

Effect of Leaf Area and Nitrogen on Root Weight and Sucrose of Sugarbeets¹

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Introduction

New cultural practices and varieties have played a major role in more efficient crop production. Selection for disease resistance and yielding ability of necessity have been emphasized. Until recent hybridizations, sugarbeet varieties generally had a broad genetic base and phenotypically were exceedingly heterogeneous. The range in phenotypic characters and performance of individual plants of the variety produced a large standard deviation from the mean. Consequently, the average performance of the variety was suboptimal as compared with a selection within the variety. The selection would eliminate some of the plants with the least desirable characteristics.

Plant characters, such as root-shoot ratio, leaf-area accretion, leaf area in relation to root weight and sucrose production, and the effect of nitrogen nutrition on leaf area, which may affect the sucrose yield, have received little direct attention. In the quest for improved varieties a knowledge of the behavior of these characters in individual plants would be very useful in establishing more precise guidelines for selection.

Watson (2)³, in his review of the physiological basis of variation in yield, has emphasized that the yield of a green plant is a function of its photosynthetic area; and he has cited data for a number of crops which relate yield per unit of land to the leaf area which covers the land. The ratio of leaf area/land area has been designated "leaf area index" (LAI). He points out that LAI depends on plant population as well as leaf area per plant and that maximum yield occurs within a limited LAI. The plant population may be adjusted easily by altering the row width and the spacing of plants within the row to attain the desired LAI.

Although the leaf area of a plant influences the yield of that plant, relatively little is known about the efficiency of leaf area in producing the commercially usable portion of the plant, i.e.

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³ Numbers in parentheses refer to literature cited.

fruits, seeds, or roots. Apparently, plants that produce a relatively large portion of usable product for a given leaf area can be selected. In sugarbeets maximum yield of recoverable sucrose per acre is dependent upon tonnage of roots and the pounds of sucrose that can be recovered per ton. Thus, in addition to plant population, the efficiency of the leaf area in producing root weight and sucrose probably contributes to the sucrose yield per unit land area under field conditions.

Ulrich (1) observed that low temperature in conjunction with restricted nitrogen nutrition accelerated sucrose accumulation in sugarbeet roots. He also reported large differences in the fresh and dry weights of leaves from plants on continuous nitrogen as compared with those receiving no nitrogen for a period prior to harvest.

This paper 1) relates leaf area of individual plants to a number of aspects of growth and yield; 2) presents evidence that individual plants, as well as varieties, differ in efficiency of producing root weight and sucrose; and 3) indicates the effect of altering nitrogen nutrition in the latter part of the growing season on leaf area, root weight, and sucrose accumulation of individual plants.

Methods and Materials

Experiments were conducted outdoors at East Lansing, Michigan, in 1961, 1962, 1963, and 1966. The sugarbeet plants were grown in tiles (15 inches diameter, 24 inches high) spaced on at least 28-inch centers on a wooden platform or on concrete slabs. The lower portion of the tile was filled with builder's sand (16 inches in 1961 and 11 inches thereafter). Vermiculite was placed on the sand to within two inches of the top of the tile.

A number of seeds were planted near the center of the tile. As the seedlings grew, they were thinned to avoid competition. The largest seedling in each tile was permitted to grow until final harvest. In 1961 and 1962, seeds from a single plant of the variety US 401 were used. For comparison with US 401 in 1962, 14 plants of monogerm hybrid 62B1x05 were grown. In 1963 and 1966, the monogerm hybrids 63B1x07 and 63B1x010 were grown, respectively.

Mineral nutrient solution of the following compositions, expressed as grams of salt per liter, was used: $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ — 0.4723, NH_4NO_3 — 0.0801, KCl — 0.2982, KNO_3 — 0.4044, KH_2PO_4 — 0.0681, $\text{NH}_4\text{H}_2\text{PO}_4$ — 0.2302, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ — 0.3697, H_3BO_3 — 0.00075, $\text{MnSO}_4 \cdot 2\text{H}_2\text{O}$ — 0.00075, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ — 0.00009, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ — 0.00003, $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$ — 0.00008, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ — 0.0090, sequestrene — 0.0100. The com-

