Fibrous Root Growth and Partitioning in Smooth Root Sugarbeet Versus Standard Root Type

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ABSTRACT

A greenhouse experiment with controlled lighting, temperature, moisture, and nutrients was conducted to compare the development of the fibrous root system for a smooth root (SR) sugarbeet genotype with that of four other diverse variety/genotypes having standard grooved root architecture. Comparisons also included partitioning of photosynthate to leaf blade, petiole, taproot, and fibrous root for the five variety/genotypes studied, and for their agronomic performance in a replicated field trial. The SR genotype produced the same ratio of taproot to fibrous roots as did the commercial hybrid variety 'Mono-Hy E4.' There was a trend for fibrous roots of the SR line to develop lower on the taproot, farther from the crown, than in standard root types. The SR type had similar leaf area, tap root/leaf blade fresh weight ratio (TLWR), and partitioning of photosynthate to leaf blades, petioles, taproots and fibrous roots as did the commercial varieties. The SR line was more closely aligned with the commercial varieties in fibrous root growth and partitioning of photosynthate to plant parts than were the two other standard root type genotypes. From these greenhouse experiments on fibrous root yield and partitioning, supported by agronomic field data, I conclude that the SR root type can produce enough fibrous roots to transport the required nutrients and water to allow yield comparable to standard root type sugarbeets.

Additional Key Words: *Beta vulgaris,* root shape

Rhizobotany, the study of plant root growth and development, is an area of needed research that is receiving increasing scientific interest. Understanding root development is particularly important in sugarbeet (*Beta vulgaris* L.), in which the taproot is the economically important part of the plant. The root system of sugarbeet typically consists of a fleshy taproot with a mass of branching fibrous roots extending from the main root in both horizontal and vertical directions. The fibrous roots arise from two grooves or depressions that extend down opposite sides of the taproot. This growth pattern is discernible in the seedling stage long before the taproot begins to swell via cell enlargement and cell division to become the storage organ where sucrose is accumulated. Recently, Brown and Dunham (1986) reviewed the growth of the fibrous root system of the beet, noting that primary lateral roots emerge at an average spacing of 2-3 mm along the taproot groove. About 30 days after seeding, these give rise to secondary laterals, which then give rise to tertiary laterals, and so on. Considerable root turnover (growth and dying) occurs during a season. Root turnover is influenced by soil depth, soil temperature, availability of nutrients and moisture, and root pruning by disease organisms, insects, or other biota in the rhizosphere (Smucker and Theurer, 1991).

The fibrous root system of sugarbeet may be one of the most important factors affecting sugar production. Snyder and Carlson (1978) determined that selection for tap root/leaf blade fresh weight ratio (TLWR) was an effective means of increasing the size of sugarbeet taproots and that the increase was mainly a difference in partitioning photosynthate between the tap root and fibrous roots. Silvius and Snyder (1979) reported that some genotypes retain relatively more photosynthate in the taproot at the expense of fibrous roots, and that invertase may be involved in deflection of sucrose into fibrous root growth. Sufficient fibrous roots need to be produced to efficiently transport water and nutrients from the soil into the taproot, and at the same time not become a sink for photosynthate that should be partitioned to taproot growth or sucrose storage.

Sugarbeet genotypes have been developed with globe- or cone-shaped smooth taproot (SR) architecture (Coe and Theurer, 1987; Mesken and Dieleman, 1988; Theurer and Zielke, 1991). Storage roots of these SR beets are devoid of the two vertical grooves that occur on standard varieties. SR beets are lifted more easily from the ground at harvest, which we propose would result in less wear and tear on harvest machinery. SR beets also are more desirable than standard root types since they can greatly reduce the quantity of soil which will be harvested and transported to beet factory receiving stations

(Theurer and Zielke, 1991). Cleaner beets with less root bruising and root tip breakage can reduce the loss of sugar that occurs primarily by respiration and overheating in storage piles prior to processing. The cost for processing the cleaner SR beets may also be less.

When fleshy taproots of sugarbeet are lifted from the soil at harvest, there is little evidence of the mass of the fibrous root system that was available to support plant growth. The standard root type shows a residual of the fibrous root system in the grooves, but the smooth root does not. The question arises as to how the SR type differs in its fibrous root system compared to standard type.

This paper reports results of a greenhouse experiment comparing the early development of the fibrous root system of an SR genotype with other diverse variety/genotypes having the standard grooved root architecture. I also compare the partitioning of assimilate to leaf blade, petiole, taproot, and fibrous root for the five variety/genotypes studied, and their agronomic performance in a replicated field trial.

MATERIALS AND METHODS

Five variety/genotypes were selected (Table 1). Two of the entries were adapted commercial hybrid varieties and the other three were genotypes developed or selected for specific characteristics that have a bearing on root growth or partitioning of photosynthate to taproots and fibrous roots (Table 1). The experiment was conducted in a greenhouse during the winter months to maintain as uniform

Table 1. Description of varieties/genotypes.

