The Relationship of Nitrogen to the Formation of Sugar in Sugar Beets[1]

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The extensive studies in Europe 011 the influence of nitrogenous fertilizers applied to sugar beets have resulted in the general conelusions that excessive quantities of nitrogen depress the sugar content of the beets, delay "ripening" at harvest time, cause excessive top growth, and increase the "harmful nitrogen" content of the beets. In contrast to an excess of nitrogen, a deficiency resulted in low sugar-beet yields.

Under the climatic conditions prevailing in Berkeley, California, beets growing in pots were found frequently to he low in sugar when they were in a stale of vigorous growth at the time of their harvest. Similar observations have been made in the field when beets had received large applications of nitrogenous fertilizers, or when beets followed several years of alfalfa. In contrast to the fields with an excess of nitrogen, preliminary studies have indicated that the low yields in many areas in California have been caused by a deficiency of nitrogen. Apparently, from these observations neither an excess nor a deficiency of nitrogen is desirable for efficient beet-sugar production.

In order to study the relationship of nitrogen to the formation of sugar, it is necessary to have some index of the nitrogen status of the sugar-beet plant. Such an index must be readily determinable and must indicate the supply of nitrogen available for growth. Recent work by Gardner and Robertson (5) has shown the suitability of the diphenylamine test for estimating the nitrate content of sugar-beet petioles. This test was applied in the present investigation, not only to the petioles but also to the blades of leaves taken from the outside and center portions of the sugar-beet plant. Since nitrates are reduced readily within most plants, the possibility remained that the total soluble-nitrogen content of the leaf portions (outside blades and petioles only) would indicate better the nitrogen status of the plants. Similarly, the total and insoluble-nitrogen contents of these plant portions were determined in order to establish their value in diagnosing nitrogen deficiencies.

Part of this study was conducted with beets grown in nutrient cultures of known nitrogen content while others were grown in 5-gallon and 33-gallon pots of Metz silty clay loam to which different

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amounts of ammonium sulfate were added. The influence of nitrogen on the sugar content of the beets was ascertained in **all** cases.

Analytical Methods.—Sugar percentages (3) (1) and purities (2) were determined by the Sprockets Sugar Company at Woodland, California. Nitrates were estimated by the spot-plate method with diphenylamine reagent after decolorizing the water extract with a carbon black that neither absorbed nor released nitrates. Soluble nitrogen (non-protein nitrogen) was ascertained by extracting the ground plant material with 2,5 percent trichloracetic acid (6) while the insoluble (protein nitrogen) remained in the residue. The total nitrogen in the original plant material, and in the extract, was estimated by the Kjeldahl method after reducing the nitrates with iron (7). Since the sum of the soluble and insoluble fractions agreed with the total nitrogen value when each was analyzed separately, the insoluble nitrogen was determined by difference.

Sugar Beets Grown in Nutrient Solutions

Procedure.—Sugar-beet seed (U.S. No. 15) was planted in Oakley blow sand on March 22, 1939. Thirty-five days later (April 26) when the beets were in the early four-leaf stage, 12 plants taken at random were transplanted to each 40-liter tank. Each plant was supported separately with cotton by a one-hole cork, the cork being cut concentrically to permit its gradual removal as the beet root expanded. The nutrient solutions which were replicated three times each (see table 1) were aerated with air by means of sintered glass aerators (4). Since the solutions tended to become alkaline with time, these were adjusted with 1N H_2SO_4 to a pH range of 6 to 7. On May 28 ammonium nitrate was added to all of the tanks in order to renew the nitrogen supply of the nutrient solutions which had become depleted in all instances except the 1.0N treatment.

