Leaf and Root Accretion by Sugarbeet Seedlings in Relation to Yield[1]

F. W. SNYDER[2]

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Yield is closely related to the length of the growing season for temperate-zone crops with indeterminate growth, such as sugarbeet. Since length of the growth period for a given geographic location varies but little from year to year, increases in yield must be achieved mainly through cultural and genetic manipulations. Once plant population has been adjusted to attain maximum yield, future increases in yield will require more sophisticated approaches to modifying crop species. Systematic study and exploitation of the physiologic and genetic regulation of leaf accretion should be one approach to future increases in yield. Sugarbeet cultivars of the future should be evaluated for 1) efficiency in producing grams of root and sucrose per unit leaf area or weight, 2) rate at which seedlings accrete leaf area and root weight, and 3) ability to accrete leaf area at lower temperatures in spring. Once the internal physiological control of leaf-area accretion is understood, accretion may even be accelerated by application of specific chemicals.

Heterosis probably increases yield via a more rapid growth rate and a more rapid accretion of leaf area, for at least part of the growing season (1,3,4,5,7,11)[3]. The growth rate of pearl-millet hybrids was significantly greater than that of the parents during only the first 10 days (12). Steward (9) points out that at a growth rate of 11%, an additional increment of 6% will double the growth in 100 days, if growth obeys the compound-interest law. Leaf areas and root weights of sugarbeets grown singly in large containers outdoors differed markedly (8). Night temperature affected shoot and root growth of sugarbeets (10).

Because of potentially large effects of environment on the size of sugarbeet plants under field conditions, large plant-to-plant variations are commonly accepted. The cause of the variation remains a topic of debate. To determine plant-to-plant variation with a minimum of environmental variation, a series of experiments was carried out in growth chambers. Specific objectives were to determine 1) size of variation in leaf and root accretion on seedlings within and among cultivars; 2) mean leaf areas for paired cultivars; 3) relation of leaf area,

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[2]Plant Physiologist, Agricultural Research Service, U.S. Department of Agriculture, East Lansing, Michigan 48823.

[3]Numbers in parentheses refer to literature cited.

leaf-blade weight, and root weight; 4) effect of temperature on leaf-area accretion; and 5) relation of seedling leaf areas and root weights in growth-chamber experiments to root weights attained in full-season field experiments for paired cultivars.

Methods and Materials

Sugarbeet (*Beta vulgaris L.*) seedlings, thinned to one plant per container very soon after emergence, were grown on vermiculite with an excess of complete mineral nutrient solution (see Table 1 for composition) applied daily to induce flushing.

For most experiments, plants were moved about the growth chamber every 2 days to minimize positional effects on growth. In one series of experiments with the plants in fixed positions in the chamber for the entire growth period, mean growth per plant by position was related to the illumination at that position. The plants received 14 hours of light (combination of fluorescent and incandescent) daily. Except for temperatures indicated in the two temperature experiments, day temperatures ranged between 25 and 28°C, and night temperatures between 15 and 17°C.

On termination of an experiment, leaves from each plant were photocopied and planimetered for area on one surface. Fresh weights of leaf blades, of petioles plus hypocotyl, and of the taproot were recorded for some experiments. Letter designations for each experiment and numbers for cultivars are consistent for all tabular data reported.

Leaf-Area Accretion in Seedlings

Leaf areas of plants of three cultivars repeatedly were closely estimated at 3- to 5-day intervals by means of plastic grids. The consecutive values for each plant were analyzed by linear correlation, beginning when leaf areas averaged at least 4 cm² per plant.

Table 1.—Composition of mineral nutrient solution.

Salt	Conc. in millimoles	Salt	Conc. in millimoles
$Ca(NO_3)_2 \cdot 4H_2O$	2	H_3BO_3	0.012
KH_2PO_4	0.5	$MnSO_4 \cdot 2H_2O$	0.004
KNO_3	4	$CuSO_4 \cdot 5H_2O$	0.00012
KCl	3	$ZnSO_4 \cdot 7H_2O$	0.00031
K_2SO_4	0.5	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.00006
$NH_4H_2PO_4$	2	$FeSO_4 \cdot 7H_2O$	0.032#
$MgSO_4 \cdot 7H_2O$	1.5		

#With sequestrene according to Geigy's liquid formulation.[5]

[5]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the United States Department of Agriculture, and does not imply its approval to the exclusion of other products that may also be suitable.

