Response of Sugar Beets to Nitrogen Depletion In Relation to Root Size[1]

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Introduction

Sugar beet yields have been increasing and sucrose concentrations decreasing in California for over 20 years (14)[3]. Increased plant populations, improved varieties and better production practices have been largely responsible for the higher yields. Lower sucrose concentration has often been associated with large beets, and higher sucrose concentrations with small beets. Whether lower sucrose concentration is inherent in large beets or results from some conditions that lead to large size is a problem of considerable interest.

Increased use of nitrogenous fertilizers has been a major factor contributing to higher yields. Continued vegetative growth under high nitrogen conditions, however, is known to be incompatible with high sucrose at harvest time (12), and the low sucrose values may be symptomatic of too much nitrogen. The observed inverse correlations between beet weight and sucrose concentration may be due to large and small beets responding differently to the normal preharvest period of nitrogen deficiency. Under the influence of high nutrition and a constant environment, the size of beet tops appears to be largely independent of root size (12). If this is the case, then one effect of nitrogen deficiency in reducing growth would be to leave small beets with the same effective leaf area for photosynthesis as large beets. Thus, for a given period of nitrogen deficiency, the greatest increase in sucrose concentration should be noted in small beets, because of greater tops relative to root size.

In the present series of experiments, the response of sugar beets to nitrogen deficiency in relation to root size was investigated with nutrient culture techniques at Berkeley and Davis, California. The primary advantage of the nutrient culture technique in this study was that it provided an easy means of controlling nitrogen nutrition precisely and providing adequate amounts of all other nutrients known to be essential to plant growth. Root size was varied by planting beets on three different dates. This appeared to be a satisfactory method for controlling root size because, after top development was complete,

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[3] Numbers in parentheses refer to literature cited.

the size and character of the tops would be determined by climate and nutrition (10, 12, 17), and the only major residual effect of the various planting dates would be in root size. The experiments as designed provided information on the main effects of root size (planting date) in relation to nitrogen depletion, and not on environmental variables that would influence root size under field conditions.

Methods

Duplicate experiments, using, as nearly as possible, the same materials and procedures, were conducted under natural environmental conditions at Berkeley and Davis in 1957. General procedures for such pot studies have been described (17).

The pots used were ten-gallon carbide cans (32 cm. diameter, 52 cm. height) painted inside with Amercoat No. 33 protective coating and outside with aluminum paint. Drainage was provided by drilling four 0.25-inch holes equidistant on the sides near the bottom of the pots. The pots were filled with No. 2 grade vermiculite as a rooting medium, and firmly settled. Sugar beet seed (variety US 75) treated with Phygon XL at the rate of one percent was planted by placing ten seedballs equidistantly in a circle (diameter 23.5 cm.) and pressing the seeds into the vermiculite to a depth of 1.9 cm. The pots were spaced in rows with a minimum of 50 cm. between cans in the growing area (concrete slab at Berkeley; gravel at Davis). After emergence, the beets were thinned periodically, retaining uniformly sized vigorous plants until at the 6 to 8 leaf stage, only two plants remained per pot. Two plants give considerably greater precision than one (15).

The pots were watered daily with complete nutrient solution, a modified half-strength Hoagland solution No. 1 prepared with tap water (18). On the nitrogen cut-off date the pots were heavily leached with tap water to remove the bulk of the residual nitrogen from the vermiculite, and the minus-nitrogen pots subsequently received a solution free of added nitrogen (Table 1).

Three mean root-size classifications were obtained by planting 26 pots on each of three dates: March 1, May 1, and June 1.

Table 1.—Composition of the Modified Half-Strength Hoagland No. 1 Nutrient Solutions.

