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RELATION OF NITROGEN TO YIELD OF SUGAR-BEET SEED AND TO ACCOMPANYING CHANGES IN COMPOSITION OF THE ROOTS[1]

By L. M. PULTZ[2][3]

Formerly *associate physiologist, Division of Sugar Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

The method of growing sugar-beet seed by overwintering the plants in the field has come into widespread use in the United States during the past decade. Overpeck (*11*),[4] 1928, was the first to report observations showing that sugar beets planted in the early fall in southern New Mexico would survive the winter and produce a satisfactory seed crop during the following summer. Since that time the growing of seed has expanded rapidly until, at the present time, commercial crops are being grown by this method in New Mexico, Utah, California, Nevada, Texas, and Arizona. Recent developments in cultural practices for the crop have been reported by Overpeck and Elcock (*4*, *12*).

From results with the sugar-beet seed crop in varicus areas, it appears that soils of good tilth and more than average fertility are desirable for growing the crop. Heavy applications of barnyard manure are employed in the Mesilla Valley of New Mexico and in southern Utah. In areas where the industry has become established, nitrogenous fertilizers, chiefly as spring applications, are used. In southern Utah many farmers also apply phosphate, usually at planting time. Experiments[5] are being carried on to determine the best fertilizer practices for the different areas now engaged in sugar-beet seed production. Because of the emphasis upon fertility investigations and the strong interest of growers in methods of stabilizing and improving yields of seed while maintaining high quality, studies that seek to establish a sound physiological basis for the fertilizing practice are needed and should have important directive influence.

The experiments reported in this paper deal chiefly with the function of nitrogenous fertilizers in the fructification stage of the sugar beet. Study has been made of physiological processes of the sugar beet, special attention being given the changes in the carbohydrate and nitrogen content of the plants during the period of fructification.

[1] Received for publication Sept. 1, 1936; issued June 1937.

[2] The writer wishes to express his appreciation of the suggestions and criticisms given by Eubanks Carsner, senior pathologist, and G. H. Coons, principal pathologist, Division of Sugar Plant Investigations, in connection with the preparation of the manuscript.

[3] Resigned Mar. 15, 1936.

[4] Reference is made by number (italic) to Literature Cited, p. 563.

[5] Cooperative experiments of the Divisions of Sugar Plant Investigations and Soil Fertility Investigations.

The accumulation by the sugar beet of a large reserve of sucrose during the period of vegetative development is a distinctive characteristic of this plant. The functioning of this accumulation of carbohydrate reserve in the life cycle of the plant has received little attention. It has commonly been assumed that at least a part of the sucrose stored in the taproot during the first season of growth was drawn upon for the development of the seed-producing structures and seed the following year; little is known about the effect of various environmental factors in conditioning such utilization.

In studying the influence of environmental factors on seed production in the sugar beet, an approach was made by determining the effect of nitrogen fertilization and other factors upon the seasonal changes in carbohydrate and nitrogen content in the roots of the sugar beet, and, where possible, these changes were correlated with yields of seed obtained.

FIELD STUDIES

METHODS

Most of the results reported in this paper were obtained from plants grown on experimental plots in the sugar-beet seed growing area near St. George, Utah. A few samples from plots located at State College, N. Mex. were tested in 1934.

In all of these tests seed of a curly top-resistant variety (U. S. 1) was planted at a rate of 20 pounds per acre. In 1931 the seed was planted on September 10. In 1932 plantings were made on August 23 and September 15. The treatments were arranged in randomized blocks and replicated either four or five times.

The quantities of fertilizers applied were in excess of those ordinarily recommended to commercial growers, the object being to produce strong differences in the physiological responses of the plants. At the time of seeding in 1931 the entire experimental field was treated with 45-percent treble superphosphate at the rate of 175 pounds per acre. In 1932 the rate of application was 125 pounds per acre. The phosphate fertilizer was applied in the row approximately 1 inch below the seed.

The experiment in 1931 was set up with the following schedule of treatments, ammonium sulphate being used as the source of nitrogen:

Treatment no. 1.—750 pounds per acre, September 25, 1931.
Treatment no. 2.—375 pounds per acre, September 25, 1931; 375 pounds per acre, March 2, 1932.
Treatment no. 3.—750 pounds per acre, March 2, 1932.
Treatment no. 4.—None.

The experiments of 1932–33 were designed to furnish further evidence concerning the effects of applications of a nitrogeneous fertilizer on seed yield and on the chemical composition of the roots, and in addition to show the effects of date of planting and spacing. Each plot consisted of eight rows 22 inches apart and 45 feet long. The thinning and fertilizer treatments were carried out according to the schedule shown as table 1.

The center two rows of each plot were harvested to obtain data on seed yield.

