Pre-Breeding to Change Sugarbeet Root Architecture

J. C. Theurer
Sugarbeet, Bean and Cereal Research Unit, USDA-Agricultural Research Service, Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824-1325

ABSTRACT

Economic improvement of sugarbeet *(Beta vulgaris)* field production and processing can be enhanced if traditional architecture of the sugarbeet is modified to a smooth root (SR) beet. Root shape of sugarbeet is a multigenic character and several generations of breeding are needed to reach any degree of homozygosity. In recent years conical-shaped SR beets have been developed in the eastern U.S. and in the Netherlands globe-shaped beets have been developed by crossing table beet with sugarbeet followed by phenotypic recurrent selection. SR beets tend to have fewer fibrous rootlets near the soil surface than traditional grooved-root beets but rootlets still proliferate mainly along two vertical planes. SR testcross progenies have shown less taproot tip breakage than a commercial hybrid cultivar. Root yield of current SR genotypes and experimental hybrids has been equal or superior to that of commercial cultivars, but sucrose content has been 1-3 percentage points less. Soil tare for SR genotypes has ranged from 30% to 70% less than for current commercial cultivars with traditional architecture. Globe-shaped beets have lower soil tare than conical-shaped SR beets. However, SR beets bred with conical-shape are more desirable than globe-shaped roots for harvesting by current sugarbeet equipment, because globe-shaped beets grow more out of the soil, often are dislodged from the row when tops are flailed, and may not be picked up by the harvester.

Additional Key Words: Harvestability, soil tare, breeding methods, root shape, root growth, phenotypic recurrent selection, sugar production.

Yield in crop plants has been reported as a function of morphology and physiology and it has been suggested that achieving superior yields will involve designing plants on an architectural and physiological basis (Donald, 1968). In some field crops, changing the architecture or morphology of the plant has contributed greatly to yield and also has been responsible for improvement in harvestability and other desirable characteristics. For example, changing dry bean plants from viney to erect 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).

The taproot of the sugarbeet is the organ for sucrose storage and the economic part of the plant that is harvested. A typical taproot of the modern sugarbeet variety is conical in shape with two large vertical grooves in the root from which a mass of fibrous roots emerge. These rootlets combined with any branching of the taproot itself result in large quantities of soil tare being lifted with the harvested roots. Plant breeding can contribute considerably to improved economics of sugarbeet production by modifying the traditional morphology of the sugarbeet taproot to a smooth root (SR) beet without grooves (Fig. 1).

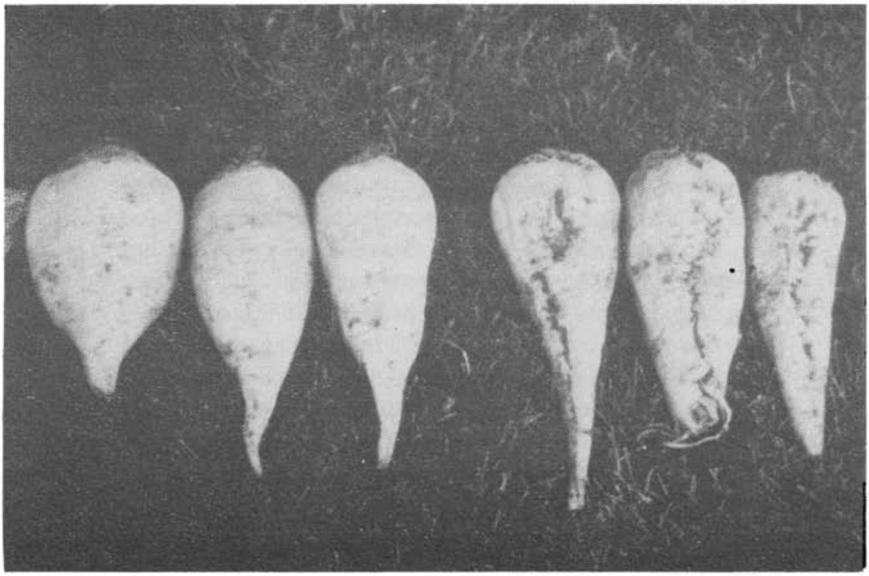

Figure 1. Smooth root architecture (left) and standard grooved root sugarbeet (right).

Variation for root shape within the sugarbeet gene pool is relatively small, however within the section Beta there is great variability. The red table beet has a globe or round shape, while globe, round, tubular and conical-shaped SR roots are found in fodder beets.