On each harvest date the four largest plants in each tank were removed. The leaves of each plant were separated into outside and

Table 1.—Composition of Nutrient Solutions
(ml. of stock solution per liter of solution)

Stock solution	0.1N	0.2N	0.4N	1.0N
M/1 $Ca(NO_3)_2$	0.75	1.5	3.0	5.0
M/1 KNO_3	——	——	——	5.0
M/1 $MgSO_4$	3.0	2.0	2.0	2.0
M/1 KH_2PO_4	1.0	1.0	1.0	1.0
M/2 K_2SO_4	5.0	5.0	5.0	...
M/1 NH_4NO_3*	0.75	1.5	3.0	7.5
0.01 $CaSO_4 . 2H_2O$†	475	350	200	....
Supplementary solution	1.0	1.0	1.0	1.0
0.5% Fe tartrate‡	1.0	1.0	1.0	1.0

* Added May 28, 1939.
† Equivalent amount added in solid form.
‡ Added 2 times per week.

inside leaves. The inside leaves included all of the center leaves up to the "first mature" leaves, while the green ones remaining were classified as outside leaves. The leaves of each group were separated into blades and petioles and then dried rapidly in an oven at 80° to 90° C.

The dried plant material was ground to pass the 40-mesh sieve of a Wiley mill, and then analyzed for nitrate, soluble, insoluble and total nitrogen. The beets (secondary roots were discarded) were dried with a towel, weighed, and on the following day were analyzed for sugar and purity.

Results.—The plants on the first harvest date, June 1, 1939, were green, and in an active state of growth. The leaves for all of the plants were approximately of the same green color, even though there were marked differences in the growth of the tops and roots (table 2). These results indicate that a good green appearance of sugar-beet leaves is no sign of an abundant supply of nitrogen, and that a high level of nitrogen at the start is conducive to rapid growth under favorable conditions.

The "beets remaining after the June 1 harvest rapidly depleted the available supply of nitrogen, and on July 4 all of the plants except those in the 1.0N solutions were deficient in nitrogen. Those in the 1.0N solutions were still growing vigorously and continued to do so until the time of the second harvest on July 14. On this date the same leaf separations were made whenever possible, as on June 1. However, in the 0.1N and 0.2N treatments, so many of the outside leaves had turned yellow or had dried up that only one leaf separation was possible, namely, the remaining outside leaves were included with the center leaves. On the following day the solutions were changed to the 1.0N solution in all of the tanks, and the remaining beets were allowed to continue their development. Within a few days (July 17) all of the beets had sent out new roots and by July 21 not only the root development was extensive, but the tops had become green and were showing signs of growth. One week later (July 28) the remaining beets were harvested in the same manner as previously.

The relationship of nitrogen to the sugar content of the beets is demonstrated by the results obtained on the various harvest dates. The sugar percentages on June 1 decreased as the nitrate content of the nutrient solutions (table 2) and of the outside petioles (table 3) increased; the range in sugar content being from 8.6 to 6.2 percent. The same relationship held true for July 14 (tables 2 and 3) when the beets in all cases except those in the 1.0N solutions were definitely deficient in nitrogen. The sugar percentages increased throughout the treatments during the 6-week period, and at the same time the range of values was extended from 13.7 percent for

Table 2.—Summary of results for sugar beets grown in nutrient solutions.

Treat-ments*	ppm. NO_3 in solutions				Fresh weight of tops (grams)			Beet yields (grams)			Percentage sugar			Purity		
Date	4/26†	6/1	7/14‡	7/28	6/1	7/14	7/28	6/1	7/14	7/28	6/1**	7/14	7/28	6/1	7/14	7/28
0.1N	93	13	0	573	99	16	92	25.7	85	61	8.6	13.7	7.2	—	81.2	67.0
0.2N	186	40	0	606	206	28	92	31.8	114	67	7.1	14.0	7.0	—	75.6	66.3
0.4N	372	50	0	547	233	84	178	60.5	185	164	6.2	12.8	7.7	—	76.6	69.0
1.0N	930	643	408	498	238	322	440	35.8	399	352	6.2	9.9	7.4	—	67.5	62.7
Difference for significance at 5 percent point	—	—	—	n.s.	67	39	136	19.3	84	126	—	2.0	n.s.	—	5.3	n.s.

