Effect of Plant Spacing and Fertilizer on Yield, Purity, Chemical Constituents and Evapotranspiration of Sugar Beets in Kansas I. Yield of Roots, Purity, Percent Sucrose and Evapotranspiration[1]

G. M. HERRON, D. W. GRIMES AND R. E. FINKNER[2]

Received for publication August 15, 1963

Sugar beets have been grown for more than 50 years in southwest Kansas. Little research information has been published regarding the particular problems of this area. Many of the practices have been imported from other areas and adapted to local conditions. The success of sugar beet production has varied greatly, with low yields of inferior quality beets being a constant problem.

In recent years yields have been increasing, however, the quality has shown somewhat less improvement. Higher yields could be attributed to many factors such as mechanization, better varieties and culture practices, improved irrigation facilities and greater use of commercial fertilizers.

Because of the limited research information available, it seemed desirable to investigate some of the practices that might contribute to yield and quality of sugar beets. In the field studies, special emphasis was placed on soil moisture, plant population and fertilization. Soil moisture was not included as a variable in this phase of the study, however, it was deemed desirable to catalog the total moisture use and pattern of extraction from the soil on certain treatments. The importance of soil moisture management has been pointed out by Haddock (8,9)[3].

Plant population studies have received much attention (2,3,4,8,18). Most studies have indicated high plant populations, e.g., 30,000 plants per acre, are desirable both from the standpoint of yield and quality. Some studies have shown narrower rows, 16 to 20 inches, would be more desirable than the current practice of 22 to 24 inch row width. The wider row width is more popular because of convenience in the use of farm machin-

[1] Contribution No. 68, Garden City Branch Experiment Station, Garden City, Kansas, a branch of Kansas State University, Manhattan, Kansas. Cooperative research between the Garden City Branch Experiment Station and the American Crystal Sugar Company, Rocky Ford, Colorado.

[2] In charge of irrigated soil fertility studies at Garden City Experiment Station; formerly in charge of irrigation studies at Garden City Experiment Station and now at Ames, Iowa; and Manager Research Station, American Crystal Sugar Company, Rocky Ford, Colorado, respectively.

[3] Numbers in parentheses refer to literature cited.

ery. Uniform stands of beets have been stressed for yield and quality (4,14).

Many research papers have been published on the influence of fertilizer and manure on sugar beet yield and quality. Nuckols (12) summarized the crop rotation and manure studies in western Nebraska. Haddock (8) studied the influence of fertilizer and manure on sugar beets in Utah. Gardner and Robertson (6) studied nitrogen requirements of beets in Colorado. In Kansas, fertilizer studies were reported by Carlson and Herring (1) and Grimes (7).

In recent years, attention has been directed toward the problems associated with the use of "excessive" amounts of nitrogen fertilizer and the resulting lower beet quality (5,10,11,13,15,17). The "low quality beet" is an old problem that has been somewhat dormant. Present emphasis on quality can be attributed to two main factors: (1) production research is less demanding than formerly; and (2) the development of the scientific tools and personnel with which to solve the "low quality beet" problem. This stage of research achievement marks an important milestone in sugar beet technology.

Results reported here are concerned with plant spacing and fertilizers as related to yield, quality of beets, and soil moisture use in southwest Kansas.

Materials and Methods

Location and soil site: The field study was conducted in 1959 and 1960 on the Irrigation Project of the Garden City Branch Experiment Station located about 10 miles northwest of Garden City, Kansas. The soil is classified as Richfield silty clay loam (silted phase)[1]. It is calcareous to a depth of 8 to 12 inches while the second foot of depth is noncalcareous. For the surface layer, a pH value of 8.0 is typical; organic matter content of 1.8 to 2.2%; available phosphorus is medium to high; and potassium is very high. This soil is deep, moderately permeable and at field capacity it will retain about two inches of available moisture per foot of depth.

Wheat was the preceding crop each year. Conventional early seedbed preparation and tillage was practiced each year. The variety HII-1 was seeded at the rate of 5.5 pounds per acre in 22 inch rows April 4, 1959, and April 15, 1960. The experimental design was a split-plot in randomized blocks with four replications. Factorial fertilizer treatments were main plots (6 rows × 75 feet long) and spacing treatments were sub-plots (6 rows × 25 feet long).

