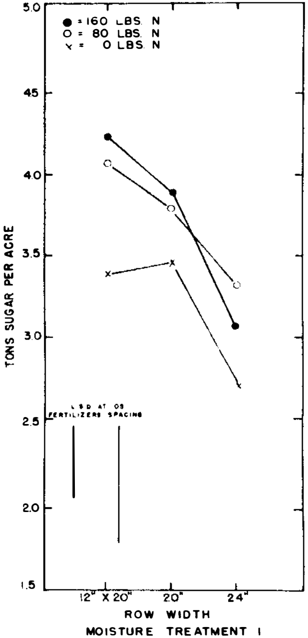
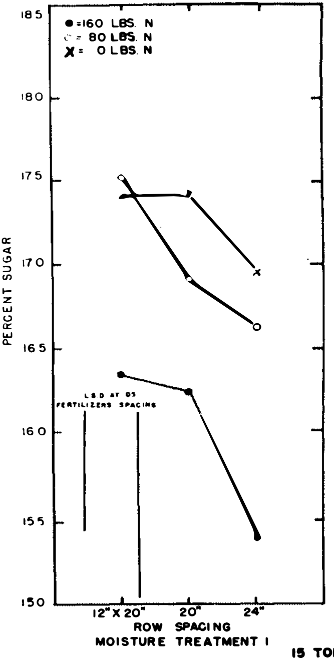
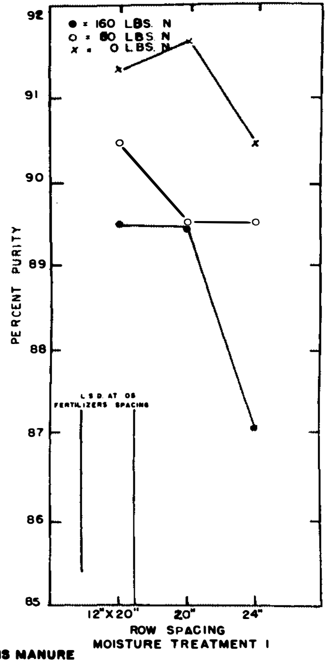


Figure 4.—Tons of sugar obtained from various row spacings and at various nitrogen-fertilizer levels.

The percentage sugar for the same treatments referred to in figures 3 and 4 is given in figure 5. Here it will be noted that the 160-pound nitrogen treatment had a marked effect upon the percentage sugar in the beets. There is no significant differences between 0 and 80 pounds of nitrogen on any of the spacings used. The data in figure 5 suggests that the higher the rate of nitrogen application and the less densely spaced the plants, the lower the sugar percentage. The same general tendency can be seen in figure 6 when these treatments are compared on a percentage purity of the extract juice basis. The data here show significant differences in the percentage purity due to nitrogen-fertilizer treatments on all spacings. The purity is high in all cases except where high nitrogen is applied in the 24-inch rows.





15 TONS MANURE

Figure 5.—Percentage sugar in sugar beets as influenced by row width and nitrogen fertilization.

Figure 6.—Percentage purity of extract juice of sugar beets as influenced by row width and nitrogen fertilization.

The importance that should be attached to percentage purity seems to be in controversy. Hence, it is not known that differences of the magnitude obtained in this experiment have any practical meaning.