TABLE 1.—*Schedule of thinning and fertilizer treatments for the experiments of 1932–33*

Treatment no.	Date planted	Date thinned [1]	Date fertilized	Ammonium sulphate per acre
				Pounds
1	Aug. 23, 1932	Sept. 25, 1932	{Sept. 25, 1932 Feb. 27, 1933	500 500
2	do	do		0
3	do	Unthinned	{Sept. 25, 1932 Feb. 27, 1933	500 500
4	do	do		0
5	Sept. 15, 1932	Oct. 22, 1932	{Oct. 22, 1932 Feb. 27, 1933	500 500
6	do	do		0
7	do	Unthinned	{Oct. 22, 1932 Feb. 27, 1933	500 500
8	do	do		0

[1] In the thinned plots the plants were spaced to 12-inch intervals; in the unthinned plots the original stand was left.

RESULTS

YIELD OF SEED

Applications of nitrogenous fertilizer were responsible for large and highly significant[6] increases in the yield of sugar-beet seed during two seasons. Although the quantities of fertilizer applied were in excess of those ordinarily recommended to commercial growers, they were effective in producing yield increases that were correlated with certain physiological responses of the plants. The pertinent yield data are given in tables 2 and 3.

Taking all the data into consideration, the effect of nitrogenous fertilizer was more pronounced than that of any other phase of treatment. In 1931–32 the plots in which ammonium sulphate was applied in the fall or early spring yielded 35 percent more seed than the unfertilized plots, but the different dates of application resulted in no significant difference in yield. Again in 1932–33 the nitrogenous fertilizer produced marked increases in the yield of seed, but in this season the effect was modified to a considerable extent by the date of planting. In the August 23 planting the application of ammonium sulphate on thinned and unthinned plots resulted in increased yields of 30 and 45 percent, respectively, while in the September 15 planting the same treatments resulted in gains of only 22 and 15 percent over the unfertilized plots.

TABLE 2.—*Effect of nitrogen on the yield and percentage of germination of sugar-beet seed, St. George, Utah, 1931–32*

Treatment no.	Season when ammonium sulphate was applied	Yield per acre	Average germination
		Pounds [1]	*Percent* [2]
1	Fall	3, 545	74. 0
2	Fall and spring	3, 642	75. 7
3	Spring	3, 790	80. 3
4	None	2, 719	76. 2

[1] Difference required for significance, 285 pounds.
[2] Differences not statistically significant.

[6] The yield data have been analyzed according to the analysis of variance method (*5*).

TABLE 3.—*Effect of date of planting, thinning, and nitrogen fertilization on yield, percentage of germination, and weight of sugar-beet seed, St. George, Utah, 1932–33*

Treatment and date of planting	Yield of seed per acre	Germination of seed	Seed balls per gram	Treatment and date of planting	Yield of seed per acre	Germination of seed	Seed balls per gram
Unthinned:				Thinned:			
No nitrogen:	*Pounds* [1]	*Percent* [2]	*Number* [2]	No nitrogen:	*Pounds* [1]	*Percent* [2]	*Number* [2]
Aug. 23	2,196	54	58.5	Aug. 23	2,625	55	58.8
Sept. 15	2,302	50	61.4	Sept. 15	2,278	56	53.5
Nitrogen:				Nitrogen:			
Aug. 23	3,189	56	59.5	Aug. 23	3,412	56	59.5
Sept. 15	2,649	44	63.3	Sept. 15	2,782	52	60.2

[1] Difference required for significance, 502.2 pounds.
[2] Differences not statistically significant.

When the effects of date of planting are considered independently of other treatments, in general the earlier planting resulted in decidedly higher seed yields. This is in accord with the results reported by Elcock and Overpeck (*4*) in New Mexico.

Thinning the plants so that they stood singly in the row increased the yield of seed approximately 19.5 percent in the case of the beets that were planted early and were not fertilized. In all other cases where direct comparisons can be made, the thinning treatment had no marked effect on the yield of seed. Since these results are for a single season they indicate only that under the conditions of this test the space available to each plant was not a factor in influencing the yield of seed, save where soil fertility was too low to permit the full development of large numbers of plants in the unthinned stands.

QUALITY OF SEED

In the season of 1931–32 the heavy applications of ammonium sulphate had little noticeable effect on the quality of the seed produced (table 2). The average germination of the seed from the fertilized plots was 76.7 percent while that of the checks was 76.2 percent.

The following year all of the seed was markedly lower in germination but only in the fertilized, unthinned series of the late planting was there any evidence that viability of the seed was altered by a particular treatment. In this case the germinative power of the seed dropped so markedly below the average for the other treatments as to suggest that caution is necessary in applying nitrogenous fertilizers to beets planted late and left unthinned.

The size of the seed appeared to be influenced somewhat by the fertilizer treatments (table 3). Although all of the seed from the 1932–33 crop was small, i. e., each gram contained more than 51 seed balls, the ammonium sulphate treatments caused small but consistent decreases in the size of the seed balls. These differences, however, are not of sufficient magnitude to be considered detrimental to the quality of the seed.

TOP DEVELOPMENT

The characteristic effects of nitrogen on top growth were noticeable soon after the ammonium sulphate was applied to the beets in the fall. During the vegetative period that preceded winter dormancy, the fertilizer caused an increase in leaf surface that was apparently related to an increase in the amount of sucrose stored in the roots (fig. 1).