Mono-Hy E4	Commercial hybrid variety developed by Great Western Sugar Co., Longmont, CO.
ACH 176	Commercial high sugar hybrid variety developed by American Crystal Sugar Co., Moorhead, MN.
EL 48	East Lansing genotype developed as a composite of three selected sugarbeet plants. This line showed superior ability to grow under heavy soil compaction in comparison with Mono-Hy E4 (A.J.M. Smucker, unpublished).
EL 46	An East Lansing inbred selected for high taproot/leaf weight ratio (TLWR).
SR 85700	A genotype selected for smooth root architecture.

an environment as possible. Ten to 12 seeds of each entry were planted in the center of 5 gal pails filled with washed white quartz sand. After emergence, seedling beets were thinned to a single plant per pail by clipping all other seedlings to avoid disturbing the root system of the surviving plant. There were 12 replications for each entry and the experiment was repeated 5 times. The greenhouse was maintained at approximately 75 F during the study. A bank of high sodium lights remained on continuously over each bench, providing a light intensity of 430 μmol m^{-2} s^{-1}. Plants were watered daily with the same volume of water. After thinning, 50 ml of 20-20-20 fertilizer plus micronutrients were given each plant once per week for 2 wk. Subsequently, fertilization was increased to 50 ml twice per week and after 30 d to 100 ml twice per week. After 50 d, plants were harvested. Each top was removed from the root, divided into laminae and petioles, and weighed. Leaf area was determined with a leaf area meter.

With the pail turned on its side, sand was washed away from the roots, leaving the fibrous roots attached to the taproot. Fibrous roots were removed and blotted dry with paper towels. Fresh weight of the taproot was determined. The 4 parts (leaf blades, petioles, taproot, and fibrous roots) were placed in small kraft paper bags and dried in an oven at 100 F for 48 h. Dry weights were taken on each plant part immediately after it was removed from the oven.

The five variety/genotypes also were planted in the field in 1987 for agronomic yield and quality evaluation. Individual plots were 2 rows 30 ft long, with 6 replications in a randomized block design. A 15-beet sample was harvested from each plot approximately 50 d after planting, and TLWR was determined for each variety/genotype. At harvest in October all roots of each plot were weighed and a 15-beet sample was taken for sugar and quality analyses. Laboratory analyses were conducted at the Michigan Sugar Company Research Laboratory in Carrollton, MI, by standard procedures outlined by the Association of Official Agricultural Chemists (1955).

Data were analyzed with the MSTAT statistical program designed at Michigan State University. TLWR was calculated as defined by Snyder and Carlson (1978).

RESULTS AND DISCUSSION

There were some differences in the overall size of plants for the five runs of the experiment. However, varieties tended to perform the same in each, and there was no significant variety x run experimental interaction. Thus, the data from the five runs were pooled for final analysis, resulting in each variety/genotype being represented by 60 plants.

Two visual observations were noted for SR type roots compared with the standard type. First, there was a marked tendency for SR beets to have fewer fibrous roots near the soil surface. Second, although the SR beets did not have the two deep grooves down the sides of the taproot, their fibrous roots tended to proliferate mainly along two vertical planes similar to those of the standard type. Several of the smooth root beets showed a broader area of fibrous root initiation compared to standard root types, but none of the taproots had fibrous root proliferation randomly over the entire surface of the taproot.

Dry matter produced by SR 85700 for leaf blades, petioles, taproots, and fibrous roots was very similar for all plant parts to that produced by Mono-Hy E4 and ACH 176 commercial varieties (Table 2). EL 48 and EL 46 yielded less taproot dry matter than either the SR line or the commercial cultivars. EL 46 had significantly lower dry matter weight than the other 4 variety/genotypes for leaf blades,

Table 2. Dry matter of leaf blades, petioles, taproot, and fibrous roots, leaf area and TLWR for 50-day-old sugarbeet plants.

	Weight (g)					
	Blade	Petiole	Tap root	Fibrous root	Leaf area cm²	TLWR[†]
Mono-Hy E4	10.82 ab[‡]	5.52 b	10.07 a	4.07 ab	1944 a	0.74 a
ACH 176	11.31 a	6.37 a	10.18 a	4.57 a	2137 a	0.70 a
EL 48	10.03 b	5.81 ab	6.66 b	4.31 ab	1950 a	0.54 b
EL 46	6.18 c	3.04 c	5.47 b	2.01 c	1215 b	0.80 a
SR 85700	10.33 ab	5.85 ab	8.97 a	3.59 b	2041 a	0.75 a

[‡] Duncan's Multiple Range Test. Means in columns with the same letter are not significantly different at the 0.05 level.

[†] $$\text{TLWR} = \frac{\text{Taproot + Hypocotyl fresh weight}}{\text{Leaf blade fresh weight}}$$

petioles, and fibrous roots, which could be expected because of inbreeding in this line. With exception of EL 46, the variety/genotypes had similar leaf area (Table 2). EL 46, as expected, was highest in TLWR, while EL 48 had significantly lower TLWR. EL 48 is a line with extremely large leaf blades. The SR line was equal to the commercial hybrids for TLWR. The 50-day-old plants harvested from the 1987 field trial showed the same relative TLWR for variety/genotype as observed in the greenhouse experiments (Table 4).