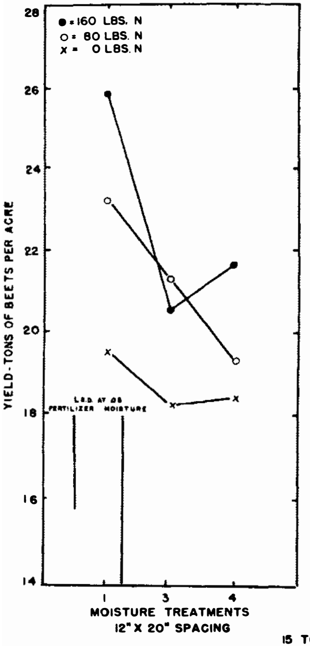
Effect of Moisture.—Figure 7 presents a comparison of moisture levels 1, 3, and 4 at three rates of nitrogen on the yield of sugar beets. Note the significant differences at all levels of nitrogen on the low moisture-stress plots, and the significant differences between low and medium rates of nitrogen on moisture treatment 3, and no difference in yield between low and medium rates of nitrogen under conditions of high moisture stress. Here nitrogen is an effective fertilizer only if moisture does not become limiting. There appears to be at least two possible explanations for the effectiveness of nitrogen on moisture level 1, and its lessened effect on moisture treatments 3 and 4. The first possibility is that added nitrogen (80 and 160 pounds) stimulated early vegetative growth, which in turn hastened the rapid depletion of water from the nitrogen-fertilized plots, and finally resulted in arrested root growth. The second explanation is, that as the surface soil became dry, the added nitrogen became unavailable to the plant, and hence ineffective in growth. At any rate the yield of sugar beets was no greater where 160 pounds of nitrogen was applied than where 80 pounds of nitrogen was used on moisture treatment 3. Yield was no greater for 80 pounds than for no nitrogen under moisture treatment 4. It is not quite clear why 160 pounds of nitrogen stimulated yield on moisture treatment 4.

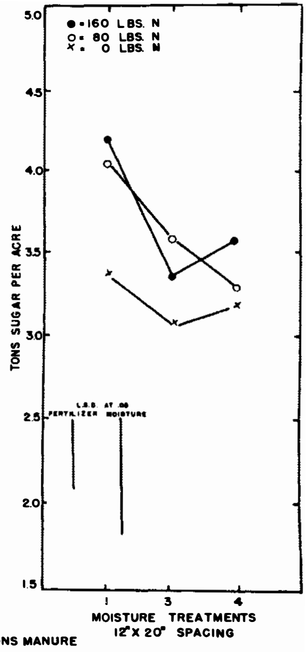
Data on the chemical analyses of beet leaf petioles indicate that the beets on all plots were getting ample nitrogen in July, but that on plots receiving 0 and 80 pounds of nitrogen on moisture treatment 4, plants were definitely deficient in nitrogen during August and September. Plots receiving 160 pounds of nitrogen per acre did not appear to be deficient in nitrogen at any time.

Resistant block reading indicate that the nitrogen-fertilized plots lost moisture slightly faster than the unfertilized plots, but this difference does not appear to be great enough to explain the response of beets to various nitrogen levels under the three moisture treatments. It appears from the information at hand that the high moisture stresses down to the 18- and 30-inch depths are associated with arrested root growth, and may be the principal factor limiting root growth under the conditions of this experiment.

This graph again emphasizes the fact that if one is to approach a maximum use of fertilizer it is necessary to have low moisture stress or adequate water. It is obvious that correct conclusions would have been difficult to arrive at, with respect to fertilizer treatment, had this experiment been conducted at only one moisture level. One would be forced to one conclusion as to the effect of nitrogen levels for sugar beets if the experiment were conducted only on moisture treatment 4, and to another conclusion, if the work were conducted on moisture treatment 3. Likewise, if moisture variables were studied on soil of low fertility one would conclude that moisture was of little or no effect on yield of sugar beets.

Figure 8 presents data which show the sugar produced for the same condition referred to and comparisons made in figure 7. Again the importance of having the right combinations of factors is brought out in the data. There is little difference for the three moisture treatments when sugar beets are grown on soil low in available nitrogen. However, there are significant differences in sugar produced when one compares sugar production on moisture treatment 1, with that on moisture treatments 3 and 4, under conditions of medium and high nitrogen levels.





15 TONS MANURE

Figure 7.—Yield of sugar beets under three conditions of moisture stress and at three different nitrogen-fertilizer levels.

Figure 8.—Tons of sugar produced under three conditions of moisture stress and at three different nitrogen-fertilizer levels.