Solution	Millimoles of Salt per Liter of Nutrient				
+N	0.5 KH_2PO_4	1.0 $MgSO_4 \cdot 7\ H_2O$	2.5 KNO_3	2.5 $Ca(NO_3)2$	0.5 Na Cl
—N	0.5 KH_2PO_4	1.0 $MgSO_4 \cdot 7\ H_2O$	2.5 K_2SO_4	2.5 Ca $Cl_2 \cdot 2\ H_2O$	0.5 Na Cl

Minor elements were added to both solutions to give a final concentration, expressed in milligrams per liter, as follows: 0.25 B, 0.25 Mn, 0.02 Zn, 0.01 Cu, 0.005 Mo, and 2.5 Fe.

On August 15, six pots from each group were harvested and the remaining 20 pots were divided into two groups of ten pots each. One of these groups continued to receive the standard solution while the other was watered with the minus-nitrogen solution. All remaining pots were harvested on October 15.

Old leaves (50 percent or more of blade dead) were gathered periodically during the growing season. These were dried so that total leaf production could be determined. Just before harvest, measurements were made of the height of tallest recently matured leaf, and the diameter of the foliage canopy. At harvest, the tops were separated from the roots at the oldest living leaf and the following measurements were obtained: (a) total fresh and dry weight of green tops; (b) total weight of the individual roots plus crown, and (c) separate weights of the crown (portion between the upper and lower leaf scar) and of the storage roots. For NO_3-N analyses (5), petioles of ten recently matured leaves were collected from each pot on the harvest dates and on September 15 (two petioles per pot). Pulp samples from individual roots and also on October 15, from crowns of beets planted on March 1, were prepared with a Kiel rasp, and analyzed for sucrose in duplicate by the method of Browne and Zerban (1). Total beet weight (roots and crowns) per pot and weighted mean sucrose percentage are reported in the results. Weighted mean sucrose percent was calculated by dividing total sucrose per pot (sum of the products of individual beet weights and sucrose percentages) by total beet weight per pot.

Results

The Berkeley and Davis harvest results are summarized separately in Tables 2 and 3.

A satisfactory range of mean root sizes were obtained by August 15 at both locations. The later planting dates, however, had not attained full top development, as shown by significant date effects on fresh and dry weight of tops at both locations and on top diameter at Davis. Immature top development was reflected in significant date effects on weighted mean sucrose percentage at both locations: small beets with small tops had the lowest concentrations of sucrose. This agrees with previous observations (12) that top growth has priority over other growth for sucrose utilization.

The failure to obtain equal top development from all plantings at the nitrogen cutoff date slightly complicates interpretation of the changes that took place between August 15 and October 15. The changes in root weight and sucrose percentage

Table 2.—Harvest Results From Berkeley for Studies of Nitrogen Depletion in Relation to Root Size, 1957. All Values on a per Pot Basis: Means of 6 Pots for August 15; Means of 10 Pots for October 15.

			Beet Root Plus Crown				Tops			
Harvest Date	N Level	Planting Date	Weight gm.	% Crown	Sucrose gm.	Sucrose %	F.W. gm.	D.W. gm.	Height cm.	Diameter cm.
August 15	+ N	March 1	3,520	9.3	421	12.0	2,618	268	45.3	73.0
		May 1	1,910	7.6	214	11.0	1,947	196	41.8	69.9
		June 1	780	1.9	77	9.9	1,340	109	44.3	70.0
		$\bar{x}$	2,070	6.3	237	11.0	1,970	191	43.8	71.0
	LSR_{01}[1] (p = 3)		770	3.9	88	1.1	500	56	7.9	8.6
	F (Planting)		60.6[4]	19.4[4]	65.7[4]	18.9[4]	31.8[4]	37.9[4]	0.89 NS	0.81 NS
	Error M.S. (15 df)		187,400	4.69	2,669	0.3440	77,070	1,001	21.73	23.37
	C.V. (%)[2]		20.9	34.6	21.7	5.3	14.1	16.6	10.6	6.8
October 15	+ N	March 1	5,210	16.8	614	11.8	2,240	238	42.3	69.5
		May 1	3,870	12.9	464	12.0	2,480	267	45.6	70.9
		June 1	2,650	12.1	306	11.5	2,120	218	45.8	70.4
	+ N	$\bar{x}$	3,910	13.9	461	11.8	2,280	241	44.6	70.3
	— N	March 1	5,230	14.9	769	14.7	890	111	26.1	62.3
		May 1	2,920	13.3	448	15.3	730	91	26.6	61.0
		June 1	1,960	8.9	329	16.9	670	87	26.6	66.5
	— N	$\bar{x}$	3,370	12.4	515	15.6	763	96	26.4	63.2
	LSR_{01}[1] (p = 6)		920	5.2	141	1.1	760	70	3.3	9.8
	F (Planting)		90.0[4]	9.28[4]	63.4[4]	6.89[4]	0.78 NS	1.49 NS	3.62[3]	0.73 NS
	F (Nitrogen)		9.00[4]	2.37 NS	3.95 NS	334.0[4]	106.0[4]	113.3[4]	796.5[4]	13.7[4]
	F (P x N)		2.64 NS	1.01 NS	3.58[3]	13.6[4]	0.69 NS	1.33 NS	1.94 NS	0.77 NS
	Error M.S. (54 df)		480,700	15.13	11,280	0.6765	325,100	2,768	6.056	54.26
	C.V. (%)		19.0	29.6	21.8	6.0	37.5	31.2	7.0	11.0