More important, however, was the effect of the fertilizer on the reproductive structures developed during the following spring and early summer. The seedstalks of the fertilized plants were taller and sturdier and were characterized by much longer seed branches than were the unfertilized plants. This latter effect is significant, since the length of the seed branches to a large extent determines the number of flowers and fruits which can be formed.

The onset of nitrogen deficiency in the unfertilized plants occurred early in May and was marked by a yellow color of the tops. As the nitrogen deficiency became more severe the elongation of the seed branches ceased and the result was a much-abbreviated period of flower production. In contrast, the fertilized plants remained green for a much longer period and the length of the seed branches and the number of flowers and fruits formed were correspondingly greater. This phase of top development was at least partly responsible for the highly significant (*16, p. 62*) correlation of +0.609, which was obtained when the green weights of tops from 26 plots were correlated with the seed yields from the same plots.

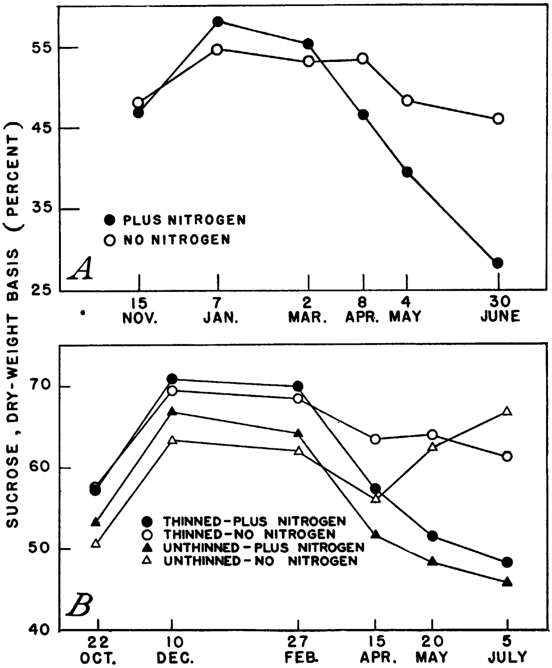

FIGURE 1.—Seasonal changes in the percentage of sucrose in the roots of sugar beets overwintered in the field: *A*, 1931–32; *B*, 1932–33.

Corroborative evidence in this connection is afforded by observations made upon effects of late heavy applications of ammonium sulphate in commercial fields at St. George in 1933. In these tests it was observed that while nitrogen applied during the flowering period increased the yield of seed in all cases, the increase was much greater in fairly good fields than in poor fields. The reason for this seemed to be that the plants in the poor fields had been definitely checked by nitrogen deficiency before the nitrogen was applied, with the result that the original growing points did not resume development. The production of new lateral branches was stimulated but these, starting late, did not mature seed by the time of harvest.

Root Development

The data presented in figure 2 and table 4 show that the nitrogenous fertilizer had little effect on the size of the roots developed during the fall and winter. When sampled on February 27, the only difference in size of roots occurred between the thinned and unthinned plots.

After seedstalk development began in the spring, the size of the roots in the unthinned plots changed only slightly. In the thinned plots fertilized with ammonium sulphate the roots increased slowly in size between April 15 and harvest time, but where no fertilizer was added the roots made a pronounced growth during this period. This condition led to a rather striking difference in the root-top ratios at harvest time and indicates that the plants receiving no nitrogen were storing materials in the roots during the period when the fertilized plants were using similar materials for top growth and seed production. Further evidence that this occurred will be brought out when the carbohydrate analyses are discussed. The fact that the plants receiving no fertilizer in the unthinned series did not show an increase in root size comparable to that in the thinned series seemed to be due to the intense competition for soil nitrogen and moisture in the plots where the stand was thick. The foliage of these plants became yellow early in May and apparently the small supply of soil nitrogen was used to mature the seed, other growth being reduced to a minimum.

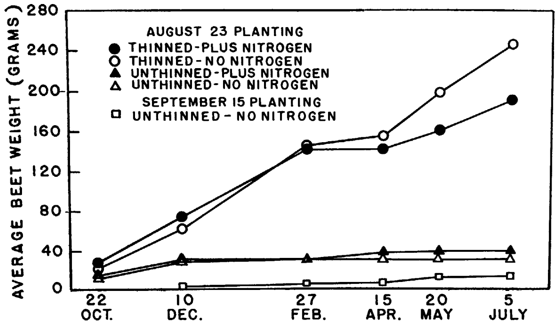

FIGURE 2.—Change in weight of roots of sugar beets overwintered in field (1932–33).