plete mineral nutrient solution was applied daily to the growing plants, except for certain nitrogen treatments in the latter part of the growing season. As the plants grew the volume applied per tile was increased to 4 liters daily. The tiles usually flushed daily, but periodically the tiles were flushed with tap water to minimize the accumulation of salts. In 1961 the tiles were flushed with water on August 1; and some of the plants received no nitrogen after that date. In 1962 the plants were measured for leaf area in a five-day period and four plants of comparable leaf area on August 1 were designated as a replication. Seven groups of four plants comprised the seven replications. Within each replication, one plant received nutrient solution with the full concentration of nitrogen continuously until harvest; a second plant received nutrient solution without any nitrogen after August 2. The third and fourth plants within the replication received nutrient solution with half the concentration of nitrogen after August 2, and then the third plant received no nitrogen after August 30 and the fourth plant none after September 27. The progressive withdrawal of nitrogen was an attempt to simulate the nitrogen nutrition under field conditions. Additional plants, not a part of the nitrogen nutrition experiment, received nitrogen continuously until harvest. In 1963 and 1966, the plants received nitrogen continuously.

The plants were sprayed with insecticides as needed to minimize the detrimental effect of aphids and worms. A systemic insecticide was used once or twice each season to minimize damage from root aphids.

At harvest in mid-October the weights of the leaves (blades plus petioles), crown, and root (portion below the lowest leaf scar) were recorded for each plant. In 1961 and 1962 the total leaf area at harvest was measured on as many plants as possible.

Leaf areas were determined repeatedly on the same living plants by methods that avoided injury to the plants. Leaf areas were measured with area grids or by tracing the leaves on tracing paper and planimetry. For the August 1, 1962 grouping of plants, a rapid method, based on length and width of leaf blades, was used. The essential steps of the procedure⁴ included measurements of the length and maximum width (measured perpendicular to the longitudinal axis) of the leaf blades, calculation of a leaf width/length factor for each plant, and the use of a factor established from a regression line of the leaf width/length factor versus a correction factor which would closely approximate the actual leaf area as determined by planimetry.

⁴Complete details of the procedure may be obtained from author upon request.

Results

Leaf-area Accretion

A typical leaf-area accretion curve for a non-competitive sugarbeet developed from seed planted on May 1 outdoors at East Lansing, Michigan, is shown in Figure 1. The logarithmic increase in leaf area was striking between 2 and 512 cm². Within this range leaf area doubled rather consistently every three days. Thereafter, doubling-time increased gradually. Sometime between 90 and 120 days after planting, the maximum area of primary leaves was attained. The leaf area of certain plants continued to increase until harvest through copious production of axillary leaves. Other plants, growing under the same environmental conditions, produced relatively few axillary leaves. Axillary leaf production appears to be under genetic control and undoubtedly is influenced by a number of environmental factors.

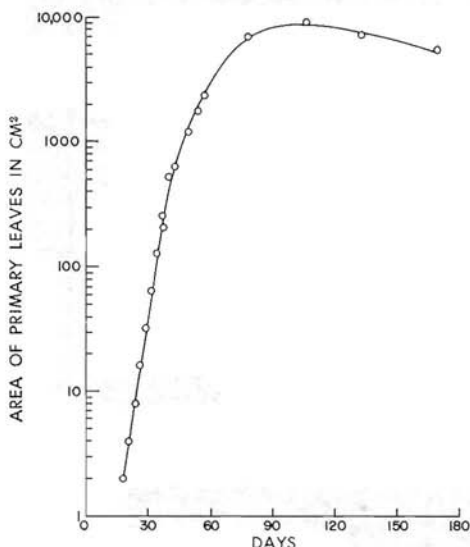


Figure 1.—Typical curve of primary leaf-area accretion for non-competitive sugarbeet grown outdoors in a tile supplied with mineral nutrient solution at East Lansing, Michigan.

In 1961 the seedlings began to emerge on May 9. The maximum and minimum leaf areas per plant for 1961 were the extreme values among 30 plants measured at selected times (Table 1). In 1962 the seedlings began to emerge on May 7. The leaf-area maxima and minima for the 46 individual plants were similar to those in 1961 (Table 1). In both years, the areas varied greatly among plants.

Table 1.—Range in leaf-area accretion of individual sugarbeet plants (variety US 401) grown outdoors in tiles with adequate mineral nutrition and without competition.