Leaf Area, Leaf Blade, and Root Weights Per Seedling for Cultivars

The plants were grown in 15-cm plastic pots. They were moved about the chamber on alternate days. Light for experiment F (Table 2) was 43,000 lux, with 21,500 lux for the other experiments. Plants within an experiment were harvested a specified number of days after emergence; however, the growth period for the different experiments ranged between 21 and 30 days.

Effect of Temperature on Leaf-Area Accretion

Twenty-four plants of cultivar US H20 were grown singly in 473-ml thermal containers. Leaf area was measured 20 days after emergence at each temperature. Illuminance was averaged for the growth chamber, and for the six temperature series it ranged from 15,300 to 18,550 lux. The day-night temperatures (duration of 14 and 10 h, respectively), adjusted within ± ½°C, were 15-5, 20-10, 20-15, 25-15, 25-20, and 30-20. These averaged as 11, 16, 18, 21, 23, and 26°C, respectively. The day temperature was measured by a thermometer centered on top of the container (out of the direct air flow from below).

Comparative Leaf-Area Accretion by Cultivars Grown at Two Temperatures

Under field conditions in the spring, seedlings of certain cultivars, by visual inspection, have greater leaf area than others. The differential could result from 1) different times of emergence, 2) genetically controlled rate of growth, or 3) differential response to temperature. To test this latter possibility, we grew ten plants of one cultivar, arranged alternately with ten of a second cultivar, for 21 days after emergence at 13 and at 22.5°C. Four pairs of cultivars were grown at each temperature. Mean relative growth rate for leaf area was calculated by the formula (6)

$$RGR_A = \frac{\ln A_2 - \ln A_1}{t_2 - t_1}$$

Relation of Seedling Parameters to Root Yield in Field Experiments

Leaf areas of 10 seedlings each of paired cultivars, grown for 21 days after emergence in growth chambers, were compared with root yields of the same cultivars grown in full-season experiments (at least two experiments in same year) in various states in the eastern sugarbeet-growing area of the United States.

Results

Leaf-Area Accretion in Seedlings

Correlation coefficients (r) for leaf area per plant at the consecutive time intervals ranged from 0.82 to 0.97, with 62% of the correlations exceeding 0.90. Most of the values below 0.90 were obtained with small leaves. When 8 to 11 days elapsed between measurements (initial areas about 15 and final areas 85 to 172 cm^2 for various experiments), r-values ranged between 0.67 and 0.94. While the association was less than perfect, the data indicated that leaf-area accretion for each plant was uniform enough to separate plants in the lowest and highest deciles with a high degree of accuracy, when leaf area per plant exceeded 100 cm^2.

Leaf Area Per Seedling Within Cultivars

Cultivars differ in degree of variation in leaf area among individual plants (Table 2). Mean leaf area for the low and the high 20% of the plants indicated the magnitude of differences much better than the mean of all plants and its standard deviation. If three standard deviations are added to the "low" mean leaf area and three are subtracted from the "high" mean, the values obtained do not overlap for cultivars 5, 6, 8, and 9 (the values for the other cultivars overlap or are very close to overlapping). Example for cultivar 5, Table 2: $630 + (43 \times 3) = 759$; $970 - (27 \times 3) = 889$. This type of test appears to measure diversity better than does the coefficient of variation (CV). The CV's for the cultivars (Table 2) ranged from 13.5 to 21.6%, and they did not relate consistently to the diversity as measured by the means of the low and high 20% of plants.

In repeated experiments with plants growing in fixed locations for the entire experiment, without any rotation about the growth chamber, the mean value for growth in each position was very closely proportional to the illumination at that position.