* Replicated 3 times

† Initial concentrations

‡ Solution culture renewed throughout with 1.0N solution on July 15, 1939

** Samples composited

n.s.=not significant

Table 3.—Summary of nitrogen analyses of sugar beets grown in nutrient solutions.

Treatments*	Percentage NO_3—N			Percentage soluble N			Percentage insoluble N			Percentage total N		
Date	6/1	7/14	7/28	6/1	7/14	7/28	6/1	7/14	7/28	6/1	7/14	7/28
						Outside Petioles						
0.1N	0.32	0	1.60	1.25	1.17	2.22	1.18	1.53	2.47	2.46	2.71	4.68
0.2N	0.97	0	1.48	2.04	1.70	2.35	1.37	1.60	2.28	3.41	3.43	4.63
0.4N	1.88	0	1.38	2.63	1.39	2.25	1.39	1.32	2.07	4.02	2.75	4.32
1.0N	1.65	0.36	1.44	2.80	1.59	2.03	1.43	1.25	1.87	4.23	2.84	3.90
Significant difference†	0.67	—	n.s.	0.52	n.s.	n.s.	n.s.	n.s.	0.36	0.64	n.s.	n.s.
						Outside Blades						
0.1N	0	trace	0.14	1.55	1.13	1.44	2.38	2.96	3.12	3.08	4.09	4.55
0.2N	0.02	0	0.23	1.95	1.54	1.62	2.82	3.12	3.25	4.75	4.06	4.87
0.4N	0.05	0	0.14	1.92	1.27	1.28	3.24	3.00	2.82	5.15	3.94	4.10
1.0N	0.09	0.08	0.07	2.01	1.08	0.87	3.30	3.51	3.92	5.32	4.59	4.78
Significant difference†	n.s.	—	0.10	n.s.	n.s.	n.s.	0.51	n.s.	0.65	0.69	n.s.	n.s.

* Replicated 3 times
† Significant different at 5 percent point (19 to 1 odds). n.s.=not significant

the 0.1X, to 9.9 percent for the 1.0N treatments. The purity coefficients likewise decreased as the nitrogen content of the original solutions increased.

When the nutrient solutions were changed to the 1.0N treatment on -July 13, the new growth which started almost immediately decreased the sugar percentages and purities on July 28 to approximately the same levels for all of the treatments. The largest decreases took place in the beets which had been deficient in nitrogen. The renewed growth drew upon the sugar reserves to such an extent that the photosynthetic activity of the leaves could not maintain the sugar content of the beets above 7.7 percent sucrose.

The nitrogen fractions of the various plant parts (tables 3 and 4) reflected to different degrees the nitrogen status of the sugar beets at the time of their harvest. The nitrate content of the outside petioles (table 3) for June 1 indicated the nitrogen status of the plants better than any other nitrogen fraction or any other plant part, except possibly the nitrate content of the inside petioles (table 4). The percentage increase in the nitrate percentages for the inside petioles (0.10 to 0.78, or a 780 percent increase) was greater than for the outside petioles (0.32 to 1.65, or 515 percent) but the differences between the treatments were significant for fewer treatments than for the outside petioles. The differences in the nitrate content of the outside blades (table 3) for June 1 were not significant, while the results for the inside blades (table 4) were erratic.

Table 4.— Summary of nitrate analyses of inside petioles of sugar beets grown in solution cultures

Treatments*	Petioles Percentage NO_3-N			Blades Percentage NO_3-N		
Date	6/1	7/14	7/28	6/1	7/14	7/28
0.1N	0.10	——	——	0.02	——	——
0.2N	0.05	——	——	0.02	——	——
0.4N	0.78	0	0.70	0.09	0	0.08
1.0N	0.72	0.05	0.63	0.05	0.07	0.04
Significant difference at 5 percent level	0.34	——	——	0.07	——	——

* Average of 3 replications.