[1] "Silted phase" is used to characterize soils in this area that have been modified in the surface layer by the accumulation of calcareous silt from ditch irrigation water.

Fertilizer: Each year 12 fertilizer treatments, consisting of three levels of nitrogen, two levels of phosphorus and two levels of potassium were used. In 1959, 80 pounds per acre of N as ammonium nitrate and 100 pounds per acre of K_20 was broadcast and worked in prior to seeding the beets. An additional 60 pounds of N as anhydrous ammonia was side dressed June 12, immediately preceding the second irrigation. In 1960 all of the N and K_2O was applied and worked in prior to seeding beets. During both years the phosphate was applied below and to the side of the seed with fertilizer attachments on the beet drill.

Spacing: Plant spacings of 8, 12, and 16 inches were accomplished by hand thinning as soon after emergence as possible. Plant counts during the season and at harvest indicated very close agreement to the planned populations of 35,640, 23,760, and 17,820 plants per acre.

Irrigation: The irrigation schedule was such that no moisture stress occurred. In 1959 the beets were irrigated six times and in 1960, five irrigations were necessary. Soil samples were taken periodically to a depth of 6 feet, by one foot increments, to determine the moisture use. Moisture was determined gravimetrically except for a few cases in 1960 when the neutron moisture meter was used. Rainfall was added to the moisture used from the surface foot. Approximately 8 inches of rainfall were received during the moisture use periods which is near normal for this area.

Sampling: The beets were harvested in the last week of October in 1959 and the first week of November in 1960.

Yields were determined by harvesting the four center rows by 23 feet in length. This allowed for two feet between sub-plots (spacing treatments) and two rows between adjacent fertilizer treatments. Two samples of the harvested beets from each subplot were taken to the American Crystal Research Laboratory, Rocky Ford, Colorado, for determination of percent sucrose, percent purity, various amino acids and mineral constituents. Laboratory procedures will be described in Part II of this paper.

Statistical methods of Snedecor (16) were employed in the analyses of the data[5].

Results and Discussion

Yields of Roots: In 1959 the root yields ranged from 26 to 31 tons per acre while in 1960 the yields varied from 29 to 32 tons per acre (Tables 1 and 2). This yield level is considerably above the area average for these years. Adequate and timely irrigation contributed to the high yields.

[5] Appreciation is expressed for the assistance provided by Dr. H. C. Fryer and associates, Statistical Laboratory, Kansas State University, Manhattan, Kansas.

Table 1.—The effect of fertilizer treatments and plant spacing of beets in 22 inch rows on yield of roots, % sucross, and % purity of the extract. 1959.

Fertilizer treatment			Yield of roots plant spacing, inches				Sucrose plant spacing, inches				Purity plant spacing, inches			
N	P_2O_5	K_2O	8	12	16	Average	8	12	16	Average	8	12	16	Average
Lb/acre			Tons per acre				Percent				Percent			
0	0	0	26.46	27.34	26.86	26.88	16.1	15.8	15.3	15.8	91.1	91.4	91.0	91.1
80	0	0	28.39	29.09	27.45	28.31	15.5	14.6	15.1	15.0	89.0	89.2	90.4	89.5
140	0	0	30.00	29.08	30.43	29.84	14.7	13.9	14.0	14.2	87.1	88.6	87.2	87.6
0	120	0	27.22	26.36	27.76	27.11	16.4	15.6	15.4	15.8	90.7	91.1	90.5	90.8
80	120	0	27.59	29.97	28.89	28.82	15.9	14.8	14.6	15.1	89.1	88.8	90.6	89.5
140	120	0	30.70	30.55	30.39	30.54	15.2	14.5	13.8	14.5	87.8	88.4	86.4	87.5
0	0	100	27.42	27.36	27.63	27.47	15.8	15.8	14.8	15.6	89.1	91.7	90.7	90.5
80	0	100	26.24	28.38	30.03	28.22	15.2	15.3	14.2	14.9	91.2	89.8	90.0	90.4
140	0	100	27.97	30.34	29.63	29.31	15.2	15.6	14.9	15.2	89.2	89.8	89.2	89.4
0	120	100	27.40	28.08	26.81	27.43	16.0	15.4	15.9	15.8	91.2	88.3	89.8	89.8
80	120	100	29.73	31.28	28.86	29.96	15.1	14.9	14.2	14.7	89.6	89.6	88.7	89.3
140	120	100	29.23	29.62	29.86	29.57	14.5	14.4	14.6	14.5	87.9	87.9	87.2	87.7
Average			28.20	28.96	28.72	28.62	15.5	15.0	14.7	15.1	89.4	89.5	89.3	89.4
Statistically significant factors @ .05 level			Nitrogen (Linear) Spacing Spacing × N × P_2O_5 × K_2O				Nitrogen (Linear) N × K_2O Spacing Spacing × K_2O				Nitrogen (Linear) Nitrogen × K_2O			