RATIONALE FOR MODIFYING SUGARBEET ROOT ARCHITECTURE

In modern varieties of sugarbeet, *Beta vulgaris* L., considerable yield losses occur during and after harvest. Root yield losses result primarily from breakage of taproots in the field, with subsequent sugar yield losses occurring because injuries to the beet root enhance respiration and rot in storage piles. In addition, the large quantities of tare soil harvested with sugarbeet taproots increase transportation costs, contribute to increased respiration, and can be a means of spreading nematodes and serious soil-borne root pathogens such as *Rhizoctonia* and *Aphanomyces* and the Rhizomania virus disease.

The development of smooth root sugarbeet without grooved roots could diminish some of these losses and reduce costs for both field production and processing. SR beets are easier to lift from the soil and will reduce yield losses as a result of less root breakage. Less soil will adhere to the roots which means that less mechanical cleaning will be needed during the harvesting of the crop. Transportation costs will be reduced since less soil tare will be transported to and from the factory. Cleaner beets will decrease respiration and sugar loss in storage piles and require less washing time in the factory. Lowering the quantity of soil tare would reduce the risk of spreading soil-borne diseases. Furthermore, should processors desire to peel roots to remove the large quantity of impurities found in the epidermal layers of cells (Narum and Martin, 1989), the SR beets would require less time and energy in the peeling process (Edwards et al., 1989).

BREEDING METHODS AND PROCEDURES

Plant breeding to alter the morphology of the sugarbeet was begun in the 1930's by Demming (1950), who 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, concerted breeding programs to alter the architecture of the sugarbeet have been carried out at two locations in the world. In the eastern U.S., G. E. Coe, J. C. Theurer and coworkers (Coe and Theurer, 1987; Theurer, 1989; Theurer and Zielke, 1991) have been developing SR conical-shaped genotypes. In the Netherlands, M. Mesken and colleagues (Mesken, 1990; Mesken and Dieleman, 1988) have been breeding for globe or round-shaped beet. Both of the current breeding programs stem from an original cross of sugarbeet with red table beet followed by phenotypic recurrent selection as outlined in Table 1. The East Lansing smooth root material originated with some of Demming's white root globe-shaped beets. These were backcrossed to sugarbeet genotypes with good Cercospora leafspot and Aphanomyces root rot resistance, followed by phenotypic recurrent selection for six generations. The best SR lines were then crossed back to sugarbeet followed by three cycles of mass selection. Elite SR selections were again crossed back to high sugar content sugarbeet lines in 1990 followed by three generations of selection, resulting in the present U.S. smooth root germplasm pool. Coe and Theurer, independently, also crossed sugarbeet with SR fodder beet and made selections for smooth root for four selection cycles. Breeding was terminated with this material because of its severe inbreeding depression and the fact that the plant material from the table beet derivatives looked more promising.

Table 1. Phenotypic recurrent selection scheme for breeding smooth root or globe-shaped sugarbeet.

F1	• conical sugarbeet x red table beet • selection of seedlings with red root • vernalization and F2 seed production
Cycle 1	• selection for seedlings with white root • selection for globe or smooth root • vernalization and seed production cycle 2
Cycle 2	• selection for globe or smooth root • selection for high sucrose content • vernalization and seed production cycle 3
Cycle n	• same as for selection cycle 2

Selection for a sugarbeet ideotype can be made in several ways: 1) appearance of the root *per se,* 2) the ease with which it can be pulled from the soil, 3) the relative quantity of soil adhering to the root compared to that for a standard commercial cultivar, or 4) a combination of all of the above. It also appears that early selection could be made in the greenhouse or in the field when roots have reached a diameter of approximately 3 cm. Selection can be made after hand or machine harvest.

For hand harvest it is recommended that progenies be planted in multiple row blocks. Individual beets then are pulled by hand and laid out with roots pointing in the same direction (see Fig. 2). Selection is based on the ease of removing the root from the soil, the overall appearance of the roots of each progeny, and the quantity of soil adhering to the beet. Each beet is scored for root smoothness on a 1 to 5 scale:

1 = Very smooth taproot, no grooves, broad fibrous root zone
2 = Smooth, slightly grooved taproot, narrow fibrous root zone
3 = Partially smooth, grooved, heavy fibrous non-branching taproot
4 = Rough shaped taproot, deep grooves, heavy fibrous roots with some sprangling
5 = Very rough, very deep grooves, multiple branched taproot

Figure 2. Two hand harvested smooth root progenies laid out in multiple row blocks. First three row on left = 92HS25, two rows on right = 92HS28.