Relation of Shoot Parameters to Taproot Weight in Seedlings

I. *Within Cultivars:* Among individual seedlings of a cultivar, leaf area and leaf-blade and shoot fresh weights correlated significantly

Table 2.—Leaf area per plant for sugarbeet cultivars in growth chambers for 23 to 30 days after emergence.

Expt.	Cultivar #	No. of plants	Leaf area − cm^2 All plants avg	Low* avg	High* avg
A	1	30	221 ± 30	180 ± 14	264 ± 13
	2	30	193 ± 31	154 ± 16	243 ± 18
B	3	24	177 ± 27	140 ± 9	214 ± 12
C	4	40	465 ± 74	363 ± 29	560 ± 46
D	5	20	792 ± 121	630 ± 43	970 ± 27
	6	20	711 ± 121	514 ± 9	859 ± 39
E	7	18	614 ± 103	485 ± 18	753 ± 80
	8	20	604 ± 123	449 ± 58	731 ± 13
F	9	40	560 ± 121	393 ± 43	731 ± 52

#1 through 8 are hybrids, 9 is a pollinator.

*Averages for 20% of the plants at the low and the high ends of the ordered rank for leaf area.

with taproot fresh weight; however, the degree of correlation varied from r = 0.45 to 0.95, depending on the cultivar (Table 3). Correlation data for 12 cultivars show that the leaf-blade weight and shoot weight correlated with root weight in a manner very similar to that for leaf area. Since fresh weights are often easier to measure, leaf-area data for each seedling could be omitted in many instances.

II. *A Hybrid and Its Components:* In the single test made thus far, shoot parameters correlated more closely with root weight in the seedlings of the male and female components of the hybrid than in the hybrid seedlings (Expt G, H, I; Table 3).

III. *Among Cultivars:* Mean shoot parameters and root weight per seedling were correlated for eight cultivars in growth chamber experiments. Root weight correlated 0.72*[4] with leaf blade weight, 0.82** with leaf area, and 0.85** with shoot weight. When data for US H20 and its male and female components were deleted, so that a correlation for only five cultivars was calculated, root weight correlated with leaf area 0.994**. A graphic plot revealed that US H20 and its components produced relatively more root in relation to leaf area than the other five cultivars, and this accounted for the lower correlation coefficient for the entire group of cultivars.

Effect of Temperature on Leaf-Area Accretion by Seedlings

The logarithm of accrued leaf area plotted as a straight line in response to temperature over the range 11 to 26°C (Fig. 1). At a mean temperature of 11°C, leaf area doubled in about 5 days, and at 26°C in about 2 days. The mean relative growth rate during the 20 days at 11°C was 0.084 and at 26°C it was 0.293.

Table 3.—Correlation between root-weight and shoot parameters of sugarbeet seedlings in growth chambers.

Expt.			Cultivar	Degrees freedom	Characters	Correlation coefficients: Leaf area	Leaf blade wt.	Shoot wt.
					Root wt.			
C	4		(3-way cross)	38		0.47**	0.47**	0.45**
D	5		(3-way cross)	18		0.49**	0.65**	0.71**
	6		(3-way cross)	18		0.55**	0.53**	0.52**
E	7		(3-way cross)	16		0.62**	0.61**	0.69**
	8		(3-way cross)	18		0.66**	0.80**	0.82**
F	9	♂		38		0.74**	0.76**	0.78**
G	4		(3-way cross)	30		0.56**	0.60**	0.61**
H	10	♁	(2-way cross)	30		0.95**	0.94**	0.94**
I	11	♂		30		0.82**	0.83**	0.81**
J	12	♂		30		—	0.89**	—

*Denotes statistical significance at the 5% level and ** at 1%.

[4]*Denotes statistical significance at the 5% level and ** at 1%.