The five entries generally partitioned dry matter to plant parts in a similar manner (Table 3). The greatest amount of assimilate was partitioned to leaf blades and taproots, and the least amount to fibrous roots. EL 48 had a higher proportion of total dry matter partitioned to petioles and fibrous roots and significantly less to taproots in comparison with Mono-Hy E4 or ACH 176. It may be the abundance of fibrous roots that accounts for the ability of EL 48 to perform better under compacted soil conditions than Mono-Hy E4. This hypothesis would need further research for proof. EL 46 had a lower percentage of the total photosynthate partitioned to fibrous roots and petioles. This finding is in agreement with reports by Snyder and Carlson (1978), and Silvius and Snyder (1979), that genotypes such as EL 46, which was selected for high TLWR, partition more photosynthate to the taproot rather than to the fibrous root system. Of particular note was the observation that SR 85700 produced nearly as many fibrous roots as the commercial cultivars.

These greenhouse data suggest that in at least the early part of the season, SR type roots have no disadvantage to currently adapted commercial hybrids in relation to the quantity of fibrous root mass

Table 3. Percentage of total dry matter partitioned to leaf-blades, petioles, taproots and fibrous roots.

Variety/Genotype	Blades	Petioles	Taproots	Fibrous Roots
Mono-Hy E4	35.30 a[1]	18.27 b	32.94 a	13.49 a
ACH 176	35.35 a	19.86 b	30.80 a	13.98 a
EL 48	37.76 a	21.97 a	24.37 b	15.89 a
EL 46	37.78 a	18.35 b	31.70 a	12.17 a
SR 85700	35.98 a	20.28 ab	31.13 a	12.62 a

[1] Duncan's Multiple Range Test - Means in columns with the same letter are not significantly different at the 0.05 level.

needed to transport nutrients and water to sustain plant growth. However, later in the growing season there could be changes in the fibrous root systems of the two architectural types; conceivably, this could affect plant growth, sucrose accumulation, or the ability to withstand drought. Smucker and Theurer (1991), in a field study on Conover loam soil, observed by means of a minirhizotron and micro-video camera technique that Mono-Hy E4 had a more rapid rate of growth of fibrous roots than SR 85700 during the growing season. The greatest accumulation of fibrous roots for Mono-Hy E4 tended to occur lower in the soil profile as the season progressed, whereas the greater amount of fibrous roots of the SR line tended to remain in the top 50 cm of soil. Root duration (growth vs. death) was similar for Mono-Hy E4 and SR 85700.

The agronomic performance for the five variety/genotypes in a replicated field trial in 1987 is shown in Table 4. As expected, the commercially adapted hybrid varieties had the highest sugar yield, root yield, sucrose percentage, and clear juice purity percentage. SR 85700, however, was not significantly different in performance from at least one of the commercial varieties with the exception of sucrose percentage and yield of sucrose per ton of beets. Low sucrose percentage in this SR line was expected since it has been noted in all other field evaluation trials with smooth root genotype (Meskin and Dieleman, 1988; Coe and Theurer, 1987; Theurer and Zielke, 1991) and remains a characteristic that must be improved before commercial smooth root hybrids can be

Table 4. Field trial. Sugar yield, root yield, sucrose percentage and clear juice purity percentage for 5 diverse varieties/genotypes.

Variety/	Sugar yield		Root yield	Sucrose	CJP	TLWR[†]
Genotype	Mg ha^{-1}	kg t^{-1}	t ha^{-1}	%	%	
Mono-Hy E4	7.839 a[‡]	106.36 ab	60.48 a	15.43 b	94.19 a	0.68 ab
ACH 176	7.344 a	116.20 a	52.19 abc	16.85 a	93.89 ab	0.63 b
EL 48	5.662 b	103.85 ab	44.58 bc	15.28 b	93.46 abc	0.45 c
EL 46	5.247 b	101.58 b	42.56 c	15.25 b	92.51 c	0.77 a
SR 85700	6.263 ab	94.26 b	54.88 ab	13.40 c	92.90 bc	0.59 b

[†] $\mathrm{TLWR} = \dfrac{\text{Taproot + hypocotyl fresh weight}}{\text{Leaf blade fresh weight}}$

[‡] Duncan's Multiple Range Test - Means in columns with the same letter are not significantly different at the 0.05 level.

made available for grower use. SR 85700 gave excellent root yield, suggesting that there were adequate fibrous roots to sustain growth throughout the season and that partitioning of photosynthate to the fibrous root system did not curtail taproot development. Apparently the low sucrose percentage in the SR beet type is not primarily a result of partitioning more photosynthate to the fibrous root system than to the storage root. Thus, these results fail to support the theory suggested by Silvius and Snyder (1979) and Snyder and Carlson (1978) that the amount of photosynthate partitioned to sucrose is inversely associated with the amount partitioned to fibrous root development.

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