One-half of each selected beet is macerated for sucrose and purity analysis and the other half kept for seed production. After laboratory analysis, the roots with highest sucrose content and the desired root shape are selected for the next selection cycle or used as a parent line for new hybrids.

To obtain a better comparison of soil retention for smooth root versus grooved root genotypes, we have developed a single row mini-harvester with puller wheels and a series of star rinks similar to those on a conventional harvester (see Fig. 3a). After the beets are lifted, they pass over the star rinks where loose soil is jarred off, then the beets fall back onto the ground (Fig. 3b). The roots in each plot are picked up carefully to avoid any further loss of soil, and placed in canvas bags. Soil is removed later by hand from each root, dried and weighed to determine soil tare. Roots also can be scored for smoothness as cited above for hand harvest. Individual roots are analyzed for sucrose content and purity by standard clear juice methods (Association of Official Agriculture Chemists, 1955), and selections are made for further breeding.

Root shapes from crosses of beets with standard root architecture and those of SR types are intermediate to the parents. The root shape character is governed by several additive genes. Several generations of selection are needed to reach any degree of homozygosity. Considerable instability (genotype x environment interaction) of root shape occurs in the breeding of smooth root type beets. Thompson (1939) reported that significant differences in sugarbeet root shape occur because of environmental factors, soil type, size of roots and growing season.

Mesken (1990) selected for round/oval roots during four cycles of selection, then began selection for globular shape. In a single generation the globe shape increased 16%, round/oval decreased 11% and conical-shaped roots decreased 5%.

Some smooth root type beets have extremely high crowns or split/hollow crowns. Others show deep growth cracks on the crown or vertically down the side of the root. These undesirable characteristics may be governed by both genetic and environmental factors. Their frequency can be reduced, however, by selection against the trait. While it is not uncommon to observe some split or hollow crowns in most cultivars they are significantly more frequent in SR than in standard commercial cultivars. In a six replicate field test in 1990the percentage ofplants with split or hollow crowns averaged2%, 2%, and5% for commercial cultivars MH E4,ACH 176,and Univers, respectively, versus 24% for A90MM (Mesken's globe-shaped triploid) and 12% for SR87 (East Lansing conical-shaped SR genotype).

FIBROUS ROOT DEVELOPMENT ON SMOOTH ROOT BEET

When the fleshy taproots are lifted from the soil at harvest, there is little evidence of the mass of fibrous roots that support plant growth. Most fibrous roots break off during the lifting process leaving the residual fibrous roots in the grooves of the standard root type; these are

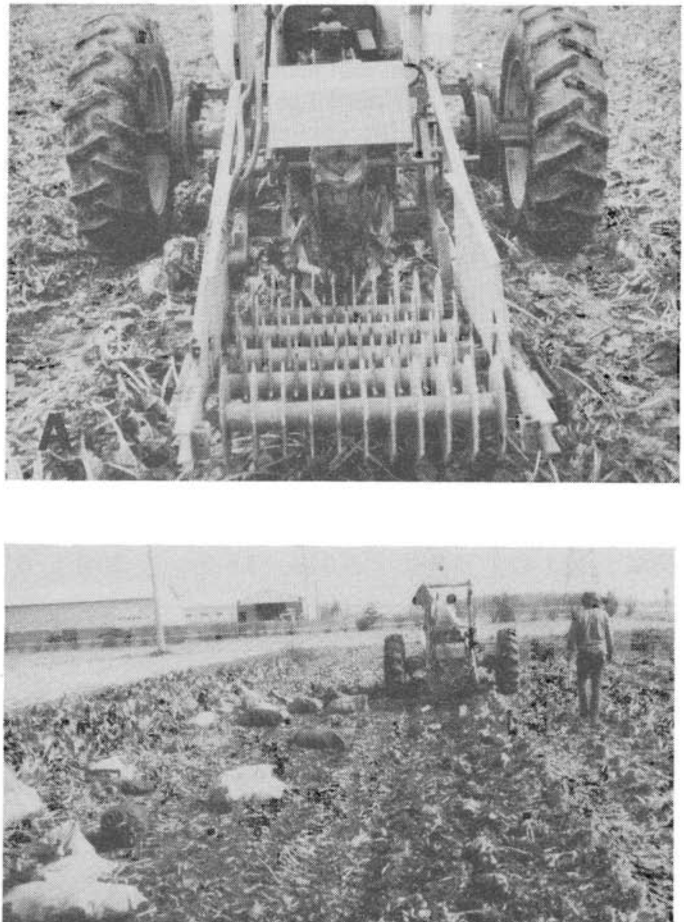

Figure 3. A) Mini-sugarbeet plot harvested with puller wheels and star rinks similar to commercial sugarbeet harvester. B) Plot harvest and bagging using single row mini-harvester.

absent from the smooth root type. Sufficient fibrous roots need to be produced to efficiently transport water and minerals from the soil into the sugarbeet taproot, and at the same time not become a sink for photosynthate that could be partitioned to taproot growth or sucrose storage.