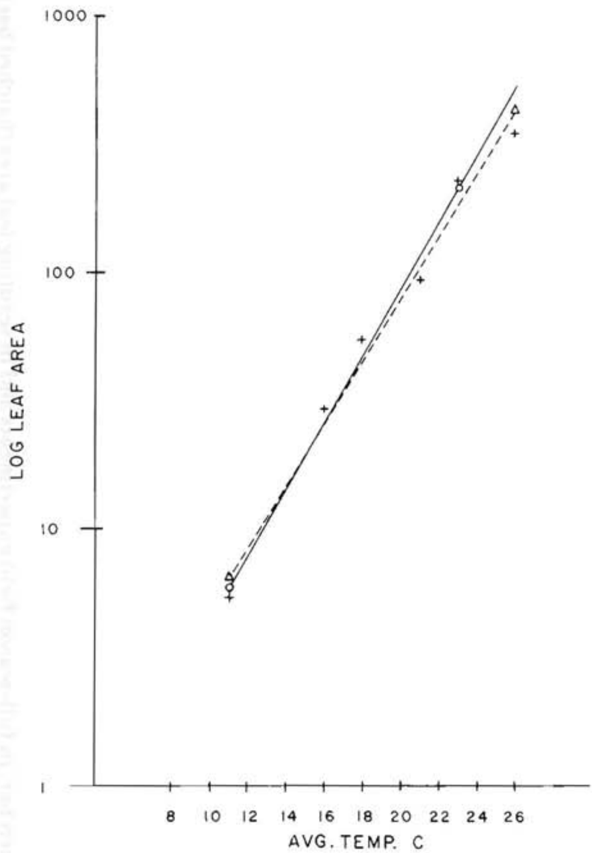

Figure 1.—Effect of temperature on leaf-area accretion by sugarbeet. + designates mean leaf area for each temperature. Dashed line is regression for all temperatures. Solid line is regression when data for 26°C are omitted. (See discussion.)

Comparative Leaf-Area Accretion by Cultivars Grown at Two Temperatures

The limited data in Table 4 suggest that it may be more difficult to detect differences in the rate of leaf-area accretion among cultivars grown at a mean temperature of 13°C than at a higher temperature.

Relation of Seedling Parameters to Root Yield in Field Experiments

Leaf area of sugarbeet 21 days after emergence in growth chambers was related to root yield in full-season field experiments (Fig. 2). Of 20 paired comparisons (18 plotted in Fig. 2), only four cultivars that had greater leaf area at 21 days failed to have consistently greater yield of roots. In three of these four comparisons, the cultivar with less leaf area at 21 days outyielded the one with more leaf area in only 1 year, when data for 2 or more years were available.

