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## Bulletin No. 362 - Sugar Beet Yield and Quality As Affected by Plan Population, Soil Moisture Condition, and Fertilization

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AS AFFECTED BY PLANT POPULATION  
SOIL MOISTURE CONDITION  
AND FERTILIZATION

By JAY L. HADDOCK



Agricultural Experiment Station  
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Logan Utah

U.S. 532  
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# Sugar Beet Yield and Quality As Affected by Plant Population, Soil Moisture Condition, and Fertilization

by JAY L. HADDOCK<sup>1</sup>

## INTRODUCTION

**I**N 1605 Oliver de Serres, French agronomist, observed that beets contained sugar—and in 1750 Andrew Marggraf, a German physicist, obtained sugar crystals from beets. It was more than 100 years from Marggraf's discovery until the first successful beet sugar factory was developed in the United States at Alvarado, California, in 1870. Since that time beet sugar has become increasingly more important in our national economy. At present continental United States produces a third of her sugar requirements, 70 to 80 percent of which is from sugar beets. The importance of the sugar beet crop in national and world economy is justification for research effort as a means to more economical production of this crop.

The early experimental work on sugar beet production was designed to answer the most practical questions relative to soil and climatic requirements, suitable spacing, soil fertility conditions, and general irrigation demands. The conclusions from these early investigations gave intelligent direction and encouragement to farmers and generally stimulated sugar beet growing.

## Need for Additional Research

The average sugar beet yield in the United States in 1950 was only 14.6 tons per acre (U. S. Dept. Agr. 1951), which is far below average yields produced by the better farmers. This fact suggested the need for a better understanding of the field conditions which affect sugar beet yields and quality.

The sugar beet crop is exacting in plant nutrient and soil moisture requirements, particularly during the early stages of growth. Numerous single factor experiments have been conducted in recent years to determine the best soil moisture (Doneen 1942, Nuckols 1942), most suitable fertilizer condition (Gardner and Robertson 1942, Haddock and Kelly 1948, Hill 1946, and Tolman 1946), and most desirable plant population

1. Soil scientist, Division of Soil Management and Irrigation Agriculture, U. S. Department of Agriculture, working in cooperation with the Utah Agricultural Experiment Station.

MOISTURE X SPACING X FERTILITY EXPT.

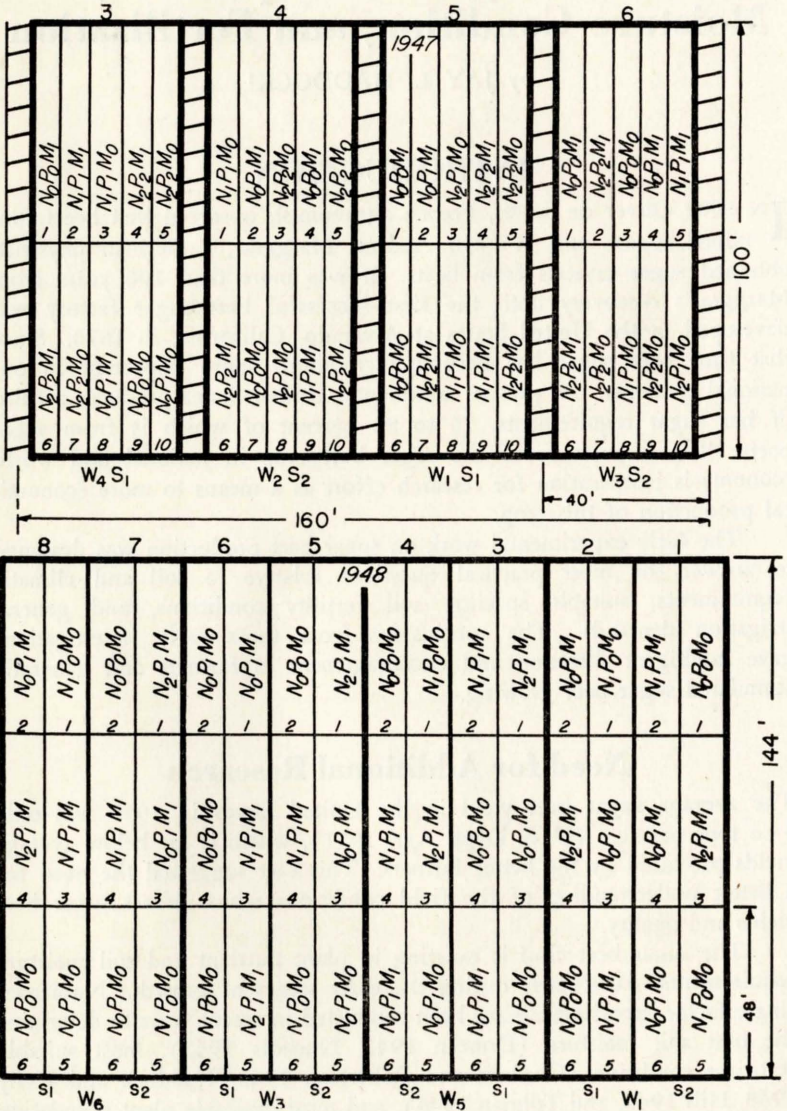


Fig. 1. Main plot and sub-plot arrangement taken from a section of the first replication to show experimental design (see tables 2, 3, and 5 for explanation of symbols)

(Deming 1940, Tolman 1946, and Venning *et al.* 1946) for economical sugar beet yields. It is not surprising that conflicting conclusions on sugar beet requirements were drawn from these widely scattered single factor experiments. Although there are real objections to multi-factor field experiments, they frequently offer the most rapid and economical solution to complex problems. Tolman (1942) pointed out the weakness of single factor field experiments 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 (1942) 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.

In view of the facts cited above, the best research approach to a better understanding of factors affecting yield and quality of sugar beets appeared to be through multi-factor experimentation. Accordingly, such an experiment was devised to study the problems of soil moisture condition, plant population, and soil fertility as they affect sugar beet production.

## MATERIALS AND METHODS

**T**HE experiments reported herein for the years 1946, 1947 and 1948 were designed to study the interrelations among soil moisture, plant population, and soil fertility as they affect the quality and yield of sugar beets. In all three years the various plots were arranged in a randomized split plot design. Two sections of the first replication for 1947 and 1948 are presented in fig. 1 to illustrate the experimental design used in these experiments. There were three complete replications in 1946, five in 1947, and four in 1948. In 1946 there were 24 main plots in each replication, made up of 4 moisture, 3 spacing, and 2 manure variables. Each main irrigation plot was 100 feet long by 32 to 48 feet wide (depending upon row spacing). Superimposed upon each of the 24 main plots were 8 commercial fertilizer plots, each of which was 4 rows of beets in width and 50 feet in length.

In 1947, there were 8 main plots in each replication made up of 4 soil moisture and 2 plant population variables. Each main plot (moisture  $\times$  spacing) was 100  $\times$  40 feet. Superimposed upon each of these plots were 10 fertilizer plots, each of which was 4 rows wide (6  $\frac{2}{3}$  feet) by 50 feet in length.

In 1948, there were 6 main irrigation plots in each replication, each 42  $\times$  144 feet. Superimposed on each row-width plot were 6 fertilizer variables. Each fertilizer plot was 6 rows wide (10 or 11 feet depending on between-row spacing) by 48 feet long.

The investigations were conducted on Millville fine sandy loam soil at Newton, Utah, in 1946, and on Millville silt loam at Garland, Utah, in 1947 and 1948. Some of the chemical characteristics of these two soils are presented in table 1. It will be observed that these are

Table 1. *Some chemical characteristics of soil samples from experimental sites*

Chemical characteristics	Soil type and location			
	Millville fine sandy loam Newton, Utah, 1946		Millville silty loam Garland, Utah, 1947 & 1948	
Depth (inches)	0-6	6-12	0-6	6-12
pH	8.10	8.18	7.92	7.95
Organic matter (percent)	2.23	2.13	2.40	1.34
CaCO <sub>3</sub> equivalent (percent)	5.50	8.20	3.80	14.90
Soluble salts (ppm)	328	328	369	402
CO <sub>2</sub> extractable PO <sub>4</sub> (ppm)	8	3	6	2
Cation exchange capacity	16.5	16.2	16.2	15.0
Exchangable cations*				
Na	1.1	1.4	0.5	0.5
K	4.0	3.5	1.1	0.9
Ca+Mg†	11.4	11.3	14.6	13.6

\*Millequivalents per 100 grams of soil.

†Ca+Mg estimated by difference between sum of Na+K and total base exchange capacity.

typical of the irrigated calcareous soils in the Great Basin Area, possibly a little higher in  $\text{CO}_2$  - extractable phosphorus than average. The soil at Newton maintained a water table between 5 and 9 feet deep while the water table at Garland was slightly deeper, or about 6 to 9 feet.

Table 2. *Irrigation regimes on sugar beet experiment\** (1946, 1947, & 1948)

Symbols of soil moisture variables	Irrigation treatments and soil moisture condition		
	1946	1947	1948
$W_1$	<i>Continuously moist</i> Below 750 cm water tension at 8 inch depth. (6 irrigations)	<i>Continuously moist</i> Below 750 cm water tension at 6 inch depth. (8 irrigations)	<i>Continuously moist</i> Below 650 cm water tension at 6 inch depth. <i>Sprinkle irrigation</i> 21 inches water used. (10 irrigations)
$W_2$	Similar to $W_1$ up to August 12. No irrigation thereafter. (4 irrigations)	Similar to $W_1$ up to July 28. No irrigation thereafter. (5 irrigations)	<i>Continuously moist</i> Same as $W_1$ . <i>Furrow irrigation</i> 30 inches water used. (9 irrigations)
$W_3$	Similar to $W_1$ up to July 15. Soil moisture tension allowed to reach equivalent of wilting at 18 inches before irrigation. (3 irrigations)	Similar to $W_1$ up to June 26. Soil moisture tension allowed to reach wilting percentage at 18 inches before irrigation. (4 irrigations)	No irrigation until July 20. Allowed to reach wilting at 6 inch depth thereafter before each irrigation. <i>Furrow irrigation</i> 18 inches water used. (5 irrigations)
$W_4$	Similar to $W_1$ up to July 15. Soil allowed to reach wilting to 30 inches before irrigation. (2 irrigations)	Similar to $W_1$ up to June 26. Soil allowed to reach wilting at 36 inches before irrigation. (3 irrigations)	Moderately moist to July 15. <i>Similar to <math>W_3</math> thereafter.</i> <i>Furrow irrigation</i> 20 inches water used. (6 irrigations)
$W_5$	-----	-----	<i>Similar to <math>W_1</math> up to July 29.</i> No irrigation thereafter. 2 <i>sprinkle</i> 1 <i>furrow</i> 7 inches water used. (3 irrigations)
$W_6$	-----	-----	Similar to $W_1$ up to August 14. No irrigation thereafter. 2 <i>sprinkle</i> 3 <i>furrow</i> 19 inches water used. (5 irrigations)

\*All plots uniformly sprinkle irrigated twice in 1946 and three times in 1947 before variables were initiated.



The apparent specific gravity of the Garland soil varied from 1.13 in the 4 to 6 inch depth to approximately 1.40 from 10 to 30 inches, gradually becoming lighter from 30 to 60 inches where it was 1.33 at 60 to 62 inches and then still lighter or 1.19 at 70 to 72 inches.

The soils had a gentle slope of from 1 to 2 percent. It will be observed from table 1 that the soils used in these studies were calcareous, with a pH of approximately 8.00. The soil at Newton had been under dry-farm management, alternately wheat and fallow, for the previous 50 years. The soil at Garland had been under irrigation for more than 50 years with alfalfa, wheat, sugar beets, and onions having been grown in rotation.

The symbols for the various soil moisture treatments used in the tables and graphs of this bulletin are described in table 2.

The plant population variables are identified in the tables and graphs of this bulletin by symbols  $S_1$ ,  $S_2$ , and  $S_3$ . These are identified in table 3.

Table 3. *Description of symbols used for various plant populations*

Symbols for plant population	Spacing of plants between and within rows and acre population		
	1946*	1947	1948*
$S_1$	Rows alternating 12 and 20 inches apart.	Rows 20 inches apart. Plants 6 inch apart in row.	Rows 20 inches apart.
	32,750 plants/A	52,270 plant/A	26,135 plants/A
$S_2$	Rows 20 inches apart.	Rows 20 inches apart.	Rows 22 inches apart.
	26,135 plants/A	26,135 plants/A	23,764 plants/A
$S_3$	Rows 24 inches apart.	-----	-----
	21,780 plants/A		

\*Except as otherwise noted, plants were spaced 12 inches apart in the row.

One hundred pounds per acre of muriate of potash (60 percent  $K_2O$ ) were broadcast uniformly over the field in 1947 and 1948 to minimize the possibility of potassium deficiency. Potassium was used as a variable in 1946. Barnyard manure was broadcast on the surface in the spring and disked into the upper four inches of soil immediately. Phosphorus was applied as treble superphosphate (43 percent  $P_2O_5$ ) and nitrogen was applied as ammonium nitrate (33 percent N). The commercial fertilizers were placed in bands four inches deep and six

Table 4. *Planting, thinning, fertilizing, and harvesting dates*

Year	Planting dates	Thinning dates	Fertilizing dates	Harvesting dates	Growing days thinning to harvest	Seed used
1946	4/22	6/7	6/1	10/24	139	U. S. No. 22 whole
1947	4/12	5/21	6/5	10/10	142	U. S. No. 22 segmented
1948	4/24	6/7	6/26	10/10	125	U. S. No. 22 segmented

inches to the side of the beet plants about thinning time. Planting, thinning, fertilizing, and harvest dates are given in table 4.

Commercial fertilizer and manure treatments used are symbolized and described in table 5.

Table 5. *Fertilizer treatments and symbols*

Symbols	Fertilizer treatment
N <sub>0</sub> =	No nitrogen
N <sub>1</sub> =	80 pounds nitrogen per acre
N <sub>2</sub> =	160 pounds nitrogen per acre
P <sub>0</sub> =	No phosphoric acid (P <sub>2</sub> O <sub>5</sub> )
P <sub>1</sub> =	100 pounds phosphoric acid per acre
P <sub>2</sub> =	200 pounds phosphoric acid per acre
K <sub>1</sub> =	150 pounds potash (K <sub>2</sub> O) per acre
M <sub>0</sub> =	No manure
M <sub>1</sub> =	15 tons barnyard manure per acre

Total rainfall by months for the three years under consideration is given in table 6. It will be observed that the rainfall is close to normal for the area, which is between 14 and 15 inches annually. The relative humidity in this area is 40 to 50 percent from June to September with 8.5 to 9 hours of sunshine daily. Evaporation from a free water surface varies from 4.5 to 8.0 inches of water per month (Utah Agr. Exp. Sta. 1902).

## Soil Moisture Data

The soil moisture condition in the experiments considered herein was followed by means of soil moisture tensiometers and gypsum resistance blocks. The tensiometer is used to indicate soil moisture conditions

Table 6. *Precipitation by months* \*

	Newton 1946	Garland 1947	Garland 1948
	<i>inches</i>	<i>inches</i>	<i>inches</i>
January	0.24	0.62	0.89
February	0.66	0.95	1.27
March	0.92	1.56	1.86
April	1.01	1.79	2.37
May	2.66	2.42	1.39
June	0.42	2.12	2.47
July	0.75	0.06	0.88
August	0.38	1.36	0.16
September	0.77	2.25	0.74
October	4.05	1.12	0.52
November	1.24	1.15	0.94
December	2.54	0.79	1.02
Totals	15.64	16.19	14.51

\*Data obtained from Fritz Ecklund, Newton, and Utah-Idaho Sugar Company, Garland.

from saturation to slightly below field capacity, while the gypsum block is used to register conditions from slightly below field capacity to the wilting percentage. Each instrument is effective over approximately 50 percent of the available soil moisture range. Both tensiometers and blocks were used in the moist plots, while blocks only were placed in the other plots. When resistance blocks were used they were placed at various depths in the soil profile so that a complete seasonal record was kept of soil moisture conditions throughout the root zone.

## Plant Sampling and Chemical Analyses Procedures

Forty sugar beet petioles were selected from each plot for analysis. The procedure suggested by Ulrich (1948) was used in sampling. Petioles from the youngest mature leaves were selected. These were washed free of soil, cut into sections two inches in length and dried in a convection oven at 70 degrees centigrade for 48 hours. The sample was ground in a Wiley mill to pass a 40 mesh screen, bottled, and stored for chemical analysis<sup>2</sup>.

2. These procedures have since been modified and can be had upon request.

Nitrate-nitrogen was determined by weighing 0.1 to 0.5 grams of dried plant material into 300 ml. erlenmeyer flasks. To this was added 25 ml. of 0.1 N sulphuric acid solution and approximately 150 mgms. of "Norit A" decolorizing carbon to remove color. This mixture was shaken 10 minutes on a mechanical shaker and filtered through Whatman no. 2 paper. Finally one drop of the filtered solution was placed on a spot plate and 7 drops of diphenylamine added to each drop. This mixture was stirred and read (in 30 to 60 seconds) in comparison with simultaneously prepared standards.

Soluble phosphorus was determined by weighing 0.2. grams of dried plant material into 300 ml. erlenmeyer flasks. To this 50 ml. of 0.1. N acetic acid solution was added and the mixture shaken for five minutes before filtering. From 5 to 15 ml. aliquot (such that colorimeter reading is between 40—80 percent light transmission) was placed in a 300 ml. beaker. To this was added 1 drop of 30 percent  $H_2O_2$  for each ml. aliquot used. This mixture was next evaporated to dryness on a steam bath, and heated a half hour after dryness to dispel traces of hydrogen peroxide. The sample was next cooled and 43 ml. distilled water added. The mixture was stirred to dissolve residue and 5 ml. of ammonium molybdate solution added. The resulting mixture was thoroughly stirred and 2 ml. of 1-amino, 2-naphthol, 4-sulfonic acid solution added. This mixture was stirred again, filtered, and poured into colorimeter tubes. The color density was read in a photoelectric colorimeter about 30 minutes after developing the color using no. 660 filter. With each lot of unknowns a set of known standards was run. The readings from the standards were plotted on semilogarithmic paper from which curve the phosphorus content of the unknowns was determined.