TABLE 4.—*Effect of date of planting, thinning, and nitrogen fertilization on weight of roots and tops at harvest, St. George, Utah, 1932–33*

Treatment and date of planting	Green weight of tops per plot	Average weight per root	Treatment and date of planting	Green weight of tops per plot	Average weight per root
Unthinned:			Thinned:		
No nitrogen:	*Kilograms*	*Grams*	No nitrogen:	*Kilograms*	*Grams*
Aug. 23	60.0	25.5	Aug. 23	79.3	245.6
Sept. 15	61.7	11.3	Sept. 15	45.1	157.0
Nitrogen:			Nitrogen:		
Aug. 23	95.4	36.8	Aug. 23	107.4	189.5
Sept. 15	82.4	14.3	Sept. 15	68.3	98.1

CHEMICAL STUDIES

METHODS

Chemical analyses were made of composite samples from the various treatments taken at intervals between November 15, 1931, and June 30, 1932, and again between October 22, 1932, and July 5, 1933. The plants were usually dug early in the morning, and approximately 24 hours elapsed before they reached the laboratory. In the laboratory, the roots were washed free from soil and dried lightly with towels, and the crowns and roots were separated by topping the beets just below the lowest leaf scar. The tissues were then minced and mixed in a wooden chopping bowl and samples were taken for moisture determination. At the same time a 30- to 40-g sample for the carbohydrate determinations was preserved by boiling for 30 minutes in neutral 80-percent alcohol. When necessary the sample was adjusted to neutrality (litmus) after boiling. The rest of the minced tissue was placed in fruit jars, sealed, and taken immediately to a cold-storage room where it was held constantly at 12.5° F. until sampled for the determination of nitrogen fractions and total nitrogen.

Carbohydrate Analysis

The preserved material was prepared for analysis by extracting with 80-percent alcohol in Soxhlet extractors until a negative Molisch (*9, p. 942*) test was obtained. All of the alcoholic filtrates were combined, and the alcohol was removed by heating on a water bath at approximately 75° C. Several small portions of water were added, when the solution became sirupy, until the removal of the alcohol was complete. The water extract was then made up nearly to volume in a 250-cc flask and cleared by the addition of 2 cc of neutral lead acetate solution (specific gravity 1.25). The sample was then diluted to volume, mixed thoroughly, and filtered through a dry paper into a beaker containing 0.75 g of anhydrous potassium oxalate. The sugar determinations were made on aliquots of this filtrate.

Direct reducing sugars were determined in a 50-cc aliquot of this filtrate. Another aliquot was hydrolyzed at room temperature by the method outlined by the Association of Official Agricultural Chemists (*2, p. 187*), before reduction. The difference in reducing power of the solution before and after hydrolysis is considered to be a measure of the sucrose present.[7] The Shaffer-Hartman (*15*) modification of the Munson-Walker method was used to determine the reducing power of all sugar solutions, and all of the results for the different carbohydrates are expressed as percentages of glucose.

The insoluble residue remaining after the extraction with alcohol was analyzed, the method outlined by Potter and Phillips (*13*) being used. The quantity of starch and dextrins present was so small that it is not reported, but these substances were always removed in the routine analysis before the insoluble residue was hydrolyzed with dilute hydrochloric acid for the determinations of other polysaccharides.

Nitrogen Analysis

The frozen tissue preserved for the determination of nitrogen fractions and total nitrogen was ground in a chilled Nixtamal mill. The ground tissue was then mixed thoroughly, a 100-g sample was taken for extraction with water, and the fractionation into soluble, coagulable,[8] and unextracted nitrogen was carried out with slight modification of the methods outlined by Nightingale et al. (*10*). Total nitrogen was determined on a sample of dried tissue. The Kjeldahl method, modified to include nitrates (*14*), was employed. Nitrate nitrogen was determined on an aliquot of the extract from

[7] No correction has been made for small amounts of raffinose that were included with the sucrose.

[8] The nitrogen content of the coagulum was determined, but no attempt is made to interpret the variations in this fraction because of the differences known to result from different amounts of grinding.

which alcohol had been removed. The removal of ammonia and amide nitrogen, and the subsequent reduction of nitrates and nitrites with finely ground Devarda's alloy, was carried out according to the method outlined by Phillips et al. (*1, p. 209*).

PLANT UTILIZATION OF NITROGEN

Seasonal changes in various fractions of nitrogen are presented in tables 5 and 6, and changes in total nitrogen are represented graphically in figure 3. All the results of analyses were calculated as percentages of fresh weight and as percentages of dry weight; but, because of the marked similarity of the trends shown by the two methods of representation, only the latter are used here. Insofar as the experiments of the two seasons duplicated each other, the analytical results from similar treatments are in close agreement. The data from the unthinned treatments of 1931–32 can be compared with the data from the unthinned treatments of the following season.

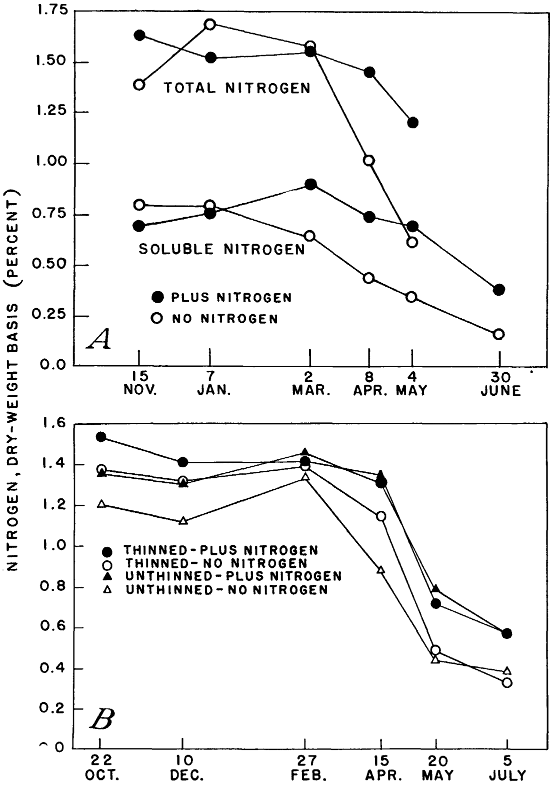

FIGURE 3.—Seasonal changes in the percentage of nitrogen in the roots of sugar beets overwintered in the field: *A*, Total and soluble nitrogen, 1931-32; *B*, total nitrogen, 1932-33.

