Agronomic Comparison of Different Types of Smooth Root and "Soil Free" Sugarbeet

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ABSTRACT

Field experiments were conducted for 3 years in Michigan to compare growth characteristics and agronomic performance of sugarbeet genotypes differing in their taproot architecture. Genotypes were MH E4, ACH 176, and ACH 185, all commercial hybrids with standard grooved taproots; SR87, a conical-shaped smooth root (SR) genotype; A90MM, a globe-shaped SR experimental triploid hybrid from the Netherlands; and Univers, a European commercial variety that has low soil tare at harvest. A90MM differed from all other genotypes, having only about 50% of the root underground. Averaged over years, root yield for SR87 was significantly greater than for A90MM, Univers, and MH E4. Sucrose content for SR87 and A90MM was 1-2 percent of root fresh weight lower than for the U.S. commercial varieties. SR87 was equal to the commercial varieties and greater than A90MM in sucrose yield per hectare. Little difference was observed in clear juice purity. A90MM had about half the soil tare of SR87 and Univers and about one-fourth that of the standard grooved root varieties. A90MM had the disadvantage of often being dislodged from the row when tops were removed with a rotobeater. With current sugarbeet defoliators and harvesters, conical-shaped smooth root beets would have the more desirable architecture.

Additional Key Words: *Beta vulgaris* L., root shape, plant architecture, sugarbeet breeding, harvesting, root storage, processing efficiency, soil tare.

The suggestion has been made that yield in crop plants is a function of morphology and physiology, and that breeders attempting to achieve superior yields should design plants based on architectural and physiological considerations (Donald, 1968). In some field crops, changing the architecture or morphology of the plant not only has contributed to yield increases but also has been responsible for improvement in harvestability and other desirable characteristics. For example, changing dry bean *(Phaseolus vulgaris* L.) plants from viney types to plants with erect architecture as proposed by Adams (1982) has increased yields as much as 45% (Izquierdo and Hosfield, 1983) and has the potential of reducing harvest losses due to lodging and disease (Stoffella et al., 1979).

In modern varieties of sugarbeet, *Beta vulgaris* L., considerable yield losses occur during and after harvest, primarily from breakage of sugarbeet taproots in the field. Sugar yield losses may occur because injuries to the beet root enhance respiration in storage piles. In addition, large quantities of tare soil adhering to sugarbeet taproots increase transportation costs, contribute to increased respiration, and can be a means of spreading serious soil-borne diseases.

Plant breeding to alter the morphology of the sugarbeet was begun by Demming (1950) in the 1930s. He crossed sugarbeet with red table beet and selected in subsequent generations for globe-shaped white roots. His globe-shaped sugarbeets were of considerable interest during World War II when labor was scarce, because the beets could be harvested with a potato digger. However, this work was discontinued when successful sugarbeet harvesters became available. Kozlowski (1947) reported a field trial in USSR for beets with round-shaped roots that were developed from crosses between sugarbeet and a white round-shaped Iranian ecotype.

In recent years, renewed interest has been generated in improving the morphology of the sugarbeet taproot and reducing the quantity of soil harvested with the roots. Sugarbeet germplasms with cone-shaped smooth root (SR) architecture have been developed in the U. S. (Coe and Theurer, 1987; Theurer, 1989), and sugarbeet with globe-shaped roots have been developed in the Netherlands (Mesken, 1990; Mesken and Dieleman, 1988). The storage roots of these SR beets are devoid of the two vertical grooves with their masses of rootlets which tend to hold large quantities of soil on the taproot of standard varieties. The SR types are lifted more easily from the ground at harvest, and they can reduce by at least 50% the quantity of soil harvested and transported to factory receiving stations. Cleaner beets with less root bruising and breakage reduce the loss of sugar that occurs primarily by respiration and overheating prior to processing. SR types also have the potential of improving processing efficiency in the factory, especially if the roots are peeled to remove impurities from the epidermal layers of the roots (Narum and Martin, 1989; Edwards et al., 1989).

Field evaluations of SR germplasms (Coe and Theurer, 1987; Mesken and Dieleman, 1988; Meskin, 1990; Theurer, 1989) and experimental hybrids with SR parentage (Meskin, 1990; Theurer and Zielke, 1991) have shown good potential for improving harvestability and increasing root yield with the new smooth root architecture. The SR germplasms have given equal or better root yield and clear juice purity than U. S. commercial hybrids, but were one to two percentage points lower in sucrose content. Significantly lower soil tare has been observed consistently for both SR87 and globe-shaped germplasms and experimental hybrids compared to locally adapted commercial varieties.