[1] LSR_{01}: Least significant range for the 1% level for random comparisons among p means (3).

[2] Coefficient of variability: $(s/\bar{x})100$.

[3] Significant at the .05 level.

[4] Significant at the .01 level.

NS = Not significant.

Table 3.—Harvest Results from Davis for Studies of Nitrogen Depletion in Relation to Root Size, 1957. All Values on a Per Pot Basis: Means of 6 Pots for August 15; Means of 10 Pots for October 15.

			Beet Root Plus Crown				Tops			
Harvest Date	N Level	Planting Date	Weight gm.	% Crown	Sucrose gm.	Sucrose %	F.W. gm.	D.W. gm.	Height cm.	Diameter cm.
August 15	+ N	March 1	2,750	4.4	353	12.9	1,460	202	33.5	67.7
		May 1	1,310	1.0	157	12.0	962	128	37.0	70.8
		June 1	550	0.0	59	10.8	556	71	35.9	60.3
		$\bar{x}$	1,540	1.8	189	11.9	993	134	35.5	66.3
	$LSR_{.01}$ (p = 3)		330	3.6	36	1.3	393	55	4.6	7.6
	F (Planting)		221.6[4]	7.80[4]	337.3[4]	12.9[4]	25.3[4]	27.2[4]	2.87 NS	9.34[4]
	Error M.S. (15 df)		33,740	4.058	398.6	0.493	48,450	951.7	6.687	18.40
	C.V. (%)		11.9	112.0	10.5	5.9	22.2	23.1	7.2	6.5
October	+ N	March 1	4,390	14.2	468	10.7	1,780	200	32.6	60.2
		May 1	3,380	10.3	365	10.8	1,840	195	36..7	64.6
		June 1	2,710	6.1	284	10.5	1,720	179	35.8	66.6
	+ N	$\bar{x}$	3,490	10.2	360	10.7	1,780	191	35.0	63.8
	— N	March 1	3,670	7.8	511	13.9	780	116	22.0	49.2
		May 1	2,480	7.7	408	16.5	600	87	25.0	54.6
		June 1	1,600	2.3	273	17.1	410	62	25.6	59.2
	— N	$\bar{x}$	2,580	5.9	397	15.8	600	88	24.2	54.3
	$LSR_{.01}$ (p = 6)		510	4.4	70	1.3	410	57	6.1	8.1
	F (Planting)		121.8[4]	21.9[4]	81.2[4]	15.5[4]	2.65 NS	4.75[3]	3.69[3]	9.17[4]
	F (Nitrogen)		85.1[4]	24.6[4]	3.45 NS	455.5[4]	214.3[4]	108.4[4]	82.2[4]	36.5[4]
	F (P x N)		1.04 NS	1.61 NS	1.84 NS	16.7[4]	1.44[4]	1.03 NS	0.13 NS	0.46 NS
	Error M.S. (54 df)		56,130,000	11.11	2,734	0.8813	98,060	1.468	21.43	36.86
	C.V. (%)		12.6	41.3	13.6	7.1	26.3	27.4	15.3	10.2

For explanation of table, see footnotes to table 2.

for these later plantings are probably smaller for the nitrogen-deficient plants than could have been obtained had top size been equal on August 15 for all plantings.