TOTAL NITROGEN

The percentage of total nitrogen in the roots from all of the treatments showed some variations during the fall and winter seasons. In general, the fertilized plants were slightly lower in total nitrogen in the spring than they were in the fall, while the reverse was true of the unfertilized plants. In both years, however, the proportion of total nitrogen was very similar in the samples from all treatments taken just prior to seedstalk initiation (Mar. 2, 1932, and Feb. 27, 1933). There was no indication in these experiments that the application of ammonium sulphate in the fall resulted in any accumulation of nitrogen in the taproots of the fertilized plants.

After seedstalk growth began in the spring, nitrogen was withdrawn rather rapidly from the taproots. During this time the effect of the fertilizer was shown by the divergence in the total nitrogen curves (fig. 3), the fertilized roots maintaining a level of total nitrogen consistently higher than that of the unfertilized roots. This relationship continued until harvest time, although in both cases from 60 to 70 percent of the nitrogen had been withdrawn by the end of the fruiting period.

TABLE 5.—*Seasonal changes in various carbohydrate and nitrogen fractions in the roots of beets overwintered in the field, St. George, Utah, 1931–32*

[Results expressed on dry-weight basis]

Date of sampling	Treatment	Carbohydrate fraction		Nitrogen fraction				
		Sucrose	Reducing sugars	Total nitrogen	Soluble nitrogen	Coagulable nitrogen	Protein nitrogen	NO_3 nitrogen
1931		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nov. 15	Unfertilized	47.74	1.64	1.4018	0.8088	0.4079	0.5930	0.0432
	Plus nitrogen	46.79	1.85	1.6411	.6825	.4367	.9586	.1669
1932 Jan. 7	Unfertilized	54.67	1.46	1.6893	.7907	.3964	.8986	.0297
	Plus nitrogen	58.13	2.25	1.5193	.7610	.3144	.7583	.1047
Mar. 2	Unfertilized	53.05	1.37	1.5766	.6439	.3003	.9327	.0884
	Plus nitrogen	55.20	1.87	1.5632	.9002	.2566	.6630	.1398
Apr. 8	Unfertilized	53.14	1.28	1.0094	.4429	.2616	.5665	.0766
	Plus nitrogen	46.54	1.11	1.4675	.7375	.2517	.7300	.2785
May 4	Unfertilized	48.15	.99	.6195	.3437	.0978	.2758	.0961
	Plus nitrogen	39.54	1.23	1.1909	.7026	.1434	.4883	.2621
June 30	Unfertilized	45.95	.89	----------	.1675	----------	----------	.0000
	Plus nitrogen	28.66	1.64	----------	.3812	----------	----------	.2090

TABLE 6.—*Seasonal changes in percentages of various nitrogen fractions in roots of sugar beets* [1] *overwintered in the field, St. George, Utah, 1932–33*

[Results expressed on dry-weight basis]

Date of sampling	Treatment	Nitrogen fraction			
		Total nitrogen	Soluble nitrogen	Insoluble protein nitrogen	NO_3 nitrogen
1932		*Percent*	*Percent*	*Percent*	*Percent*
Oct. 22	Unthinned, no nitrogen	1.207	0.686	0.521	0.103
	Unthinned, nitrogen	1.359	.778	.581	.140
	Thinned, nitrogen	1.539	.875	.664	.112
	Thinned, no nitrogen	1.377	.819	.558	.068
Dec. 10	Unthinned, no nitrogen	1.176	.677	.499	.094
	Unthinned, nitrogen	1.306	.803	.503	.111
	Thinned, nitrogen	1.412	.931	.481	.107
	Thinned, no nitrogen	1.318	.832	.486	.080
1933					
Feb. 27	Unthinned, no nitrogen	1.332	.783	.549	.100
	Unthinned, nitrogen	1.457	.991	.466	.135
	Thinned, nitrogen	1.415	1.006	.409	.129
	Thinned, no nitrogen	1.390	.906	.484	.089
Apr. 15	Unthinned, no nitrogen	.881	.478	.403	.075
	Unthinned, nitrogen	1.309	.763	.546	.244
	Thinned, nitrogen	1.268	.732	.536	.263
	Thinned, no nitrogen	1.151	.535	.616	.169
May 20	Unthinned, no nitrogen	.443	.140	.303	.013
	Unthinned, nitrogen	.788	.392	.396	.165
	Thinned, nitrogen	.720	.351	.369	.143
	Thinned, no nitrogen	.497	.169	.328	.015
July 5	Unthinned, no nitrogen	.387	.127	.260	.000
	Unthinned, nitrogen	.573	.366	.207	.114
	Thinned, nitrogen	.573	.338	.235	.098
	Thinned, no nitrogen	.339	.099	.206	.000

[1] Planted Aug. 23, 1932.