Sucrose and purity percentages of the extract juice of sugar beets were determined in the U. S. Sugar Plant Field Laboratory at Salt Lake City, with the cooperation of C. H. Smith and F. V. Owen. The standard cold water extraction procedure of the laboratory was followed.

## EXPERIMENTAL RESULTS

### Plant Population

PREVIOUS RESEARCH in the Intermountain area has given good reason for maintaining a within-row spacing of about 12 inches and a between-row spacing of about 20 inches. It has long been recognized that as space allotment for each sugar beet plant increases, the size of the root likewise increases, but not strictly in proportion to the space allotment.

In the early development of sugar beet production practices, close between-row and within-row spacings were the rule. Recent rapid changes toward more complete mechanization in methods of thinning, weeding, and harvesting sugar beets have made it advisable to re-examine field plant spacing patterns.

#### Effect on Yield and Quality

A complete review of the literature dealing with the effect of plant population on yield and quality of sugar beets is given by Coons (1948). The conclusions which one would draw from a study of available data must be modified to encourage complete mechanization of sugar beet production.

Since it had been shown by Tolman *et al.* (1948), Doxtator (1948), Deming (1948), and Doxtator and Skuderna (1946), that sugar beets respond best to a space pattern which provides rows 20 inches apart, this row spacing was used at the Utah Station as a basis for comparing other between-row spacings.

**Between-Row Spacing Variables.** In 1946 three row spacings were studied at eight fertility levels and under three soil moisture conditions. Significant yield increases were obtained for 80 pounds of nitrogen at the three row spacings studied (fig. 2). However, only at the 20 and the alternate 12 and 20 inch spacing was it possible to obtain significant yield increases for a second increment of 80 pounds of nitrogen. Differences required for significance at the 5 percent level for the treatments being compared are indicated by vertical bars on the graph. This device is used freely in this bulletin to indicate the least significant difference between treatments at the five percent point. 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 vertical position.

The results reported here were on moisture treatment  $W_1$  (see table 2) and on a reasonably fertile soil to which 15 tons of manure

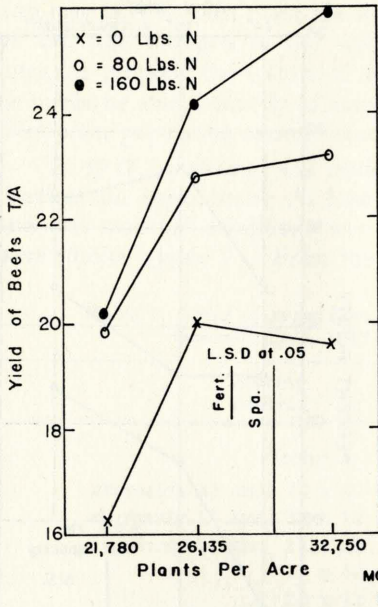


Fig. 2. Yield of sugar beets as affected by various row-width spacings and nitrogen fertilizer treatments

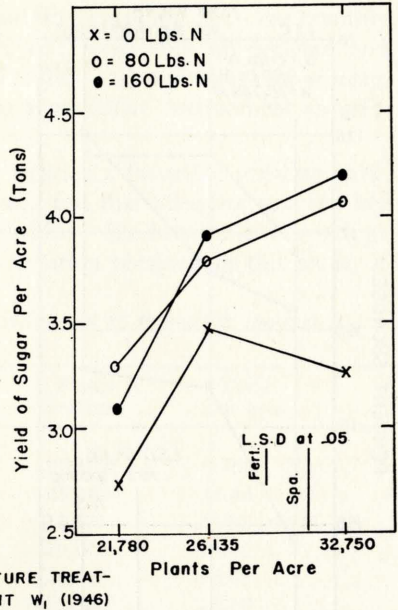
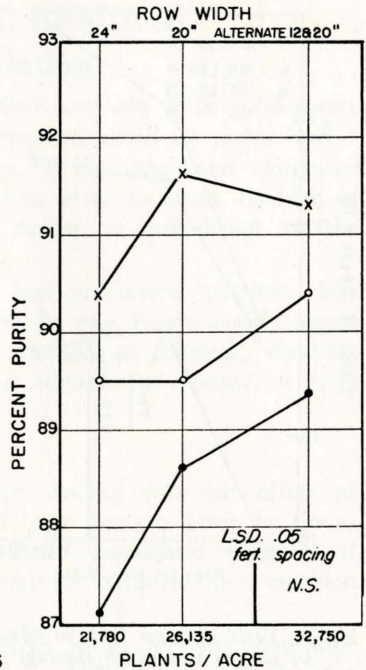
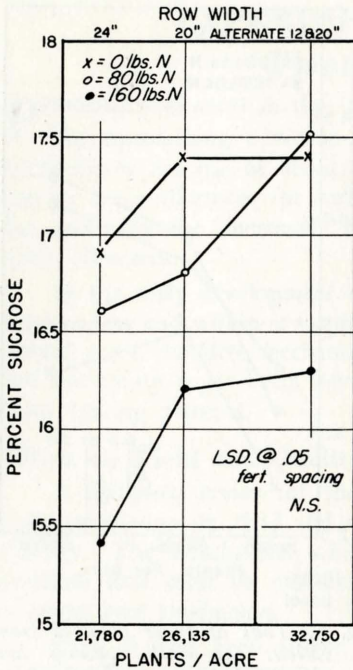


Fig. 3. Tons of sugar obtained from various row-width spacings and nitrogen fertilizer treatments

had been applied. The conclusion one must draw from these facts is that soils of high fertility and favorable soil moisture condition will support a higher plant population with concomitant yield increases than will soils of lower fertility.

The tons of sugar produced per acre for the same treatments shown in fig. 2 are given in fig. 3. When one compares the sugar yield at the 20 inch and the alternate 12 and 20 inch row 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. Although the yield of beets at the 20 and alternate 12 and 20 inch spacing was significantly increased for the second increment of nitrogen, the yield of sugar was not increased at these between-row spacings. This is because the second 80 pound increment of nitrogen unduly depressed the sugar percentage. There was a marked depression in sugar percentage caused by the addition of 160 pounds of nitrogen per acre as shown in fig. 4. There was little effect on sugar percentage as a



1946

MOISTURE TREATMENT W1

Fig. 4. Percentage sugar in sugar beets as influenced by row-width and nitrogen fertilization

Fig. 5. Percentage purity of extract juice of sugar beets as influenced by row-width and nitrogen fertilization

result of applying 80 pounds of nitrogen at the alternate 12 and 20 inch row spacing. An abrupt depression in sugar percentage occurred for 160 pounds of nitrogen at the 24 inch row spacing as contrasted to the 20 inch row. The response of plant population to available nitrogen as measured by sucrose percentage and percent purity is shown in figs. 4 and 5. The purity of extract juice and the sugar percentage are unduly depressed by excess available nitrogen when plant populations are relatively low. It will be observed in table 3 that there were nearly 22,000 plants per acre with 24 inch rows and nearly 33,000 plants at the alternate 12 and 20 inch spacing.

From these data it would appear that many environmental factors may dictate the most efficient plant population pattern if one is to be governed by quality as well as yield. It is conceivable that each field or

area may have its own plant spacing pattern depending upon the quantity of available nitrogen in the soil. If one were able to evaluate and integrate properly the factors of soil fertility, soil moisture, and climate, he might be able definitely to assign to a particular environment an efficient plant population arrangement.

In 1947, an attempt was made to provide a favorable growing environment for sugar beets. At least it was felt that adequate soil fertility and soil moisture conditions were provided. Six between-row spacings were studied (table 7). From the information obtained in this study, it

Table 7. *Yield of sugar beets as influenced by row-width spacing, Garland, Utah, 1947*

Spacing patterns		Plants per acre	Yield per acre
<i>inches</i>		<i>number</i>	<i>tons</i>
alternately 12 and	20 x 6	65,340	25.84
alternately 12 and	20 x 12	32,670	25.81
alternately 12 and	24 x 12	29,040	24.36
	20 x 12	26,135	26.63
	22 x 12	23,760	26.19
	24 x 12	21,780	24.17
L. S. D. at .05			2.27 T/A

would appear that plant population may be varied widely (65,340 to 23,760 per acre) without markedly influencing total yield, providing the between-row spacing is not greater than 22 inches. There is a decided tendency for yields to decrease when 24 inch rows are used. It will be observed that there is a significant difference in yield between 24 inch rows and 20 inch rows. Also, there is a significant difference in yield between 20 inch rows and alternating 12 and 24 inch rows.

In 1948 a detailed study was made of two row-width spacings (20 inch and 22 inch) in which the spacing interval in the row was held constant at 12 inches. The results of this study are found in table 8. It will be observed that absolute differences, if any, are small and none is significant.

For the four irrigations and soil fertility conditions imposed upon sugar beets, yields for the two between-row spacings are similar. There are many farmers who feel that a 22 inch row is necessary where mechanical harvesting is practiced. If there are important advantages from the point of view of machinery operation of using a 22 inch row the data in table 8 would not greatly discourage its use from a yield standpoint.



Table 8. *Yield and quality of sugar beets as influenced by between-row spacings, Garland, Utah, 1948\**

Relative irrigation & fertilizer treatments	Yield per acre		Sucrose		Purity	
	20-inch	22-inch	20-inch	22-inch	20-inch	22-inch
	<i>tons</i>	<i>tons</i>	<i>percent</i>	<i>percent</i>	<i>percent</i>	<i>percent</i>
No fertilization inadequate irrigation	9.81	10.38	14.11	13.66	91.33	89.47
Mean of six irrigation & six fertilizer treatment	13.39	13.29	15.32	15.21	90.33	89.84
Mean of six irrigation regimes, adequate ferti- lizer treatment	15.84	15.62	14.03	13.92	87.73	86.67
Adequate fertilization adequate irrigation	17.28	16.90	13.00	13.38	88.53	86.57

\*Within-row interval was 12 inches throughout.

It will be observed, however, that there is a slight tendency for lower sucrose and a definite tendency to decrease the purity of extract juice with the 22 inch row as compared to the 20 inch spacing.

**Within-Row Spacing.** The data previously presented on between-row spacing experiments indicate that yields of beets cannot be held at their maximum in the Intermountain Area when spacings between rows exceed 22 inches regardless of the plant interval within the row. In 1947 an experiment was designed to study the effect of increasing the plant population within the standard 20 inch row.

No significant difference in yield was obtained from plots having 26,000 plants per acre (20 × 12 inch pattern) and those having 52,000 plants (20 × 6 inch pattern). Yield data for these two spacing treatments are given in table 9. It is obvious from these data that under the conditions of this experiment there is no advantage in increasing the plant population by the spacing of plants closer than 12 inches. There are obvious disadvantages. It requires more time to thin and harvest a thickly spaced field if hand labor is involved.

Since many farmers believe that the 20 inch row is a little narrow for many wide-tired tractors, it was thought advisable to study a number of within-row spacings at the 22 inch row spacing. Such a study was made in 1948 under as near optimum soil moisture and soil fertility conditions as could be provided for the rather adverse season. The results of this experiment are given in table 10. There are no significant yield differences between the actual plant intervals of from 10 to 22 inches

Table 9. *Yield of sugar beets as influenced by within-row spacing, Garland, Utah, 1947\**

Soil condition	Within-row spacing interval	
	six inches	twelve inches
	<i>T/A</i>	<i>T/A</i>
Mean of 4 soil moisture conditions at low fertility level	20.00	20.69
Mean of 4 soil moisture conditions at high fertility level	26.31	26.48
Mean of 10 fertility treatments with soil kept continuously moist	25.83	25.86

\*All rows spaced 20 inches apart.

within the 22 inch row. Although there are no actual yield differences, there are some obvious objections to within-row spacings wider than 15 inches. These will be pointed out subsequently under the discussion of beet quality.

Throughout the spacing range of 12 to 22 inches the lack of plant numbers appeared to be wholly compensated for by increase in size of beets.

**Quality of Beets as Influenced by Plant Population.** The yield of sugar beets is not always an adequate measure of the value of field

Table 10. *Yield and quality of sugar beets as influenced by within-row spacing, Garland, Utah, 1948\**

Within-row interval		Plants per acre	Yield per acre	Quality of sugar beets	
Attempted	Achieved			Sucrose	Purity
<i>inches</i>	<i>inches</i>	<i>thousands</i>	<i>tons</i>	<i>percent</i>	<i>percent</i>
8	9.7	36.0	18.7	16.49	90.66
12	12.9	23.7	20.4	16.37	90.17
15	14.4	19.0	19.7	16.14	90.82
17	15.1	16.8	18.8	15.87	88.67
20	19.3	14.3	18.6	16.60	89.65
24	22.4	11.9	19.1	15.44	88.44

L. S. D. at .05

N. S.

N. S.

2.00

\*All rows spaced 22 inches apart. Mean of four replications.

practices. The quality of the crop is frequently as important as the quantity. It has been shown by Skuderna (1948) and Doxtator (1948) that in general as sugar beet plant population increased above 14,000 and 20,000 plants per acre, sucrose percentage increased. This same tendency is shown in figs. 4 and 5 for plant populations between 22,000 and 33,000 per acre. Although significant differences are shown between fertilizer nitrogen treatments, there are no significant differences in sucrose and purity as a result of differences in plant populations. The trend is definite and consistent for the three plant populations studied, however.

As noted previously no significant yield differences were obtained in 1948 from a wide variety of plant populations varying from 12,000 to 36,000 per acre (see table 10). However, it is obvious from the data in table 10 that a tendency for depression in purity percentage occurred when spacings were wider than 15 inches between plants.

That excess available soil nitrogen at harvest time tends to stimulate vegetative growth of sugar beets and hence tends to lower both the sucrose percentage in the root and the percent purity of the expressed juice of the beet is well established.

Data have been accumulated which show clearly the delicate balance that exists among the three factors, available nitrogen, plant population, and sugar beet quality. When sugar beets are grown on a soil of a given nitrogen-supplying power, the percent purity and percent sugar increase as the plant population increases. This tendency appears to strengthen as the nitrogen-supplying power of the soil increases. These facts would seem to suggest that when soil fertility is low, a wider than normal spacing of sugar beets may be justified. On the other hand, when soil fertility is high, closer than normal spacing may be desirable for the best yield and quality, particularly if soil moisture is not limiting.

**Plant Population and Nutrition.** When a plant population is increased, the competition among plants for nutrients will increase. This statement is made on the assumption that available plant nutrients in the soil are not greatly in excess of the amounts required by a normal plant population. The effect of doubling the plant population on nitrate-nitrogen uptake by sugar beets is illustrated in fig. 6. Significant differences were found between  $S_1$  (52,270 plants per acre) and  $S_2$  (26,135 plants per acre) for the first three and the last sampling date in 1947. In 1946 significant increases in nitrogen content of petioles with decreasing plant population at the first sampling date were found but only between  $S_2$  and  $S_3$  at the second sampling date. It will be recalled that there were no significant yield differences in 1947 for the within-row spacing experiment (see table 9). The mobile-nitrogen content in a plant apparently

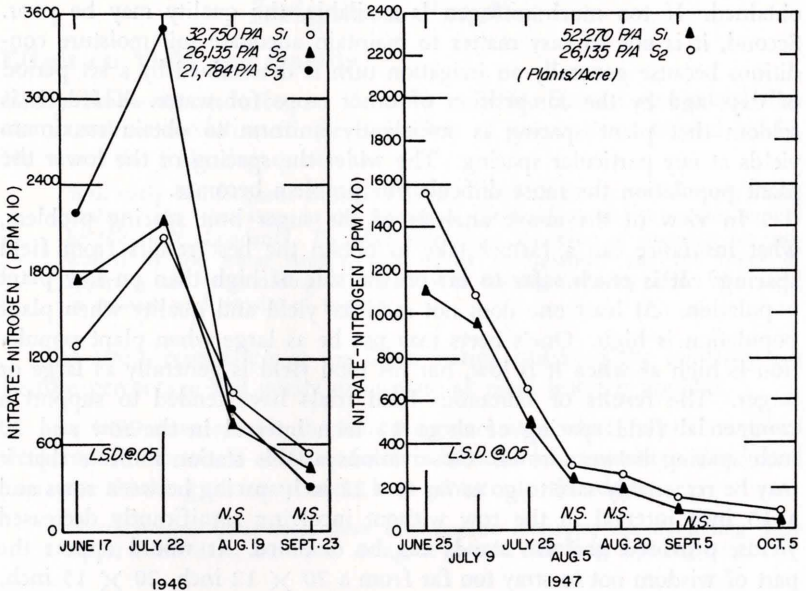


Fig. 6. Seasonal weak acid extractable nitrate-nitrogen content of sugar beet petioles as influenced by plant population

determines the emphasis which that plant gives at the moment to carbohydrate storage in the root on the one hand and vegetative growth on the other.

### Conclusions on Plant Spacing of Sugar Beets

One of the first questions that occurs to a man growing sugar beets is: What is one to conclude from these research data relative to the actual spacing of sugar beets in a commercial field?

From the data given in this report and from other accumulated data, it appears obvious that considerable variation in plant population may be tolerated without affecting the total yield, provided soil moisture and available soil nitrogen do not become excessive or limiting, and provided further that plant spacing is uniform throughout.

While it is possible to accomplish all these conditions on experimental plots, there are some obvious difficulties in achieving them in commercial sugar beet fields. First of all it is not easy to judge or control the nitrogen-supplying power of the soil just to fit the sugar beet crop. Many factors influence this, such as past cropping and fertilizer practice, natural climatic conditions, and soil texture. If too little nitrogen is available for the plant population, best growth will not be

obtained. If too much nitrogen is available, the quality may be poor. Second, it is not an easy matter to maintain adequate soil moisture conditions because generally an irrigation turn is determined by a set period of days and by the competition of other crops for water. Third, it is seldom that plant spacing is sufficiently uniform to obtain maximum yields at any particular spacing. The wider the spacing or the lower the plant population the more difficult this problem becomes.