Plants of SP85700 SR genotype and commercial cultivars MH E4 and ACH 176 were grown in the greenhouse in 20 liter white plastic buckets for 50 days to compare fibrous root growth of SR beets with those having standard grooved root architecture (Theurer 1993). All plants were subjected to the same lighting and received identical moisture and fertilizer. At 50 days after emergence the SR germplasm produced a similar mass of fibrous roots as the commercial hybrid cultivars, MH E4 and ACH 176 (Tables 2 and 3). There was a mark-

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

	Dry Weight (gm)					
Genotype	Blade	Petiole	Tap root	Fibrous root	Leaf area(cm)	TLWR[†]
MH E4	10.8 ab[‡]	5.5 b	10.1 a	4.1 ab	1944 a	0.74 a
ACH 176	11.3 a	6.4 a	10.2 a	4.6 a	2137 a	0.70 a
SP85700	10.3 ab	5.9 ab	9.0 a	3.6 b	2041 a	0.75 a

[†] Tap root leaf blade weight ratio (Snyder and Carlson 1978)

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

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

Genotype	Blades %	Petioles %	Taproots %	Fibrous roots %
MH E4	35.30 a[†]	18.27 a	32.94 a	13.49 a
ACH 176	35.35 a	19.86 a	30.80 a	13.98 a
SP85700	35.98 a	20.28 a	31.13 a	12.62 a

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

ed tendency for the SR beets to have less fibrous root mass near the soil surface (personal observation).

Later than the 50 day growing period of this experiment, differences in the fibrous root system may occur that could have an effect on plant growth, sucrose accumulation, or the ability of the SR type to withstand drought. However, no evidence of detrimental factors due to the fibrous root structure of SR beets has been observed. High yields of SR beets in field trials (Coe and Theurer 1987, Theurer 1989, Theurer and Zielke 1991) indicate that they produce adequate fibrous roots to sustain growth throughout the season.

Data indicate that low sucrose percentage in the SR type beet is not primarily a result of partitioning more photosynthate to the fibrous root system as suggested by Silvius and Snyder (1979), and Snyder and Carlson (1978). The SR type had similar leaf area and taproot leaf weight ratio (TLWR) as the checks (Table 2). The percentage of photosynthate partitioned to leaf blades, petioles, taproots and fibrous roots for SR type was also similar to that of the commercial varieties (Table 3). Approximately 35% of the total plant dry matter was partitioned to leaf blades, 19% to petioles, 31% to taproots and 13% to fibrous roots.

Although SR beets do not have the two standard deep grooves down the sides of the taproot (Figure 1), the fibrous roots tend to proliferate mainly along two vertical planes similarly to the standard type (see beet on left, Figure 4). Several of the smooth root beets showed a broader

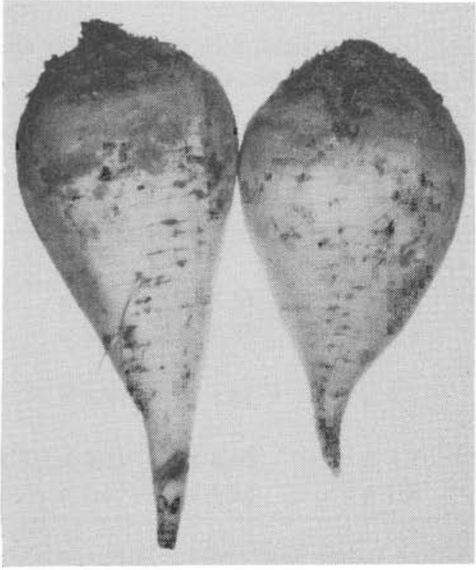

Figure 4. Conical shaped SR architecture beets: (left) root hairs emerge in narrow area similar to grooved beets, (right) broad area of root hair development.

root types (see beet on right, Fig. 4), but it is unlikely that we could develop a germplasm with fibrous root proliferation at random over the entire surface of the taproot.