Figures 9 and 10 present a comparison of the same factors of moisture and fertility presented in figure 7, in relation to their influence on percentage sugar and percentage purity. It may not be easy to properly interpret and explain the effect of moisture treatment on the percentage sugar and percentage purity. The effect of high levels of nitrogen is seen in about the same manner as was shown in figures 5 and 6. Significant difference in percentage sugar is obtained when a comparison is made between nitrogen treatments under all conditions of moisture stress. It is readily observed that high levels of nitrogen will decrease percentage of sugar. There appears to be little if any effect on sugar percentage for 80 pounds of nitrogen. Purity is definitely affected by high fertilization but it is not quite clear what value should be placed upon this information. It is not definitely known why the percentage sugar and percentage purity should be low in moisture treatment 3. This may be due to the fact that the irrigation treatment made the last of August and the resulting available nitrogen may have stimulated late growth. Late vegetative growth is associated with decreased sugar percentage and percentage purity. Two observations argue against this explanation. Beets receiving no added nitrogen showed a depressed sugar percentage as much as those receiving 160 pounds per acre. Petiole analyses in September showed only slightly greater amounts of nitrogen in leaves from beets growing under conditions of moisture treatment 3 than those from beets on moisture treatments 1 and 4.

Barnyard Manure.—The beneficial effects obtained from barnyard manure differed with different moisture treatments, different spacing of plants, and with different levels of nitrogen. In the comparison of manure versus no manure it probably should be pointed out that regardless of the amount of commercial fertilizer added in this experiment there is strong evidence that beneficial effects were still obtained with the 15-ton application of barnyard manure.

Figures 11 and 12 present a good picture of increases due to the addition of manure at different nitrogen levels, and the importance of moisture in the response obtained from manure. It can be seen that there are significant differences between the manure and no manure plots for all levels of nitrogen for the plots receiving moisture treatment 1, that is, those held at a low soil-moisture stress throughout the season. While the tendency under moisture treatment 3 is for the manure plots to yield more than the no manure plots, the differences between manure treatments are not significant. There are significant differences in yield between the low and medium nitrogen levels, even under conditions of high moisture stress. These comparisons in figures 11 and 12 are made at the close spacing of plants and the data in the graphs point again to the importance of approaching optimum conditions for the various factors affecting plant growth.

Figures 13 and 14 show the effect of the treatments discussed in figures 11 and 12, on the yield of sugar per acre. Under conditions of low moisture stress there are significant differences between manure and no manure at all levels of nitrogen. When a comparison is made on the basis of nitrogen fertilization, on the other hand, the only significant differences in yield of sugar are those between 0- and 80-pound rates of application. Under conditions of high moisture stress (figure 14), there are no significant differences in yield of sugar for either nitrogen fertilization or manurial treatment.

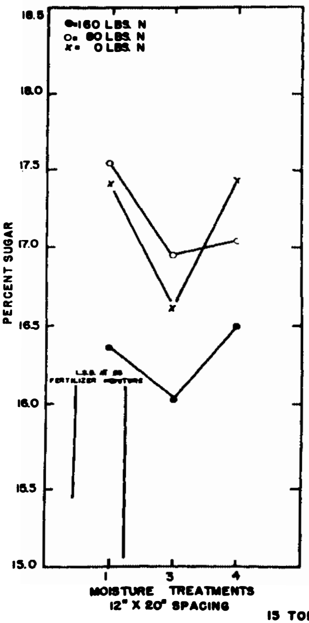


Figure 9.—Percentage sugar as influenced by moisture treatment and nitrogen fertilization.

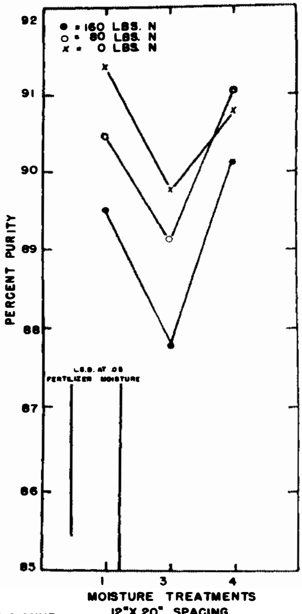
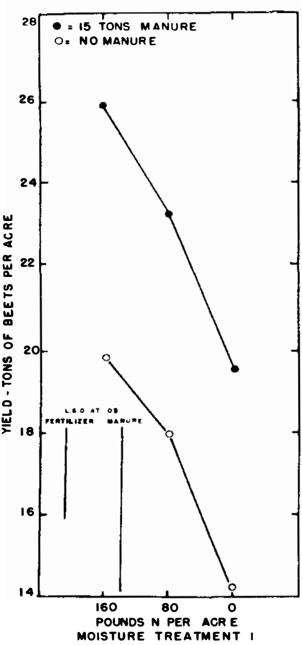
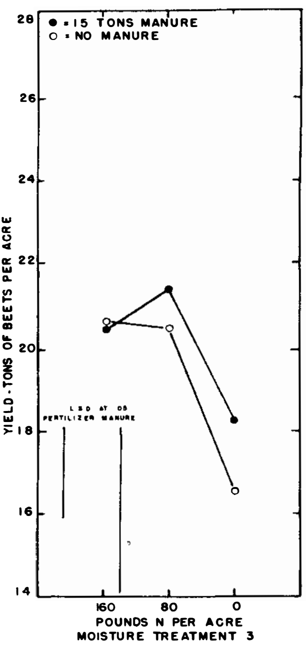