In view of the above analysis of the sugar beet spacing problem, what insurance can a farmer take to obtain the best results from field spacing? It is much safer to err on the side of high than on low plant population. At least one does not sacrifice yield and quality when plant population is high. One's beets may not be as large when plant population is high as when it is low, but his total yield is generally as large or larger. The results of numerous field trials have tended to support a commercial field spacing of about 12 inch interval in the row and 20 inch spacing between rows. Observations at this station indicate that it may be reasonably safe to go as far as a 22 inch spacing between rows and a 15 inch interval in the row without incurring significantly decreased yields, provided uniform stands can be obtained. It would appear the part of wisdom not to stray too far from a  $20 \times 12$  inch,  $20 \times 15$  inch, or a  $22 \times 12$  inch spacing pattern, which means from 24,000 to 25,000 plants per acre. A reasonable number of skips can be tolerated under spacing patterns of this kind without seriously affecting yield or quality. If plant populations fall much below this, both yield and quality may suffer.

## Irrigation Practice

### Effect on Yield and Quality

**Early Recommendations.** As early as 1898, Stewart recognized that many problems relative to the irrigation of sugar beets needed study. He raised the following questions:

Will early and frequent irrigation modify the root form, or affect the sugar content? At what stage in the growth of the beets should the water supply be the most abundant? To what extent can the time of maturity be controlled by the water supply; that is, by the quantity and the times of applying and withholding it? How will forcing maturity affect the yield in tonnage and percent of sugar?

In 1902, researchers at the Utah Station observed the tendency for sucrose percentage and purity to increase as more water is applied.

In 1899, Foster made the following statement which must have taken deep root in the minds of many farmers because it has not been eliminated from the thinking of many sugar beet growers to this day.

Never irrigate until beets show they require moisture, usually letting them suffer a few days, and by so doing, it gives a nice long tapering beet.

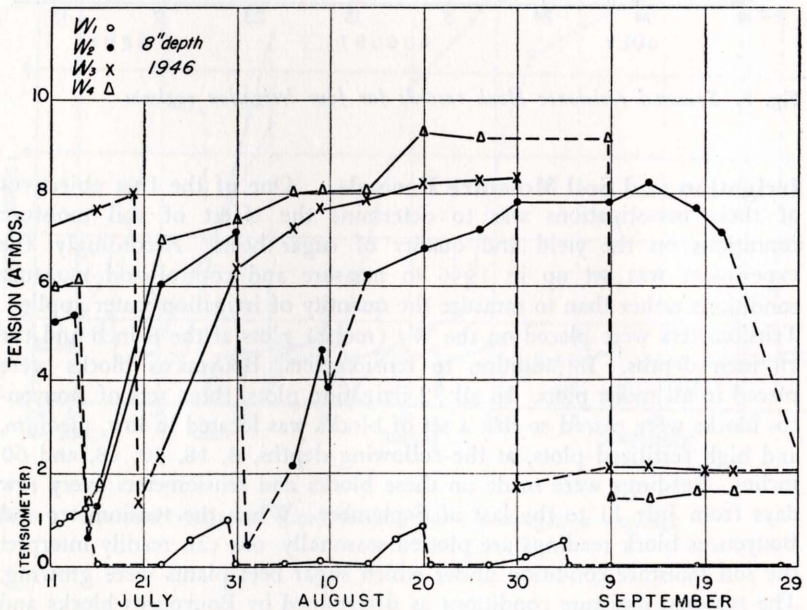


Fig. 7. Seasonal tensiometers and resistance block records at four irrigation regimes

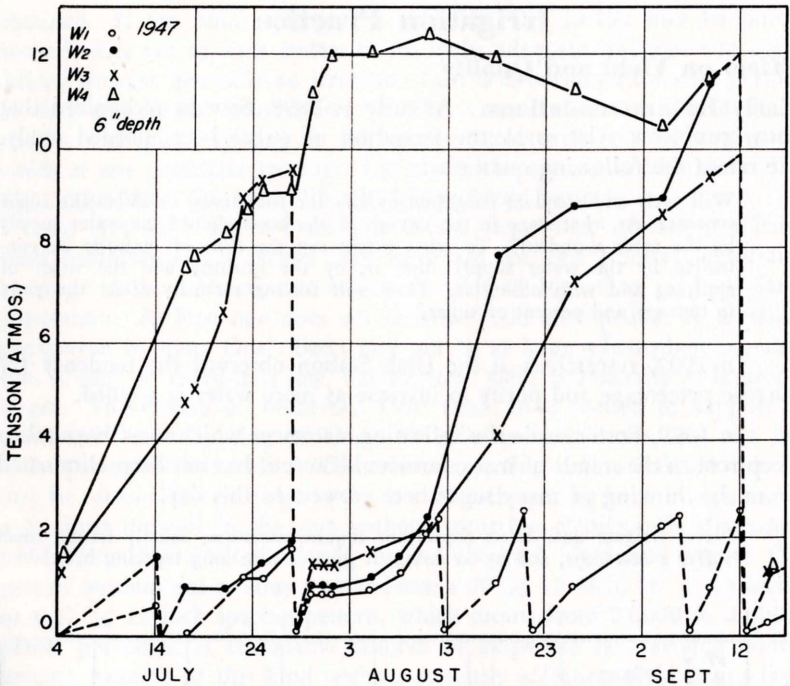


Fig. 8. Seasonal resistance block records for four irrigation regimes

**Irrigation and Soil Moisture Records.** One of the first objectives of these investigations was to determine the effect of soil moisture conditions on the yield and quality of sugar beets. Accordingly, the experiment was set up in 1946 to measure and control soil moisture conditions rather than to measure the quantity of irrigation water applied. Tensiometers were placed on the W<sub>1</sub> (moist) plots at the 8 inch and the 18 inch depths. In addition to tensiometers, Bouyoucos blocks were placed in all moist plots. In all 72 irrigation plots, three sets of Bouyoucos blocks were placed so that a set of blocks was located in low, medium, and high fertilized plots, at the following depths, 8, 18, 30, 48, and 60 inches. Readings were made on these blocks and tensiometers every few days from July 11 to the last of September. When the tensiometer and Bouyoucos block readings are plotted seasonally, one can readily interpret the soil moisture condition under which sugar beet plants were growing. The seasonal moisture conditions as determined by Bouyoucos blocks and tensiometers are shown in fig. 7. The seasonal tensiometer record is

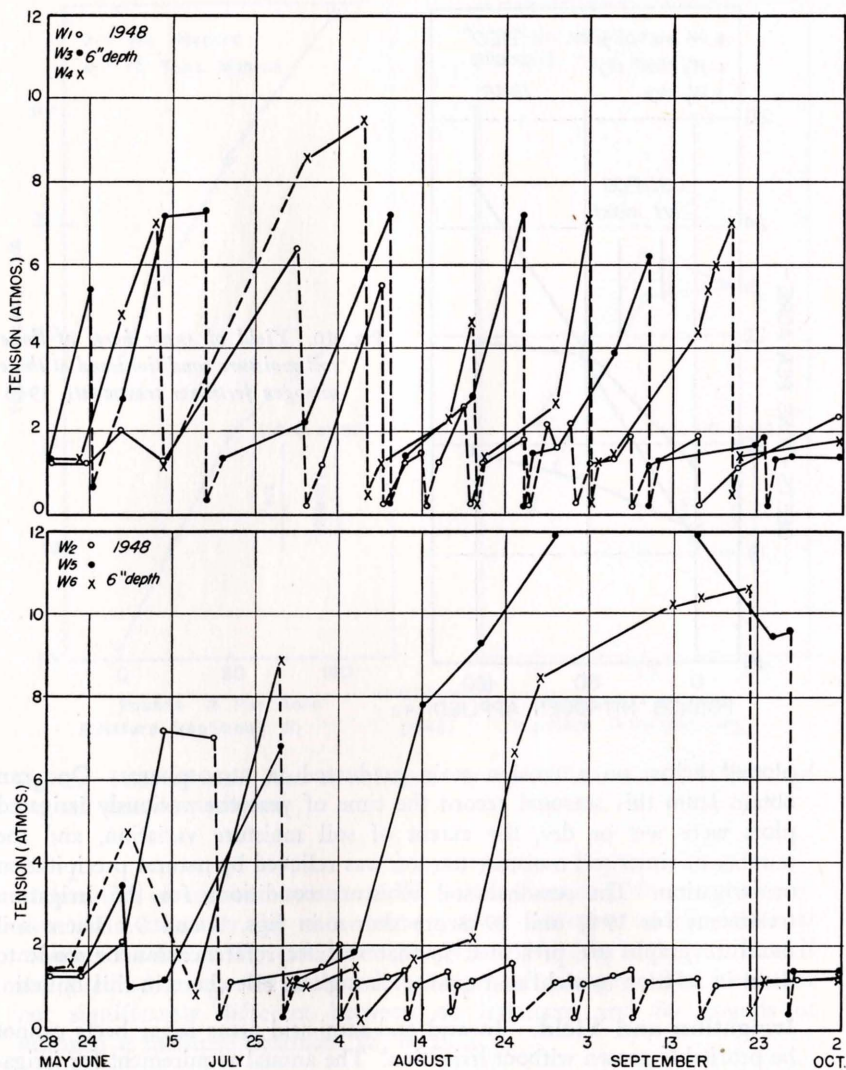


Fig. 9. Seasonal resistance block records for six irrigation regimes



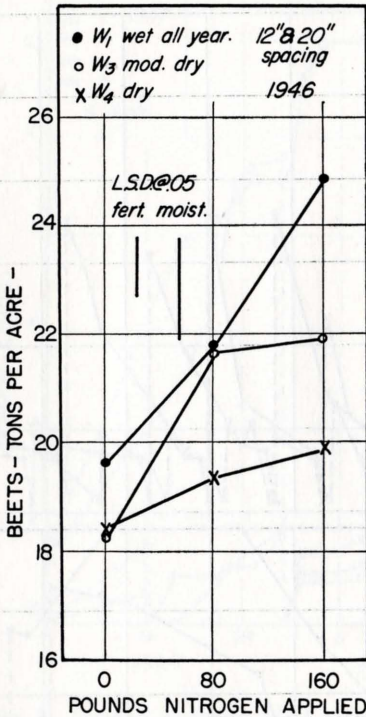


Fig. 10. Yield of sugar beets at three soil moisture conditions and at three nitrogen fertilizer treatments, 1946

plotted below on a tension scale graduated in atmospheres. One can obtain from this seasonal record the time of year the variously irrigated plots were wet or dry, the extent of soil moisture variation, and the number of times soil moisture tension was relieved by natural precipitation or irrigation. The seasonal soil moisture conditions for the irrigation treatments for 1947 and 1948 are shown in figs. 8 and 9. These soil moisture graphs are presented so that specific reference can be made to them in relation to yield and quality data given elsewhere in this bulletin.

**Irrigation and Yield.** In arid and semi-arid areas sugar beets cannot be profitably grown without irrigation. The annual requirement for irrigation and time of irrigation vary with the natural precipitation pattern. In the Great Basin and some other areas the natural precipitation during July and August is so meager as to be of little or no value in crop production (table 6).

The yield data obtained at three soil nitrogen levels and at three soil moisture conditions at Newton (1946) for the alternate 12 and 20 inch between-row spacing treatments are given in fig. 10. It will be

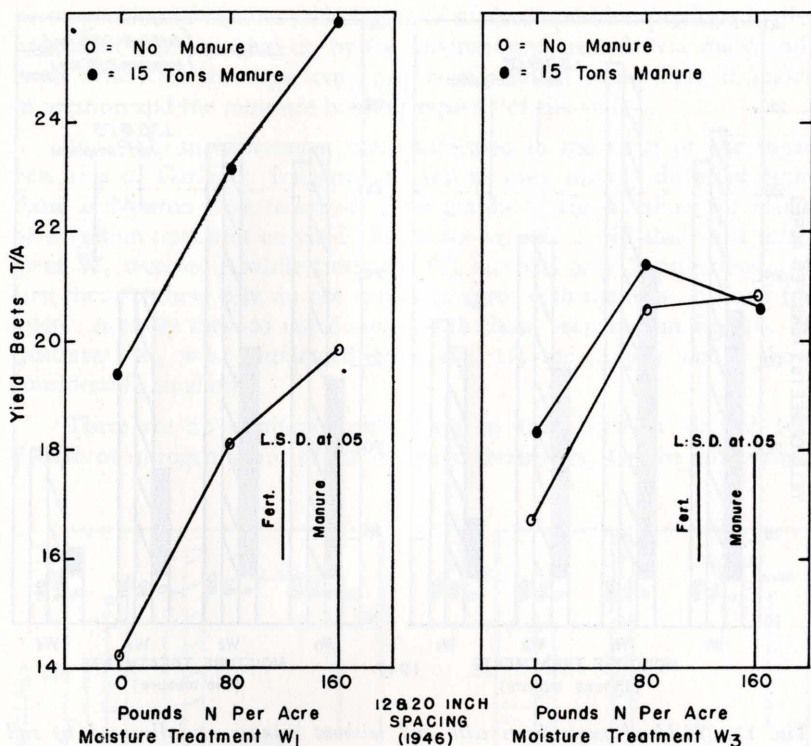


Fig. 11. Yield of sugar beets as influenced by manurial, nitrogen fertilizer, and soil moisture treatments

noticed that on moisture treatment W<sub>1</sub> (wet all season), there are significant yield increases for each increment of nitrogen added, while at moisture treatment W<sub>3</sub> (moderately-dry) and W<sub>4</sub> (dry), there is little if any yield advantage for a second increment of nitrogen. The yields are not significantly different between no treatment and 80 pounds of nitrogen at moisture treatment W<sub>4</sub> in 1946.

The influence of soil moisture on the yield of sugar beets under various soil fertility conditions is striking. The differences between the two sets of curves in fig. 11 is brought about by variation in soil moisture condition (see fig. 7). Yields are creditable with both moisture treatments. Had this experiment been conducted only on moisture treatment W<sub>3</sub> (moderately-dry), it would have been imperative to conclude that manure is not effective in increasing sugar beet yields on Millville

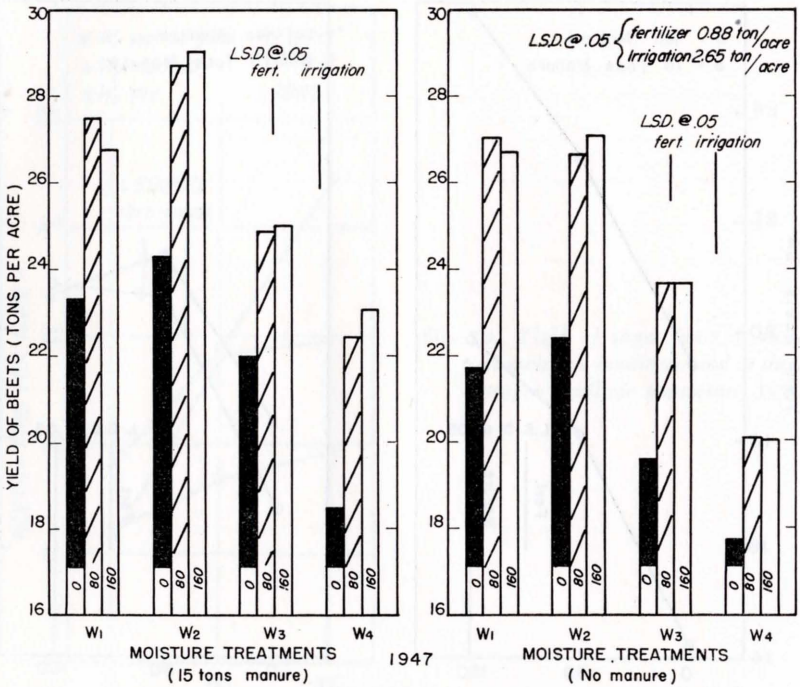


Fig. 12. Yield of sugar beets with and without manure as influenced by soil moisture condition with three levels of nitrogen fertilizer

fine sandy loam. But under moisture treatment  $W_1$  (continuously moist) manure has been effective in increasing yields from 5 to 6 tons per acre.

Why manure on the continuously moist plots is more beneficial in increasing yields than it is on the moderately dry plots is not difficult to see. It is less obvious why the unmanured areas produce lower yields on the continuously moist plots than on the moderately-dry ones. It must be remembered that this is a fine sandy loam soil. In order to maintain this soil in a continuously moist condition, six irrigations were needed (see table 2). Considerable water was undoubtedly lost by deep percolation, and with this water much of the nitrate-nitrogen was taken beyond the reach of the sugar beet roots. Under moisture treatment  $W_3$  fertility conditions may have been better than on moisture treatment  $W_1$  where no manure was applied.

Continuously moist soil was apparently an important factor in obtaining the most value from manure. This may have been because the

decomposition of manure and utilization of decomposition products by the beet plant were speeded up by the environment created in a moist soil. Some benefit to the sugar crop may have resulted from slight increases in aeration and the moisture holding capacity of the soil.

In 1947, an experiment was established in the heart of the sugar beet area of Garland. Irrigation treatments only slightly different from those at Newton were followed. Two graphs of fig. 12 show the effect of irrigation treatment on yield. Reference to table 2 will show that treatment  $W_1$  received 8 while treatment  $W_2$  received only 5 irrigations. At first thought these data do not appear to agree with the data obtained for 1946. Actually they do not disagree with those presented in fig. 10. If treatment  $W_2$  were eliminated from fig. 12, the graphs would show considerable similarity.