AGRONOMIC PERFORMANCE OF SMOOTH ROOT SELECTIONS

Theoretically, SR type beets should be easier to lift from the soil with less root tip breakage than standard grooved cultivars. Mesken (1990) conducted root breakage studies at two lifting depths, with varieties having different root architecture. Round shaped testcross beets had 7% and 5% root breakage at the 2-3 cm and 7-8 cm depths, respectively, compared with a two year average of 2.5% and 7.5% for Regina, a standard root type cultivar.

SR selections have shown slightly less sugar yield, equal or significantly better root yield, significantly lower sucrose content, and about equal clear juice purity (CJP) as locally adapted commercial hybrid cultivars. For example, Table 4 shows a summary of the sugar yield, root yield, sucrose percentage, CJP, and quantity of soil tare per ton of beets for 21 experimental SR lines evaluated in field trials at East Lansing, MI in 1989. The SR selections ranged from equal to almost 2.5 Mg/ha less sugar yield than MH E4. SR selections averaged 1.4 Mg/ha sugar yield less than this high yielding commercial hybrid. Root yield on average was similar for the selections and

Table 4. Sucrose yield, root yield, sucrose percentage and CJP percentage for 21 SR genotypes and two commercial hybrid cultivars. East Lansing, MI 1989.

Genotype	Sugar Yield Mg/ha	Root Yield t/ha	Sucrose %	CJP %	kg soil/ t beets
Commercial Hybrids					
MH E4	8.3 a[†]	61.7 a	16.6 a	92.8 a	53 b
ACH 176	8.2 a	58.5 a	16.8 a	93.6 a	75 a
SR Progenies					
Mean	6.9 a	58.1 a	14.8 b	92.1 a	12 d
Range					
low	5.8 b	46.6 b	13.8 b	88.5 b	7 d
high	8.3 a	65.4 a	16.1 a	93.9 a	18 c

[†] Duncans Multiple Range Test - means with same suffix letter are not significant at the 0.05 level.

commercial hybrids with the SR genotypes having a range of 15 t/ha less to 3.8 t/ha more root yield than the highest yielding check. The mean of the SR selections was significantly lower than MH E4 and ACH 176 in sucrose percentage; however, the high sucrose SR selections were not different from the checks. A few SR genotypes were significantly lower in CJP percentage. The quantity of soil per ton of beet for the SR genotypes ranged from 13% to 34% of that lifted with the commercial cultivar MH E4.

Results based on field trials in the Netherlands (Mesken and Dieleman, 1988), comparing globe-shaped families with the commercial cultivar Monohil, were similar to those cited above for comparisons between conical-shaped SR genotypes and adapted commercial hybrids grown in Michigan, i.e., only two families had significantly lower root yield than the check variety. All 35 families were lower in sucrose content. Fifteen of the families were significantly lower than Monohil in sugar yield. The round/oval beets were higher than Monohil in K, Na and amino N impurities.

AGRONOMIC PERFORMANCE OF EXPERIMENTAL SR HYBRIDS

SR87, a smooth root architecture genotype, was crossed with cytoplasmic male sterile lines to develop experimental hybrids for assaying combining ability of SR genotypes. Data from 1988 and 1989 replicated field experiments of four SR experimental hybrids and three commercial hybrid cultivars are shown in Table 5. With the exception of WC87018, the SR experimental hybrids were not significantly different in root yield from the commercial hybrids. The sugar yield of the SR hybrids was consistently less than for MH E4 but the difference was not significant for WC 87016. All of the SR experimental varieties were significantly lower in sucrose percentage. Two experimental hybrids had CJP percentage similar to that of the checks for both years. SR hybrids consistently were scored better for smoothness of root and they averaged about 50% less soil per ton of beets than the checks. A field evaluation in the Netherlands compared sugar yield, root yield, sugar content, and sugar extractability for five globe-shaped SR triploid testcross progenies with agronomic performance of the commercial cultivar Regina (Mesken and Dieleman, 1988). Testcross progenies were equal to or better than the commercial variety, Regina, in root yield, but were significantly lower in sucrose content and sugar yield. One testcross family had extractability which was not significantly different from the commercial cultivar.

Table 5. Sugar yield, root yield, sucrose percentage, clear juice percentage, smoothness score and kg soil per ton beet for three commercial cultivars and four SR experimental hybrids. East Lansing, MI 1988 and 1989.