The beets responded rapidly when watered with the minus-nitrogen solution after August 15. Within seven days, yellowing was apparent and immature leaves stopped growing. On September 15 and October 15, the minus-nitrogen beets showed petiole NO_3-N levels indicative of extreme nitrogen deficiency (Table 4). The tops of the low-nitrogen beets had small-bladed, short-petioled, yellow leaves in flattened rosettes typical of nitrogen-deficient plants. It thus appeared that nitrogen cutoff was rather sharp, not a slow transition, and that the nitrogen-deficient period before the October 15 harvest was longer than seven weeks.

Table 4.—Nitrate-Nitrogen Content (p.p.m.; Dry Basis) of Petioles of Recently Matured Leaves[1].

Sampling Date	Location[2]	N Level	Planting Date			Mean[3]
			March 1	May 1	June 1	
Aug. 15	B	High	9,760	9,530	9,720	9 670
	D	High	9,270	7,960	9,640	8,960
Sept. 15	B	High	8,670	8,160	8,810	8,540
	D	High	6,440	6,660	7,180	6,760
	B	Low	385	242	212	280
	D	Low	308	333	121	254
Oct. 15	B	High	5,840	5,930	7,360	6,380
	D	High	8,110	6,680	9,340	8,040
	B	Low	268	236	192	232
	D	Low	544	292	142	326

[1] Critical level: 1000 p.p.m.

[2] B (Berkeley); D (Davis).

[3] On October 15, at Berkeley, high N value for June 1 is significantly different (.05 level) from the means of the other two planting dates; no other planting date effects are significant. All differences between high and low N at one location and one sampling date are highly significant (.01 level).

By October 15 at both locations, total beet root weight had increased about one kilogram per pot in the minus-nitrogen series and nearly two kilograms per pot with full nutrition. The interactions between planting date and nitrogen level were not significant, though total beet weights for the March 1 planting at Berkeley showed the same increases as both nitrogen levels. This may indicate that pot size limited the growth of the plus-nitrogen beets in that instance.

The crown percentage of total beet weight was highest with the large, early-planted beets, and plus-nitrogen beets tended to have a larger percentage of crown than nitrogen-deficient beets. This was related to a greater old-leaf production (not shown in tables) for the early plantings.

The March 1 plus-nitrogen tops showed little change in size between August 15 and October 15. During that period the later plantings attained full top development, equalled the March 1 beets by October 15. Careful examination revealed slightly larger leaf size and lighter color in the late plantings. Fresh and dry weights, heights and diameters were rather uniform within each location, but the Berkeley plants had greater top development as well as larger roots. Large differences between nitrogen levels were apparent in all top measurements except diameter—the relatively small decrease in top diameter with nitrogen deficiency was indicative of the rosette habit. The decrease in top weight in the minus-nitrogen series with later planting was not significant (except as measured by dry weight at Davis), thus indicating that the nitrogen-deficient plants also tended toward a uniform top size at each location.

Weighted mean sucrose percent on October 15 was uniformly low with high nitrogen for all planting dates at both locations (Tables 2 and 3). These values were slightly different from those obtained on August 15 in two respects: (a) the late-planted beets no longer showed lower values than the early-planted beets, and (b) the early-planted beets showed a lower sucrose percentage at Davis (12.9% compared to 10.7%) and no significant change at Berkeley (12.0% compared to 11.8%). The nitrogen-deficient beets for all planting dates showed marked increases in sucrose concentration over those of plus-nitrogen beets for both August 15 and October 15. The highest values, 17.1 percent at Davis and 16.9 percent at Berkeley, were obtained with the small June 1 beets, while March 1 plantings yielded the lowest sucrose percentages of the series, 13.9 percent at Davis and 14.7 percent at Berkeley. All these values were significantly greater than in the plus-nitrogen series.