There are no significant differences in yield between 80 and 160 pounds of nitrogen at any of the irrigation treatments. On the other hand,

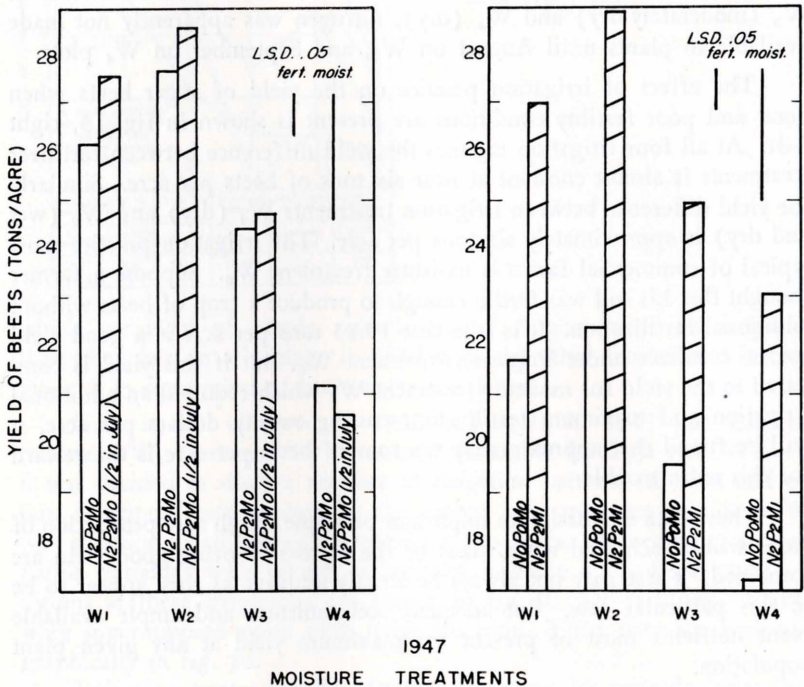


Fig. 13. Yield of sugar beets as influenced by soil moisture condition and fertilizer treatments

significant differences are evident at all moisture levels between no nitrogen and 80 or 160 pounds per acre. This is true regardless of the use of manure. The yield differences between treatment  $W_1$  and  $W_2$  are not great but they are consistent for all fertilizer treatments, including manure.

Favorable soil moisture conditions should assist in better utilization of side-dressed fertilizer. The left half of fig. 13 is given to show what benefits may be expected from mid-season nitrogen fertilization of sugar beets. In this study the same amount of fertilizer was applied to the variously irrigated plots. In one case all the fertilizer was applied previous to thinning. On the other plots all the phosphorus and half the nitrogen were applied previous to thinning and the other half of the nitrogen was side-dressed the latter part of July. The yield response tends to be in proportion to the amount and time of water application. There is a significant difference in yield of beets for side-dressed nitrogen vs. nitrogen applied early in the season on moisture treatment  $W_1$  (moist all season) but hardly significant on moisture treatment  $W_2$  (moist early; dry late). Because of the dry condition of the soil under moisture treatment  $W_3$  (moderately-dry) and  $W_4$  (dry), nitrogen was apparently not made available to plants until August on  $W_3$ , and September on  $W_4$  plots.

The effect of irrigation practice on the yield of sugar beets when good and poor fertility conditions are present is shown in fig. 13, right half. At all four irrigation regimes the yield difference between fertilizer treatments is almost constant at near six tons of beets per acre. Similarly the yield difference between irrigation treatments  $W_4$  (dry) and  $W_2$  (wet and dry) is approximately six tons per acre. The irrigation practice most typical of commercial farms is moisture treatment  $W_3$ . Suppose a farmer thought that his soil was fertile enough to produce a crop of beets without additional fertilization. It is true that 19.25 tons per acre is a good yield for no fertilizer under irrigation treatment  $W_3$ . But if this yield is compared to the yield for moisture treatment  $W_2$  which required an additional irrigation and maximum fertilization costing twenty dollars per acre, it will be found that approximately ten tons of beets per acre is the reward for this extra trouble.

These data emphasize an important principle. High acre production of crops will be achieved when many of the factors favoring good yield are combined. These may not always be strictly additive as they appear to be in this particular case. But adequate soil moisture and ample available plant nutrients must be present for maximum yield at any given plant population.

**Time vs. Quantity of Irrigation.** Many of the data accumulated on irrigation of crops have to do with the total quantity of irrigation water

applied to the soil as this is related to yield. The factor, time of application, has received too little attention.

Strong evidence that the irrigation of sugar beets may not be so much a matter of number of irrigations or quantity of water as time of application is shown by the data in fig. 12. Moisture treatment  $W_2$ ,

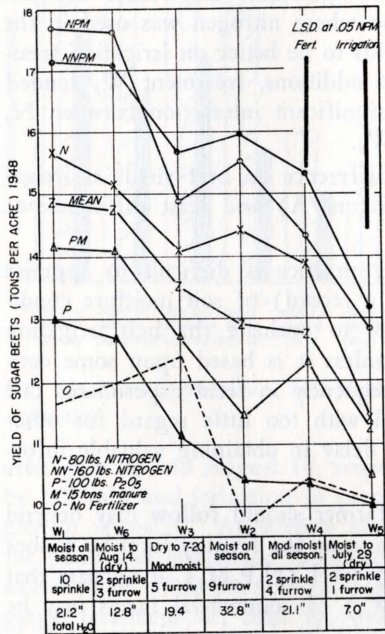


Fig. 14. Yield of sugar beets as affected by irrigation regime and fertilizer treatments, 1948

which consisted of ample moisture until August with no irrigation thereafter, has an advantage in yield over the other treatments; furthermore, it is economical of both water and labor.

Since it was observed in 1946 and again in 1947 that moisture treatment  $W_2$  (wet and dry) was most favorable for high yield of beets, it was decided to study a number of irrigation patterns in 1948 and obtain additional information on the reason why moisture treatment  $W_2$  was superior to all others the previous two years. Accordingly, six irrigation variables were set up as outlined in table 4. Soil moisture conditions at these irrigations are shown in fig. 9. Six fertilizer variables were superimposed upon each irrigation plot. Yield data are presented graphically in fig. 14.

Irrigation treatments  $W_1$  (moist all season by sprinkle irrigation) and  $W_6$  (moist to August 14, dry thereafter) are significantly better than treatment  $W_3$  (dry to July; moderately-dry thereafter) with

$N_1P_1M_1$  fertility treatment and  $W_2$  (moist all season by furrow irrigation) is significantly better than  $W_5$  (moist to July 29; dry thereafter) with the same fertility treatment. With all fertility treatments in which nitrogen was used, irrigation treatments  $W_1$ ,  $W_6$ , and  $W_2$  were significantly better than  $W_5$ . At all fertility treatments where commercial nitrogen was excluded, there were no significant differences between irrigation treatment  $W_2$  and  $W_5$ . Also where nitrogen was used in the fertilizer, there was a tendency for yields to be better on irrigation treatment  $W_2$  than  $W_3$ . Without nitrogen additions, treatment  $W_3$  tended to be better than  $W_2$ . There was a significant interaction between  $N_0$  vs.  $N_1 \times W_2$  vs.  $W_3$ ,  $W_1$ ,  $W_4$ , and  $W_6$ .

Fertilizers exerted their greatest difference on beet yields at irrigation treatments  $W_1$ ,  $W_6$ , and  $W_2$  (6 tons/A) and least difference at  $W_5$  (3 tons/A).

The value of any given fertilizer practice is difficult to appraise without control (or at least obtaining a record) of soil moisture conditions (fig. 14). Likewise, an attempt to evaluate the best irrigation procedure is fraught with great risk unless it is based upon some controlled soil fertility condition. Too frequently in field experiments one factor affecting plant growth is tested with too little regard for other factors. This adds to the cost of, and delay in obtaining valuable information.

The irrigation program which a farmer should follow may depend upon the character of his soil as well as upon the fertility level he wishes to maintain (fig. 14). On low fertility level ( $N_0P_0M_0$ ), it appears that the more typical irrigation practice ( $W_3$ ) of commercial farms may be better than trying to keep the soil moist by furrow irrigation ( $W_2$ ). However, when fertility is high ( $N_1P_1M_1$ ), it is better to attempt to keep the soil moist ( $W_2$ ), with attendant nutrient losses by leaching, than to interfere with plant growth by lack of soil moisture and attendant conditions.

**Irrigation and Quality.** The data obtained in 1946 on sucrose percentage and purity indicate no significant difference in the quality of sugar beets as affected by irrigation treatment. In 1947, sugar beet pulp samples were stored in a commercial cold storage plant. The temperature became so high that some mold growth developed and made quality determinations unreliable.

In 1948, irrigation treatment did not significantly affect the percent purity of extract juice of sugar beets. However, percent sucrose was markedly depressed by irrigation treatments  $W_5$  and  $W_6$  in contrast to sucrose percentage of beets grown under treatments  $W_1$  and  $W_2$ . It will be recalled that treatments  $W_5$  and  $W_6$  left the soil dry

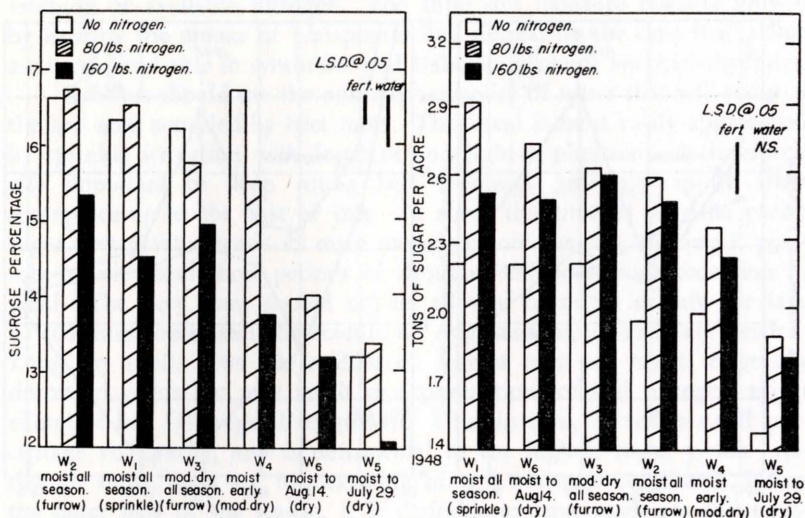


Fig. 15. Sucrose percentage and yield of sugar beets as influenced by irrigation practice

after July 29 and August 14, respectively. When the soil was moistened by fall rain and irrigation in preparation for harvesting, new vegetative growth appeared. Apparently accumulated soil nitrate-nitrogen entered the plant and stimulated rapid vegetative growth at the expense of the stored sugar. This phenomenon appeared to be more pronounced in irrigation treatment  $W_5$  than  $W_6$  (see fig. 15). The soil that received the largest quantity of water ( $W_2$ ) produced beets with the highest sucrose. The plots that received the lowest quantity of water ( $W_5$ ) produced beets of lowest sucrose percentage. Without any manure or commercial fertilizer this particular soil needs about 20 inches of irrigation water for sugar beets in order to maintain good quality. The farmer should manage his irrigation program so as to avoid stimulation of sugar beets vegetatively immediately previous to harvest.

**Irrigation and Plant Nutrition.** Jenny and Overstreet (1939) have emphasized the importance of ionic exchange between plant roots and soil colloids. Nevertheless, the importance of soil moisture condition on plant nutrition can be easily demonstrated. Haddock (1952) has shown from a number of experiments that soil moisture condition markedly affects the phosphorus uptake by sugar beets. This is shown graphically by fig. 16. As the soil becomes dry, the soluble phosphorus content of the beet petioles falls markedly. Also, as soil moisture tension is decreased the soluble phosphorus content of beet petioles is increased against



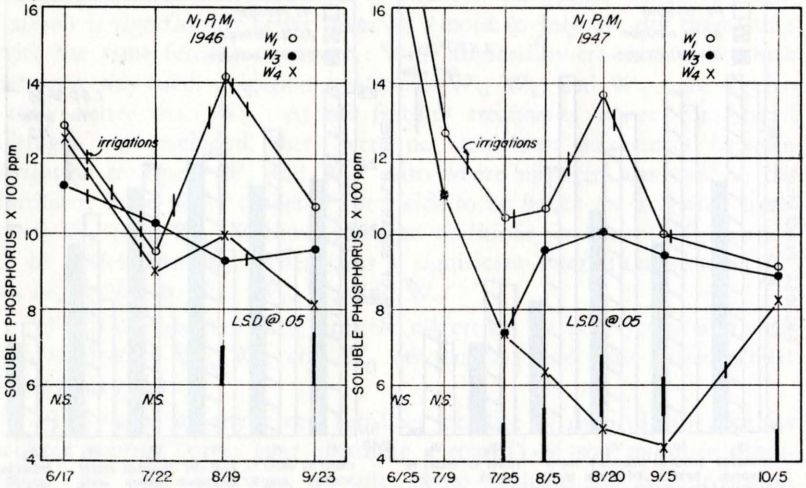


Fig. 16. Seasonal phosphorus content of sugar beet petioles as affected by soil moisture condition

the normal seasonal tendency to decrease. On the other hand, irrigation tends to influence nitrogen nutrition in the opposite manner. Under conditions where soil moisture is kept relatively high all season, the soluble nitrate-nitrogen content of beet petioles becomes low by mid-season and continues to decline throughout the season. Considerable improvement in nitrate-nitrogen content of beet petioles is observed under conditions where the soil moisture tension remains high. This may be caused by the accumulation of nitrogen in the plant where plant growth is restricted by lack of available soil moisture and where there is little plant demand for soil nitrogen. It may be that where an attempt is made to maintain high soil moisture conditions, much of the available nitrogen is leached beyond the reach of plant roots as found by Stewart and Greaves (1909). Both factors probably operate to bring about the observations noted in fig. 16.

### Conclusions on Irrigation Practice

Since growers are paid on the basis of both quality and yield of sugar beets, it is important to know the effect of various irrigation practices on these factors.

Like most crops sugar beets can be over- or under-irrigated. Too much water restricts growth by limiting soil aeration and by downward

leaching of available nitrogen. Too little soil moisture restricts growth by limiting the uptake of phosphorus and decreasing the time that plants are turgid and able to synthesize and elaborate proteins and carbohydrates.

Growers should use the minimum quantity of water that will moisten the soil area occupied by beet roots. This ideal is most easily approached by sprinkle irrigation with frequent and light applications. It is especially important to keep young beet seedlings growing rapidly from emergence up to the first of July. At about this time of year the young sugar beet plant extends its main root deep into the soil, making it possible to withstand short periods of drought without serious reduction in yield. The beet plant should not be allowed to suffer unduly for lack of moisture until after the middle of August if high yields are desired. Long dry spells after the middle of August may not result in greatly decreased yields but may result in accumulations of soil nitrogen which stimulate late fall vegetative growth. This, in turn, decreases sugar percentage and purity, and is detrimental to the highest sugar yields. Although sugar beets are less exacting of soil moisture conditions during the latter half of the season, it is desirable to have moderate soil moisture available to them for continued growth and nitrogen utilization throughout the entire season.

Since sprinkle irrigation is not available to most sugar beet growers, what then should be the aim under furrow irrigation?

In the Great Basin area sugar beets should be furrowed when planted or soon thereafter. Light irrigations should be applied as frequently as water turn and weather conditions dictate up to July. Increasingly heavier applications of water are needed at each irrigation turn from the first of July to the last of August unless rains intervene. After this time irrigation applications should gradually be decreased until the middle of September when they may be discontinued.

Growers who follow the general program outlined above will approach that soil moisture condition which will encourage maximum plant growth, optimum phosphorus availability, and minimum nitrogen loss. Furthermore, this program will assist in the production of good yields of high quality beets.

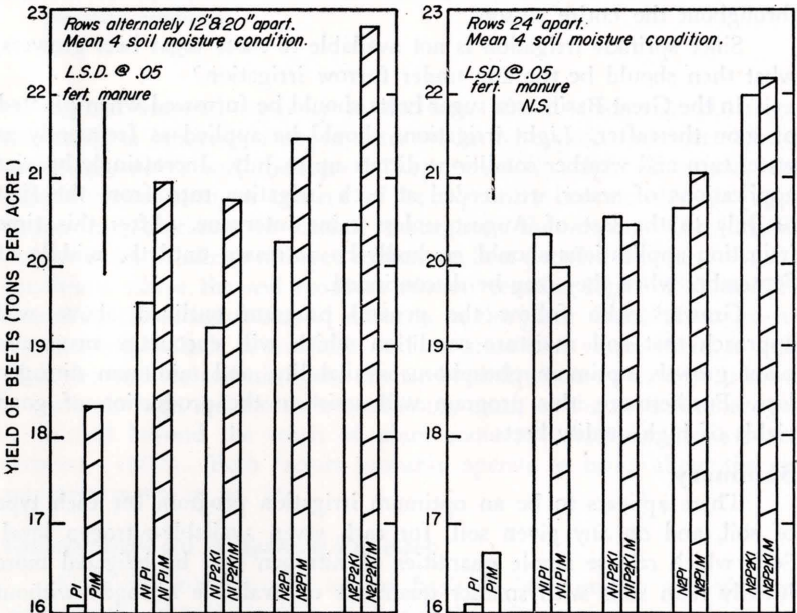
### **Summary**

There appears to be an optimum irrigation program for each type of soil, and on any given soil, for each given available-nitrogen level. Soils which release ample quantities of nitrogen may be irrigated more heavily than soils with smaller quantities of available nitrogen without depleting the soil of needed plant nitrogen. However, the minimum quantity of water that will produce the maximum quantity of sugar beets is economical of both available nitrogen and water. This latter objective should be sought by beet growers.

## Fertilization of Sugar Beets

A decade ago the standard fertilizer recommendation for sugar beets in the Great Basin area was 6 to 10 tons of barnyard manure and 150 pounds of treble superphosphate per acre. Field experiments conducted in this area by experiment stations and sugar companies during the past ten years have increasingly emphasized the need for commercial nitrogen to supplement previously recommended fertilizer practice.

Brown and Irving (1942) report that a 15 ton crop of sugar beets (roots and tops) contains 142 pounds of nitrogen, 42 pounds of phosphoric acid, 180 pounds of potash, and 72 pounds of calcium oxide. Although the average yield of beets varies from 14 to 16 tons per acre, a 20 ton crop is frequent and readily attainable. Such a crop would require 190 pounds of nitrogen and 56 pounds of phosphoric acid per acre. Because of the high acre value of the crop and because yield and quality are markedly effected by soil fertility, attention should be given to fertility requirements of the sugar beet crop.