The nitrate analyses of the outside petioles for the remaining harvest dates (July 14 and 28, table 3) were again in accord with the condition of the plants. On July 14 there was still an appreciable quantity of nitrates in the outside petioles of the 1.0N treatment, which had plants still growing vigorously, while in the petioles of the plants of the remaining treatments, which were nitrogen deficient, nitrates were not present. The blades (table 3) for the same date likewise reflected the nitrogen status of the plants, but to a lesser extent. On the final harvest date (July 28), the nitrate values for the outside petioles were not significantly different from one another which would be expected from the fact that all solution cultures had been changed 2 weeks earlier to the 1.0N level. The nitrate content of the blades varied significantly, but the variations were not related to the previous supply of nitrogen in the nutrient solutions.

The values for the remaining nitrogen fractions (table 3) were in some instances correlated with the nitrogen status of the plants, but when this correlation occurred the differences for the soluble, insoluble, and total-nitrogen values resulting from the treatments were not nearly so great as for the nitrate determinations. The insoluble (protein) nitrogen of the outside petioles could not be correlated with the fertilizer treatments, even for the first harvest date, when the very large differences in the nitrate content occurred. The significant differences in the insoluble-nitrogen content of the outside petioles and blades on July 28 could not be correlated with the nutrient treatments.

Sugar Beets Grown in Metz Silty Clay Loam—(5-gallon pots)

Procedure.—Sugar beets were planted on May 15. 1939, in 5-gallon pots containing 45 pounds of air-dry soil (Metz silty clay loam) which in previous experiments had been found to give large increases in yield when supplied with nitrogen. The pots, which were galvanized-iron buckets painted on the inside with black asphaltum varnish, were provided for drainage with a 3-inch hole covered with an inverted china saucer. The drainage water was caught in a 2.6-ii1er milk pan, and returned to the soil prior to the next watering. This prevented the loss of nutrients, particularly nitrates, from the soil.

As soon as the cotyledons of the sugar-beet seedlings were fully developed, the plants for each pot were decreased to approximately 12 in number. On June 3, when the plants were in the late two-leaf and early four-leaf stage, one series of pots (N) was given 10 grams of aTrimoiiium sulfate, a second series (2N) was given 20 grams of ammonium sulfate, while a third series was left untreated.

On June 13, just, 30 days from the time of planting, when the beets were in the six-leaf stage, five pots from each treatment were harvested. Since the beet leaves for the first harvest date were small, they were not separated as in subsequent harvests into outside and inside leaves before making the blade and petiole separations for the nitrate determinations. Likewise, the beet roots were too small for sugar analyses, and were discarded after they had been weighed. For comparative purposes, however, the beet and top weiglits were placed on a four-beet basis, since the number of plants in the remaining pots were reduced to four on the following day. Thereafter, five pots were harvested from the untreated and (N) and (2N) treatments at approximately 30-day intervals. In the case of the untreated pots, these were harvested for the third and last time on August 10. On August 10 another 10 grams of ammonium sulfate were added to part of the (N) series. These are designated as the (N+N) series.

Results.—The results for the 5-gallon-pot experiment summarized in table 5 again favor the analysis of the outside petioles for nitrates as a means of evaluating the nitrogen status of the sugar-beet plant. The other plant parts could be used if necessary, but for sensitivity and ease of sampling, the outside petioles are preferable to the inside petioles and blades, or to the outside blades.