Sucrose yields from minus-nitrogen beets tended to be slightly higher than from the plus-nitrogen beets, especially with the March 1 planting (significant only for Berkeley, at 5 percent level). Thus the increased sucrose percentage in the roots more than offset the reduced growth of the minus-nitrogen plants. As expected, sucrose yield declined with later planting.

Weighted mean sucrose percentage in the crowns was of interest, but only the March 1 beets had crowns that were large enough by October 15 to permit sampling for sucrose determination (Table 5). The sucrose percentage of crowns and roots of the plus-nitrogen plants was not greatly different (roots greater than crowns; significant, 5 percent level, only, at Berk-

Table 5.—Weighted Mean Sucrose Percentages of Crowns and Roots on October 15 for the March 1 Planting. All Values on a per Pot Basis: Means of 10 Pots.

N Level	Part	Location	
		Berkeley	Davis
+ N	Crown	10.3	10.5
	Root	11.8	10.7
— N	Crown	12.5	12.7
	Root	14.7	13.9
	$LSR_{.05}$ (p = 4)	1.3	1.0
	$LSR_{.01}$ (p = 4)	1.8	1.3
	F (Nitrogen)	34.4[2]	77.2[2]
	F (Part)	18.4[2]	4.95[1]
	F (N x P)	0.82 NS	2.72 NS
	Error M.S. (36 df)	1.877	0.9763
	C.V. (%)	11.1	8.3

For explanation of table, see footnotes to Table 2.

eley) while under minus-nitrogen conditions crowns contained significantly lower sucrose concentrations than roots. Sucrose levels were higher in the minus-nitrogen plants in both the crowns and roots.

Ulrich (12), with beets grown in nutrient culture under high nitrogen conditions in a controlled-temperature greenhouse, also found that root mean sucrose did not differ greatly from crown mean sucrose during the first season of growth. Considering the entire beet, root plus crown, it appears that under high nitrogen conditions, the over-all sucrose percent is not appreciably influenced by the presence of the crown. Under low nitrogen conditions the presence of crown tissue contributes to a lower sucrose percent for the whole beet.

Discussion

The means for beet root weight and weighted mean sucrose percent for the minus-nitrogen series show a clear inverse correlation; small beets had high sucrose levels. The increases in sucrose percentages of the minus-nitrogen plants over the plus-nitrogen plants were rather large and, in terms of sucrose produced, more than compensated for the lower beet yields. The net carbon assimilation rates were apparently nearly equal for the seven-week interval of nitrogen deficiency in both series, since the very slightly lower yields of sucrose in the plus-nitrogen group appear to have been offset by greater weights of roots and total tops. This indicates that sucrose yields would probably also have been equal for shorter intervals of nitrogen deficiency. There is an upper limit to the sucrose concentration that the sugar beet plant can attain, and the rate of accumulation probably declines as this limit is approached. Large beets, from the data presented here, approach that limit more slowly and would require a longer period of nitrogen deficiency to attain a given sucrose level. A longer period of nitrogen deficiency for large beets, however, might be subject to the hazards of further loss of tops and hence reduced carbon assimilation rates.

It is worth nothing that the more rapid increase in sucrose percent in small roots with nitrogen deficiency may indicate that the response in sucrose percent to any change in the environment would be more rapid in small roots than in large roots. Thus a change from warm to cool climate or from long to short days would be reflected more quickly by the small roots. This may account in part for Ulrich's report (15) of higher sucrose concentrations in small, crowded plants than in large, uncrowded plants.