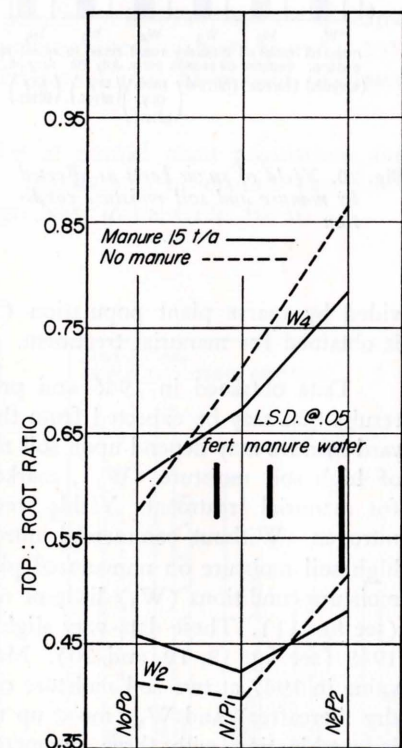
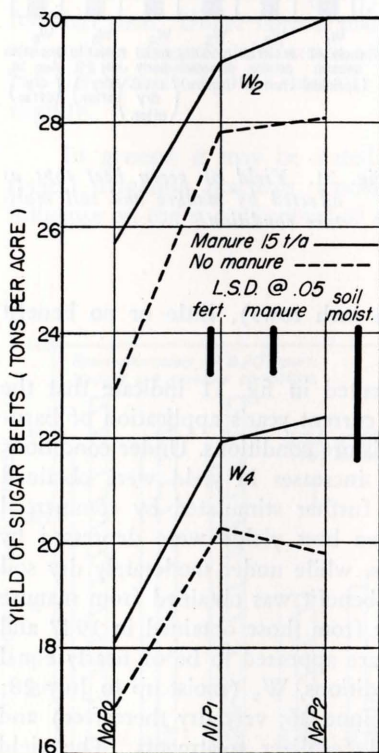


1946

Fig. 17. Influence of row-widths, manure, and commercial fertilizer on yield of sugar beets

## Barnyard Manure

**Effect on Yield.** It may not be possible in short term experiments to evaluate completely the effects of barnyard manure but such experiments give a fair estimate of its value. Gardner and Robertson (1942) present data indicating increased yields of sugar beets from 2 to 4 tons per acre for 15 tons of fresh manure. Nuckols (1942) obtained an increase of 2 and 4 tons of beets from 6 and 12 tons of manure per acre, respectively. The data in fig. 17 indicate that the benefit one can expect from manure may depend upon the presence of other growth factors. The growth response to manure tends to be positive at all levels of commercial fertilizer when the plant population is relatively high (rows alternately 12 and 20 inches apart), but when less competition is pro-



1947

Fig. 18. Yield of sugar beets as affected by barnyard manure and commercial fertilizer

Fig. 19. Top:root ratio of sugar beets as affected by barnyard manure and commercial fertilizer

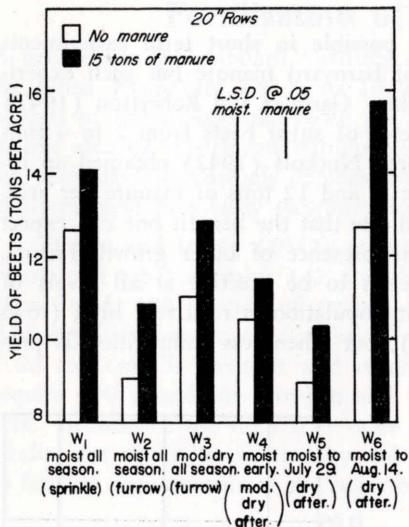


Fig. 20. Yield of sugar beets as affected by manure and soil moisture condition

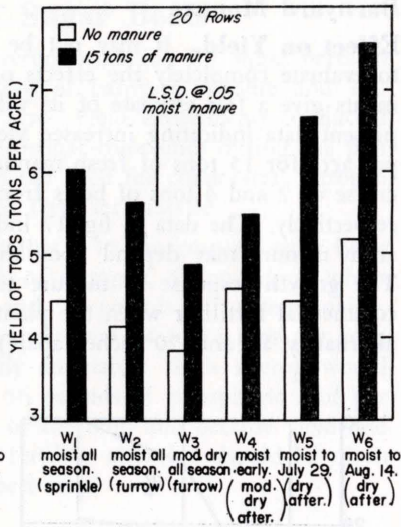


Fig. 21. Yield of green beet tops as affected by manure and soil moisture condition

vided by sparse plant population (24 inch rows), little or no benefit is obtained for manurial treatment.

Data obtained in 1946 and presented in fig. 11 indicate that the results that may be expected from the current year's application of barnyard manure may depend upon soil moisture conditions. Under conditions of high soil moisture (W<sub>1</sub>), marked increases in yield were obtained for manurial treatment. Yields were further stimulated by commercial nitrogen. Without commercial nitrogen beet yields were depressed by high soil moisture on unmanured plots, while under moderately dry soil moisture conditions (W<sub>3</sub>) little or no benefit was obtained from manure (see fig. 11). These data vary slightly from those obtained in 1947 and 1948 (see fig. 18, 19, and 20). Manure appeared to be of nearly equal value in 1947 at two soil moisture conditions, W<sub>2</sub> (moist up to July 28; dry thereafter) and W<sub>4</sub> (moist up to June 26; very dry thereafter) and in combination with three commercial fertilizer treatments. The yield of sugar beets under soil moisture condition W<sub>2</sub> was much better than W<sub>4</sub>, but manure appeared to be equally beneficial under the two soil moisture conditions. In 1948 (figs. 20 and 21), manure gave a yield advantage at six irrigation regimes varying from 1 to 3 tons of beets

and 1 to 2 tons of beet tops per acre depending on soil moisture conditions. Apparently the response from manurial treatment depends upon the presence of other soil factors such as soil fertility, soil moisture, and soil physical condition. The author does not have a good explanation for the variation in response to manure shown during these three years. The character of the manure may have had an influence. It can be categorically stated that barnyard manure is not harmful to sugar beet production under normal circumstances. Good farming practices enhance the benefits from manurial treatments.

**Effect on Quality.** Manure did not seriously affect sucrose percentage when the plant population was relatively high (fig. 22). However, when the plant population was low (24 inch rows), manure consistently tended to depress sucrose percentage regardless of kind of commercial fertilizer used. Under normal plant population in 1948, manure appeared to exert no consistent influence on sucrose content of beets (see fig. 23), but the data in fig. 24 indicate that purity may have been depressed slightly.

In general it may be stated that at normal plant populations and typical irrigation practices, moderate applications of manure have little influence on the sugar content of sugar beets in the Great Basin.

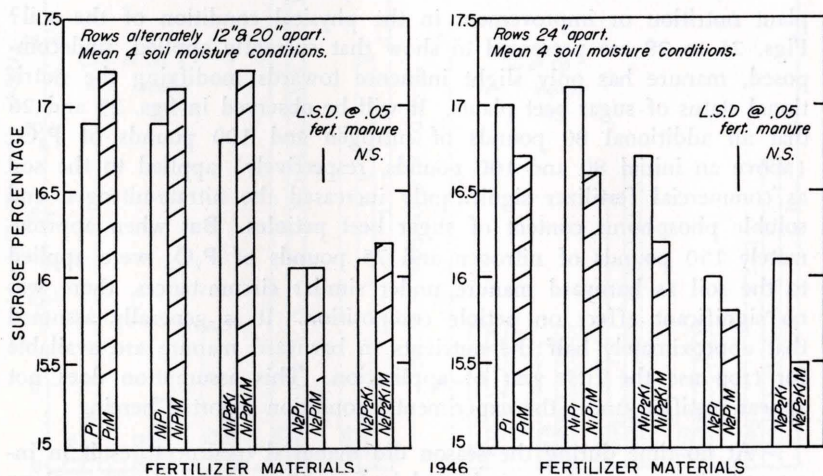


Fig. 22. Sucrose content of sugar beets as influenced by barnyard manure and commercial fertilizer

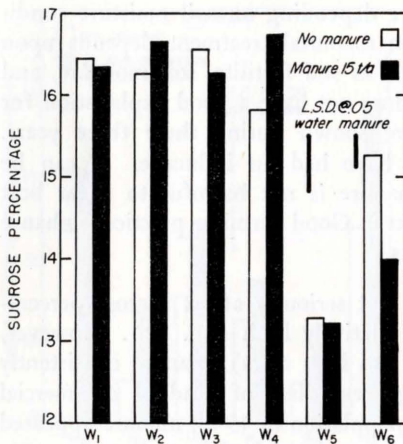


Fig. 23. Sucrose percentage of sugar beets as influenced by manure and soil moisture condition

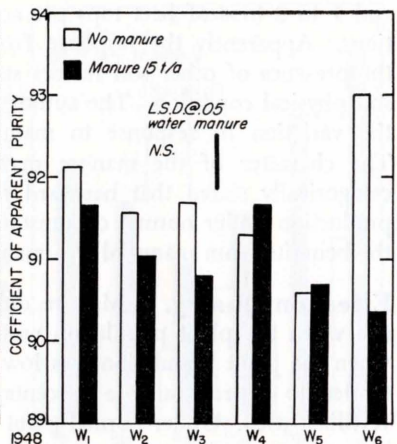


Fig. 24. Coefficient of apparent purity of sugar beets as influenced by manure and soil moisture condition

When barnyard manure is used in moderate quantities, it has a beneficial effect on the yield of sugar beets, while its influence on quality is insignificant.

Is the beneficial effect of manure on yield of beets a result of better plant nutrition or improvement in the physical condition of the soil? Figs. 25 to 28 are presented to show that currently applied, undecomposed, manure has only slight influence towards modifying the nutritional status of sugar beet plants. It will be observed in figs. 25 and 26 that an additional 80 pounds of nitrogen and 100 pounds of  $P_2O_5$  (above an initial 80 and 100 pounds, respectively) applied to the soil as commercial fertilizer significantly increased the nitrate-nitrogen and soluble phosphorus content of sugar beet petioles. But when approximately 150 pounds of nitrogen and 75 pounds of  $P_2O_5$  were applied to the soil as barnyard manure under similar circumstances, there was no significant effect on petiole composition. It is generally assumed that approximately half the nutrients in barnyard manure are available for crop use the first year of application. This assumption does not appear justified under the experimental condition reported herein.

At no time during the season did manurial treatment result in increased nitrogen uptake as indicated in figs. 27 and 28. However, there was strong and consistent tendency for such treatment to increase the phosphorus uptake during the last half of the growing season.

Each year of the experiment, it was observed that plots treated with barnyard manure without supplemental commercial nitrogen showed a marked yellowing of leaf blades until August. After this time a healthy green color appeared in beets grown on manured plots. From these field observations it was assumed that the decomposition process had progressed to a point where extra nitrogen was being released for plant use. This does not appear to be substantiated by the data in fig. 27.

The value of manure in increasing sugar beet yields has been well established but the reason for this beneficial effect may be explained quite as readily on changes in the physical condition of the soil as on nutritional changes in the plant. The data presented here indicate that as a fertilizer, undecomposed, currently applied manure is not impressive.

## Phosphorus

**Effect on Yield.** Yields of sugar beets were not increased as a result of phosphorus applications during the three years under consideration. This is probably because available phosphorus was not limiting sugar beet yields under the conditions of these experiments.

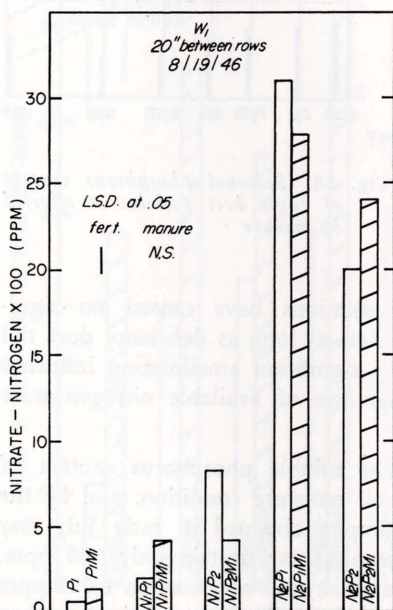


Fig. 25. Nitrate-nitrogen content of sugar beet petioles as affected by manure and commercial fertilizer

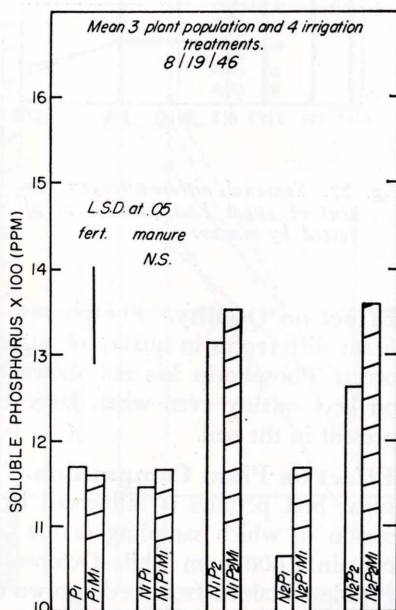


Fig. 26. Phosphorus content of sugar beet petioles as affected by manure and commercial fertilizer



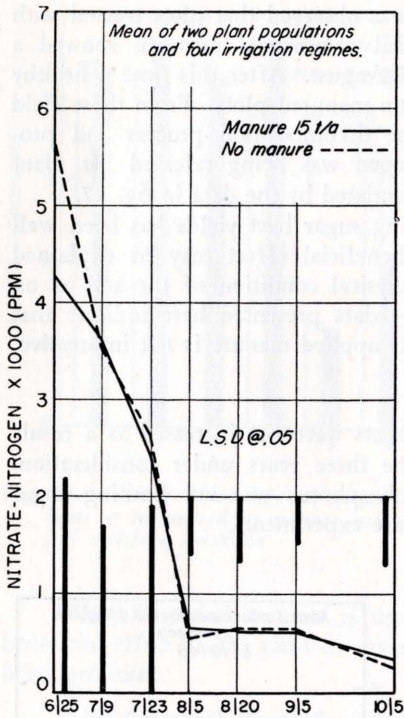


Fig. 27. Seasonal nitrate-nitrogen content of sugar beet petioles as affected by manure

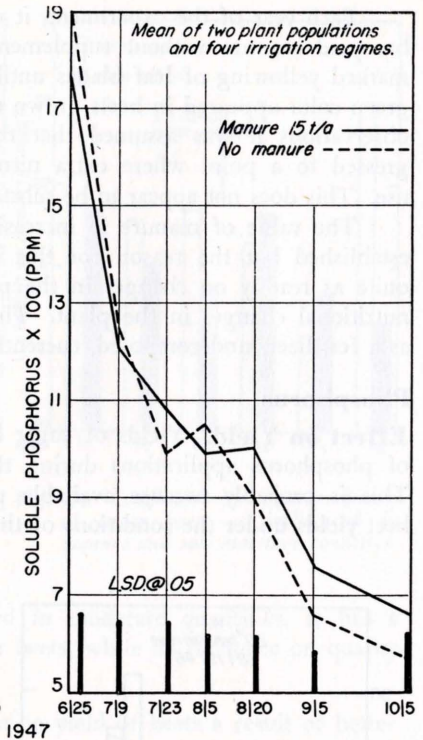


Fig. 28. Seasonal phosphorus content of sugar beet petioles as affected by manure

**Effect on Quality.** Phosphorus applications have caused no significant differences in quality of sugar beets as long as deficiency does not occur. Phosphorus has not shown any significant ameliorating influence on beet quality even when large quantities of available nitrogen were present in the soil.

**Effect on Plant Composition.** The soluble phosphorus content of sugar beet petioles is influenced by soil moisture condition, and by the season in which sampling occurs. Samples obtained in early July may contain 2,000 ppm while October samples may contain only 500 ppm. Petioles obtained from beets grown on moist soils may contain 1,000 ppm while petioles obtained from beets on dry soils may contain less than 400 ppm at the same time of year. Excess phosphorus fertilizer may result in an increase of 200 to 300 ppm of soluble phosphorus in beet

petioles. Phosphorus content of beet petioles on manured plots tended to increase the latter part of the season in 1946 (fig. 26) and was increased significantly the latter part of the season in 1947 as shown in fig. 28. The absolute range in phosphorus content of beet petioles as influenced by environmental conditions is small.