The relationship of the nitrate content of the outside petioles of sugar beets to their sugar percentage, beet yields and top growth is given in figures 1 to 3. Figure 1 shows that the nitrate content of the (2X) beets is higher than the (X) treated beets for the first harvest date on June 14. On the next harvest date, July 13. the (2X) beets have a much higher nitrate content than the (N) beets, and this is reflected in the lower sugar percentage of the (2N) beets. On August .10, when the nitrate percentages are very low for the

Table 5.- Summary of results of sugar beets prrown in Metz silty clay loam (5-gallon pots)

Harvest	Treat-	Beets			Tops	LEAF ANALYSES ppm. Nitrate -N			
	ments*	Yields	Percentage		Fresh	Blades		Petioles	
Dates		gm.	Sugar	Purity	wt.gm.	Out.	In.	Out.	In.
June 14	Untreated	1.7	—	—	18	158		2589	
	(N)	1.8	—	—	22	476		6762	
	(2N)	1.4	—	—	18	971		8788	
July 13	Untreated	26	16.5	81.1	26	0	17	153	63
	(N)	109	13.8	70.0	227	221	53	2387	701
	(2N)	113	11.5	74.4	320	1827	818	8236	2404
Aug. 10	Untreated	57	17.8	90.2	21	Tr		19	
	(N)	304	17.1	87.6	217	0	0	Tr	Tr
	(2N)	445	17.1	85.5	409	0	0	588	Tr
Aug. 24	(N)	484	18.2	87.7	202	0	0	11	17
	(N+N)	472	15.2	85.1	201	496	242	1090	1795
Sept. 7	(N)	498	16.3	80.1	172	0	0	Tr	17
	(2N)	704	17.1	89.6	323	0	0	50	11
	(N+N)	560	16.1	87.0	427	0	0	501	37
Oct. 5	(N)	580	16.8	88.0	142	0	0	Tr	50
	(2N)	966	17.1	88.9	245	0	0	0	45
	(N+N)	833	16.6	88.8	316	0	0	34	11
Difference for significance at the 5-percent point		70	0.8	1.8	32	—	—	—	—

All treatments were replicated five times except in the untreated pots of August 10, which had 3 replications.

(N) and (2N) beets, the sugar percentages are identical. The addition of another unit of nitrogen to the (N) beets (N+N) resulted in an increase in the nitrate content of the petioles and a significant decrease in the sugar percentage. The nitrate content of the (N+N) beets continued to depress the sugar content until the last harvest-dale, October 5, when all of the sugar percentages were practically identical.

The purities of the sugar beets (table 5) followed nearly the same pallern as the sugar percentages. A minor difference occurred on August 10, when the purity of the (2N) beets was still significantly less than the (X) beets, while there was no difference in their sugar percentages. Another difference occurred on September 7, when the sugar percentages of the (X) and (2X) treatments were significantly different from the (N+X) treatment, while the purity coefficients were not.

The relationship of the nitrate content of the petioles to the sugar-beet yields (figure 2) is of interest. On July 13, the much higher nitrate content of the (2X) beets did not result in a higher yield, but on the next harvest date, August 10, the effect of the higher nitrogen supply upou the yields was considerable as shown

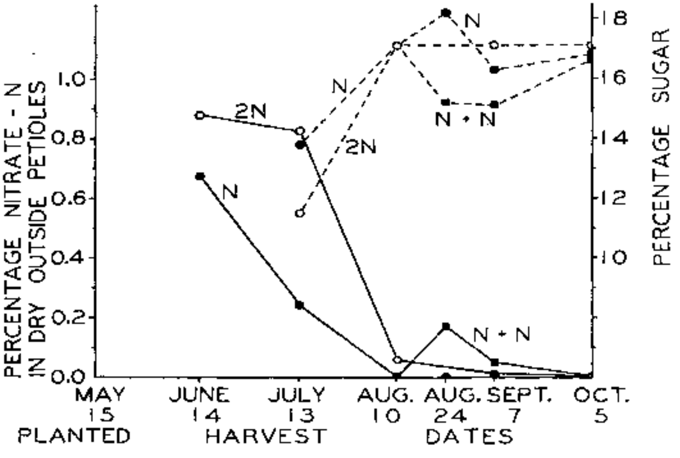

Figure 1,—Relationship of nitrate content of outside petioles to sugar percentages. N equals 10 grams of ammonium sulfate per pot; N + N designates the addition of a second unit of N on August 10.