Soluble and Insoluble Nitrogen

The soluble nitrogen in the roots tended to reach highest levels about the time growth of the plants was resumed in the spring. At that time the insoluble nitrogen, calculated as percentage of total nitrogen, was low, indicating that some hydrolysis of proteins occurred before seedstalk development started. The fact that this relation between soluble and insoluble nitrogen was much more pronounced in the fertilized plants than it was in those not fertilized indicates that the fall applications of ammonium sulphate had some influence on the form of nitrogen in the roots, even though they did not affect the total amount of nitrogen accumulated. On March 2, 1932, approximately 58 percent of the nitrogen in the fertilized roots was soluble as compared with 41 percent in the unfertilized roots. A similar relationship was shown by the samples taken on February 27, 1933.

The tendency of the plants receiving nitrogenous fertilizer to attain a high ratio of soluble to insoluble nitrogen at this stage of development may be related to the earlier and more vigorous seedstalk growth that has been observed in both field and greenhouse experiments where abundant nitrogen has been supplied to the plants during the vegetative period.

During April, May, and June, when the fruiting structures were being developed, the percentage of insoluble nitrogen decreased at about the same rate in the roots from all treatments. Soluble nitrogen decreased at the same time, but the decrease was more rapid and reached lower levels in the unfertilized plants than it did in those receiving ammonium sulphate.

Nitrate Nitrogen

Insofar as the percentage of nitrate nitrogen found in the roots at the various dates can be considered indicative of the availability of nitrogen in the soil, these data show that the unfertilized plants had reduced the supply of soil nitrogen to a very low point fully 6 weeks before the seed was harvested. In the fertilized plants determinable amounts of nitrate nitrogen were found in the roots until the end of the season.

PLANT UTILIZATION OF CARBOHYDRATES

Sucrose

Seasonal changes in the sucrose percentage of the roots, presented in tables 5 and 7 and represented graphically in figure 1, show that sucrose reached a maximum in early winter and declined only slightly between that time and early spring. During this period, however, the treatments caused definite differences in the percentage of sucrose in the roots. Where the plants were spaced in the row, the roots were markedly higher in sucrose than were the roots in the corresponding unthinned plots. The fall applications of ammonium sulphate also resulted in a definite increase in sucrose accumulation in the roots of the plants receiving the fertilizer. In general, these differences remained constant until spring.

After seedstalk development began in the spring, the early effects on sucrose percentage caused by spacing were overshadowed by the pronounced effect of the spring application of nitrogenous fertilizer. In general, the sucrose percentage of all the roots decreased rapidly in the interval between the March and April samplings, but after the middle of April there was a striking divergence in the sucrose curves. The roots of the plants that received ammonium sulphate in the spring underwent a consistent decrease in sucrose until the seed was harvested, while the roots of the unfertilized plants showed only slight decreases or actual gains in the percentage of sucrose. The rather contrasting behavior of the thinned and unthinned plants that received no fertilizer in the spring is probably more apparent than real, since the root weight of the thinned plants increased rapidly during May and June, whereas the unthinned plants maintained relatively constant weight during this period (fig. 2). It is probable that the thinned plants accumulated sucrose in much the same way that the unthinned plants did, but the increase is not apparent when the results are calculated on the dry-weight basis.

This storage of sucrose by plants not receiving applications of ammonium sulphate is interpreted as having very significant relationships to the yield and will be discussed more fully later.

REDUCING SUGARS

The changes in reducing sugars presented in tables 5 and 7 do not show definite trends in all cases, but in general the plants receiving nitrogen gave higher values for reducing sugars throughout the season than did the unfertilized plants. The difference was especially marked during the fructification stages of late spring and early summer. The significance of these trends is not clear, but a somewhat similar relationship found in sugarcane (*3*) has been attributed to the greater hydration of tissue that results from nitrogen fertilization.

TABLE 7.—*Seasonal changes in percentages of various carbohydrate fractions in roots of sugar beets* [1] *overwintered in the field, St. George, Utah, 1932–33*

[Results expressed on dry-weight basis]