## Nitrogen

**Effect on Yield.** Of all the factors studied in these experiments affecting the yield of sugar beets in the Great Basin area, nitrogen fertilizers were the most spectacular. Manure treatments may slightly modify the effect of commercial nitrogen fertilizer on yield of beets as shown in figs. 11 and 12. In addition to these data the data in figs. 18, 19, 31, and 32 emphasize the fact that irrigation regime may determine the nature and extent of the response one might expect from nitrogen fertilization. However, none of these other factors affecting growth

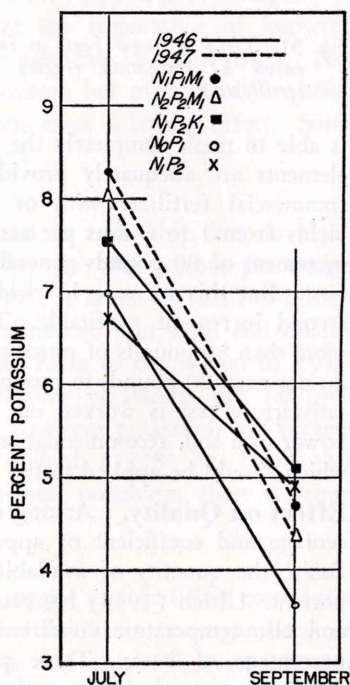
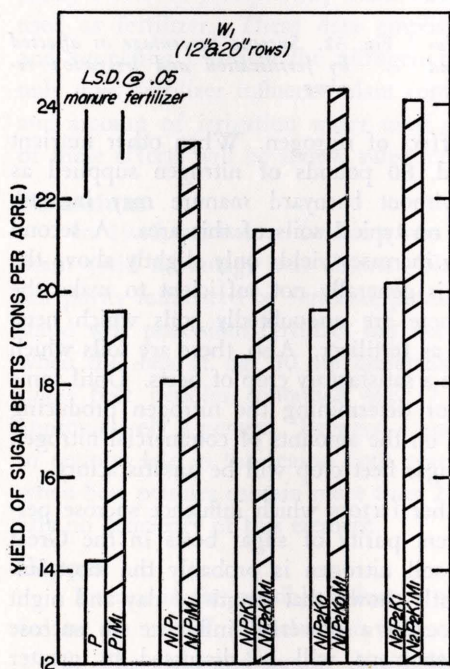


Fig. 29. Yield of sugar beets as affected by manure and commercial fertilizers, 1946

Fig. 30. Seasonal potassium content of sugar beet petioles

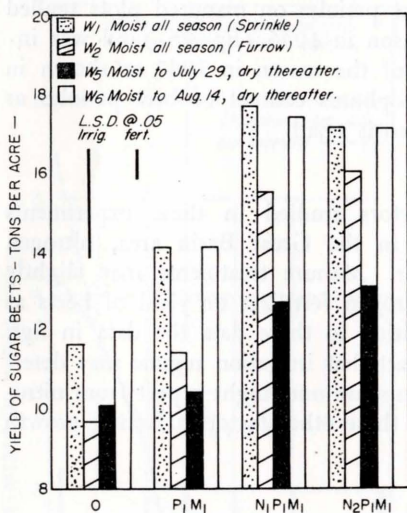


Fig. 31. Yield of sugar beets as influenced by irrigation regime and fertilization

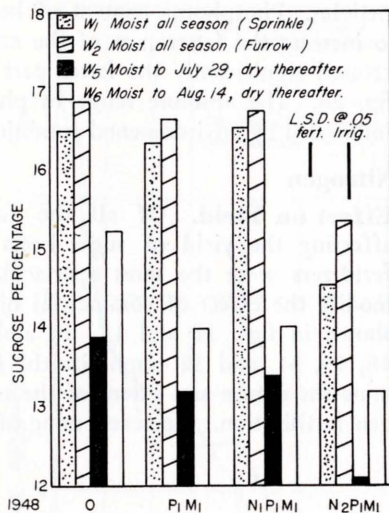


Fig. 32. Sucrose percentage as affected by fertilization and irrigation regime

is able to mask completely the effect of nitrogen. When other nutrient elements are adequately provided, 80 pounds of nitrogen supplied as commercial fertilizer with or without barnyard manure may increase yields from 1 to 6 tons per acre on typical soils of this area. A second increment of 80 pounds generally increases yields only slightly above the first. But this increase in yield is generally not sufficient to make the second increment profitable. There are undoubtedly soils which need more than 80 pounds of nitrogen as fertilizer. Also, there are soils which do not need 80 pounds to produce a satisfactory crop of beets. Until some satisfactory test is worked out for determining the nitrogen producing power of a soil, recommendations on the amounts of commercial nitrogen which should be applied to the sugar beet crop will be unsatisfactory.

**Effect on Quality.** Among other factors which influence sucrose percentage and coefficient of apparent purity of sugar beets in the Great Basin, the quantity of available soil nitrogen is probably the most important. Ulrich (1948) has recently shown that length of day and night and also temperature conditions exert a powerful influence on sucrose percentage of beets. These phenomena will be discussed in greater detail subsequently in the section on yield and quality of sugar beet roots.

**Effect on Plant Composition.** In the course of this experiment it was observed that approximately half the soluble nitrogen moving through

leaf petioles was nitrate-nitrogen. It appears as though nitrate-nitrogen is the principal nitrogen form absorbed from soils by sugar beets. Soluble organic nitrogen is mineralized rapidly and ammonia-nitrogen is oxidized to nitrate-nitrogen readily in arable soils. These processes occur over a wide range of soil moisture conditions. Plant roots are able to absorb nitrates at low as well as high soil moisture conditions. Salts and ions other than nitrates apparently have slight influence on the movement of nitrate ions into and within plants. The soluble nitrogen content of conducting plant tissue, therefore, is a good criterion of available soil nitrogen. Seasonal nitrate-nitrogen content of sugar beet petioles is shown in table 11. It will be noted that plant composition is roughly proportional to fertilizer applied. It is of interest to observe that sugar beet yields were increased when 20 pounds or more of nitrogen fertilizer were applied, but that little or no advantage in yield was obtained for more than 40 pounds of nitrogen per acre. The sucrose percentage and purity decreased precipitously when more than 80 pounds of nitrogen was used as fertilizer. These data emphasize the importance of knowing and supplying precisely the nitrogen requirements of sugar beets. Not only does fertilizer influence plant composition but method of irrigation and amount of irrigation water used each exert a strong effect. Some of these effects will be shown subsequently.

### **Potassium**

In 1946, potassium fertilizer was used as a variable, but no significant yield advantage was shown. Neither was the sucrose percentage nor purity influenced by fertilizer potassium. It is not difficult to understand why potassium fertilizer has not influenced beet yield and quality when the data of fig. 30 are understood. Early in the season of 1946, sugar beet petioles contained over 7 percent potassium and in 1947 approximately 8 percent. Between 4 and 5 percent potassium was present in petioles late in the season both years. Ulrich (1948) has found that when beet petioles contain more than 2 percent potassium, there is generally no deficiency of this element.

### **Copper**

Interest in the possible influence of copper as a fertilizer constituent led to the use of this element with other fertilizers on sugar beets in 1946. The yield and quality data indicate that copper did not influence yield or sucrose percentage of beet petioles. Nor was any significant increase in copper content of plant tissue detected where 50 pounds per acre of copper sulfate was applied.

Table 11. Yield and quality of sugar beets and seasonal petiole composition as influenced by nitrogen fertilizer, 1948

Nitrogen applied	Yield beets	Sucrose	Coeff. app. purity	Gross sugar	Nitrate-nitrogen in beet petioles				
					7/13	8/2	8/23	9/18	10/9
<i>lbs/a</i>	<i>t/a</i>	<i>percent</i>	<i>percent</i>	<i>t/a</i>	<i>ppm.</i>	<i>ppm.</i>	<i>ppm.</i>	<i>ppm.</i>	<i>ppm.</i>
0	17.61	16.72	92.27	2.94	4,725	2,975	962	220	132
20	18.87	16.75	90.63	3.16	6,850	5,550	947	238	36
40	19.73	16.39	91.35	3.23	8,100	9,850	2,230	224	48
80	19.69	16.28	90.54	3.21	8,200	10,650	3,581	232	456
80 ( $\frac{1}{2}$ in Aug.)	20.10	14.93	88.37	3.00	8,100	9,850	3,370	2,740	1,536
160	19.79	15.15	87.09	3.00	8,850	13,100	9,775	1,780	792
160 ( $\frac{1}{2}$ in Aug.)	21.57	13.25	83.97	2.86	8,200	10,650	4,925	5,830	2,476
320	19.45	12.96	83.93	2.52	8,850	15,300	14,050	4,790	1,848
L. S. D. at .05	1.72	0.83	1.29	N.S.	1,918	2,388	2,734	1,687	688

## Discussion of Fertilizer Practices

Adequate fertilizer application offers one of the most rapid and profitable means of obtaining high yields in sugar beet production. However, this practice is costly and should be followed with care and judgment.

Barnyard manure has been shown to be beneficial to the sugar beet crop. Over a period of years it undoubtedly supplies nutrients in substantial quantities and exerts a favorable influence on the physical condition of the soil. Many sugar beet growers rely too heavily on current year's treatment with barnyard manure. Although it provides large quantities of nutrients, these are frequently much less effective on sugar beet yields during the season applied than equivalent nutrients supplied by commercial fertilizers. The current value of manure probably lies quite as much in its physical as in its chemical effect.

Both phosphorus and nitrogen carrying fertilizers have been demonstrated to be necessary to supplement manure on most soils in the Great Basin. At the present time most cultivated and irrigated soils have received phosphorus fertilizers. Nevertheless, it is necessary to supply phosphorus fertilizer occasionally in order to maintain an adequate available phosphorus supply in the soil. Two hundred fifty pounds of treble superphosphate or its equivalent applied every five years appears to be adequate for general farm crops on typical soils of this area.

The nature of the sugar beet crop is such that its nitrogen requirement should be known and supplied with precision. A 20 ton crop of beets requires approximately 200 pounds of nitrogen per acre. Imperfect recovery from the soil by plants and inevitable irrigation losses by deep percolation make it necessary that the soil supply somewhat more than 200 pounds of available nitrogen per acre throughout the growing season in order to produce a 20 ton crop of beets. Until some direct soil test is developed that will provide an adequate estimate of the nitrogen supplying power of a soil, plant tissue analysis must be used as a guide to fertilizer practice. Data are cited that demonstrate the disastrous effects of too little available soil nitrogen and the uneconomical practice of supplying too much nitrogen as fertilizer. Nitrogen fertilization has become a "must" in the profitable production of sugar beets in the Intermountain Area, but until a direct soil test is developed and standardized, the fertilizer supplement will remain an unsatisfactory approximation.

## Fertilizer Summary

The sugar beet crop is as responsive to barnyard manure as most field crops. Insofar as it is available, manure should be used up to 12 to 15 tons per acre. However, manure is not adequate fertilizer for sugar beets. The practice of applying manure should be supplemented with

commercial nitrogen. If superphosphate has not been supplied to some crop within five years previous to growing sugar beets on the land, it would be advisable to apply the equivalent of 250 pounds of treble superphosphate with or without manure.

Until a more satisfactory soil test for available nitrogen is developed, it is suggested that the equivalent of 60 to 100 pounds of nitrogen per acre be used with sugar beets in the Great Basin.

## Interrelationships

Success in controlling the growth rate and quality of plants would be difficult without an understanding of the influence of environmental conditions upon growth processes. One must understand not only the effect of one factor alone but the interrelationships among all the factors of soil, water, and plants. Furthermore, in order to exercise the most intelligent control of these factors of plant growth, one must be able to manipulate them to take advantage of natural climatic conditions.

### Plant Population and Fertilization

Previously, fig. 2 was cited to indicate the value of obtaining a sugar beet population of 26,000 to 33,000 plants per acre in order to ob-

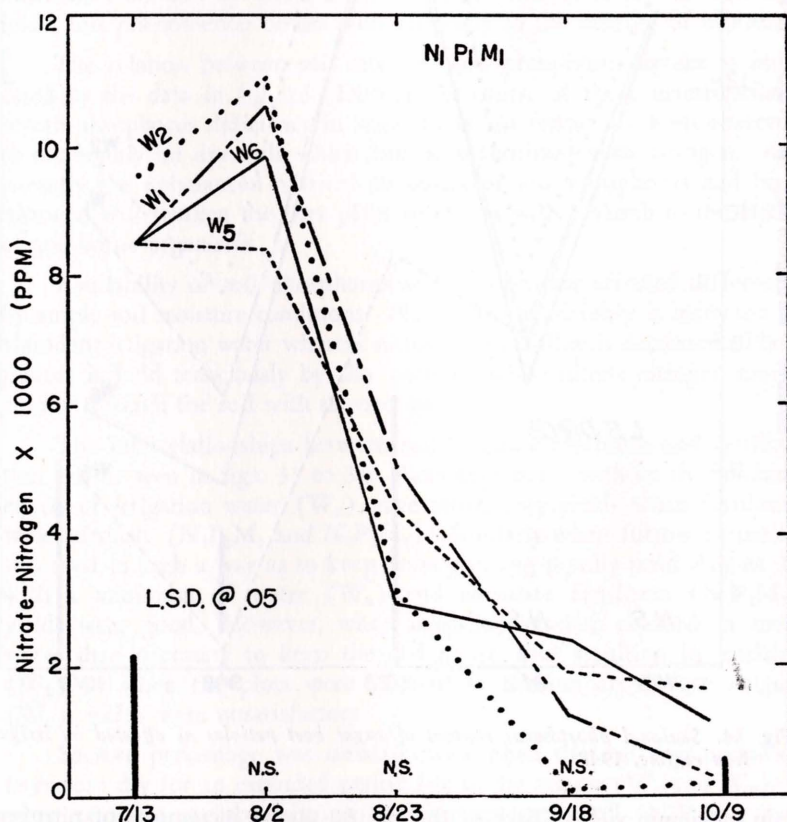


Fig. 33. Seasonal  $\text{NO}_3\text{-N}$  in sugar beet petioles as affected by irrigation regime, 1948



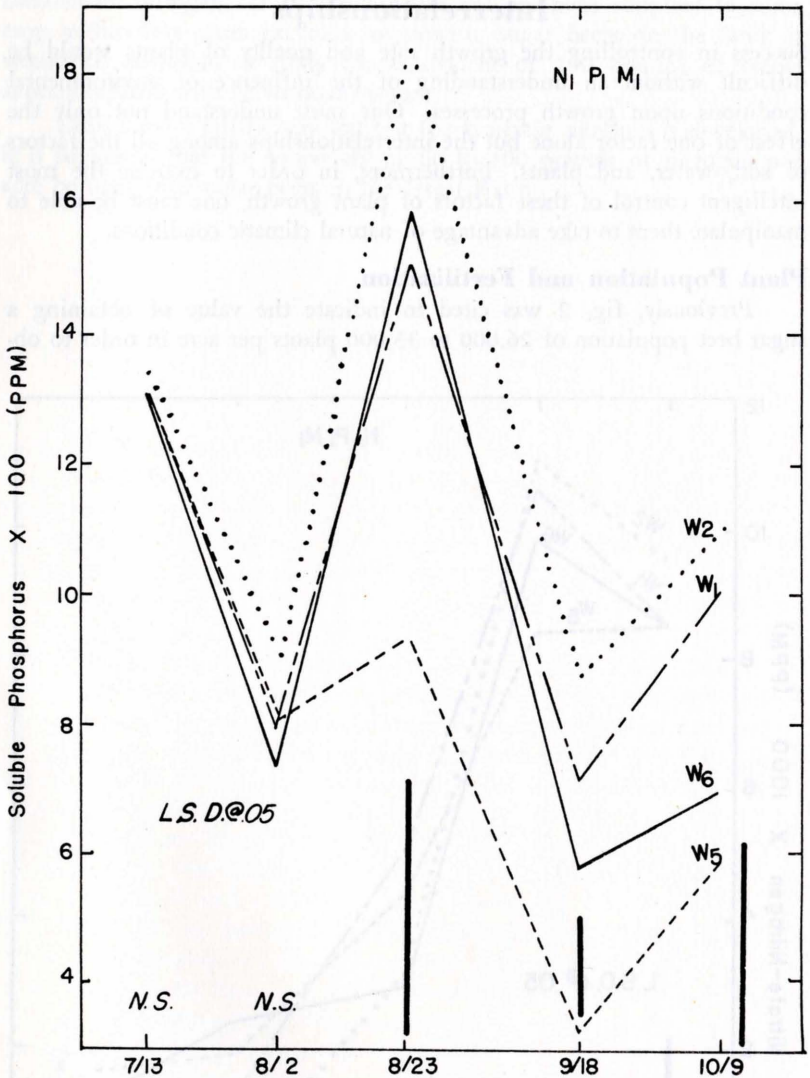


Fig. 34. Seasonal phosphorus content of sugar beet petioles as affected by irrigation regime, 1948

tain maximum yields. Each of the two 80 pound increments of nitrogen gave significant yield increases when the plant population was approximately 33,000 plants per acre (alternate 12 and 20 inches between rows).

When the plant population was 26,000 (20 inches between rows) and 22,000 (24 inches between rows) plants per acre, a significant yield increase was not obtained for the second increment. It will also be observed in fig. 3 that at 22,000 plants per acre, the sucrose percentage was depressed to such an extent that the yield of sugar tended to be less for 160 pounds of nitrogen than for 80 pounds. This was not so when plant populations were maintained at 26,000 and 33,000 plants per acre.

### Soil Moisture and Fertilization

It is customary to think that the only purpose of irrigation is to make moisture readily available to crop plants. While this is one purpose, it is not its only value. Although it may be possible for plants to absorb nutrients from soil by direct contact of plant root colloids with soil colloids, this phenomenon occurs with difficulty in the absence of moisture.

The relation between soil moisture and phosphorus uptake is indicated by the data in fig. 16. During the course of these investigations, severe phosphorus deficiency in sugar beets has frequently been observed to occur only on dry soils which had been fertilized with nitrogen. Apparently the unbalanced nutrient condition of low phosphorus and high nitrogen will weaken the beet plant so that it will succumb to the attack of soil-borne organisms.

Availability of soil phosphorus and nitrogen are affected differently by ample soil moisture conditions. Phosphorus availability is increased by abundant irrigation water whereas nitrogen availability is decreased. Phosphorus is held tenaciously by clay particles while nitrate-nitrogen moves readily through the soil with moving water.

The interrelationships between soil moisture condition and fertilization can be seen in figs. 31 to 34. Plots kept moist without the leaching effects of irrigation water ( $W_1$ ) gave satisfactory yields when fertilizers were adequate ( $N_1P_1M_1$  and  $N_2P_1M_1$ ). Similarly when furrow irrigation was used in such a way as to keep beets growing rapidly until August 15 with a minimum of water ( $W_6$ ) and adequate fertilizers ( $N_1P_1M_1$ ) yields were good. However, when irrigation practice resulted in more water than necessary to keep the soil moist, thus resulting in leaching ( $W_2$ ) or when the plots were allowed to become dry before August ( $W_5$ ), yields were unsatisfactory.

Sucrose percentage was unsatisfactory when the soil was permitted to remain dry for an extended period late in the season ( $W_5$  and  $W_6$ ) or when excessive available nitrogen was present in the soil ( $N_2P_1M_1$ ) (see fig. 32).

Why is it that yields are relatively low under treatments  $W_2$  (wet all season by furrow irrigation) and  $W_5$  (moist to August; dry thereafter)? It can be seen from the data in fig. 31 that nitrogen fertilizer has a marked beneficial effect on the yield of sugar beets. This effect is more pronounced under conditions of high water usage ( $W_2$ ) than under moderate usage ( $W_1$ ). A glance at fig. 33 may lead to the conclusion that the cause of the relatively low yields under irrigation treatment ( $W_2$ ) may be decreased availability of nitrogen from midseason until harvest. It appears likely that excessive irrigation water had carried soluble nitrogen beyond the reach of the sugar beet plants (Stewart and Greaves 1909).