Days from plant.	Approx. calendar date	Leaf area in cm ²									
		1961				1962					
		Minimum		Maximum		Minimum		Maximum		Average	
		Actual	Log ₂	Actual	Log ₂	Actual	Log ₂	Actual	Log ₂	Actual	Log ₂
28	May 31	7	2.81	19	4.25	7	2.81	40	5.32	21	4.39
33	Jun 5	19	4.25	58	5.85	10	3.32	128	7.00	—	—
38	10	107	6.74	210	7.71	53	5.73	385	8.59	—	—
43	15	272	8.08	633	9.30	128	7.00	1,020	9.99	449	8.81
49	21	585	9.19	1,260	10.29	—	—	—	—	—	—
54	26	855	9.73	1,980	10.94	—	—	—	—	—	—
57	29	1,085	10.08	2,650	11.36	—	—	—	—	—	—
78	Jul 20	2,820	11.46	8,130	12.98	—	—	—	—	—	—
90	Aug 1	3,120	11.60	8,230	13.00	2,900	11.50	9,600	13.23	6,770	12.72
170*	Oct. 20	7,599	12.88	27,082	14.72	2,510	11.29	20,076	14.29	8,625	13.07

*At harvest, area included both primary and axillary leaves.

The large differences in leaf area of individual plants on a given date in 1961 did not seem to be caused solely by dates of emergence. Therefore, the 1962 experiment was designed to examine each seedling as it emerged to determine what may affect leaf-area accretion. Dates were recorded when each seedling emerged and when the leaf area was 2 cm² and subsequently each time it doubled. Of the 135 small seedlings examined, 50 were free of attack by damping-off fungi; and 76 were discolored in varying degree by fungal attack in the hypocotyledonary and transition-zone areas. Nine to 19 days were required after emergence (17 to 27 days from time of planting) to attain 2 cm² of leaf area. The average number of days required for 55 healthy versus 74 diseased seedlings to attain 4 cm² suggested that the diseased seedlings may have a somewhat slower rate of leaf-area accretion.

After the seedlings were thinned to one per tile, measurements of leaf-area accretion were continued on 46 of them. Seedlings required from 11 to 20 days to increase leaf area from 2 to 64 cm². The mode was at 14 days. From emergence until the seedlings attained 64 cm² of leaf area, the average time for the seedlings that had been attacked by fungi was approximately 5% greater than for the non-diseased seedlings. These seedlings were kept because of the greatest leaf growth and the seedlings with the most severe fungal attack were discarded in the thinning operation. Thus, no data on the effect of a more severe fungal attack on leaf area accretion were available.

The range in leaf-area accretion for healthy seedlings in 1962 is illustrated by plants number 7 and 43. Both plants attained 2 cm² on the same day. Fourteen days later, plant #7 had 512 cm² of leaf area, whereas #43 had 64. Expressed in terms of the number of times the leaf area doubled, plant #7 had doubled its leaf area nine times while plant #43 had doubled its area only six times. At harvest, plant #43 still had a relatively small leaf area. In 1962, individual plants, which received a complete nutrient solution until harvest, had leaf areas at harvest which ranged from 2,510 to 20,076 cm² or expressed as log_e, 11.29 to 14.28. (These logarithmic values indicate the number of times leaf area doubled on each plant after attaining 2 cm².)

For seedlings grown under uniform conditions, these data indicate that differences in leaf area of seedlings at any given time may result from different dates of emergence, a possible retarding effect by attack of damping-off fungi, and probable differences in genetic potential for leaf-area accretion. The data for the entire growing season also strongly suggest that plants differ in their genetic potential to accrete leaf area.

Number of Leaves

In 1961, plants, grown hydroponically, produced from 70 to 113 primary leaves in approximately 160 days. The range in number and size of living primary leaves on different plants of US 401 during the growing season was great (Table 2). Similar ranges were noted in 1962.

Table 2.—Range in number and size of living primary leaves of sugarbeet variety US 401 during growing season, 1961.

Date	Number	Avg size in cm ²
June 26-29	18-25	47-93
July 19-Aug. 10	27-55	94-214
Oct. 16-20	27-54	+N nutrition 35-121 -N nutrition 25-50

The leaves were numbered in order of development. Leaves numbers 20 through 30 usually had the largest area. Even though there was ample time for expansion, leaves that developed later chronologically failed to become as large. While the number of live primary leaves may remain almost constant or increase slightly, the total area of primary leaves later in the season will decrease because the very large leaves die, and they are replaced by smaller leaves. Nitrogen deficiency tends to hasten the death of older leaves, reduce the size of developing leaves, and may reduce the number of living leaves.

Stewart⁵ observed in the field at Rocky Ford, Colorado that the longevity of the first leaves that developed was 25 to 40 days. Leaves that developed later had a longer life-span. Observations in 1961 confirm those of Stewart. Leaves numbers 20 to 30 generally expanded between June 15 and 30 and had a life-span of about 70-80 days. Leaves that expanded about August 1 remained functional until harvest in mid-October. At harvest, the first 40 to 60 leaves had died or were nonfunctional.