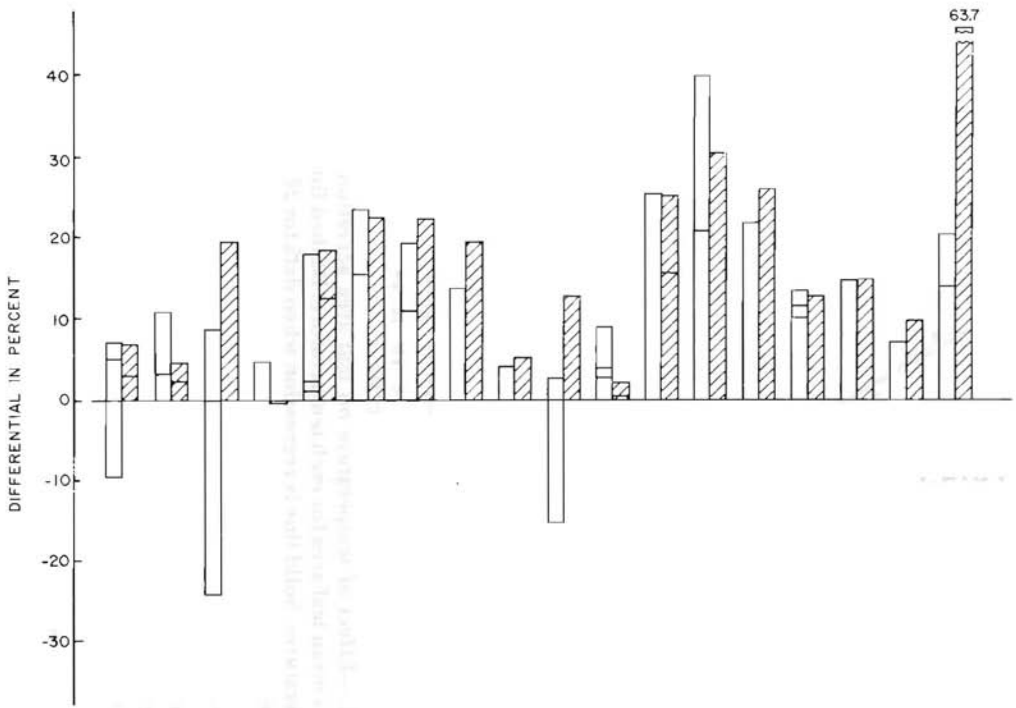

Figure 2.—The differential in root yield (open bar) in full-season field experiments and in seedling leaf area (hatched bar) 21 days after emergence in growth chamber is shown for 18 sets of paired cultivars of sugarbeet. Each horizontal line within the open bar denotes root yield data for a given year, some paired cultvars being tested 3 years. Leaf area data from a second comparison is indicated by a horizontal line within the hatched bar.

Table 4.—Leaf-area accrued by paired cultivars of sugarbeet at two mean temperatures for 21 days in growth chambers.

Cultivar	Mean temperature 13°C		Mean temperature 22.5°C	
	Leaf area	Ratio	Leaf area	Ratio
	Cm^2		Cm^2	
1	6.1 ± 1.2 #	1.089	162 ± 40	1.306
17	5.6 1.2 #	1.000	124 27	1.000
12	26.9 ± 7.3	1.269	214 ± 23	1.390
2	21.2 6.2	1.000	154 26	1.000
13	24.8 ± 6.1	1.000	239 ± 39	1.091
6	25.1 4.3	1.012	219 34	1.000
4	15.7 ± 3.8	1.026	231 ± 49	1.185
15	15.3 2.7	1.000	195 37	1.000

#This initial experiment at mean temperature of 11°C.

When both leaf area and root weight of the seedlings were compared for two pairs of cultivars, the cultivar with the larger leaf area and seedling root weight also had greater root yield in full-season field experiments.

Discussion

The large variation in root yield of mature individual plants of sugarbeet reported by Snyder (8) seems to be related to similar large plant-to-plant variation in both leaf area and root weight of seedlings in the growth chamber. Present evidence indicates that microenvironmental variations cannot account for the magnitude of the variation. Of perhaps greater significance is the question, "Does this large plant-to-plant variation contribute to a lower yield per unit of land?" We probably will not be able to answer this question until some screening and selection technique is available to remove the large variation and to test only the more rapidly growing plants.

Yield correlates positively with leaf area for the individual plant. The correlation data cited for seedlings indicate that the relationship between shoot parameters and root weight is established very early in the life of the plant. Also, the data clearly indicate that the degree of association between shoot parameters and root weight may vary considerably for different cultivars. For the single test of a 3-way-cross hybrid and its male and female components, the degree of association for the components was much greater than for the hybrid, thereby indicating that degree of association may not be predictable in advance. The rather low association between shoot parameters and root weight in the hybrid US H20 suggests that possible diverse physiological reactions may occur as different individuals of the male and female unite to produce hybrids.

In the effect of temperature on leaf-area accretion, the actual leaf area per plant in 20 days at 26°C was relatively lower than indicated by the regression for the other five temperature regimes (Fig. 1). This could have resulted either from these larger plants being more restricted by the container (this test also had the lowest average illumination) or by an adverse effect of the higher temperature on leaf-area accretion.

The comparative leaf-area accretion by cultivars grown at two temperatures was not completely consistent, probably because of sample size, but the paired cultivars appear to perform in similar order at both temperatures.

The leaf-growth and root-weight parameters for seedlings of certain cultivars in this study confirm a previous observation (8) for mature plants, that these parameters may combine more or less independently in any given progeny. However, leaf and root parameters may be highly associated within at least some components of hybrids. If these two parameters are not highly and positively associated, selection for them must be synchronized to gain maximum yield improvement.