Date of sampling	Treatment	Carbohydrate fraction: Sucrose	Carbohydrate fraction: Reducing sugars	Carbohydrate fraction: Acid hydrolyzable polysaccharides
		Percent	*Percent*	*Percent*
1932				
Oct. 22	Unthinned, no nitrogen	50.64	1.14	23.86
	Unthinned, nitrogen	53.33	.97	23.15
	Thinned, nitrogen	57.24	.95	22.51
	Thinned, no nitrogen	57.66	.86	23.78
Dec. 10	Unthinned, no nitrogen	63.43	1.26	23.10
	Unthinned, nitrogen	66.85	1.94	23.25
	Thinned, nitrogen	70.98	1.57	24.10
	Thinned, no nitrogen	69.50	1.57	22.80
1933				
Feb. 27	Unthinned, no nitrogen	61.94	1.17	17.50
	Unthinned, nitrogen	64.18	1.36	19.85
	Thinned, nitrogen	69.97	1.27	21.07
	Thinned, no nitrogen	68.43	1.31	22.35
Apr. 15	Unthinned, no nitrogen	56.06	1.29	23.24
	Unthinned, nitrogen	51.63	1.21	18.40
	Thinned, nitrogen	57.33	1.38	18.00
	Thinned, no nitrogen	63.41	1.05	20.05
May 20	Unthinned, no nitrogen	62.40	.97	21.67
	Unthinned, nitrogen	48.36	1.29	16.98
	Thinned, nitrogen	51.50	1.34	17.06
	Thinned, no nitrogen	63.95	1.13	19.73
July 5	Unthinned, no nitrogen	66.73	.87	21.70
	Unthinned, nitrogen	45.71	1.14	15.66
	Thinned, nitrogen	48.20	1.25	15.22
	Thinned, no nitrogen	61.32	.93	16.97

[1] Planted Aug. 23, 1932.

Acid Hydrolyzable Polysaccharides

Seasonal changes in the percentage of acid hydrolyzable polysaccharides (2 percent hydrochloric acid) in the roots are, in general, similar to the trends shown by sucrose. The plants receiving nitrogenous fertilizer showed a steady decrease in complex carbohydrates during the period of seed production, while in the unfertilized plants the decrease in this fraction was much less marked. The variations in polysaccharides are of less magnitude than those found in sucrose but are sufficient to indicate that the general effect of the nitrogenous fertilizer was to cause a decrease in the more labile forms of carbohydrates of the roots, presumably owing to increased use of these substances in other parts of the plants.

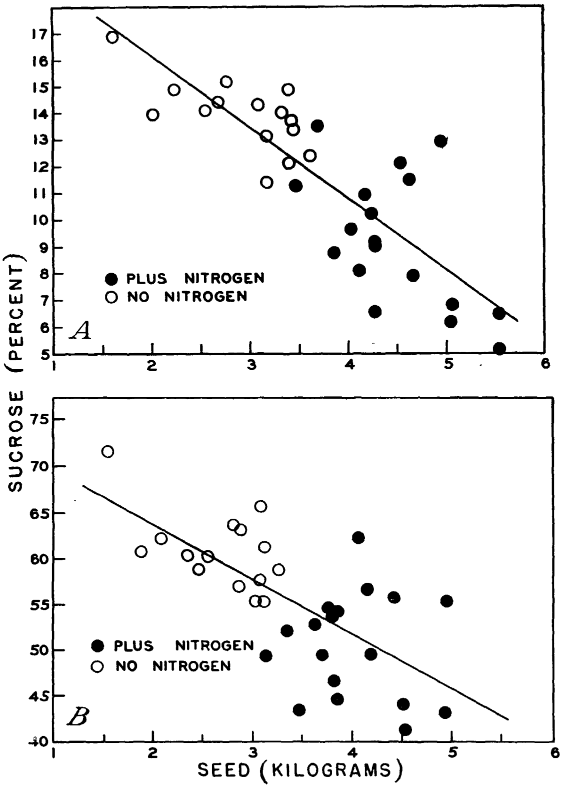

Figure 4.—Diagram showing relation between sucrose percentage on July 5, 1933, and seed yield of sugar beets. Results of the August 23 and September 15, 1932, plantings are combined in this graph: *A*, Fresh-weight basis (correlation coefficient, −0.830); *B*, dry-weight basis (correlation coefficient, −0.681).

Correlation Between Sucrose in Roots at Harvest and Yield of Seed

When it became evident from the analyses of composite samples that nitrogen fertilization reduced the percentage of sucrose in the roots and at the same time increased the yield of seed, it was desired to obtain a more definite estimate of the relationship existing between these two factors. At harvest time, samples of roots were taken from 19 plots of the early planting and from 14 plots of the late planting. The percentage of sucrose in these samples was correlated with the yield of seed from the same plots. The relations between these two sets of observations are plotted in figure 4, with sucrose expressed both as percentage of fresh weight and as percentage of dry weight. The method of Wallace and Snedecor (*16*) was used in calculating the correlation coefficients. The results are summarized in table 8.

The highly significant negative coefficients obtained in every case where the sucrose percentage of the roots at harvest time was correlated with the yield of seed indicate that the sucrose removed from the roots during the period of seed production was utilized in increasing the fruiting processes of the plants. The effect of nitrogen in furthering this utilization of sucrose is shown in figure 4 by the fact that the plots which received ammonium sulphate are definitely lower in sucrose and higher in seed yield than are the unfertilized plots.

When it is considered that samples from both thinned and unthinned plots, comprising widely different sizes of beets, were included when the estimates of correlation were made, it appears that the sucrose was utilized with about the same degree of efficiency whether it was contained in a single large root or a number of smaller roots.