Correlation of Leaf Area with Leaf Weight

At harvest the leaf weights (blades plus petioles) were determined for all plants on which planimetered leaf areas were made. In 1961 the correlation coefficient was 0.937 for 14 plants; and in 1962, 0.956 for 28 plants. These data were for plants of variety US 401 that received nitrogen until harvest, as well as others under three levels of nitrogen stress in 1962. Another group of 16 plants, including 10 of variety 62B1x05 and six of US 401, had a coefficient of 0.958. The correlation may be sufficiently high for many studies so that leaf weights may be taken, and by use of a regression line, an approximation of leaf area per plant may be obtained for any given variety.

⁵ Dewey Stewart, Former Leader, Sugarbeet Investigations, ARS, U.S. Department of Agriculture—written communication on unpublished research.

Relation of Leaf Area and Weight, Root Weight, and Sucrose Content as Influenced by Nitrogen Nutrition

1961 Experiment: Twenty-three plants were harvested between October 16 and 20. Only 12 of the plants had comparable leaf areas to permit valid comparisons within the nitrogen treatments. The influence of leaf area and nitrogen nutrition on root weight and sucrose content is pronounced (Table 3). The total leaf area of plants on continuous nitrogen until harvest increased markedly over that of August 1. Development of axillary leaves was largely responsible for the increased area. In contrast, at harvest, the plants on restricted nitrogen had about 68% of the leaf area they had on August 1. The dependence of root weight on leaf area was demonstrated clearly for plants receiving continuous nitrogen, where a genetic potential for leaf-area accretion seemed to operate; as well as where leaf area was controlled by a lack of nitrogen. Although the lack of nitrogen decreased root weight, the sucrose in the root was sufficiently greater to yield total sucrose per root about equal to plants on adequate nitrogen.

Table 3.—Influence of leaf area and nitrogen on root weight and sucrose content of sugarbeet variety US 401 in 1961*.

Nitrogen Nutrition	Leaf area cm ²			Root weight at harvest	Sucrose in root
	Primary Leaves		All leaves		
	August 1	Harvest	Harvest		
Continuous	4,150 ± 1,187	3,386 ± 1,078	8,920 ± 1,590	1,355 ± 629	147 ± 80
Continuous	7,233 ± 671	4,758 ± 1,290	16,140 ± 7,703	2,320 ± 713	265 ± 72
None applied after Aug. 2	7,318 ± 1,067	1,742 ± 773	4,969 ± 2,546	1,874 ± 230	272 ± 27

* Each value represents mean with standard deviation for 4 plants.

1962 Experiment: Recall that four plants with closely matched leaf areas constituted a replication, and that each plant in the replication was on a different nitrogen regime. August 1 leaf area correlates well with the various weights (Table 4). The almost constant ratio between August 1 leaf area and root weight at harvest may be of special significance, particularly since the plants in the different replications were selected to give a range in leaf areas. The value under each nitrogen regime in Table 5 is an average of seven plants, one from each replication. The analysis of variance data for the effect of nitrogen on root weight was significant at the 10% level, but not at 5%. With a more uniform variety and with a larger sample, the chances for demonstrating that the differences are real, would be improved. The

Table 4.—Comparison of averages of replications having differing leaf areas on August 1 (sugarbeet variety US 401 grown in tiles in 1962).

Replic. number	Leaf area*		Weights in g at harvest					Ratios	
	August 1	Harvest	Leaf	Crown	Root	Total plant	Sucrose in root**	August 1 leaf area	August 1 leaf area
	cm ²	cm ²						Root wt.	Total plant wt.
1	4,140	2,886	406	192	1,103	1,761	164	3.56	2.35
2	5,475	2,831	393	274	1,544	2,211	184	3.55	2.48
3	6,700	4,888	644	370	1,879	2,893	239	3.57	2.32
4	7,250	7,100	985	369	1,892	3,246	260	3.83	2.23
5	7,875	10,631	1,327	451	2,225	4,003	305	3.54	1.97
6	8,315	11,790	1,417	520	2,333	4,270	292	3.56	1.95
7	8,575	12,833	1,630	567	2,423	4,620	317	3.54	1.86

* Each value is an average of four plants.

** Total sucrose.

Table 5.—Influence of nitrogen nutrition on performance of sugarbeet plants (US 401), paired for leaf area on August 1, grown outdoors in tiles at East Lansing, Michigan in 1962.