Table 2.—The effect of fertilizer treatments and plant spacing of beets in 22 inch rows on yield of roots, % sucrose, and % purity of the extract. 1960.

Fertilizer treatment			Yield of roots plant spacing, inches				Sucrose plant spacing, inches				Purity plant spacing, inches			
N	P_2O_5	K_2O	8	12	16	Average	8	12	16	Average	8	12	16	Average
Lb/acre			Tons per acre				Percent				Percent			
0	0	0	29.22	30.07	30.54	29.94	17.9	17.7	17.8	17.8	91.2	89.8	88.7	89.5
60	0	0	30.45	30.68	31.02	30.72	17.6	17.5	17.4	17.5	89.5	90.5	88.9	89.7
120	0	0	30.14	30.83	31.46	30.81	16.8	16.4	16.5	16.6	89.1	88.5	88.3	88.6
0	120	0	30.24	30.79	31.53	30.85	18.2	17.8	17.9	18.0	89.5	88.3	89.9	89.3
60	120	0	28.82	30.34	30.38	29.93	17.7	17.0	17.2	17.3	90.4	89.9	89.8	90.0
120	120	0	30.76	31.32	32.33	31.47	16.9	17.2	16.6	16.9	88.1	87.5	87.1	87.6
0	0	100	30.23	30.80	28.68	29.90	17.4	16.8	16.5	16.9	90.4	89.2	89.3	89.6
60	0	100	29.16	30.82	30.31	30.10	16.8	17.2	17.5	17.1	90.4	89.5	86.9	88.9
120	0	100	29.50	31.74	31.29	30.84	17.3	16.6	17.1	17.0	88.3	88.3	90.0	88.9
0	120	100	29.71	30.32	28.98	29.67	17.7	17.5	17.4	17.5	91.2	89.0	89.4	89.9
60	120	100	30.44	31.00	30.19	30.54	17.6	17.5	17.2	17.4	90.2	89.7	88.9	89.6
120	120	100	30.81	31.58	31.66	31.35	17.2	17.1	15.6	16.6	89.5	89.4	85.5	88.1
Average			29.96	30.86	30.70	30.51	17.4	17.2	17.0	17.2	89.8	89.1	88.6	89.2
Statistically significant factors @ .05 level			Nitrogen (Linear) Spacing				Nitrogen (Linear) Spacing				Nitrogen (Linear) Spacing			

Both spacing and fertilizer treatments resulted in statistically significant yield differences. Yield increase from fertilizer was in a linear relationship to the applied nitrogen. Neither phosphorus nor potassium significantly influenced yields. This soil is generally considered to be adequately supplied with available phosphorus and potassium. Nitrogen carry-over from previous crops and the short summer fallow period after the previous wheat crop would account for a high level of soil nitrogen.

A spacing interval of 12 inches produced the highest average yield both years. Lowest average yield resulted from the 8-inch spacing interval. Although mean differences due to spacing were less than one ton per acre, the differences were statistically significant at the 5% probability level. Under the conditions of these experiments, the highest yields occurred with approximately 25,000 plants per acre.

Percent Sucrose: Each year the percent sucrose was in an inverse and linear relationship to the amount of applied nitrogen. As an average, each 14 pounds per acre of fertilizer N decreased the sucrose content by 0.1%. Regression equations are given in Table 3. Phosphorus or potassium did not influence sucrose content.

Plant spacing interval of 8 inches resulted in the highest sucrose content each year. Decreasing the population resulted in lower sucrose content. Regression equations are given in Table 3. In 1959, each inch of space above 8 inches decreased the sucrose content by 0.1%, but, in 1960 about two inches of additional space above 8 inches were required for the same reduction in sucrose.

Coefficients of determination (Table 3) indicate 39% of the variation in sucrose could be attributed to spacing and 47% to nitrogen in 1959. The degree of association was much less for both nitrogen and spacing in 1960.