Figure 10.—Percentage purity as influenced by moisture treatment and nitrogen fertilization.

A study of the data in figures 13 and 14 may make it easier to understand why so many apparently conflicting reports have been made on the response of sugar beets to manure and fertilizer. Under soil-moisture conditions of figure 13, differences in yield of sugar are evident while there are no yield differences under conditions of figure 14.

In order to avoid using an undue number of graphs, tables 1 and 2 are given. Data from only four of the eight fertilizer treatments are presented. Since no significant increases in yield were obtained from more than 100 pounds of phosphoric acid, or from 150 pounds of potash, or 50 pounds of copper sulfate, the data from plots receiving variables of these fertilizer treatments are not presented here.





12" X 20" SPACING

Figure 11.—Yield of sugar beets under condition of low moisture stress as influenced by manure and nitrogen fertilization.

Figure 12.—Yield of sugar beets under high moisture stress as influenced by manure and nitrogen fertilization.

Many interesting comparisons may be made from the data in tables 1 and 2. If one should compare the mean yield of beets for each of the three spacing variables he will observe a very interesting tendency. It will be observed in table 1, where manure has been applied, that as the spacing is increased between rows the yield tends to decrease. This tendency is reversed in table 2.

It is plain from a study of tables 1 and 2 that with each successive increment of nitrogen fertilizer there is a tendency for increased yields. Significant differences in yield occur at all spacing variables between the 0- and 80-pound nitrogen applications.

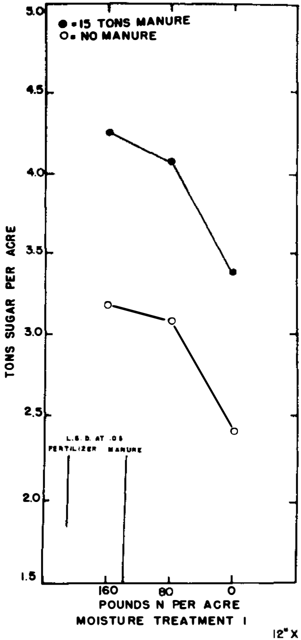
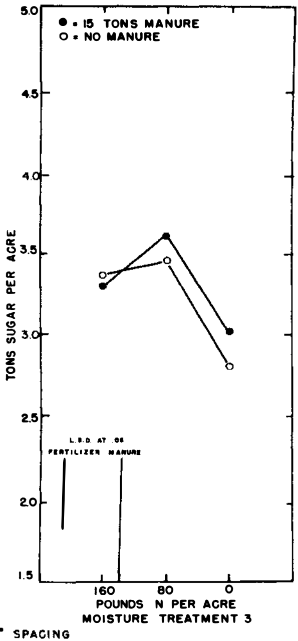


Figure 13. Yield of sugar under conditions of low moisture stress as influenced by manurial treatment and nitrogen fertilization.



12" X 20" SPACING

Figure 14. Yield of sugar under conditions of high moisture stress as influenced by manurial treatment and nitrogen fertilization.