Character	Nitrogen applied in nutrient solution			
	Continuous	None after Sept. 27	None after Aug. 30	None after Aug. 2
Leaf area, primary leaves in cm ²	8,854	6,441	6,257	4,438
Leaf area, all leaves	9,887	7,329	7,155	5,891
Leaf weight in g	1,192	1,034	993	757
Crown weight	478	356	393	340
Shoot weight*	1,670	1,390	1,296	1,097
Root weight	1,829	2,173	2,036	1,653
Sucrose in root	225	276	277	228
Ratios of				
Crown/Root	0.26	0.16	0.19	0.21
Root/Shoot	1.10	1.56	1.57	1.51
Root/Total plant wt.	0.52	0.61	0.61	0.60
Root wt./Leaf wt.	1.53	2.10	2.25	2.18
Root + crown/Leaf wt.	1.94	2.45	2.69	2.63
Sucrose in Root/Leaf wt.	0.19	0.27	0.31	0.30
Leaf area/Root wt.	5.41	3.37	3.51	3.56
Leaf area/Sucrose in root	43.9	26.6	25.8	25.8

* Leaves + crown

harvest data for leaf area, and leaf, crown, and shoot weights were not affected significantly by the nitrogen regimes used in the experiment. On the other hand, the structuring of the plants into replications of uniform leaf area, as of August 1, caused significant differences in leaf area, and leaf, crown, and shoot weights among some of the replications at harvest (Table 6).

In comparing the leaf areas at harvest, nitrogen nutrition had relatively less effect on leaf area than did the August 1 grouping of the plants for leaf area. In Table 5, leaf area ranged from 9,887 cm² ($2^{13.26}$) for the continuous nitrogen treatment to 5,891 ($2^{12.52}$) for the treatment in which nitrogen was withheld after August 2. In Table 6, the mean leaf areas at harvest for the replications varied from 2,831 cm² ($2^{11.16}$) to 12,833 ($2^{13.64}$). The variable leaf area (Table 6) required a difference greater than one unit in the exponential power of \log_2 for significance. In contrast to the lack of significance for this range in leaf area, root weight was significantly affected within a much narrower range of leaf area (See root weight data, Table 6). In Table 6, with the exception of Replication #4, the mean leaf areas for August 1 plotted against root weight at harvest produce an almost perfect straight line. Since the leaf area of the individual plants at harvest varied greatly, it is apparent that the leaf area at harvest did not correlate well with root weight.

Table 6.—Analysis of variance of harvest data for the May 1 planting of sugarbeet variety US 401 grown outdoors in tiles in 1962.

Aug. 1 Leaf area	Repl. no.	Leaf area			Leaf weight			Crown weight		
		Mean	Significance		Mean	Significance		Mean	Significance	
cm ²		cm ²	5%	1%	g	5%	1%	g	5%	1%
4,140	1	2,886	a	a	406	a	a	192	a	a
5,475	2	2,831	a	a	393	a	a	274	ab	ab
6,700	3	4,888	a	ab	644	ab	ab	370	bc	abc
7,250	4	7,100	ab	abc	985	bc	abc	369	bc	abc
7,875	5	10,631	bc	bc	1,327	cd	bc	451	cd	bc
8,315	6	11,790	c	c	1,417	cd	c	520	cd	c
8,575	7	12,833	c	c	1,630	d	c	567	d	c
		R-value	4.592	6.015	—	589	772	—	172	225
	Repl. no.	Shoot weight			Root weight					
		Mean	Significance		Mean	Significance				
		g	5%	1%	g	5%	1%			
	1	598	a	a	1,163	a	a			
	2	667	ab	a	1,544	ab	ab			
	3	1,014	ab	ab	1,879	bc	bc			
	4	1,354	bc	abc	1,892	bcd	bc			
	5	1,778	cd	bc	2,225	cde	c			
	6	1,937	cd	c	2,333	de	c			
	7	2,197	d	c	2,423	e	c			
		R-value	699	915		452	592			

Variation Within and Among Varieties

Some of the extreme variations among the plants grown in 1961 and 1962 have been tabulated in Table 7. The ratios in the right-hand three columns indicate relationships and relative efficiencies of some of the commercially usable parts of the plants. These extremes indicate why correlations based on individual plants tend to be low, as compared with correlations based on averages of a number of plants.