Because SR type beets can be developed with conical shape or globe shape, it was reasoned that a comparison should be made of the pros and cons for each shape. This would allow the breeder to focus efforts on the development of root architecture that would be most beneficial to the sugarbeet industry. In this paper I report the results from three years of field tests comparing the agronomic performance and some morphological differences for two SR type germplasms, a variety selected for low soil tare, and standard root type commercial hybrids.

MATERIALS AND METHODS

The performance of six genotypes with diverse root architecture was compared in replicated field evaluation trials conducted in the years 1990 to 1992. Three entries were standard root type commercial hybrids: MH E4, currently one of the predominant varieties being grown in Michigan, and ACH 176 and ACH 185, commercial varieties with high sugar content. The fourth entry was Univers, a European commercial variety that was selected specifically for low soil tare. Two entries were smooth root types: SR 87, a conical-shaped genotype developed at East Lansing, MI, and A90MM, a globe-shaped experimental smooth root triploid hybrid bred by M. Mesken in the Netherlands. Four genotypes, MH E4, SR87, A90MM, and Univers were included in the field trials all three years. ACH 176 was included in the 1990 and 1991 field trials and ACH 185 was included in 1991 and 1992.

The 1990 experiment was planted at the Beet and Bean Research Farm near Saginaw, MI, on Charity clay soil. The 1991 and 1992 experiments were planted at the Botany Research Farm at East Lansing on sandy loam soil. Individual plots each year consisted of two rows 71 cm (28 in) apart and 9 m (30 ft) long with plants spaced 20 to 30 cm

(8-12 in) within the row. There were four, four, and five replications for 1990, 1991, and 1992, respectively.

Plots were harvested in late October or early November using an experimental single row mini-harvester with puller wheels and a series of rotating star rinks similar to those on a conventional sugarbeet harvester. A triple drum rotobeater was used to remove tops just prior to lifting. In 1992 a sample of two representative tops was taken from each plot prior to top removal. The petioles and blades from each sample were weighed then chopped and dried in a 29C (85F) oven for 48 hr and reweighed to calculate an estimate of top dry weight for each genotype. All beets in each plot were bagged carefully to retain all soil adhering to the roots. The soil was removed later by hand from each root. Beet weight and soil weight were determined for each plot. Soil tare samples from the beets were dried in an oven at 29C (85F) for 72 hr to determine soil moisture content and convert the soil measurements to a dry weight basis. In 1992 the roots in each plot were scored for smoothness of root on a 1 to 5 scale:

1. Very smooth taproot, no grooves, broad fibrous root zone;
2. Smooth root, slightly grooved, narrow fibrous root zone;
3. Partially smooth taproot, grooved, with heavy amount of fibrous roots along grooves, non-branching taproot;
4. Rough shaped taproot, deep grooves, heavy fibrous roots with some sprangled taproots;
5. Very rough, very deeply grooved, multiple branched taproot.

A random sample of 15 beets was taken from each plot and sawed with a 10-blade Spreckels saw to obtain brei for laboratory analysis. Sugar percentage and Clear Juice Purity (CJP) were determined at Michigan Sugar Company's laboratory at Carrollton, MI, by standard methods (Association of Official Agricultural Chemists; 1955). Data were analyzed with the MSTAT program developed at Michigan State University.

RESULTS

1990 Field Experiment

The roots of A90MM, the globe-shaped beet, were similar to a table beet in growth habit with a large portion of the root growing above ground. They were somewhat difficult to harvest with the lifter wheels on our standard sugarbeet harvester as they tended to tilt to one side or were dislodged from the row when they were topped with the rotobeater. By contrast, few beets of the conical-shaped SR87 were dislodged when they were topped.

A90MM had smaller tops than the other genotypes in the test. Split or hollow crown tendency is a characteristic that has been noted much more in smooth root genotypes than in commercial cultivars. Careful observation of each beet showed 24% split/hollow crowns for A90MM, 12% for SR87, 5% for Univers, and 2% for the commercial hybrids MH E4 and ACH 176. The roots of Univers had a long conical shape; however, it was apparent that the taproots of this cultivar had shallower or smaller grooves than the other commercial cultivars.

Significant differences were observed for all of the agronomic characteristics that were measured (Table 1). The smooth root entries,

Table 1. Sugar yield, root yield, root weight, sucrose, purity, and kg soil per ton of harvested beets for smooth root type beets and commercial hybrid varieties. Saginaw, MI. 1990.