TABLE 8.—*Correlations between percentage of sucrose in the roots at harvest time and yield of seed*

Correlation between—	Planting date	Value of *r*	Significant value (P=0.01)
	1932		
Sucrose (fresh weight) and seed yield [1]	Aug. 23	−0.823	0.575
	Sept. 15	−.757	.661
	Both dates	−.830	.449
Sucrose (dry weight) and seed yield [1]	Aug. 23	−.705	.575
	Sept. 15	−.676	.661
	Both dates	−.681	.449

[1] Determined July 5, 1933.

DISCUSSION

The results of these experiments show that from the time the beets were planted in August or September until the period of winter dormancy carbohydrates increased rapidly in the roots. The highest percentages of sucrose were found in root samples taken in December and January. Applications of nitrogenous fertilizers in the fall caused a gain in carbohydrate accumulation, probably as a result of the greater leaf surface available for photosynthesis.

During the same period of fall growth the percentages of nitrogenous compounds in the roots changed only slightly. Even where heavy applications of ammonium sulphate were made in the fall, there was no evidence that they caused any storage of nitrogen in excess of that which took place under conditions of average fertility. There was, however, some indication that the fertilizer caused an increase in the proportion of soluble nitrogen found in the roots in early spring, and it is possible that this condition rather than the percentage of total nitrogen is responsible for the earlier and more vigorous seedstalk production that is commonly observed where beets are given adequate supplies of nitrogen during the vegetative period.

After seedstalk development begins in the spring there occurs a rapid disappearance of carbohydrates and nitrogenous materials from the roots. The movement of these materials from the roots early in the season is undoubtedly related to their use in the development of new leaves and seedstalks. As soon as a sufficiently large leaf area has been developed, however, it would seem that the function of providing carbohydrates for the fabrication of leaves, flowers, and fruits might be taken over by the leaves, thus making unnecessary the further withdrawal of sugars from the roots. As shown in figure 1, *B*, such a condition was actually found in the unfertilized plants early in the flowering period. From the latter part of April until the seed was harvested, the percentages of sucrose in the roots either decreased slightly or, as in the case of the unfertilized plants in 1933, showed a marked increase in sucrose during the last 2 months. As has been pointed out, this condition was correlated with a pronounced shortening of the flowering period, which in turn resulted in greatly decreased yields of seed.

The trend of the sucrose curves in plants that received a spring application of nitrogenous fertilizer presents a striking contrast. In these plants the percentages of sucrose in the roots decreased steadily from the time seedstalk development began until the seed was ready to harvest. This condition was associated with a lengthened period of flower production and was definitely correlated with higher seed yields. From the standpoint of securing maximum seed production, it seems clear that the plants must be so conditioned that some use is made of the carbohydrate reserves of the roots. This seems well shown as the functions of nitrogenous fertilizers are followed throughout these tests.

It may be pointed out that the economy of food reserves in the sugar beet differs somewhat from the situation encountered in other plants. Haller and Magness (*7*) conclude from studies with apples that by adjusting the size of the crop to provide the proper leaf area per fruit not only is the highest quality of fruit produced but also sufficient excess of carbohydrate is left over to allow for normal vegetative growth and the formation of fruit buds for the following season. In the case of forage crops and grasses (*6*, *8*), it has been found that frequent cutting accompanied by applications of nitrogenous fertilizers results in the depletion of carbohydrates stored in the roots, so that the plants are much less vigorous the following year. In these plants the development of top growth, whether it be fruits or vegetative structures, must be regulated to allow for the accumulation of reserves in the perennial organs. Since the parts of the sugar beet remaining after seed harvest are of little value, there is no advantage in conserving carbohydrates in the roots if they can be utilized in the production of a heavier seed crop. In the present study the carbohydrates in the roots did not approach exhaustion even with heavy nitrogen treatment, but the data presented indicate that maintaining soil nutrients, particularly nitrogen, at adequate levels throughout the season increases the use of these reserves in the production of seed.

SUMMARY

Tests conducted during two seasons have shown that nitrogenous fertilizers play an important role in the production of sugar-beet seed. Heavy applications of ammonium sulphate have resulted in marked increases in yield of seed, but no consistent differences in quality can be attributed to treatment.

Chemical analyses showed that carbohydrates and nitrogenous compounds attain maximum levels in the roots at the time of winter dormancy. After seedstalk development begins in the spring, sugars and nitrogen are withdrawn rapidly from the roots. The loss of stored nitrogen from the roots is only slightly affected by fertilizer treatment and continues until most of the nitrogen has been withdrawn.

The amount of sugar moved from the root appears to depend upon the supply of nitrogen in the soil. When nitrogen is continuously available during the fruiting period, the percentage of sucrose in the roots decreases steadily until the seed is matured. This condition is related to a long period of flower production and results in high seed yields. If nitrogen becomes a limiting factor during the fruiting period the loss of sucrose from the roots ceases and the accumulation of sucrose in the roots begins. Under these conditions the formation of flowers stops prematurely and seed yield from such plants is correspondingly low.

Highly significant negative correlations have been established between sucrose percentages found in the roots at time of seed harvest and seed yields. The utilization of stored reserves in the sugar-beet root has been found to be dependent upon the supply of nitrogen available to the plant during the fruiting period and, therefore, this study affords a better understanding of the physiological basis for a fertilization program.

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