Table 7.—Some examples of variations among two varieties of sugarbeet plants grown outdoors in tiles on complete mineral nutrient solution until harvest.

Year	Plant no.	Root wt.*	Crown wt.	Shoot wt.	Total leaf area at harvest	Ratios			
						Root Shoot	Crown Root	Total leaf area - harvest Root weight	
		g	g	g	cm ²	cm ² /g			
US 401									
62	43	520	238	1,315	6,351	0.40	0.46	12.21	
61	13	834	369	1,596	9,804	0.52	0.44	11.76	
62	17	1,590	183	540	2,554	2.94	0.12	1.61	
61	16	1,594	1,722	3,510		0.45	1.08		
62	3	1,778	398	1,014	4,599	1.75	0.22	2.59	
62	20	2,300	875	3,432	20,076	0.67	0.38	8.73	
61	1	2,390	1,070	4,138	27,082	0.58	0.45	11.33	
61	2	3,155	915	2,383	15,403	1.32	0.29	4.88	
62	9	3,255	560	3,050		1.07	0.17		
62B1x05 Hybrid									
62	50	1,973	616	1,710	8,975	1.15	0.31	4.55	
	53	2,045	203	950	5,852	2.15	0.10	2.86	
	87	2,115	257	930	6,973	2.27	0.12	3.30	
	49	3,180	473	2,115	12,939	1.50	0.15	4.07	
	84	3,715	710	2,790	15,615	1.33	0.19	4.20	

* Portion below lowest leaf scar.

The variation and relationships for a number of weight attributes of four varieties are indicated by means of correlation coefficients (Table 8). The relatively small number of plants in the samples probably accounts for some of the differences in magnitude and significance. However, relatively consistent patterns of relationship emerge from the data for the four varieties. The first four lines of correlations of Table 8 are valid single correlations, while the last six lines have "built-in" combinations which contribute to the larger correlation coefficients.

The tendency toward low correlation coefficients between the weights of root and the weights of leaves and of crown for US 401 and the hybrids is evident. Only variety 62B1x05 has a high correlation between roots and leaves. Except for hybrid variety 63B1x07, the correlation coefficients are relatively low for weights of leaves versus weights of crown. The data suggest

Table 8.—Correlation coefficients for various weight attributes of sugarbeet plants grown outdoors in tiles on continuous nitrogen until harvest in October.

Attributes	Correlation coefficients for						
	Year	1961		1962		1963	1966
	Date	May 3	May 1	May 15	May 1	May 20	May 2
	Plant. Var.	US 401	US 401	US 401	62B1x05	63B1x07	63B1x010
Root vs. Leaves		0.145	0.693**	0.460	0.903**	0.493*	0.533**
vs Crown		0.336	0.537*	0.387	0.623*	0.503*	0.539**
vs Shoot		0.244	0.682**	0.483	0.887**	0.506*	0.590**
Leaves vs Crown		0.343	0.778**	0.516*	0.679*	0.899**	0.569**
Shoot vs Leaves		0.936**	0.985**	0.985**	0.980**	0.993**	0.965**
vs Crown		0.652**	0.876**	0.657**	0.812**	0.946**	0.765**
Total vs Leaves		0.759**	0.937**	0.942**	0.967**	0.906**	0.843**
vs Crown		0.653**	0.797**	0.653**	0.734**	0.878**	0.733**
vs Shoot		0.858**	0.941**	0.961**	0.969**	0.917**	0.894**
vs Root		0.708**	0.889**	0.699**	0.974**	0.809**	0.889**
No. plants in correlations		16	17	15	12	18	55
r 5%		0.497	0.482	0.514	0.576	0.468	0.267
r 1%		0.623	0.606	0.641	0.708	0.590	0.345

that the hybrids may differ in the relationship of these various characteristics to such a degree that sugarbeet breeders can synthesize hybrids with more favorable characters. Recently, we obtained evidence^a that the proportion of root and shoot in the sugarbeet is under genetic control.

The relation of leaf area during the growing season to some of the plant attributes which influence yield is indicated in Table 9. Generally, leaf area does not correlate as highly with root weight and total plant weight as would be predicted. Leaf area of the plants in June correlates relatively poorly with the weights at harvest. As the growing season progresses into July and August, leaf area tends to correlate better with the weights at harvest.

The most surprising result of this study was the low correlation between leaf areas of the same living plants at different times during the growing season. For example, leaf areas taken on June 12 and 26, only 14 days apart, correlated 0.792**, while the June 12 and July 30 data correlated 0.477. Only three coefficients out of 10 exceeded 0.750, and six of them were less than 0.500. Further studies would be needed to determine a possible cause for the poor correlations.