Genotype	Sugar yield		Root wt.	Sucrose	CJP	kg soil/
	Mg ha^{-1}	kg t^{-1}	t ha^{-1}	%	%	ton beet
MH E4	6.85 bc†	113.16 a	58.82 b	18.47 a	95.15 a	877.5 a
ACH 176	7.61 ab	118.88 a	62.04 b	19.40 a	95.06 a	600.8 ab
UNIVERS	8.13 a	99.90 b	78.96 a	16.88 b	93.40 b	459.5 ab
A90MM	6.61 c	83.59 c	76.52 a	14.71 c	92.55 c	197.7 b
SR87	7.49 ab	98.79 b	73.58 a	16.56 b	94.18 ab	416.7 ab
MEAN	7.33	102.86	69.98	17.20	94.07	510.4
C.V.	7.03	4.99	5.83	3.62	0.68	50.55

† Within columns, means with same letter suffix are not significantly different at 0.05 level by Duncan's Multiple Range Test.

A90MM and SR87, and Univers were significantly higher in root yield than the two standard root type check cultivars. Univers had the highest sugar yield per hectare, but was not significantly better than SR87 or ACH 176. A90MM was significantly lower in sugar yield than all genotypes except MH E4. The five entries fell into three groupings for sucrose percentage, sugar yield per ton, and CJP. MH E4 and ACH 176 had over 1.5% higher sucrose percentage than the SR and soil-free genotypes. SR87 and Univers were both significantly lower than the U.S. commercial cultivars and higher than A90MM in sucrose percentage and sugar yield per ton. The CJP of SR87 was equivalent to that of the U.S. commercial hybrids and significantly higher than that of A90MM. The quantity of soil adhering to the roots of A90MM was only about half the amount obtained with the other genotypes. This was mainly because the A90MM beets grew mostly above of the ground with far less surface area for soil adherence. At harvest this year, the heavy clay soil was saturated with moisture from recent rain storms, and soil clung to the roots even on smooth surfaces. Therefore, the data comparing soil adherence of SR versus commercial varieties cannot be considered representative of usual conditions.

1991 Field Experiment

The long growing season and the relatively high soil fertility under which the beets were grown in 1991 resulted in beets with extremely large tops and roots. Significant differences were observed between the genotypes for all agronomic variables except for sugar yield ha^{-1} (Table 2). SR87 significantly outyielded all other entries in root yield.

Table 2. Sugar yield, root yield, root weight, sucrose, purity, and kg soil per ton of harvested beets for smooth root type beets and commercial hybrid varieties. East Lansing, MI. 1991.

Genotype	Sugar yield		Root wt.	Sucrose	CJP	kg soil/
	Mg ha^{-1}	kg t^{-1}	t ha^{-1}	%	%	ton beet
MH E4	8.34 a†	89.52 ab	76.67 b	16.68 b	92.59 a	292.9 a
ACH 176	8.85 a	93.06 ab	78.40 b	16.42 b	92.08 a	263.1 a
ACH 185	8.73 a	93.93 a	76.65 b	17.89 a	91.69 ab	273.7 a
UNIVERS	7.87 a	82.31 ab	78.78 b	15.04 c	90.90 ab	136.8 b
A90MM	8.35 a	82.36 ab	82.75 b	13.88 d	90.77 b	67.0 c
SR87	9.15 a	77.04 b	98.13 a	13.87 d	90.48 b	104.0 bc
MEAN	8.55	86.37	81.90	15.63	91.42	189.6
C.V.	14.32	12.64	5.35	3.87	1.18	15.45

† Within columns, means with same letter suffix are not significantly different at 0.05 level by Duncan's Multiple Range Test.

The three commercial hybrids averaged almost 2% higher sucrose percentage than Univers and nearly 3% greater sucrose percentage than the SR genotypes. Univers, SR87, and A90MM were lower in CJP percentage than the commercial cultivars, but not significantly different from ACH 185. In 1991, SR87 was not better than A90MM for sucrose percentage and CJP as it was in the 1990 field test. The quantity of soil adhering to the roots of the U.S. commercial cultivars was 2- to 4-fold higher than that harvested with the smooth root type beets. The globe-shaped root variety, A90MM, had only 67 kg of soil harvested per ton of beets.