The uniform sucrose concentrations observed under high nitrogen conditions for all planting dates are of interest since this agrees with the concept of an equilibrium sucrose value determined primarily by climate (particularly night temperature) and variety (11, 13, 17). Sucrose percentages for high-nitrogen beets planted on March 1 at Berkeley were nearly equal on the two harvest dates, and accumulated temperature sums for 28 days prior to harvest (Table 6) also showed little change. At Davis, however, with comparable minimum temperatures, there was a noticeable decline in sucrose percentage from August 15 to October 15. Day lengths at the two locations were nearly equal, but light intensity and maximum temperatures might explain the discrepancy. Davis normally has higher light intensities than Berkeley (16), but in 1957 there were ten days

Table 6.—Minimum Night and Maximum Day Temperatures above 32° F. Summed Daily for Four Weeks Prior to Harvest.

Harvest Date	Temperature	Location: Berkeley	Location: Davis
August 15	Minimum	663	635
	Maximum	1,150	1,820
October 15	Minimum	709	572
	Maximum	1,160	1,340

of partial or complete overcast in late September and October, and the low light intensities may have contributed to lower sucrose values. A further possibility is the occurrence of higher maximum temperatures prior to August 15. The resultant temporary daily wilting may have reduced vegetative growth, thus accounting for some of the differences.

The goal in the commercial production of sugar beets is a high yield of sucrose. A high yield of roots containing a low percentage of sucrose obtained under high-nitrogen conditions has several disadvantages: to the grower there is an increased cost of fertilizing and harvesting; and to the processor, a low processing quality. Thus, economic sucrose production with present varieties is partially dependent on a period of nitrogen deficiency prior to harvest. The present experiments indicate that the net result of a nitrogen deficiency period is dependent on beet root size.

In applying these results to field conditions, several things need to be considered. Until sugar beet varieties are available that will "ripen" naturally to a high sucrose concentration under high-nitrogen conditions, it may be possible for the grower to take advantage of the knowledge that small beets respond more rapidly than large beets to changes in nitrogen status. It would not be practical for a grower to reduce the mean root size by delaying planting date. Two obvious alternatives remain: (a) reduce the average plant spacing, thus increasing the plant population, and (b) alter the length of the period of nitrogen deficiency prior to harvest.

The results reported here do not bear directly on either of these alternatives, although, considering the first alternative, most evidence (2) indicates that maximum beet yields are obtained by a wide range of populations as long as enough plants are grown to canopy the available space completely with leaves at an early date, yet not so many that small, unmarketable roots result. Within this range, top development per plant will be influenced by competition from adjacent plants for heat, light, and carbon dioxide as well as water and nutrients from the soil. Thus, under field conditions, small, crowded plants would not have the same size of tops as larger, uncrowded plants, but proportionally, top development for crowded plants would be greater than root development (15), tops having priority over storage root growth. Under such conditions, the effects of nitrogen deficiency in relation to root size might be greater or less than in the present experiments. An inverse correlation between beet root size and sucrose percentage in the field might still be anticipated.

The second alternative also appears reasonable since sucrose yields for a planting date were nearly the same at both nitrogen levels after seven weeks of nitrogen deficiency. However, as pointed out earlier, hazards might be encountered with longer periods of nitrogen deficiency. Fields with large beet roots (high yields and/or low populations) could be expected to have lower sucrose percent than fields with small roots (low yields and/or high populations) unless they were allowed longer intervals of nitrogen deficiency. If the small roots result from some factor such as disease, then this relationship might not be valid.

Negative correlations between sucrose percent and beet weight have been frequently reported for field-grown beets (4, 8, 9), though this is not always the case (e.g., significant positive correlations may be calculated for the data of Hills reported by McGinnis (7)). In previous work (unpublished) with beets grown under high-nitrogen nutrition in nutrient culture, no correlation was found between beet root weight and sucrose percent within a variety. Comparisons between varieties were not made.

In the present study, correlation coefficients (Table 7) for the October 15 harvest were calculated for each treatment. Per-pot values were used rather than those of individual beets because of the association (competition, exposure, etc.) between the two beets in the same pot. Correlations computed from individual root values show more significant values (positive and negative), but the conclusions are the same.