Percent Purity: Purity of the extract had an inverse and linear relationship to the amount of applied nitrogen each year. Phosphorus or potassium did not significantly influence purity either year.

Plant spacing had no effect on purity in 1959, but in 1960, purity was significantly lowered by wider within-row plant-spacing intervals. Purity varied from 88% to 91% during both years of the study (Tables 1 and 2).

Gross Sugar Yield: Total sugar production was not significantly influenced by fertilizer treatments. Yield increases resulting from fertilizer were sufficient to compensate for the accompanying decrease in percent sucrose. Average gross sugar production was 8,614 pounds per acre in 1959 and 10,503 pounds per acre in 1960 (Table 4).

Table 3.—Regression equations, relating the rate of nitrogen and within-row spacing to sucrose content and weight per beet.

Year	Regression equation	Correlation coefficient, r	Coefficient of determination r^2
	% Sucrose (Y) — N rate (X)		
1959	$\hat{Y} = 15.65 - 0.0078X$	0.683**	46.6%
1960	$\hat{Y} = 17.59 - 0.0066X$	0.604**	36.5%
	% Sucrose (Y) — plant spacing (X)		
1959	$\hat{Y} = 16.78 - .0906X$	0.628**	39.4%
1960	$\hat{Y} = 17.79 - .0469X$	0.364**	13.2%
	Beet size (Y) — plant spacing (X)		
1959	$\hat{Y} = .2889 + .1553X$	.973**	94.7%
1960	$\hat{Y} = .3694 + .1594X$	.975**	95.1%

* Significant at 0.05 n = 36
** Significant at 0.01

Table 4.—The mean calculated value for gross sugar production and extractable sugar as influenced by nitrogen, phosphorus, or potassium fertilizers and spacing intervals of plants.

Treatments	Gross sugar 1959	Gross sugar 1960	Extractable sugar[1] 1959	Extractable sugar[1] 1960
	cwt/A		cwt/A	
Nitrogen, lbs/A of N				
0	85.35	105.62	74.36	89.73
60- 80	86.11	105.18	74.09	90.97
120-140	87.01	104.31	72.48	86.70
LSD (.05)	NS	NS	-----	-----
Phosphorus, lbs/A of P_2O_5				
0	85.40	106.12	73.52	88.67
120	86.90	103.96	73.77	89.60
LSD (.05)	NS	NS	-----	-----
Potassium, lbs/A of K_2O				
0	85.92	104.20	73.41	88.88
100	86.39	105.88	73.87	89.39
LSD (.05)	NS	NS	-----	-----
Spacing, inches between plants				
8	87.06	104.48	74.57	89.37
12	87.04	106.01	74.52	89.32
16	84.36	104.62	71.86	88.73
LSD (.05)	2.45	NS	-----	-----

[1] Extractable sugar was calculated on the means of four replications, using the formula developed for the Rocky Ford factory for the 1954 through 1958 campaigns.

In 1959, the 16-inch spacing resulted in significantly lower sugar production than other spacing treatments. In 1960, there were no differences resulting from spacing treatment. In 1959, there was a significant interaction between plant population and the potassium fertilizer treatment. This did not occur in 1960, therefore, it may have resulted from random variation.

Extractable Sugar Yield: The extractable sugar, i.e., the amount of sugar bagged, was decreased by nitrogen fertilization. Only the last increment of nitrogen fertilizer decreased the extractable sugar a substantial amount. These data would seem to confirm the observation that "excess" nitrogen results in "low quality beets". It will be noted that under the conditions of these experiments, rather liberal amounts of nitrogen could be applied (60 to 80 pounds per acre) before the "excess" N was instrumental in reducing extractable sugar. From an economical standpoint it would not have been profitable to supply the larger rates of nitrogen.

Phosphorus and potassium fertilizers produced no substantial difference in extractable sugar. In general, the same trend existed between gross sugar production and extractable sugar regardless of the application of phosphorus and potassium. Data for the average of the variables studied are reported in Table 4.

During both years, little differences were observed between 8- and 12-inch with-in row spacing, but 16-inch spacing decreased both gross and extractable sugar.