At first thought one is inclined to the belief that lack of water has limited the growth of plants under irrigation treatment  $W_5$ . It is probable that lack of water as such may only be an indirect cause. The data in fig. 34 show that the dry soil condition of  $W_5$  has sharply limited the uptake of phosphorus late in the season. It is not entirely clear whether inadequate soil moisture or unavailability of phosphorus or some other factor or combination of factors associated with dry soil is the real cause of decreased yields of beets. It is not easy to determine which of the factors of growth,—moisture or nutrients—has the most powerful influence on yield and quality of sugar beets. The unfortunate fact is that soil moisture enthusiasts naively credit soil moisture tension with all the mischief while plant physiologists see nutrient unavailability as the chief villain.

### Discussion on Interactions

Plant growth is a result of many factors. Frequently plants are given an environment in which some growth factors are favorable and others are unfavorable to maximum growth. Ofttimes ignorance of all the facts leads one to assume a simple explanation for a specific growth response when in reality the assumed cause of growth is only slightly related to it.

For any given soil fertility level, it is probable that there is an irrigation regime most suited to the specific fertility conditions of a soil.

The two plant nutrients most generally found deficient in the Great Basin area—nitrogen and phosphorus—respond to soil moisture conditions in a different manner. Both of these nutrients are generally available to plants as anions— $\text{NO}_3$  and  $\text{PO}_4$ . This is about the only resemblance one has to the other. Nitrates are highly soluble, easily leached from the root zone and mobile within and without the plant. Nitrates accumulate in soils with low moisture content. None of these things properly describes available soil phosphates.

In order to make the most effective utilization of high fertility levels and ample moisture, plant populations must likewise be relatively high.

Irrigation and fertilizer practices are subject to a high degree of control and should be manipulated so as to encourage high quality and yield of crops on a permanent basis. Since most factors affecting quality and yield may exert a detrimental as well as a beneficial influence, it is important to know at what concentrations these growth factors bring about desirable plant responses.

## Sugar Beet Top Relationships

Although sugar beets are grown primarily for the roots, the leaves and crown, designated "beet tops" are important by-products. It is claimed that pound for pound of dry substance beet tops are equivalent in feeding value to alfalfa hay.

The green weight of sugar beet tops is approximately half the weight of roots. The green tops contain from 12 to 16 percent oven dry matter. The field-cured weight of beet tops is near a tenth and the oven dry weight is about a thirteenth the fresh weight of roots. This ratio may vary considerably because of soil moisture and soil fertility conditions.

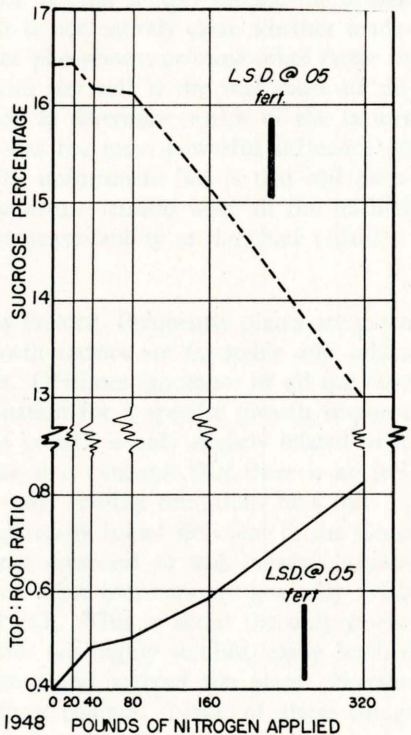
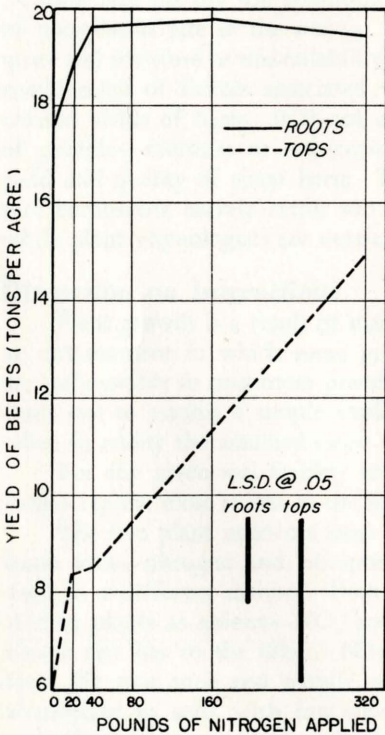


Fig. 35. Yield of tops and roots as influenced by nitrogen fertilizer

Fig. 36. Top:root ratio of sugar percentage as affected by nitrogen fertilizer

### Top:Root Ratios

The relation between top and root yields is conveniently expressed in terms of top:root ratios. The green weight is most commonly used to express this ratio. The top:root ratio is of doubtful value for general use. This is because it is affected in so many ways by many growth factors. However, it may be useful as an indicator of favorable or unfavorable conditions on a specific field or experiment.

### Nitrogen and Top Growth

The yield of tops increases as available soil nitrogen increases (figs. 35, 38, 39, 40, 41). Likewise, the top:root ratio tends to increase as

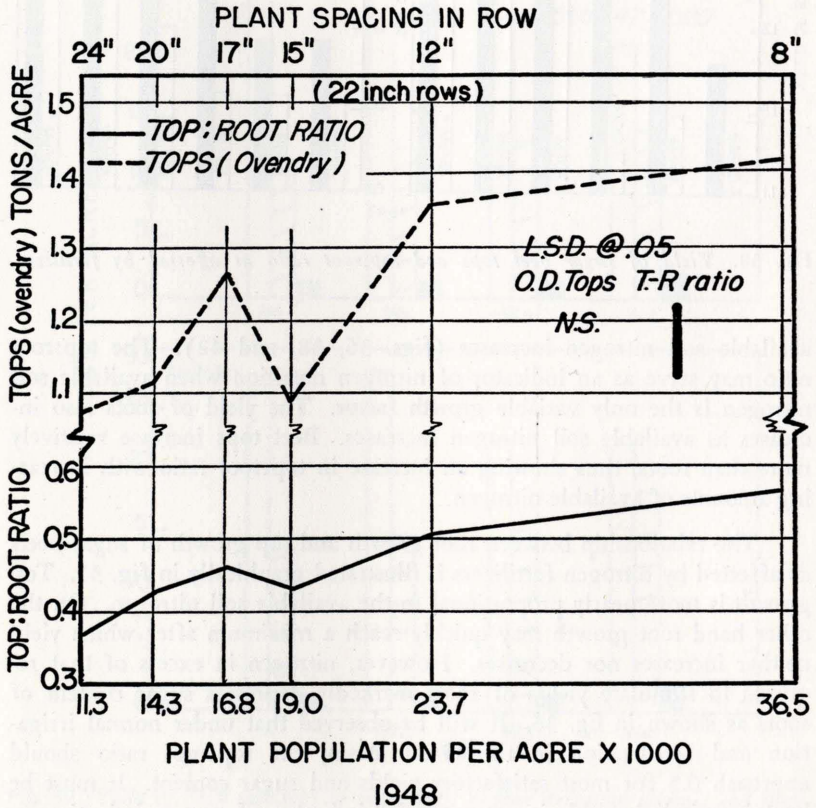


Fig. 37. Yield of sugar beet tops and top:root ratio as affected by plant spacing in the row

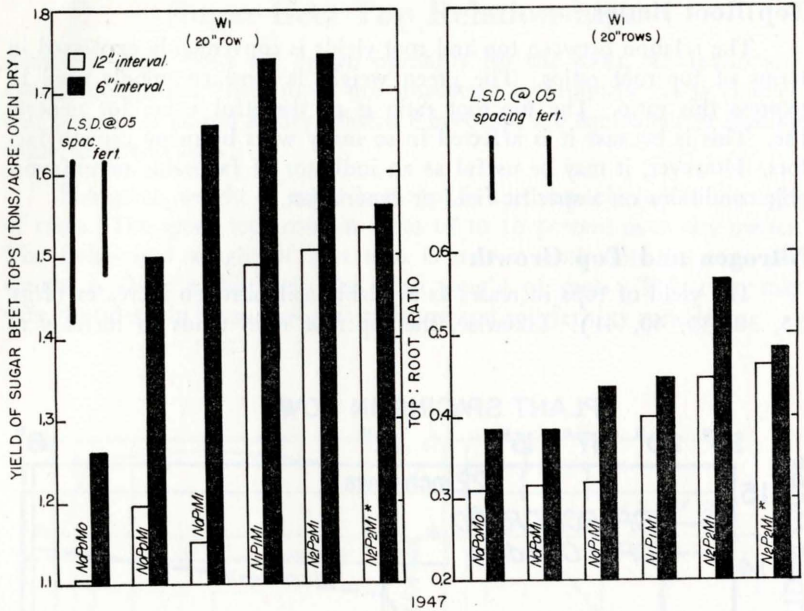


Fig. 38. Yield of sugar beet tops and top:root ratio as affected by fertilizer

available soil nitrogen increases (figs. 36, 38, and 42). The top:root ratio may serve as an indicator of nitrogen nutrition when available soil nitrogen is the only variable growth factor. The yield of roots also increases as available soil nitrogen increases. Beet tops increase relatively more than roots, thus showing an increase in top:root ratio with increasing amounts of available nitrogen.

The relationship between root growth and top growth of sugar beets as affected by nitrogen fertilizers is illustrated graphically in fig. 35. Top growth is more nearly proportional to the available soil nitrogen. On the other hand root growth may quickly reach a maximum after which yield neither increases nor decreases. However, nitrogen in excess of that required to stimulate yields of roots markedly depresses sugar content of roots as shown in fig. 36. It will be observed that under normal irrigation and fertilization in the Great Basin, the top:root ratio should approach 0.5 for most satisfactory yields and sugar content. It must be kept in mind that this is not a precise indicator of proper irrigation or fertilizer practice. The relationship of root growth to top growth of sugar beets at various soil fertility and soil moisture conditions for 1947 and

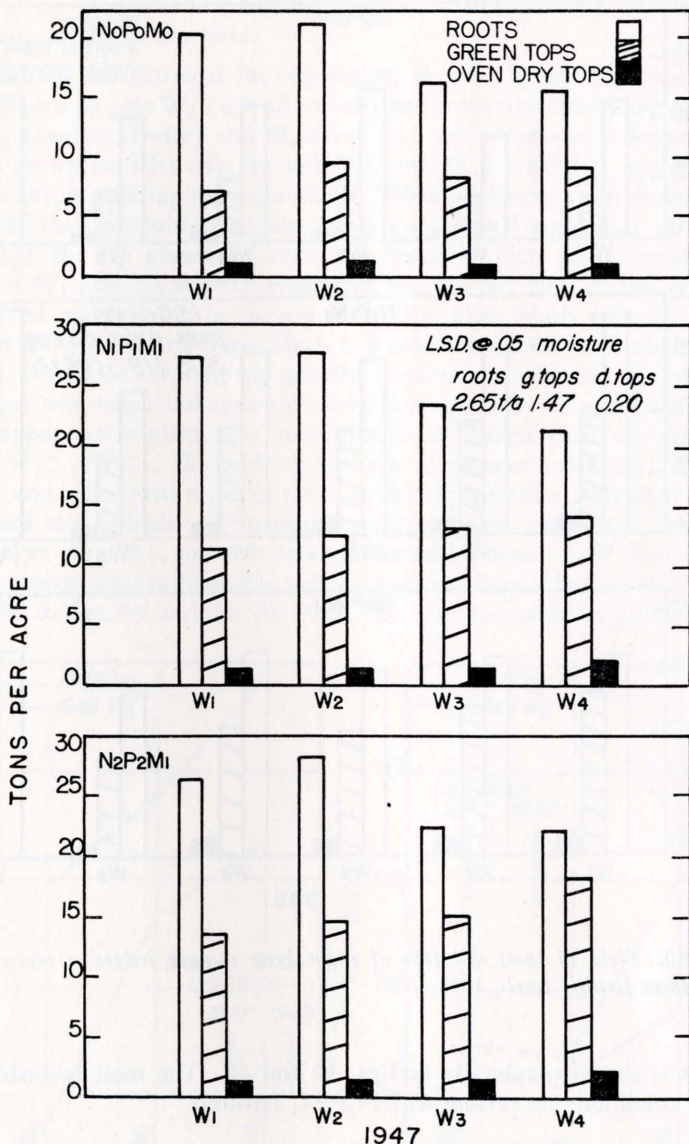


Fig. 39. Yield of roots and tops of sugar beets at four irrigation regimes and three fertility levels, 1947



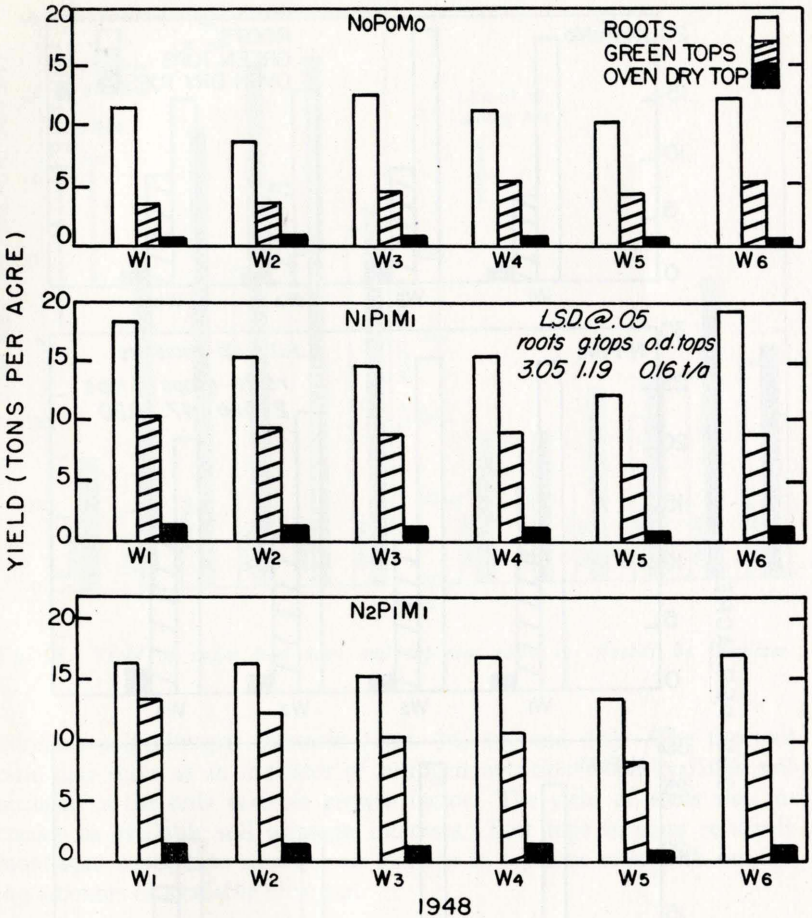


Fig. 40. Yield of roots and tops of sugar beets at four irrigation regimes and three fertility levels, 1948

1948 is shown graphically in figs. 39 and 40. The most favorable fertility conditions are present with N<sub>1</sub>P<sub>1</sub>M<sub>1</sub> fertilizer.

**Soil Moisture and Top Growth**

The yield of roots increases from W<sub>1</sub> to W<sub>2</sub> and then decreases from W<sub>2</sub> to W<sub>4</sub> (fig. 43). It is generally assumed that as soil moisture conditions become more favorable to growth, top growth increases. The

data in fig. 43 appear to contradict this idea. The following explanation may help to clarify the facts:

During the course of the experiment in 1947, it was observed that beets grown on plot  $W_1$  (wet all season) had more tops than those grown on  $W_3$  (moderately-dry) and  $W_4$  (very dry) until September. Sugar beet plants grown on relatively dry soil ( $W_3$  and  $W_4$ ) tended to accumulate nitrate-nitrogen during the dry summer. When September rains moistened the soil, the accumulated nitrate-nitrogen stimulated rapid leaf growth. Although the top growth of beets was lower on plots given treatments  $W_3$  and  $W_4$  than those given treatments  $W_1$  and  $W_2$  most of the season, this effect was reversed by harvest time. The plots which were driest at harvest time, and hence those which had accumulated the most nitrate-nitrogen, developed the most top growth. Concomitant with late top growth the sugar percentage and apparent purity were lowered. The above related facts appear to explain why root growth at harvest time was in the order  $W_2 > W_3 > W_4$  and top growth in reverse order  $W_2 < W_3 < W_4$ , and hence, why top:root ratios in this experiment are inversely proportional to favorable soil moisture conditions (fig. 44). Had samples been taken August 1, top:root ratios undoubtedly would have been more nearly proportional to favorable soil moisture condition. Further attention is called to figs. 39 and 40. In 1947, the most favorable irrigation with

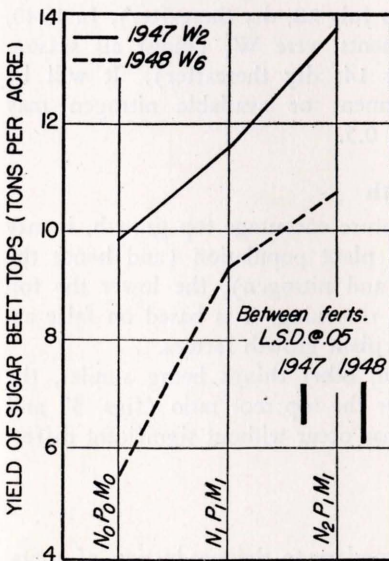


Fig. 41. Green weight of sugar beet tops as affected by fertilizer

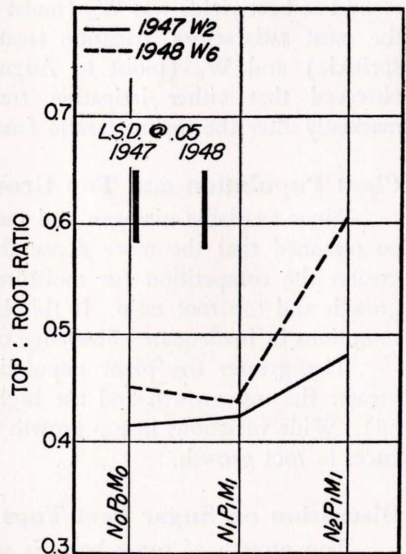


Fig. 42. Top:root ratio of sugar beets as affected by fertilizer

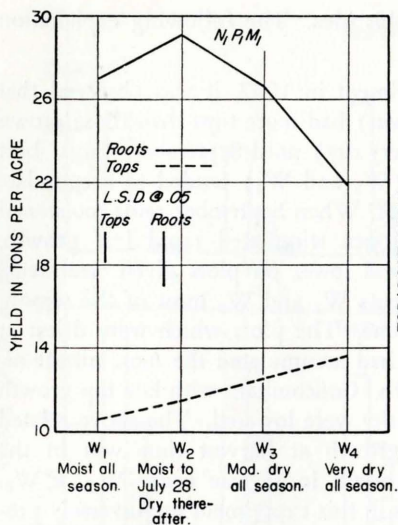


Fig. 43. Yield of sugar beet tops and roots at various soil moisture conditions

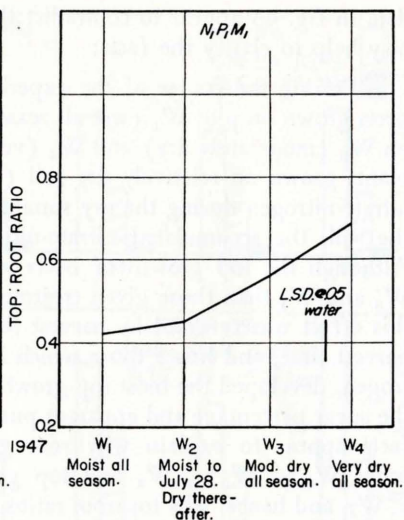


Fig. 44. Top:root ratio of sugar beets as affected by soil moisture conditions

respect to beet yields was W<sub>2</sub> (moist to July 28; dry thereafter). In 1948, the most satisfactory irrigation treatments were W<sub>1</sub> (moist all season, sprinkle) and W<sub>6</sub> (moist to August 14; dry thereafter). It will be observed that either irrigation treatment or available nitrogen may markedly alter the top:root ratio from 0.5.