1988

Genotype	Sugar yield Mg/ha	Root yield t/ha	Sucrose %	CJP %	Smoothness score[†]	Kg soil/ t beet
Commercial Cultivars						
MH E4	8.5 a[‡]	57.2 abc	17.8 a	93.9 ab	3.4 a	287.3 a
ACH 176	8.1 ab	55.6 bc	17.3 a	94.1 ab	3.3 a	208.3 bcd
USH 23	7.6 bcd	55.4 bc	16.4 b	94.3 a	3.3 a	244.1 ab
SR Experimental Hybrids						
WC87016	8.0 abc	60.3 ab	15.9 bc	93.9 ab	2.6 b	155.1 d
WC87017	7.6 bcd	59.2 abc	15.6 cd	93.7 ab	2.9 b	172.2 cd
WC87018	6.9 d	53.4 c	15.5 cd	93.8 ab	2.7 b	187.4 cd
WC87019	8.1 ab	63.2 a	15.6 cd	93.3 ac	2.7 b	165.5 cd
Commercial Cultivars						
MH E4	9.5 a	64.79 a	17.5 a	94.0 a	3.5 a	44 b
ACH 176	9.1 ab	61.66 a	17.5 a	94.2 a	3.5 a	48 ab
USH 23	8.3 bcd	61.66 a	16.0 b	95.0 a	3.5 a	53 a
SR Experimental Hybrids						
WC87016	8.5 abc	67.7 a	15.2 cd	93.8 ab	2.9 d	17 cd
WC87017	8.0 cd	67.0 a	14.5 de	93.2 bc	2.8 d	12 d
WC87018	8.3 bcd	61.9 a	15.9 bc	94.3 a	3.1 bc	23 c
WC87019	8.4 bc	67.0 a	15.4 bc	92.9 cd	3.0 cd	22 c

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

[‡] Duncans Multiple range Test - Means in columns followed by the same suffix letter are not significantly different at 0.05 level.

COMPARATIVE STUDY OF GLOBE AND CONE-SHAPED SR GENOTYPES AND A LOW SOIL TARE VARIETY

SR beets can have many root shapes, such as conical, ovate, round, globular, or tubular. Mesken and Dieleman (1988) selected for round/oval beets for four generations, but because of instability in root shape they switched to selection for globe-shaped roots in the fifth generation. At East Lansing selection always has been directed towards conical-shaped SR beets. During 1990 to 1992 a comparison was made at East Lansing, MI of the growth characteristics and agronomic performance of four genotypes with diverse root architecture. Two of the genotypes were smooth root types: SR87, a conical-shaped line developed at East Lansing, MI and A90MM, a globe-shaped experimental smooth root triploid hybrid bred by Mesken in the Netherlands. The third architectural type was represented by Univers, a Van der Have European commercial cultivar, which had been bred specifically for low soil tare. The fourth type was the standard grooved root represented by MH E4, the predominant commercial cultivar being grown at that time in Michigan. This study was designed to help the breeder focus efforts on developing genotypes with the type of root architecture that would be most beneficial to the sugarbeet industry. Plots were harvested each year in late October or early November by use of our experimental single row mini-harvester (Fig. 3a, 3b). The roots of A90MM, the globe-shaped beet, were similar to table beet in growth habit with a large portion of the root growing above ground (Fig. 5). They were somewhat difficult to harvest with the standard harvester lifter wheels as they tended to tilt to one side or were dislodged from the row when they were topped with a rotobeater. By contrast, the conical-shaped SR87 beets grew deeper in the soil (Fig. 6) and were not dislodged when they were topped.

The roots of Univers had more shallow or smaller taproot grooves than MH E4. A90MM had smaller tops than the other genotypes in the test, producing only 42 g top weight dry matter per plant compared to 75, 106, and 108 g for Univers, SR 87, and MH E4, respectively.

Significant differences were observed for all of the agronomic characteristics that were measured (Table 6). SR87 produced greater root weight than any of the other genotypes while Univers and A90MM significantly outyielded MH E4. The four genotypes had similar sugar yield. Each genotype differed significantly from all others for sucrose percentage. Univers was approximately 1.5 points lower, SR87 2.2 points lower, and A90MM 3 points lower in sucrose than MH E4. The genotypes were similar in CJP percentage. Univers was harvested with only 52% of the soil tare of MH E4. SR87 and A90MM had respectively

Figure 5. A90MM Globe-shaped roots showing root growth above soil surface.

Figure 6. SR 87 conical-shaped roots showing growth in relation to soil surface.

47% and 24% of the soil tare compared to MH E4. A90MM averaged about half the quantity of soil harvested with SR87 and Univers, but the difference was not statistically significant. An example of the relative quantity of soil adhering to hand pulled roots of the four genotypes is shown in Fig. 7.

Table 6. Comparison of agronomic performance of Univers, MH E4, SR87 and A90MM summed over three years.