Size of Roots: In 1959, applied N gave a significant linear relationship to beet size, but not in 1960 (Figure 1). Beet size was significantly increased both years by a wider within-row plant spacing. An additional inch of in-row space resulted in a 0.16 pound increase in the average weight per beet. Regression equations, correlation coefficients and coefficients of determination (Table 3) indicate that plant spacing was the principal factor determining average beet size in these experiments.

Large size roots generally are assumed to contain less sucrose and extractable sugar. It is very difficult to determine that beet size directly influences sucrose content or purity because the factors that alter the size of beets also change such things as the nutritional status of a plant. For example, increasing the spacing interval increases the amount of soil nitrogen and moisture available to an individual plant. Thus, if top growth isn't markedly increased, there may be sufficient "excessive" nitrogen to decrease sucrose content. In these experiments it was impossible to separate the effect of beet size on sucrose content or purity by covariance analyses, thus, large beets were not necessarily lower in

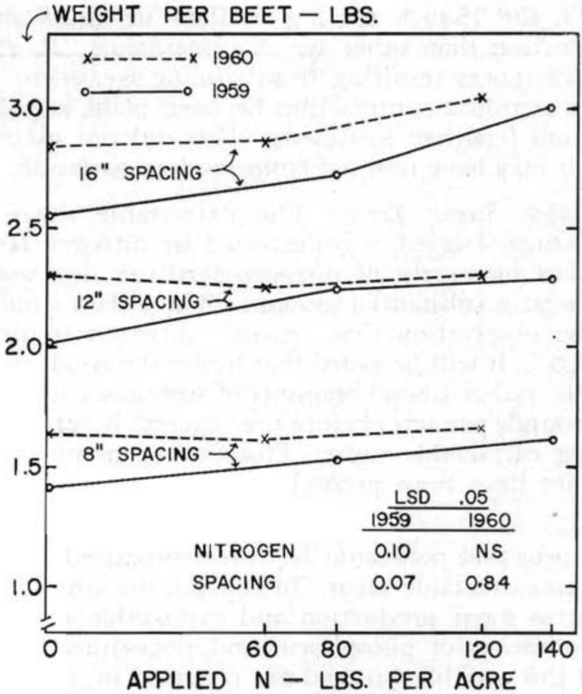

Figure 1.—The relationship between sugar beet size and applied nitrogen fertilizer.

quality. Loomis and Ulrich (10) found no direct relationship between beet size and percent sucrose.

Soil Moisture Use: Moisture use (evapotranspiration) was determined only for fertilizer treatments receiving the three nitrogen levels on plots receiving phosphorus and potassium. Data reported are averages of four replications.

Accumulative seasonal evapotranspiration for 1959 ranged from 32 to 40 acre-inches. Differences were not significant for fertilizer or spacing, however, the interaction was statistically significant. In 1960 evapotranspiration varied from 32 to 35 acre-inches, with differences not statistically significant (Table 5).

Maximum rate of moisture use of about 0.3 inch per day occurred in July. After the period of peak use, the moisture requirement declined until harvest when little more than 0.1 inch was used daily (Figures 2 and 3).

The extraction pattern (Figure 4) indicates most of the moisture use was from the surface three feet of soil. Moisture extraction from the 4th, 5th, and 6th feet of depth was mostly

Table 5.—Evapotranspiration of sugar beets as influenced by nitrogen fertilization and within-row plant spacing at Garden City, Kansas.

Applied	1959				1960			
	Plant spacing in 22 inch rows				Plant spacing in 22 inch rows			
N, lb/A	8	12	16	Average	8	12	16	Average
				Acre-inches per acre				
0	35.3	32.1	34.4	33.9	34.4	32.8	32.5	33.2
60- 80	37.6	34.0	39.0	36.8	32.5	32.6	33.6	32.9
120-140	39.8	40.4	36.9	39.1	35.0	32.6	35.1	34.2
Average	37.6	35.5	36.8	36.6	33.9	32.7	33.7	33.5

Differences in evapotranspiration are not statistically different for nitrogen and spacing treatments, however, a significant interaction between spacing and nitrogen occurred in 1959.