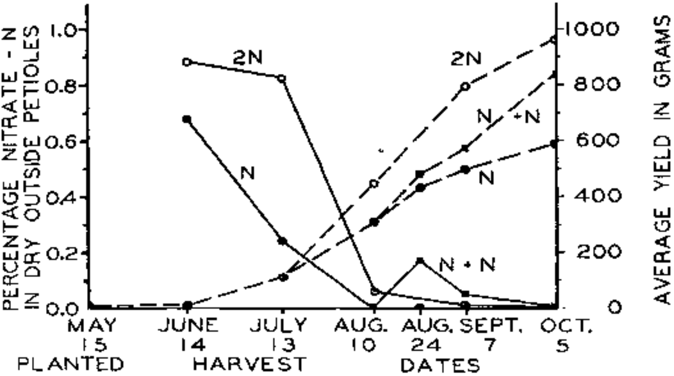

Figure 2.— Relationship of nitrate conteur of outside petioles to sugar-beet yields. X equals 10 grams of ammonium sulfate per pot ; X + X designates the addition of a. second unit of N on August 10.

by the average yield of 445 grams for the (2N) beets as compared to 304 grams for the (N) beets. Thereafter, the differences resulting from the greater nitrogen supply became even greater; a yield of i)6o' grams was obtained on September 7 for the (2N) beets in comparison to 589 grams for the (N) beets. When another unit of nitrogen was added to part of the (N) beets on August 10, the effect of the nitrogen on the yields was not appreciable until September 7. The beet yields for the (N+N) treatment were still increasing on the last harvest date (October 5) and apparently would have reached ultimately the yields for the (2N) beets. Unfortunately, 1 he supply of beets at this point was exhausted and additional yields could not be obtained. It is significant, however, that by waiting until the nitrate supply in the outside petioles became depleted before, adding nitrogen, valuable growing time was lost which could not be made-up readily, if at all.

The growth in tops (figure 3) tended to follow the nitrate content of the outside sugar-beet petioles. There was, as in the case of the beet roots, a lag in growth in comparison to the nitrate supply, but this lag was not as great as for the beet roots. The maximum fresh weight for the tops of the (N) beets occurred on July 13 and thereafter there was only a slight decrease up to the time of the last harvest on October 5. The beet roots (figure 2) on the other hand continued to increase rapidly from July 13 to August 24, and then more gradually to the date of the last harvest. The fresh weight of the tops for the (2N) beets on August 10 reached a higher maximum than the (N) beets on July 13. After August 10 the decrease in top weight was gradual but at a greater rate than for the (N) beets. In contrast to the top growth the (2N) beet roots (figure 2) grew very rapidly from July 13 to September 7, and thereafter increased more slowly. When another unit of nitrogen was applied to the (N) beets on August 10, the tops (figure 3) started to grow almost immediately, and these reached a new maximum on September 7. The beet roots (figure 2) reached their maximum rate of growth between September 7 and October 5, and since it was impossible to obtain additional data, the growth rate thereafter could not be observed.

Sugar Beets Grown in Metz Silty Clay Loam—(33-gallon pots)

Procedure.—Metz silty clay loam in 33-gallon containers (galvanized-iron garbage cans painted on the inside with black asphaltum varnish, and on the outside with aluminum paint) was planted to sugar beets on March 14, 1939. The beets were thinned to four plants per pot when they reached the four to six-leaf stage. On May 16 these were fertilized with ammonium sulfate. The treatments