Selecting plants that develop the taproot earlier and more rapidly could aid yield, since Humphries and French (2) reported that "increasing the root growth of sugar beet by growing seedlings in growth cabinets enhanced the photosynthetic efficiency of their leaves for the rest of the season in the field and increased the yield of roots." More rapid accretion of leaf area would enlarge the capacity of the plant to photosynthesize during the period of maximum light. Early development of the root, functioning as a sink for the photosynthate, should enhance the rate of growth. These effects should be additive, at the least.

If the patterns of growth for cultivars between 30 and 150 days after emergence are very similar, then the trends in the seedling stage could be used with more assurance to predict relative yield at harvest.

Summary

A number of cultivars of sugarbeet (*Beta vulgaris* L.) were grown in pots on vermiculite and mineral nutrient solution in growth chambers for 18 to 30 days after emergence. The relation between certain shoot parameters and root weight was established among plants and cultivars.

Within this interval of growth, up to 2-fold variations in leaf area, leaf weight, and root weight occurred between seedlings of a cultivar, and coefficients of variation usually ranged between 15 and 25%.

In paired comparisons, leaf area of cultivars differed by as much as 60% in 21 days after emergence. In experiments where both leaf and root parameters were measured, the percentage differences for leaf and root parameters were similar.

For 20 paired cultivars, the cultivar that had the greater leaf area as 21-day-old seedlings usually had the greater root yield in full-season field experiments.

Within mean temperatures of 11 and 26°C, the logarithm of leaf area plotted as a straight line in response to temperature.

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Literature Cited

(1) HANSON, W. D. 1971. Selection for differential productivity among juvenile maize plants: Associated net photosynthetic rate and leaf area changes. Crop Sci. 11:334-339.

(2) HUMPHRIES, E. C. and S. A. W. FRENCH. 1969. Photosynthesis in sugar beet depends on root growth. Planta 88:87-90.

(3) MCKEE, G. W. and M. L. RISIUS. 1970. Varietal differences in crownvetch cotyledon size. Agron. J. 62:711-714.

(4) MURAMOTO, H., J. HESKETH, and M. EL-SHARKAWY. 1965. Relationships among rate of leaf area development, photosynthetic rate, and rate of dry matter production among American cultivated cottons and other species. Crop Sci. 5: 163-166.

(5) PATANOTHAI, A. and R. E. ATKINS. 1971. Heterotic response for vegetative growth and fruiting development in grain sorghum, *Sorghum bicolor* (L.) Moench. Crop Sci. 11: 839-843.

(6) SESTAK, Z., J. CATSKY, and P. G. JARVIS. 1971. Plant Photosynthetic Methods. Manual of Methods. Dr. W. Junk N. V. Publishers, The Hague, Netherlands. 818 pp.

(7) SHIBLES, R. M., and H. A. MACDONALD. 1962. Photosynthetic area and rate in relation to seedling vigor of birdsfoot trefoil (*Lotus corniculatus* L.). Crop Sci. 2: 299-302.

(8) SNYDER, F. W. 1970. Effect of leaf area and nitrogen on root weight and sucrose of sugarbeets. J. Am. Soc. Sugar Beet Technol. 16: 8-25.

(9) STEWARD, F. C. 1968. Growth and organization in plants. Addison-Wesley Publ. Co., Inc., Reading, Massachusetts.

(10) ULRICH, A. 1955. Influence of night temperature and nitrogen nutrition on the growth, sucrose accumulation and leaf minerals of sugar beet plants. Plant Physiology 30: 250-257.

(11) WATSON, D. J. 1947. Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties and in and between years. Ann. Bot. 11: 41-76.

(12) YADAV, R. P. and S. P. SINGH. 1970. Effect of heterosis on growth rate in pearl-millet (*Pennisetum typhoides* (Burm. f.) Stapf and C. E. Hubb.). Indian J. Agric. Sci. 40: 428-430.