Table 7.—Correlation Coefficients for Weighted Mean Sucrose Percentage Versus Total Beet Weight per Pot for the October 15 Harvest (n = 10).

N Level	Planting Date	Location: Berkeley	Location: Davis
+ N	March 1	+ 0.181	— 0.141
	May 1	— 0.055	— 0.261
	June 1	+ 0.378	— 0.352
— N	March 1	+ 0.138	+ 0.030
	May 1	+ 0.584	— 0.222
	June 1	— 0.643	— 0.326

Required r-values (n = 10): $r_{.05}$ = 0.602 $r_{.01}$ = 0.735

Considering the values in Table 7, the only significant correlation (negative) was with the June 1 minus-nitrogen beets at Berkeley: the May 1 minus-nitrogen beets at the same location approached a significant positive value. Thus the most likely conclusion from these correlations is that the open-pollinated variety, US 75, over a wide range of root sizes and nitrogen nutrition conditions, shows little or no genotypic (within a treatment) correlation between beet root size and sucrose percent. It may be possible that the selective thinning for uniform vigorous plants reduced the genetic variability for root size. However, seedling stands were generally quite uniform and the only obvious selection pressure was against late-germinating plants and plants weakened by seedling diseases.

The inverse relationship between beet root size and sucrose percent shown in these experiments by the minus-nitrogen plants is an environmental, or phenotypic (6), correlation. With high nutrition, the highest sucrose values observed under favorable environmental conditions (cool nights and long days) are about 16 percent (17). Thus, under field conditions, when using high sucrose percent, say 16 percent or over as a selection base, the plants selected may have merely been situated in a favorable micro-environment for the phenotypic expression of high sucrose. Appreciable genetic variability may exist relating to the response of the sugar beet plant to cool temperatures and nitrogen deficiency but other environmental effects may be so variable under field conditions that such selections, though desirable, would have low heritability.

The results reported here indicate that one way to reduce environmental variability appreciably, and hence increase heritability, would be to avoid any degree of nitrogen deficiency among the plants to be selected for high sucrose percent. If it appears desirable to select under "normal field conditions," i.e., deficient nitrogen at harvest time, sucrose percent will have little meaning unless the degree and length of the nitrogen deficiency is uniform for all plants. Such uniformity cannot be achieved in the field, and appears possible only in nutrient culture. Since for any one planting date sucrose yields were equal at both nitrogen levels, a low nitrogen selection might be made more effectively on the basis of sucrose yields (8) than on sucrose percentages alone.

Summary

The responses of sugar beets to nitrogen depletion in relation to root size were investigated outdoors at Berkeley and Davis, California, using ten-gallon cans with vermiculite and nutrient solutions as a culture medium. Three root size classifications were obtained by planting beets on three different dates: March 1, May 1, and June 1. All plants were watered daily with a complete nutrient solution until August 15. Then one group of pots continued to receive complete solution while the other

group was watered with a solution lacking nitrogen. Harvests were made on August 15 and October 15.

On October 15, plus-nitrogen beets, regardless of root size (planting date), had uniform top development and sucrose concentration at each location. The minus-nitrogen plants had smaller (typical nitrogen-deficient type), tops and lower root yields than the plus-nitrogen plants. Sucrose concentrations, however, were much higher and showed a striking inverse relationship to mean root size. Sucrose yields, however, were about equal for plus- and minus-nitrogen beets. Starting from a high-nitrogen status, small beets increased faster in sucrose concentration with the onset of nitrogen deficiency than did large roots.

Under plus-nitrogen conditions, sucrose percentages in the crowns were slightly less than in roots. Under minus-nitrogen conditions, sucrose concentrations increased in both roots and crowns, with the largest increases observed for roots.

Within each treatment (planting date x nitrogen level combination) there was no evident correlation between sucrose concentration and beet root weight, indicating that such correlations when observed are largely environmental responses and not inherent properties of large or small roots.

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