Little reference has been made to moisture treatment 2 in the above discussion. For those who are interested in this moisture treatment, the data are available in tables 1 and 2. It will be observed that when manure was used in the closely spaced rows (12- by 20-inch) moisture treatment 2 gave yields very similar to those obtained under moisture treatment 3. With the normal 20-inch spacing the yield under moisture treatment 2 was mid-way between those of moisture treatments 1 and 3. Under conditions of wide row spacing moisture treatment 2 was better than moisture treatments 1 and 4 and equal to moisture treatment 3.

Under conditions of wide row spacing and without manure moisture treatment 2 was easily the best moisture condition.

Table 1.– Yield of sugar beets in tons per acre under various fertility, moisture and spacing conditions with 15 tons manure per acre (1946).

Treatments: Row width 12x20 inches	$N_0P_1K_0$	$N_1P_1K_0$	$N_2P_2K_0$	$N_2P_2K_1$	**Mean**
W_1	19.6[1]	23.2	25.9	24.1	23.2
W_2	17.1	20.2	22.0	23.7	20.8
W_3	18.3	21.4	20.7	22.9	20.8
W_4	18.4	19.3	21.8	20.3	20.0
Mean	18.4	21.0	22.6	22.8	21.2
Row width 20 inches					
W_1	20.0	22.8	24.2	26.4	23.4
W_2	18.1	21.3	23.4	21.8	21.2
W_3	17.0	19.1	20.2	20.7	19.3
W_4	14.3	19.9	21.0	21.8	19.3
Mean	17.4	20.8	22.2	22.7	20.8
Row width 24 inches					
W_1	16.2	19.9	20.1	21.2	19.4
W_2	17.8	23.0	23.4	24.4	22.1
W_3	19.2	20.2	24.6	24.6	22.2
W_4	13.7	16.8	19.5	18.4	17.1
Mean	16.7	20.0	21.9	22.2	20.2
Average	17.5	20.6	22.2	22.6	20.7

Table 2.—Yield of sugar beets in tons per acre under various fertility, moisture and spacing conditions without additions of manure (1946).

Treatments: Row width 12x20 inches	$N_0P_1K_0$	$N_1P_1K_0$	$N_2P_2K_0$	$N_2P_2K_1$	**Mean**
W_1	14.2[1]	18.1	19.8	20.2	18.1
W_2	17.3	21.3	21.2	20.1	20.0
W_3	16.7	20.6	20.8	21.7	19.9
W_4	15.6	18.4	20.9	19.9	18.7
Mean	15.9	19.6	20.7	20.5	19.2
Row width 20 inches					
W_1	17.9	20.7	22.4	23.0	21.0
W_2	16.0	19.8	21.9	20.4	19.5
W_3	14.4	17.5	19.8	20.4	18.0
W_4	17.5	21.9	21.9	23.4	21.2
Mean	16.5	20.0	21.5	21.8	19.9
Row width 24 inches					
W_1	12.8	18.2	21.4	22.0	18.6
W_2	20.4	22.4	23.6	23.5	22.5
W_3	16.2	20.8	22.5	21.8	20.3
W_4	15.0	20.2	22.5	20.6	19.6
Mean	16.1	20.4	22.5	22.0	20.3
Average	16.2	20.0	21.6	21.4	19.8

[1]Mean of three replications.

Significant differences at P=.05.

Between fertility levels -- 2.50 t/a

Between spacing, moisture or manure variables ---------------------- 4.16 t/a

Discussion

The data presented point out the need for having optimum conditions for the various factors affecting plant growth and the need for controlling or measuring all important factors. For instance, to be of greater value a fertility rate experiment conducted under irrigation must have moisture as a variable, or at least as a controlled factor, with a complete moisture-stress record. It is obvious from this experiment that if one is to obtain maximum return from added fertilizer, there must be a sufficient number of plants per acre to make a fairly complete use of all the fertilizer added. In this experiment the largest response occurred only on the wettest plots. In other words, regardless of the number of plants per acre and the nutritional level, maximum production will not be obtained unless the soil moisture is adequate to produce a maximum crop. If only one moisture level were used in an experiment of this type, the fertility response and recommendations based upon it would apply only to that particular treatment, and unless that treatment happened to be one supplying adequate moisture at all times, erroneous conclusions would be drawn with respect to maximum yields and maximum use of fertilizers. It is only when the best combination of all the factors affecting plant growth can be brought together, that we can expect a maximum economic production.