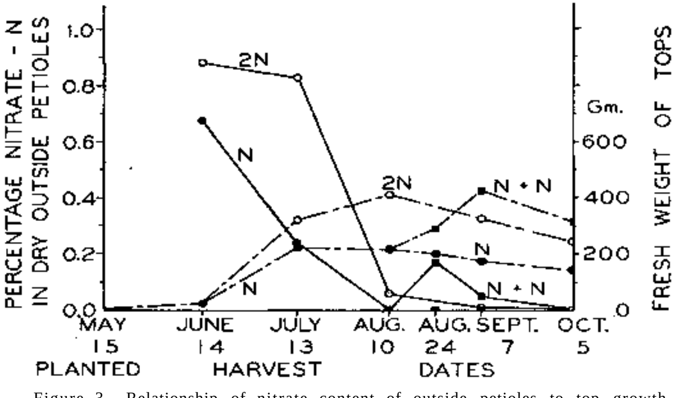

Figure 3.—Relationship of nitrate content of outside petioles to top growth. N equals 10 grams of ammonium sulfate per pot; N + N designates the addition of a second unit of X on August 10.

were replicated six times and were as follows: Untreated, 27.8 (N), 55.6 (2X), and 111.2 (4N) grains of ammonium sulfate per pot. In the case of the (4N) treatment, one-half of the material was applied on May 16 and the other half 4 weeks later. The first lot of beets was harvested on August 1, and as in the 5-gallon-pot experiment, the same leaf separations used for nitrate determinations were made. To one-half of the 12 (N) pots remaining on August 1, another unit of nitrogen (N) was added, and the others were left untreated. The beets in these pots were harvested on August 15), and the results for the two harvest, dates are given in table 6.

Results.—On June 17 the untreated beets showed a pronounced nitrogen deficiency, while the beets receiving different amounts of nitrogen were green, and had made approximately the same growth in all cases. At the time of their harvest, on August 1. the (N) beets wore distinctly deficient in nitrogen, the (2N) beets were much larger and had greener leaves than the (N) beets, and the (4N) beets were greener and considerably larger than the (2N) beets. The results from the August 1 harvest, which are summarized in table 6. follow the general pattern observed in the series with the 5-gallon pots. The larger the amount of ammonium sulfate applied to the soil, the greater the nitrate percentage in the outside petioles, and the lower the sugar percentage of the beets. The addition of another unit of (N) to the (N) treated beets retarded the accumulation of sugar significantly, but the effect was less after 2 weeks than in the corresponding treatment in the 5-gallon, pots. The smaller decrease in sugar percentage in the 33-gallon pots may be inherent in the containers, or the result of a difference in weather (e.g. cooler weather would retard both the formation of and the absorption of nitrates).

Discussion

The general conclusions which may be drawn from the nutrient-solution experiments, and from the 5 and 33-gallon-pot experiments concerning the influence of nitrogen on sugar formation are the same regardless of the technique employed. In the solution experiments the nutrients supplied to the beets may be controlled carefully, which is a distinct advantage over soil cultures, particularly when the gradual formation of nitrates from the organic matter in the soil could be enough under some conditions to depress the sugar percentage of the beets. In spite of this possible difficulty, and even though the main beet roots in the smaller pots were curved near the tips when they reached the bottom of the container, the results from the 5-gallon pots proved to be comparable with those from the 33-gallon pots. The curved beets in the 5-gallon pots were not constricted at the point of curvature, but in fact the gradual

Table 6.—Summary of results of sugar beets grown in Metz silty clay loam (33-gallon pots)

Harvest dates	Treatments*	Fresh weight tops (grams)	Beet yields (grams)	Percentage sugar	Sugar produced (grams)	Purity	Leaf analyses (dried material) percentage NO_3—N			
							Outside petioles	Inside petioles	Outside blades	Inside blades
Aug. 1	Untreated	233	800	17.1	136	87.6	0.004	0.001	0.001	0.001
"	(N)	1,106	1,702	16.2	276	87.1	0.002	0	0	0
"	(2N)	1,715	2,156	15.7	337	86.7	0.107	0.002	0.003	0.001
"	(4N)	2,789	2,292	14.0	320	83.7	1.184	0.242	0.106	0.015
Aug. 15	(N) (control)	966	1,860	17.5	325	88.8	0.003	0	0.005	0
"	(N+N)	1,065	1,947	16.1	313	88.1	0.050	0.107	0.015	0.020
Dif. for 5-percentage point		205	162	0.7	26	1.3	—	—	—	—
Observed F value		140	88.7	23.9	72	15.1	—	—	—	—
Required F value 5-percentage point		2.5	2.5	2.5	2.5	2.5	—	—	—	—