^a Presented orally as "Evidence for Genetic Control of the Proportion of Root and Shoot in Sugarbeet" by F. W. Snyder, G. J. Hogaboam, and R. C. Zielke at 15th General Meeting of Am. Soc. Sugar Beet Technol.

Table 9.—Correlation coefficients for leaf areas versus various attributes of sugarbeet plants grown outdoors in tiles on a complete nutrient solution until harvest in October.

Attributes	Correlation coefficients for				
	Year	1961		1962	
	Date Variety	May 3 US 401	May 1 US 401	May 15 US 401	May 1 62B1x05
Leaf area vs leaf area					
June 12 vs June 26			0.792**		
June 12 vs July 30			0.477		
June 12 vs Mid-Oct.			0.462		
June 26 vs mid-Oct.		0.758*	0.668* [@]		
July 30 vs mid-Oct.			0.810**		
June 15 vs July 12				0.403	
June 15 vs Aug. 15				-0.367	
July 12 vs Aug. 15				0.262	
June 15 vs Aug. 9					-0.383
Leaf area vs leaf weight					
June 12 vs mid-Oct.			0.523* [#]		
June 26 vs mid-Oct.		0.415	0.783**		
July 30 vs mid-Oct.			0.819**		
June 15 vs mid-Oct.				0.238	
July 12 vs mid-Oct.				0.343	
Aug. 15 vs mid-Oct.				0.324	
June 15 vs mid-Oct.					-0.179
Aug. 9 vs mid-Oct.					0.454
Leaf area vs root weight					
June 12 vs mid-Oct.			0.699** [#]		
June 26 vs mid-Oct.		0.796**	0.624*		
July 30 vs mid-Oct.			0.785**		
Mid-Oct. vs mid-Oct.		0.529	0.600*		
June 15 vs mid-Oct.				0.168	
July 12 vs mid-Oct.				0.333	
Aug. 15 vs mid-Oct.				0.503	
June 15 vs mid-Oct.					-0.236
Aug. 9 vs mid-Oct.					0.426
Mid-Oct. vs mid-Oct.					0.948**
Leaf area vs total plant weight					
June 12 vs mid-Oct.			0.684** [#]		
June 26 vs mid-Oct.		0.716**	0.823**		
July 30 vs mid-Oct.			0.876**		
June 15 vs mid-Oct.				0.235	
July 12 vs mid-Oct.				0.412	
Aug. 15 vs mid-Oct.				0.434	
June 15 vs mid-Oct.					-0.119
Aug. 9 vs mid-Oct.					0.445
No plants in correlations		10-13	15-17 [@] 10 [#] 21-25	14-15	10-11

Discussion

The physiological principle that yield is a function of leaf area is valid. Although data on individual sugarbeet plants presented herein appear to deviate from this principle, genetic variability in other parameters which contribute to yield (whether expressed as total yield, root yield, or sucrose yield) most likely account for the deviations noted. Since each parameter may vary independently, and since each plant may have a somewhat different combination of these parameters, yield and leaf area in the unselected grouping of plants examined in this study tended to correlate less closely than anticipated on the basis of a physiological principle. Some of the parameters which appear to be operative are: 1) Leaf-area accretion, which may be divided into production of primary and axillary leaves; 2) root weight; and 3) probably crown weight. In Table 7 for example, plant #84 had a large leaf area and a large root, plant #1 had a very large leaf area and a relatively small root, plant #43 had a small leaf area coupled with a small root, and plant #17 had a small leaf area in relation to a relatively large root. Thus, excluding a possible crown-weight parameter, the four possible combinations could account for the poor correlation between leaf area and root weight. When different indices of efficiency are calculated, such as the last column in Table 7, the values for individual plants may vary greatly. Large deviations in the value of an index calculated for individual plants may indicate that the two items will not be highly correlated.

In attempting to assess the role of leaf area in growth of plants, leaf area expressed as a logarithmic function (\log_2) is a very valuable concept because it focuses attention on the rate of doubling. To illustrate, an increase from two (2^1) to four (2^2) cm^2 of leaf area is a doubling. This increase of 2 cm^2 of leaf area in the early life of the plant is as significant as an increase from 4,096 (2^{12}) to 8,192 (2^{13}) cm^2 in the later life of that plant. On an arithmetic basis, a leaf area of 5,822 cm^2 as compared with 4,096 would appear capable of supporting a substantial increase in yield for a given plant; since it represents an increase of 1,726 cm^2 of leaf area, or slightly over 42% more leaf area. However, expressed on a logarithmic basis, 5,822 is $2^{12.5}$ and this increase of 1,726 actually is only a half unit in terms of leaf-area doubling. In these studies the relation of leaf area to root weight and total weight at harvest for individual sugarbeet plants was sufficiently variable to require an exponential difference of at least 0.5 in leaf area to detect any difference in root or in total plant weight.