Under conditions of moderate-to-low soil fertility there is a tendency for sugar beets to give a smaller response to added fertilizers when the between-row spacing is wide than when this spacing is close. Also under conditions of wide spacing there is a tendency for the sugar percentage of beets to be lower than under conditions of close spacing. Nitrogen fertilization accentuates this difference.

Sugar beets grown under conditions of high moisture stress show little if any benefit from manurial treatment or nitrogen fertilization. However, when grown under conditions of low moisture stress marked yield increases are obtained from barnyard manure and added nitrogen fertilization.

High nitrogen fertiliaztion and manurial treatment tend to lower the percentage purity of extract juice of sugar beets.

The outstanding fact of this study is, that in order to properly interpret the results of any particular field treatment, as many of the factors of growth as possible should be accurately known, if not controlled.

Summary

1.—Yield of sugar beets was increased approximately 3 tons per acre for application of 80 pounds of nitrogen under conditions of low moisture stress. This was true for all spacing conditions studied. Sugar beet yields were significantly increased under conditions of low moisture stress only under close spacing (12- by 20-inch rows) for an additional 80 pounds of nitrogen above the initial 80 pounds.

2.—Yield of sugar was increased approximately ½ ton per acre under low moisture stress and with all row-width spacings studied for 80 pounds of nitrogen. An additional 80 pounds of nitrogen did not further increase yields of sugar under any of the spacings studied.

3.—There was a tendency for added commercial nitrogen to lower the percentage sugar and percentage purity of extract sugar beet juice. This difference was not significant for the first addition of 80 pounds of nitrogen. The percentage sugar was lowered from $\frac{5}{10}$ to 1 percent for the second addition of 80 pounds of nitrogen per acre. The purity was lowered approximately 2 percent for all spacing conditions when beets from plots receiving no nitrogen are compared with those receiving 160 pounds nitrogen per acre.

4.—Under conditions of low moisture stress and with close row spacing (12- by 20-inch) yield differences were obtained between each of the three nitrogen levels (0, 80, and 160 pounds) with a difference of 6 ton of beets between 0 and 160 pounds of nitrogen per acre. Under conditions of moderate moisture stress there was no difference in yield between 80- and 160-pound levels of nitrogen and under high moisture stress no difference in yield between 0 and 80 pounds of nitrogen per acre.

5.—Under all conditions of moisture stress and with close spacing there was no difference in yield of sugar between 80 and 160 pounds of ntirogen. Under conditions of low and moderate moisture stress there was about ½ ton of sugar increase for 80 pounds of nitrogen over no nitrogen. Under conditions of high moisture stress there was no significant difference in yield of sugar between any variation in nitrogen fertilization.

6.—Moisture stress had no effect upon percentage sugar or percentage purity. High nitrogen fertilization (160 pounds per acre) depressed both percentage sugar and percentage purity under all conditions of moisture stress studied with the following exception: Under conditions of high moisture stress there was no significant difference in percentage purity between any of the nitrogen treatments.

There was no difference in percentage sugar or percentage purity between sugar beets grown under conditions with no nitrogen and 80 pounds of nitrogen per acre under the conditions of moisture stress studied.

7. Under conditions of low moisture stress and with the close row-spacing of sugar beets 15 tons of barnyard manure increased yields from 5 to 6 tons per acre irrespective of the amount of nitrogen added (0, 80, or 160 pounds per acre).

Under conditions of moderate-to-high moisture stress there was no increased yield for additions of manure at any level of nitrogen.

8.—Under conditions of low moisture stress and close row-spacing, 15 tons manure increased the yield of sugar 1 ton per acre with all levels of added commercial nitrogen. Under conditions of moderate-to-high moisture stress there was no difference in yield of sugar between manure treatments at any nitrogen level.

9.—The only interactions obtained in this experiment were those obtained under conditions of low moisture stress.

10.—No differences in yield of beets or sugar, percentage sugar, or percentage purity were obtained for differential treatments involving phosphorus, potassium, or copper.

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