1992 Field Experiment

SR87 produced significantly more sucrose per hectare than A90MM, but they were similar in sugar yield per ton (Table 3). The commercial cultivars MH E4 and ACH 185 had significantly higher sucrose percentage than the other genotypes. SR87 and A90MM were 2-3 percentage points lower than the checks in sucrose and also significantly lower in CJP percentage this year. Univers had 1% higher sucrose percentage than the two SR genotypes. Similar to the 1990 test, SR87 produced the greatest root yield among all genotypes. The smooth root genotypes and Univers had the lowest root smoothness scores. A90MM had about half the quantity of soil adhering to the taproots as did SR87 and Univers, and about one-fourth of the quantity of soil that was harvested with the grooved standard root type varieties. The A90MM hybrid had noticeably smaller tops than other genotypes. A90MM produced only 42 g of top dry matter per plant compared to 75, 106, 108 and 121 g for Univers, SR87, MH E4 and ACH 185, respectively.

Three years combined

Four of the genotypes, MH E4, Univers, A90MM and SR87, were grown in the experiment during all 3 years. The combined years ANOVA showed significant year x genotype interactions only for the variables t ha^{-1}, root yield and kg soil tare t^{-1}. In 1990, the two SR genotypes and Univers had similar root yields and all three significantly exceeded the root yield of MH E4. In the two subsequent years, the root yield of SR87 was significantly greater than A90MM, Univers, and MH E4 (Tables 1-3). Significant interactions for the quantity of soil harvested with the roots can be attributed to the failure in 1990 of SR87 and Univers to show less soil harvested with roots than the standard root varieties.

Agronomic performance for the four varieties summed over years is summarized in Table 4. The globe-shaped beet A90MM had significantly the lowest sugar yield. The two SR genotypes and Univers had higher root yield than MH E4, and SR87 produced significantly greater root weight than Univers or A90MM. Each of the four genotypes differed significantly for sucrose percentage with sequential reduction of approximately 1% sucrose from MH E4 to Univers, Univers to SR87 and SR87 to A90MM. The genotypes were similar in CJP percentage. The two SR genotypes and Univers were harvested with about 50% or less of the soil harvested with MH E4. A90MM averaged about half the quantity harvested with SR87 and Univers; however, the difference was not statistically significant.

Table 3. Sugar yield, root weight, top yield dry weight, sucrose, purity, smoothness score, and kg soil per ton of harvested beets for smooth root type beets and commercial hybrid varieties. East Lansing, MI. 1992.

Genotype	Sugar yield		Root wt.	Top wt.	Sucrose	CJP	Smoothness	kg soil/
	Mg ha⁻¹	kg t⁻¹	t ha⁻¹	g/plant	%	%	score[†]	ton beet
MH E4	6.25 a[‡]	101.83 b	50.60 b	107.7 b	17.40[‡]	93.28 ab	3.38 a	178.9 a
ACH 185	6.16 ab	110.48 a	45.88 b	121.2 a	18.65 a	93.60 a	3.03 a	198.4 a
UNIVERS	6.31 a	93.39 c	55.66 b	74.9 c	16.23 c	92.81 b	2.58 b	103.1 b
A90MM	5.04 b	83.01 d	50.29 b	42.3 d	14.97 d	91.51 d	2.00 c	50.0 c
SR87	6.90 a	84.17 d	67.54 a	106.1 b	14.94 d	92.16 c	1.58 d	94.8 b
MEAN	6.13	94.58	53.99	90.4	16.44	92.67	2.52	125.0
C.V.	13.83	4.77	13.56	7.41	4.27	0.52	11.48	25.03

[†] Individual roots scored on a 1-5 scale (see materials and methods for details).

[‡] Within columns, means with same letter suffix are not significantly different at 0.05 level by Duncan's Multiple Range Test.

Table 4. Comparison of agronomic performance of the sugarbeet genotypes SR87, A90MM, Univers and MH E4 over three years.

Genotype	Sugar yield		Root wt.	Sucrose	CJP	kg soil/
	Mg ha^{-1}	kg t^{-1}	t ha^{-1}	%	%	ton beet
MHE4	7.17 ab†	101.05 a	62.38 c	17.47 a	92.87 a	395.2 a
UNIVERS	7.56 a	91.62 b	72.33 b	15.98 b	92.62 a	205.8 b
A90MM	6.75 b	82.89 c	70.72 b	14.50 d	91.64 a	93.2 b
SR87	7.86 a	86.93 bc	79.86 a	15.31 c	92.34 a	184.3 b
MEAN	7.34	90.62	71.00	15.82	92.47	219.6
C.V.	12.27	7.53	8.60	4.67	1.79	60.31

† Within columns, means with same letter suffix are not significantly different at 0.05 level by Duncan's Multiple Range Test.