### Plant Population and Top Growth

Since available nitrogen and moisture encourage top growth, it may be reasoned that the more dense the plant population (and hence the greater the competition for moisture and nitrogen), the lower the top growth and top:root ratio. If this be reasoning, it is based on false assumptions or inadequate knowledge of plant growth factors.

The greater the plant population, other things being similar, the greater the top growth and the higher the top:root ratio (figs. 37 and 38). Wide variations in top growth may occur without significant differences in root growth.

### Discussion on Sugar Beet Tops

Top growth of sugar beets is secondary to the production of roots. However, since top growth is used as a source of animal feed and must be disposed of in preparing roots for processing, it is desirable to know

the effect of plant population, irrigation practice, and fertilization on the production of tops. Within the fertility range studied in these experiments, top growth is roughly proportional to available soil nitrogen. Under climatic conditions of the Great Basin area, it is not practicable to produce beets with a top:root ratio far from 0.5. A lower ratio than this indicates insufficient nitrogen or too sparse plant population. Higher ratios suggest that too much nitrogen or too heavy plant populations are being used. Top growth late in the season indicates that sugar beet plants have been fertilized with too much nitrogen or that they have been allowed to remain dry over too long a period during the regular growing period.

Under some climatic conditions such as found in Alberta, Canada, it is difficult to fertilize sugar beets with too much nitrogen. The cold nights preceding harvest limit the availability of natural organic nitrogen and favor ripening of beets and hence, they have a high sucrose content at all available soil nitrogen levels. If it were possible to delay beet harvest until the last of October in the Great Basin, a similar condition would prevail here also. Under the mild climatic conditions of California and elsewhere, it is necessary for the sugar beet to exhaust nearly all available soil nitrogen before the beet crop can mature and the sugar content of the root be raised to a high level. Maturity of the crop under some climatic conditions is a result of available soil nitrogen exhaustion.

Table 12. Summary of studies on correlations among seasonal nitrogen fractions in sugar beet petioles and yield and quality of sugar beets

	Date sampled	Nitrate-N (r)	Organic-N (r)	Amine-N (r)	Total Sol-N (r)
Yield	7/13	0.2629	-0.1786	-0.2347	0.2161
	8/2	0.3808*	0.0616	0.0616	0.3754
	8/23	0.2698	0.3650*	0.2775	0.3332*
	9/18	0.3708	0.4730**	0.4889	0.4246**
	10/9	0.2454	0.4040*	0.4522	0.3730*
Multiple correlations		R=0.4945	R=0.5248*	R=0.9903**	R=0.4977
Sucrose	7/13	-0.2653	-0.2929	-0.2098	-0.3463*
	8/2	-0.5403**	-0.2700	-0.0141	-0.5203**
	8/23	-0.6288**	-0.6165**	-0.5719**	-0.7502**
	9/18	-0.7460**	-0.8501**	-0.8243**	-0.8165**
	10/9	-0.7143**	-0.8587**	-0.8480**	-0.8852**
Multiple correlations		R=0.8585**	R=0.9011**	R=0.9003**	R=0.9052**
Purity	7/13	-0.2926	-0.0447	-0.0906	-0.2823
	8/2	-0.4672**	-0.3946*	-0.0557	-0.4886**
	8/23	-0.6480**	-0.7171**	-0.6041**	-0.7080**
	9/18	-0.7679**	-0.8531**	-0.8359**	-0.8323**
	10/9	-0.6136**	-0.8375**	-0.9450**	-0.8235**
Multiple correlations		R=0.8543**	R=0.9043**	R=0.9081**	R=0.8643**

## Yield and Quality of Sugar Beet Roots as Correlated with Seasonal Nitrogen Fractions in Beet Petioles

The nitrate-nitrogen content of sugar beet petioles has been used for a number of years as a basis for estimating the nitrogen nutrition of sugar beets and the ability of a soil to supply nitrogen for subsequent crops. The author has used this factor as a basis for comparing the uptake of nitrogen by sugar beets from variously fertilized and irrigated plots.

Nitrate-nitrogen has been useful in all the studies previously mentioned. However, it has been observed at the Logan Station at harvest time, that frequently when the nitrate-nitrogen content of sugar beet petioles obtained from variously treated plots was similar, the nitrogen supply in the variously treated plants was obviously different. The color of beet leaves and quality of the extract juice in roots have been used as a basis for assuming that nitrogen nutrition was different. Furthermore, for a number of years it has been observed that low sucrose and purity are closely associated with high nitrogen fertilization and particularly an abundant supply in the tops and roots of sugar beets late in the season.

A study of the nitrogen fractions in the sugar beet petioles was undertaken, to see if some nitrogen fraction other than nitrate may not be a better measure of the nutritional status of sugar beets near harvest time, and thus more closely related to sucrose percentage and purity of extract juice of beet roots.

A multiple correlation study was undertaken on some experimental data obtained in 1948 (table 12). There were five replications and eight levels of nitrogen fertilization as follows: 20, 40, 80, 160, 80\*, 320, and 160\* pounds of nitrogen per acre side-dressed near thinning time. Half of the nitrogen was applied at thinning time and half in August on treatments 80\* and 160\*.

Samples of beet petioles were taken at five dates (table 12). The correlation becomes much better as harvest time is approached. However, there are a number of instances which show a higher correlation at the 9/18 than at 10/9 date. The only significant multiple correlations between nitrogen fraction and yield are those between organic and/or amine-nitrogen and yield. All fractions except nitrate-nitrogen are significantly correlated at the last sampling date. All fractions are significantly correlated at next to last sampling date.

All nitrogen fractions showed a highly significant multiple correlation with sucrose and purity percentages. But sucrose and purity always show a lower correlation with the nitrate-nitrogen than with other nitrogen

fractions studied. It is of interest to observe that at the last two sampling dates and particularly at the last sampling date, the difference in the correlation among the several nitrogen fractions strongly favors the organic nitrogen as being most closely correlated with yield and quality of beets.

In order to determine whether or not one form of nitrogen was more highly correlated with yield, sucrose, and purity than another, the correlations at the last sampling date were subjected to test (Hotelling 1940). Differences in correlations between various nitrogen fractions in sugar beet petioles and yield were not significant. However, differences in correlation of organic, amine, total soluble-nitrogen, and sucrose in comparison with nitrate-nitrogen and sucrose were highly significant. Similarly differences in correlation of organic, amine, total soluble-nitrogen, and purity in comparison with nitrate-nitrogen and purity were highly significant. The actual  $t$  value at 37 degrees of freedom for comparing the correlations, total soluble-nitrogen, and sucrose vs. nitrate-nitrogen and sucrose is 3.21. Similarly the  $t$  value at 37 degrees of freedom for comparing the correlations total soluble nitrogen and purity vs. nitrate-nitrogen and purity is 3.20. This is conclusive that the organic nitrogen fraction in sugar beet petioles is more closely related to the factors of quality of sugar beet roots than is nitrate-nitrogen.

However, the study also shows nitrate-nitrogen content of beet petioles is highly correlated with sucrose and purity of beet roots. For many practical purposes the nitrate-nitrogen content of beet petioles is a satisfactory index of nitrogen nutritional status. Furthermore, it is a simple and rapid determination.

## GENERAL DISCUSSION

**S**UGAR BEET growing has been observed to stimulate better farming practices wherever this crop has been introduced. Improvement in general farm practice results from the fact that sugar beet growing demands more careful consideration to weed control, fertilization, irrigation, and seeding time than do many crops.

Considerable variation in plant population may be tolerated without unduly affecting the maximum yield of sugar provided that soil moisture and available soil nitrogen do not become excessive or limiting — and provided further that plant spacing be uniform throughout the field. It has been found necessary to compromise row-width spacing between yield and convenience in mechanizing sugar beet production. It is of both academic interest and practical value to know the fundamental relationships which exist among plant population, soil moisture condition, and soil fertility. Once the fundamental relationships are understood, practical adaptation can be advantageously made. In the course of the study reported herein only those between-row and within-row plant spacings have been studied which appeared practicable. Within this limited range of plant populations (22,000 to 52,000 plants per acre), it was observed that soil moisture conditions and available nitrogen exhibited some fundamental relations to plant population as expressed in yield and quality of sugar beets.

A study was made of the various forms of nitrogen found in the sugar beet roots as these are related to dry matter, yield, sucrose content and coefficient of apparent purity. These correlations are shown in table 13. It is quite apparent that the amine-nitrogen, which constitutes the bulk of the organic-nitrogen fraction, and organic-nitrogen are most closely related to the purity of extract juice of beet roots. All nitrogen fractions appear to be equally, negatively correlated with sucrose percentage in this particular study.

In this study as available nitrogen and soil moisture were increased, the greater was the yield advantage for dense plant populations. These relationships were what one might reasonably expect within the moderate limits studied. The greater the plant population, the greater the competition for plant nutrients and soil moisture. When one or both of these factors of plant growth is limited, growth is curtailed. On soils of a given fertility level, there is an irrigation regime and plant population best suited for maximum quality and yield. Since all three of these factors can be readily controlled, the farmer must decide what he is willing and able to do towards modifying his irrigation practice and soil fertility





level before he can decide which plant spacing is best for his condition. Since it is unprofitable to grow sugar beets unless yield or sugar is near maximum for the limitations of climate and mechanization of cultural practices, it is possible to specify the plant population, soil moisture condition, and fertility requirement for maximum yield of sugar.

If the assumptions stated previously are accepted, it appears as though sugar beets should be planted in rows 20 to 22 inches apart and thinned so as to leave plants 10 to 15 inches apart in the row.

Full advantage must be taken of the short growing season if good production is to be obtained in the Great Basin. The maximum period from planting to harvest time is about 180 days. Good farmers commonly obtain 20 tons of beets per acre while 30 tons are occasionally produced. A 20 ton beet crop requires 200 pounds of nitrogen. Soils of average nitrogen producing power in the Great Basin area are able to supply approximately 120 pounds of nitrogen during a growing season. The additional 80 pounds of nitrogen for a 20 ton beet crop must be supplied by barnyard manure or commercial fertilizer. It is desirable that the nitrogen-supplying capacity of a soil be known with accuracy. A deficiency of available nitrogen sharply limits growth but an excess depresses sucrose percentage of the beets. At present no standard procedure has been developed which satisfactorily appraises the nitrogen-supplying power of soils in this area. Such a procedure is urgently needed. Until such a soil test is available, it will be necessary to make rough approximations of manure and fertilizer requirements for a satisfactory sugar beet yield.

If it is assumed that the plant population and soil fertility are near optimum for this area, it is not difficult to outline a desirable irrigation practice. In order to take full advantage of a normally short growing season, early planted beets should be kept growing rapidly until late summer. In this climate this frequently means one or more light irrigations before thinning and weeding and one as soon as possible after thinning. The frequency and quantity of irrigations throughout the growing season may depend upon rainfall and temperature. The dry soil should be moistened once each week up to the middle of August and less frequently from the middle of August until harvest time. Each irrigation should be made with the minimum water necessary to moisten the dry soil completely to the rooting depth of plants.

A dry soil places limitations upon rate of nutrient uptake (particularly phosphorus) while excess water passes down through the soil carrying with it nitrate-nitrogen and influences nitrogen nutrition.

In order for a sugar beet grower to obtain maximum yields of sugar, he must balance his plant population with adequate but not excessive irrigation water and fertilizers. When a soil remains dry for an extended

period preceding harvest or when excess nitrogen fertilizer is in the soil, sugar content of beets is low. Under these conditions, phosphorus uptake by plants is limited and this in turn limits growth of beets. When soils receive excess water, plant growth may be decreased by nitrogen deficiency.

The important thing in the growing of sugar beets is not that the crop be properly fertilized or irrigated or planted with a given number of plants, but that the right combination of all these factors be supplied at the same time. A plant population which is ideal when the soil is properly fertilized and irrigated is not ideal when improperly fertilized or irrigated. A field of beets which is correctly fertilized when irrigation is proper, is either inadequately or excessively fertilized when irrigation is incorrect.

It appears from the data which have been obtained from experiments over a three year period, that sugar beets in the Great Basin area should have a top:root ratio of approximately 0.5. If the ratio is much greater than this, it indicates that the soil has been dry for an extended period late in the season or that too much nitrogen is available to the crop. If the ratio is much less than 0.5, it indicates that too little nitrogen was available to the crop or that excessive amounts of irrigation water may have leached it beyond reach of plant roots.

Nutritional status of sugar beet plants can be accurately determined by chemical analyses of leaf petioles. In the Great Basin sugar beet petioles should contain 8,000 to 10,000 ppm of weak acid extractable nitrate-nitrogen early in July; 3,000 to 6,000 ppm by early August; 1,000 to 2,000 by mid-September; and about 500 ppm by harvest time. Phosphorus content for comparable extracts and dates should be 1,200 to 1,500 ppm; 1,00 to 1,200 ppm; 700 to 800 ppm; and 600 to 800 ppm.

There is some question as to the factors responsible for low sucrose and purity in sugar beets. Data accumulated in a study of this problem suggest that organic nitrogen compounds in the sugar beet root are intimately associated with changes in sucrose percentages, if not completely responsible for them. It is probable that inorganic salts of various kinds may enter the sugar beet root with the organic and inorganic nitrogen materials, but it appears as though the most common cause of low sugar percentages and purities is accumulation of soluble organic-nitrogen compounds in the root.

## GENERAL SUMMARY

1. The sugar beet industry has had a spectacular development during the past 100 years. During this period the sugar beet has attained an important position in our national and world economy. Approximately one quarter of the total sugar consumed in the United States comes from sugar beets. Forty percent of the sugar consumed in the world is from this source. Seventy to 80 percent of the sugar produced in the continental United States is from sugar beets.
2. Diagrams and description of the field experiments are given. Chemical characteristics of soil are tabulated. Irrigation and fertilizer treatments are explained and symbolized for use in graphs and tables.
3. Between-row and within-row spacing of sugar beet plants is a compromise between yield and convenience in mechanizing production. Rows should be 20 to 22 inches apart and plants should be spaced 10 to 15 inches apart in the row.
4. Until a reliable soil test is developed for the nitrogen-producing power of a soil, sugar beet crops should be fertilized with 60 to 100 pounds of nitrogen per acre.
5. Nutritional status of sugar beet plants was determined by making chemical analyses of 0.1 normal sulfuric and 2 percent acetic acid extract of leaf petioles. Plant population, fertilization, and irrigation regimes influence the nutritional condition of plants.
6. Sucrose and purity percentages of sugar beets are increased by heavy, frequent irrigations and deficiency of available nitrogen. Light irrigation and heavy nitrogen fertilization depress sucrose and purity percentages.
7. The sugar beet plant should be kept growing as rapidly as possible from emergence to late summer. This frequently necessitates an irrigation preceding and one immediately following thinning, as well as frequent light irrigations up to late summer. Irrigations from late summer to harvest may be spaced at two-week intervals.
8. Three years' study on the interrelations among the factors of soil moisture condition, plant population, and fertilization have revealed some fundamental relationships which are of both academic interest and practical value.
  - A. The greater the plant population, the greater the competition for soil moisture and plant nutrients.

- B. The more moist a soil is kept, the higher the phosphorus composition and the lower the nitrogen content of sugar beet petioles.
  - C. For any given irrigation regime, there is a definite available nitrogen level best calculated to give maximum sugar production.
9. In order to obtain good yields of high quality sugar beets, it is necessary to combine proper plant spacing, adequate fertilization, and timely irrigation practice with early planting and weed control.
  10. When all factors of plant growth are favorable, sugar beets have a top:root ratio of near 0.5 in the Great Basin. It does not follow that such a ratio means that all cultural practices have been favorable.
  11. Soluble organic-nitrogen compounds in sugar beet roots appear to be responsible for or highly correlated with low sucrose and purity percentages.
  12. Sugar beets have a yield potential of not less than 20 tons per acre in the Great Basin. This can readily be obtained by combining good cultural practices with irrigation and fertilizer programs suggested in this bulletin.

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