Genotype	Sugar Yield Mg/ha	Root Wt. t/ha	Sucrose %	CJP %	kg soil/ t beets
MH E4	7.2 ab[†]	62.4 c	17.5 a	92.9 a	395 a
UNIVERS	7.6 a	72.3 b	16.0 b	92.6 a	206 b
SR87	7.9 a	79.9 a	15.3 c	92.3 a	184 b
A90MM	6.8 b	70.7 b	14.5 d	91.6 a	93 b
MEAN	7.4	71.0	15.8	92.57	220

[†] Duncans Multiple Range Test - Means with the same suffix letter are not significantly different at the 0.05 level.

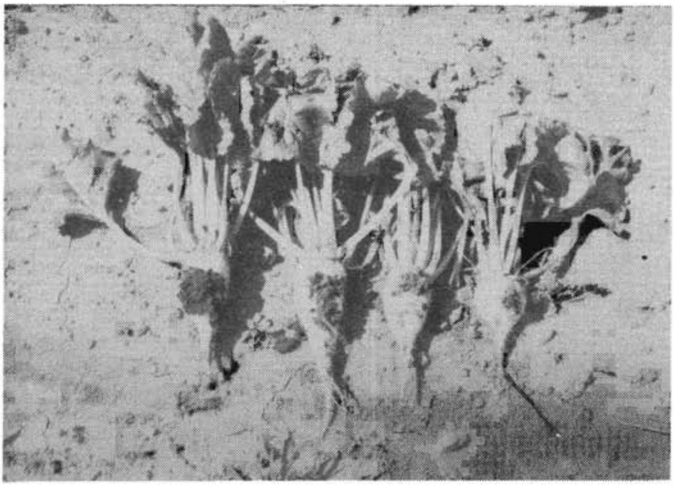

Figure 7. An example of the relative quantity of soil adhering to hand pulled beets. From left to right: MH E4, commercial hybrid cultivar; Univers, low soil tare cultivar; SR 87, conical shaped SR beet; A90MM globe-shaped SR hybrid.

ENHANCING SUCROSE CONTENT IN SR GENOTYPES

The sugar content of SR plant material, as observed in Tables 4, 5 and 6, is low in comparison to current sugarbeet cultivars. This is the greatest detriment to the production of high yielding, high sucrose content SR genotypes that could be used directly as parental lines for commercial hybrid seed production.

Only a modest improvement in sucrose content has been made when individual SR beets from good SR families have been selected for high sucrose content and intercrossed for the next generation. It was evident after a few cycles of selection that SR material would have to be outcrossed to high sugar genotypes to obtain SR genotypes with sucrose content equal to that of current commercial hybrids. Crossing SR lines to high sucrose inbreds with two subsequent cycles of selection for SR and sucrose percentage exceeding that of the high sugar commercial hybrid ACH 185 has resulted in SR progenies with increased sucrose content. Table 7 shows some 1992 progenies

Table 7. Mean sucrose percentage of 11 families derived from 1991 individual beet selections with 5% to 16% greater sucrose percentage than the commercial variety ACH 185. These comparisons were with ACH 185 grown in 1992 = 16.83%. Also included are the relative sucrose percentabes of the original 1991 selections, compared with ACH 185 grown in 1991 = 16.03%.

	Mean Sucrose %		
1992		1992 Progenies	
Progeny Seed No.	1991 Selected Roots Relative to ACH 185	Actual	Relative to ACH 185
92HS22	105	16.99	101
92HS24	112	15.94	95
92HS29	104	15.86	94
92HS31	113	16.14	96
92HS32	106	16.10	96
92HS33	113	16.42	98
92HS41	116	18.04	107
92HS42	113	17.03	101
92HS44	112	17.50	104
92HS45	110	16.74	99
92HS46	110	17.19	102

developed from high sucrose SR selections made in 1991. These progenies were developed from groups of 3 to 10 individual SR roots that averaged 5% to 16% higher sucrose than ACH 185. Only five of the 1992 progenies had sucrose percentage equal or better than ACH 185. These results demonstrate that progress in enhancement of sucrose content in SR material by individual beet selection is slow. Root yield equal to that of the commercial hybrid check was maintained in all of these progenies.