DISCUSSION

In this study I demonstrated that a sugarbeet selected for shallow grooves in the taproot, as the cultivar Univers, had greatly reduced quantity of soil adhering to the roots at harvest. A further refinement can be made by changing the architecture of the sugarbeet taproot to one that has a smooth root instead of the typical grooved root of current varieties. The SR genotypes in this study were harvested with 50 to 75% less soil tare than was retained on the roots of the grooved root commercial cultivars.

Summed over the three years, the SR genotypes had equal or better root yield and equal CJP percentage to that of the commercial cultivar MH E4. The major disadvantage of the current SR types was their one to three percentage points lower sucrose. Similar results of high yield and low sucrose percentage for SR genotypes also have been observed in several other field experiments (Coe and Theurer, 1987; Demming, 1950; Meskin, 1990; Meskin and Dieleman, 1988; Theurer, 1989; Theurer and Zielke, 1991). Crosses have been made to high sugar lines and selection is currently underway to improve the sucrose content in SR breeding material.

SR genotypes can have many shapes, e.g., round, oval, globular, tubular, or conical. The conical shape is predominant but considerable variation has been observed by breeders in segregating generations from all different shapes. It is apparent that root shape is governed by many additive genetic factors (Coe and Theurer, 1987; Meskin and Dieleman, 1988; Shevtsov, 1982). Thompson (1939) made a technical study of factors that influence the taproot morphology and reported that significant differences in shape also occurred because of environmental factors, soil type, size of roots, and length of growing season.

A major objective in this experiment was to compare the performance of A90MM, a globe-shaped SR beet developed in The Netherlands (Meskin, 1990; Mesken and Dieleman, 1988) with SR87, the conical-shaped SR beet developed at East Lansing (Coe and Theurer, 1987; Theurer, 1989). Both SR selections came from sugarbeet x red table beet crosses, followed by several generations of phenotypic recurrent selection. There was considerable variation in root shape for each of the SR genotypes, as homogeneity in shape is difficult to attain. However, SR87 was about 85% conical shaped, and A90MM was about 85% globe or oval.

SR87 was higher in root yield, sugar yield per hectare and sucrose percentage than the globe-shaped A90MM genotype. The smooth root genotypes were equal in CJP percentage. A90MM was harvested with significantly less soil adhering to the taproot. This was expected since the globe-shaped beets grew more out of the ground than SR87. A disadvantage of A90MM was that the beets were dislodged frequently from the soil and tossed out of the plot row when the tops were being removed with the rotobeater. SR87 had smoother roots than A90MM. The globe-shaped roots of A90MM often were convoluted, or had a somewhat square shape. Tops on A90MM beets were significantly smaller than those of SR87, which were similar to those of the commercial cultivars. It has been demonstrated by Narum and Martin (1989) and Edwards et al. (1989) that peeling beet roots can remove a significant amount of the impurities that interfere with sucrose extraction. Studies also have indicated that more total sugar can be extracted from a peeled beet than from a whole beet (Martin, personal communication). If processors elected to peel roots to remove impurities, it is reasonable to conclude from the significant differences observed in smoothness scores (Table 3) that smooth root varieties could be peeled more easily than our currently adapted commercial cultivars with their grooved standard root type. It would take less time and less root tissue would be lost in the peeling process in proportion to the degree of smoothness of the root. The SR87 beets may be better for peeling than A90MM because the latter has some convoluted roots.

Globe-shaped SR beets can be harvested with significantly less soil than conical-shaped SR beets, because the globe-shaped beets grow mostly out of the soil. The globe-shaped roots have the disadvantage that they are frequently dislodged from the row when tops are removed with a rotobeater, and may not be picked up by current commercial harvesters. With current sugarbeet harvesting equipment, it would appear that the best architecture for the sugarbeet taproot would be a conical or top-shaped SR root. If the industry prefers to have the lowest possible soil tare, we could modify harvesters for lifting globe-shaped roots. For example, instead of topping roots with a rotobeater before lifting, the beets easily could be pulled from the soil by their tops and then separated from their roots as was done years ago with the Scott Viner harvester. Grab rolls and other cleaning devices would not be needed on the harvester and piler, and beets would be subjected to less injury.

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