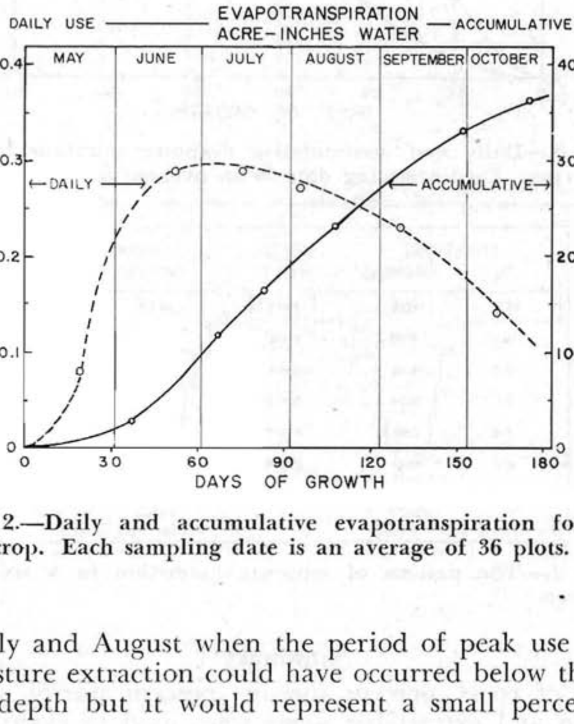

Figure 2.—Daily and accumulative evapotranspiration for the 1959 sugar beet crop. Each sampling date is an average of 36 plots.

during July and August when the period of peak use occurred. Some moisture extraction could have occurred below the six-foot sampling depth but it would represent a small percent of the total.

Rainfall and irrigation water management drastically influences moisture extraction patterns. In Figure 4 all rainfall was included in the surface foot, although a heavy rain or rains on successive days may have influenced the moisture status at lower soil depths. A moisture extraction pattern in which a high percentage of total evapotranspiration is from near the surface would generally indicate the absence of moisture stress during the season.

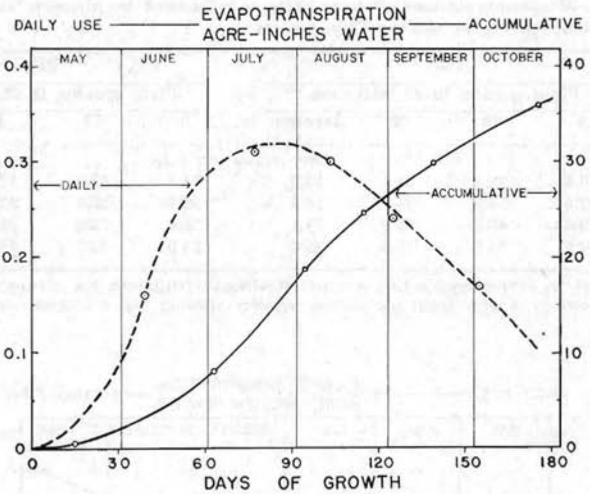

Figure 3.—Daily and accumulative evapotranspiration for the 1960 sugar beet crop. Each sampling date is an average of 36 plots.

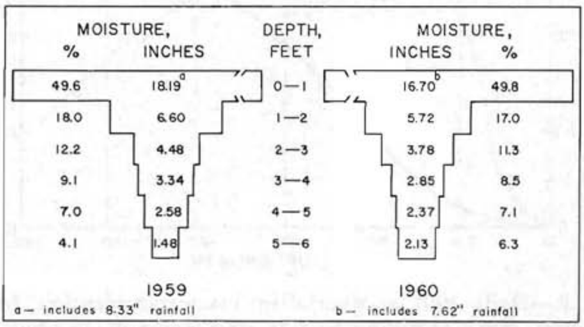

Figure 4.—The pattern of moisture extraction in a six-foot profile by sugar beets.

Summary

Yields of roots, percent sucrose, percent purity, gross sugar production and extractable sugar were used to evaluate the influence of applied fertilizer. Nitrogen exerted a major influence while phosphorus and potassium had little or no effect. The decrease in percent sucrose and purity associated with applied nitrogen was about equal to the gain in root yield. The 60 to 80 pounds per acre of N appeared not to be "excessive", however, 120 to 140 pounds per acre was definitely "excessive" and reduced quality. This soil was quite high in natural fertility.

Within-row plant spacing was important to sugar production. Wide spacing resulted in inferior beet quality, lower percent sucrose and purity. The 8- and 12-inch spacing proved more desirable than the 16-inch spacing in all respects. Larger size beets were produced when the spacing interval was increased. The beet quality, i.e., percent sucrose or purity, could not be directly related to beet size through covariance analyses.