SUMMARY

1. Sugarbeet with SR architecture have the potential of improving the efficiency of both field production and factory processing. Breeding programs to develop SR type beets carried out in East Lansing, MI and Wageningen, Netherlands have given similar results.
2. SR is a multigenic character and progeny from crosses are mid-parent in root architecture. There is a great amount of genetic and environmental variation in SR type beets in both smoothness of root and root shape.
3. Present SR genotypes have good yield and quality. Field studies have shown that the best SR material was equal to or better than adapted commercial cultivars in root yield. Sugar yield has been slightly lower for the SR genotypes and hybrids. CJP % has been similar or slightly lower compared to the checks.
4. Sucrose content continues to be the greatest challenge in breeding smooth root varieties. It has been consistently one to three percentage points lower in SR genotypes than in current commercial cultivars. This is primarily because the SR selections came from crosses of sugarbeet x red table beet which had low sucrose content.
5. SR genotypes were harvested with 30% to 70% less soil than was retained on the roots of beets with the standard grooved root architecture of current commercial cultivars. Round or globe-shaped SR beets can be harvested with significantly less soil tare adhering to the taproots than conical-shaped SR beets. This is because globe-shaped beets grow more out of the ground. It may be difficult to harvest all roots of globe-shaped beets since some of the roots become dislodged from the row when tops are removed with a rotobeater. With current sugarbeet harvesting equipment, it would appear that the best architecture for the sugarbeet taproot would be a conical-shaped SR root.
6. Selection of sugarbeets with shallow grooves in the taproot, such as the cultivar Univers possesses, can reduce significantly the quantity of soil adhering to roots at harvest. The more shallow the grooves and

the more smooth rooted the standard beet lines are, the better the root architecture of standard x SR hybrids.

7. Additional desirable factors that need to be bred into SR type beets are monogerm, cytoplasmic male sterile, and O-type genotypes. Present monogerm material is low in yield as well as low in sucrose percentage. Improvement also is needed in resistance to Cercospora leafspot, Rhizoctonia root rot and other diseases.

REFERENCES

Association of Official Agricultural Chemists. 1955. Official methods of analysis (8th Ed.), p. 564-568. Washington, D.C.

Coe, G. E. and J. C. Theurer. 1987. Progress in the development of soil-free sugarbeets. J. Amer. Soc. Sugar Beet Technol. 24:49-56

Demming, G. W. 1950. Recent results with sugar x red garden beet hybrids. Proc. Amer. Soc. Sugar Beet Technol. 6:180-183.

Donald, C. M. 1968. The breeding of crop idiotypes. Euphytica 17:385-403.

Edwards, R. H., J. M. Randall, W. M. Camirand, and D. W. Wong. 1989. Pilot plant scale high pressure steam peeling of sugarbeets. J. Sugar Beet Res. 26:40-54.

Izquierdo, J. A., and G. L. Hosfield. 1983. The relationship of seed-filling to yield among dry beans with differing architectural forms. J. Amer. Soc. Hort. Sci. 108:106-111.

Kozlowski, A. I. 1947. Sugar beet with round shaped roots. Proc. Lenin Acad. of Agric. Sci. USSR:20-21.

Mesken, M. 1990. Breeding sugar beets with globe-shaped roots to reduce dirt tare. IIRB Proc. 53rd Winter Congress. pp. 111-119.

Mesken, M. and Dieleman, J. 1988. Breeding sugar beets with globe-shaped roots: Selection and agronomic performance. Euphytica S:37-44.

Narum, J. A. and S. S. Martin. 1989. Impurities and sucrose in the root, peel, and interior of diverse sugarbeet lines. J. Sugar Beet Res. 26:A18-A19.

Silvius, J. W. and F. W. Snyder. 1979. Comparative enzymaticm studies of sucrose metabolism in the taproots and fibrous roots of *Beta vulgaris* L. Plant Physiol. 64:1070-1073.

Snyder, F. W. and G. E. Carlson. 1978. Photosynthate partitioning in sugarbeet. Crop Sci. 18:657-661.

Stoffella, P. J., R. T. Sandsted, R. W. Zobel, and W. L. Hymes. 1979. Root characteristics of black beans. I. Relationship of root size to lodging and seed yield. Crop Sci. 19:823-826.

Theurer, J. C. 1989. Progress and performance in development of smooth root sugarbeet varieties. J. Sugar Beet Res. 26:A25.

Theurer, J. C. 1993. Fibrous root growth and partitioning in smooth root sugarbeet versus standard root type. J. Sugar Beet Res. 30 (In Press).

Theurer, J. C. and R. C. Zielke. 1991. Field evaluation of SR87 smooth root sugarbeet hybrids. J. Sugar Beet Res. 28:105-113.

Thompson, R. C. 1939. Influence of various factors on the shape of beet roots. J. Agr. Res. 58:733-746.