Individual plants differ in the rate at which leaf area accretes, particularly during the early seedling stage. The large differential in the rate of accretion by plants #7 and #43 in 1962 suggests that individuals may contain varying quantities of the factors which control leaf-area accretion. If the mechanism of accretion were understood, it might be possible to manipulate the plants to accrete leaf area more rapidly and thus trap more radiant energy for photosynthesis. Particularly for a short growing season, yield might be increased by selecting plants which accrete leaf area more rapidly.

The correlation studies of individual plants within the varieties indicate a number of aspects which merit further attention. Although the three hybrids had slightly higher correlation coefficients for most of the characters than the broad-base variety US 401, the values were lower than expected. The low correlation coefficients indicate considerable variability in the relationship of the correlated characters. Thus from the practical standpoint, the data indicate a significant potential for improving some of the characters, such as proportion of root to the other plant parts, through selection. Ideally, the correlation coefficients for characters of a hybrid should approach unity. To approach more nearly such desired uniformity in hybrids, each component of the hybrid may require selection for specific characters prior to synthesis into the hybrid.

The leaf-area accretion data, gathered as collateral information in this study of the relation of leaf area to yield, are interesting. The correlation data indicate that individual plants did not increase their leaf area in any consistent pattern; otherwise the correlations, involving the same living plants during the season, should have been higher. Although it is difficult to conceive how the climatic and nutritional environments of the plants in these experiments could have caused some individual plants to accrete leaf area slowly for a time and then speed up, (while other plants apparently were out of phase with this cycle of development), environment cannot totally be ruled out as a contributor to this behavior. While no evidence is presently available, this inconsistent pattern of leaf-area accretion among individuals of a variety might result from non-synchronized fluctuations in the hormonal controls of individual plants. In contrast, some plants differed consistently in the rate of accretion through most of the growing season. Plants that had a slower rate of accretion naturally tended to have smaller root and total weights than those that increased leaf area more rapidly.

A study of leaf-area accretion on young plants under more carefully controlled conditions would be profitable, particularly when the patterns of accretion between a genetically uniform cultivar of some species might be compared with the more genetically diverse sugarbeet cultivars.

In the present studies, the plants grew non-competitively. Unfortunately, very little is known about the possible modifying influence of plant competition on the genetic potentials for root-shoot and crown-root ratios, and root and leaf accretion. Under field conditions, certain sugarbeet plants, seemingly under similar competition, tend to grow larger than others. Presumably these plants have a greater genetic potential to become large in competitive conditions. While competition definitely reduces the overall size of the sugarbeet plant, we have no way of experimentally determining whether the percentages of deviation are similar for competitive and non-competitive conditions.

Summary

Single sugarbeet plants were grown outdoors at East Lansing, Michigan, in large tiles filled with sand and vermiculite. Some plants received a complete mineral nutrient solution until harvest, while others received no nitrogen after certain dates. Leaf areas were determined a number of times on the living plants during the growing season. Leaf areas were related to the weights of various plant parts and sucrose content of the roots at harvest.

Data on the individual plants indicate a large range in genetic potential. Within the range of 2 to 512 cm², leaf area doubled rather consistently every three days. Thereafter, doubling-time increased gradually. Leaf area accretion was not uniform for all plants, nor were the rates of accretion always synchronized. Leaf areas, obtained from approximately 40 to 100 days after planting, generally did not correlate very well with each other nor with the weights of the plant parts at harvest. However, the correlations usually improved as the samplings were made closer to harvest. The variability noted suggests that sugarbeet breeders could select successfully for the desired characters, such as improved root-shoot and crown-root ratios.

Withholding of nitrogen after August 2 reduced leaf area significantly by harvest and tended to reduce root yields, but not statistically significant (5% level) in the 1962 experiment. However, sucrose in the roots of plants deficient in nitrogen increased sufficiently to equal or exceed total sucrose in roots of plants on continuous nitrogen. Crown weights were reduced considerably by restricting nitrogen nutrition.

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