Moisture use ranged from 32 to 40 acre-inches per acre. July was the month of maximum daily evapotranspiration of near 0.3 acre-inch per day. Nitrogen fertilizer seemed to increase moisture requirements. The surface 3 feet of depth supplied most of the soil moisture, however, the lower horizions were important during the peak daily use period.

Literature Cited

(1) Carlson, Carl W. and Roy B. Herring. 1954. The effect of fertilizer treatments upon yield and sugar content of sugar beets at Garden City, Kansas. Proc. Am. Soc. Sugar Beet Technol. VIII: 42-47.

(2) Deming, G. W. 1948. The effect of variation in row width and plant population on root yields and sucrose percentage of sugar beets at Fort Collins, Colorado. Proc. Am. Soc. Sugar Beet Technol. V: 280-281.

(3) Deming, G. W. 1950. Plant population experiments with sugar beets at Fort Collins, Colorado. Proc. Am. Soc. Sugar Beet Technol. VI: 256-260.

(4) Doxtator, C. W. 1948. Sugar beet yields from varying row spacing and acre populations. Proc. Am. Soc. Sugar Beet Technol. V: 276-279.

(5) Finkner, R. E., D. B. Ogden, P. C. Hanzas, and R. F. Olson. 1958. The effect of fertilizer treatment on the calcium, sodium, potassium, raffinose, galactinal, nine amino acids and total amino acid content of three varieties of sugar beets grown in the Red River Valley of Minnesota. J. Am. Soc. of Sugar Beet Technol. X: 272-280.

(6) Gardner, Robert, and D. W. Robertson. 1942. The nitrogen requirement of sugar beets. Colo. Agri. Expt. Sta. Tech. Bull. No. 28.

(7) Grimes, Donald W. 1959. Effect of crop rotation, manure and commercial fertilizer upon yield, percent sugar and gross sugar production of sugar beets in Southwestern Kansas. J. Am. Soc. of Sugar Beet Technol. X: 364-370.

(8) Haddock, Jay L. 1953. Sugar beet yield and quality as affected by plant population, soil moisture condition and fertility. Utah State Agr. Expt. Sta. Bull. No. 362.

(9) Haddock, Jay L. 1959. Yield, quality and nutrient content of sugar beets as affected by irrigation regime and fertilizers. J. Am. Soc. Sugar Beet Technol. X: 344-355.

(10) LOOMIS, R. S. and ALBERT ULRICH. 1959. Response of sugar beets to nitrogen depletion in relation to root size. J. Am. Soc. Sugar Beet Technol. X: 499-511.

(11) MCKENZIE, A. J., K. R. STOCKINGER and B. A. KRANTZ. 1957. Growth and nutrient uptake of sugar beets in the Imperial Valley, California. J. Am. Soc. of Sugar Beet Technol. IX: 400-407.

(12) NUCKOLS, S. B. 1948. Effect of crop rotation and manure on the yield and quality of sugar beets, United States Scotts Bluff (Nebr.) Field Station, 1930-41. United States Dept. Agr. Circular No. 779.

(13) OGDEN, D. B., R. E. FINKNER, R. F. OLSON and P. C. HANZAS. 1958. The effect of fertilizer treatment upon three different varieties in the Red River Valley of Minnesota for: I. Stand, yield, sugar, purity, and non-sugars. J. Am. Soc. of Sugar Beet Technol. X: 265-271.

(14) RIRIE, DAVID and F. J. HILLS. 1957. Effects of in-the-row spacing of singles, doubles, and multiple plant hills on sugar beet production. J. Am. Soc. of Sugar Beet Technol. IX: 360-366.

(15) ROBBINS, J. S., C. E. NELSON and C. E. DOMIGO. 1956. Some effects of excess water application on utilization of applied nitrogen by sugar beets. J. Am. Soc. of Sugar Beet Technol. IX: 180-188.

(16) SNEDECOR, GEORGE W. 1946. Statistiral Methods. Iowa State College Press, Ames, Iowa.

(17) STOUT, MYRON. 1961. A new look at some nitrogen relationship effecting the quality of sugar beets. J. Am. Soc. of Sugar Beet Technol. XI: 388-398.

(18) TOLMAN, BION, RONALD JOHNSON and A. J. BIGLER. 1948. Row width and sugar beet production. Proc. Am. Soc. of Sugar Beet Technol. V: 282-286.