* Replicated 6 times. N=27.8 grams of ammonium sulfate per pot.

tapering of the beefs continued to the tip even around the elbow of the curve. From the viewpoint of experimental costs, the smaller pots are certainly preferable over the more expensive 33-gallon pots.

Although the results from the present experiments have shown that nitrogen depresses the sugar percentage of the beet, it is not to he inferred that all sugar beets high in nitrogen will be 1OW in sugar, or that beets deficient in nitrogen will always be high in sugar. In some environments beets high in nitrogen may also be high in sugar, and likewise in another environment beets low in nitrogen could be low in sugar. The conditions which would favor the storage of sugar by heels, even when the nitrogen supply is high, would occur in localities where sunlight is intense, the days warm to hot, and the nights cool. Under these conditions photosynthesis would be at a maximum, and respiration would be at a minimum, thus resulting in the formation of sugar faster than it can be utilized to form new tissues (leaves and roots), even when large amounts of nitrogen are available for growth (other nutrients are assumed to be adequate). Beets low in nitrogen under these conditions would be very high in sugar.

The conditions which would not favor the storage of sugar would occur in localities with high day and night temperatures. Under these conditions, photosynthetic activity could be at a maximum, and yet the high temperatures would increase respiration to such an extent that the sugar percentage would be maintained at a very low level, even 1 hough the nitrogen supply was also low. If the nitrogen supply is high, tissue formation may be so rapid as to result in beets with a sugar percentage approaching zero.

Under most circumstances beets which are high in nitrogen would he lower in sugar content than comparable beets which are low in nitrogeu. Sugar beets which are both high in nitrogen and sugar content wouhl grow rapidly, and would continue to do so as long as the nitrogen and carbohydrate supplies were maintained, or until some other factor became limiting. At harvest time the sugar content of the heels would be a function of growth, leaf area, light intensity, temperature, etc. The final equilibrium between these factors, with its many possible variations could account for the high and low-sugar areas in the United States, and for the high and low-sugar years which occur.

Summary

Sugar beets were grown at different levels of nitrogen in nutrient solutions and with Metz silty clay loam in 5- and 33-gallon pots. These were harvested at different stages of development to observe the relationship of yield, sugar percentage, and top growth of the beets to the nitrogen content of the blades and petioles taken from the center and outside leaves of the sugar-beet plant.

Of the nitrogen fractions (nitrate, soluble, insoluble, and total) which were determined only in the nutrient-solutions experiments, the nitrate content of the outside petioles reflected the nitrogen status of the sugar-beet plants better than for any other nitrogen fraction or leaf portion. In the other experiments in which nitrates alone were determined, the best indication of the nitrogen status of the plants was given by the nitrate content of the outside petioles.

Whenever the nitrate content of the outside petioles was high, the sugar percentage of the beets was lower than in corresponding beets in which the nitrate content was low. A nitrogen deficiency produced beets with a high sugar-percentage, while an excess resulted in beets with a low sugar-percentage.

When the nitrate content of the beets was high, and the growing conditions favorable, rapid top growth took place, and continued until the nitrogen supply was depleted. Thereafter the growth of the tops as measured by their fresh weight decreased gradually while the root weights increased rapidly at first, and then more slowly until the time of the last harvest.

In order to obtain maximum sugar formation, a large supply of nitrogen must be available continuously early in the season. The available nitrogen must be utilized completely at the time of harvest, otherwise beets of a relatively low sugar-percentage will be obtained. By carefully controlling the nitrogen supply, beets both high in yield and in sugar percentage may be grown.

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