Row Spacing and Plant Density Effects on Smooth Root Sugarbeets

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ABSTRACT

Agronomic performance of smooth root (SR) type sugarbeet genotypes was compared with that of standard commercial cultivars under different row spacings and plant densities during the years 1988-1990. In one experiment smooth root types SR 87 and 87H1-00 were compared with commercial cultivars MH E-4 and ACH 176 in plant population densities of approximately 69,200; 96,800; and 79,100 plants ha^{-1}. Individual plant spacings were 71 cm (between rows) x 20 cm (between plants within rows), 56 x 20 cm, and 46 x 46 cm respectively. In a second experiment in 1989, SR 87 was compared with MH E-4 at six plant spacings of 71 x 30 cm, 56 x 30 cm, 46 x 30 cm, 71 x 15 cm, 56 x 15 cm, and 46 x 15 cm. This experiment was repeated in 1990 with these six plus two additional plant densities, 51 x 30 cm and 51 x 15 cm. Although SR sugarbeets have a different fibrous root system than today's standard root type, there were no adverse effects of SR plants when grown in narrow rows under higher plant densities compared with present conventional 71 cm row width. Smooth root sugarbeet genotypes responded to plant density in different environments similarly to adapted standard root commercial cultivars. SR productivity was enhanced when sugarbeets were grown at the higher density of 71,760 plants ha^{-1} (46 row width x 30 cm plant spacing).

Additional Key Words: *Beta vulgaris,* root shape

Development of smooth root (SR) hybrid sugarbeet *(Beta vulgaris* L.) cultivars is desired by the sugarbeet industry world-wide. SR sugarbeets have direct advantages over present day commercial hybrids of easier lifting from the soil, less bruising and root tip breakage, less soil transported with the roots, and indirectly, less loss of sucrose in storage piles awaiting processing. They also have potential in improving processing efficiency. Many of the precipitable impurities that must be removed in the processing factory are located in the epidermal or rind layer of the taproot (Narum and Martin, 1989). SR sugarbeets lend themselves better to peeling of the taproot which would greatly reduce these impurities with little loss of sucrose (Edwards et al., 1989).

In recent years, SR sugarbeet germplasm has been developed in the United States (Coe and Theurer, 1987; Theurer, 1989, 1993b; Theurer and Zielke, 1991) and the Netherlands (Mesken, 1990; Mesken and Dieleman, 1988) and used to develop experimental hybrids. These hybrids have shown good root yield, but lower sucrose percentage than current commercial cultivars, when grown in the field under conventional cultural practices (Theurer, 1994; Theurer and Zielke, 1991). When sucrose percentage is improved, SR hybrids could be grown commercially within a few years.

Unlike in many other sugarbeet growing areas, the standard practice of growers in Michigan and Ohio has been to grow sugarbeets in comparatively wide rows, spaced 71-76 cm (28-30 in.) apart. This was primarily because growers set up farm equipment to grow beans, soybeans, corn, or other row crops and did not want to adjust their planting and cultivation equipment or move the wheels on their tractor. Recently, there has been research in Michigan to assess the merit of growing all row crops in narrower row widths. Preliminary data tends to show an advantage in most crops for reduction in row width to about 56 cm (22 in.) (Christenson et al., 1978; personal communication with D.R. Christenson relative to 1989-1990 unpublished field trials). Sugar companies are also now recommending 64,000 to 69,000 plants ha^{-1} (140-150 beets per 31 m (100 ft.) for rows 28-30 in. apart) for efficient production and processing. This is a slight increase in population from recommendations of a decade ago.

SR sugarbeets tend to have fibrous roots more widely spread over the surface of the taproot and also show a trend for fewer fibrous roots near the soil surface than standard cultivars (Theurer, 1993a; Smucker and Theurer, 1991, 1992). Because most sugarbeet growing areas use 50-56 cm (20-22 in.) spacing between rows, and with emphasis on changing to narrow rows in Michigan and Ohio, we need to know how the smooth root types respond to high density planting. In this paper we present data from two density experiments conducted at the Bean and Beet Research Farm near Saginaw, MI in the years 1988-1990.

MATERIALS AND METHODS

Experiment 1. Two SR lines of sugarbeet, SR 87 and 87H1-00, and two commercial cultivars, MH E-4 and ACH 176, were planted in 1988 and 1989 in a split plot randomized block experiment of six replications with row spacing as whole plots. Individual plots were planted between tractor wheels spaced 2.13 m (84 in.) apart. Three row spacings were used: 1) the conventional 71 cm (28 in.) row spacing, with plants 20 cm (8 in.) apart within the row; 2) rows 51 cm (20 in.) apart with 20 cm within row spacing; and 3) rows 35.5 cm (14 in.) apart with plants spaced 35.5 cm within the row. Plant densities for these three treatments were approximately 69,200; 96,800; and 79,100 plants ha^{-1} (28,000; 39,200; and 32,000 plants $acre^{-1}$).

Individual plots were 9 m (30 ft.) in length. The 71 cm plots consisted of three rows, the 51 cm plots of four rows, and the 35.5 cm plots of five rows. The experiment was harvested each year during the first week of October by hand digging all of the roots in the center row(s) of each plot. The two outside rows of each plot served as borders between treatments and were not harvested. Tops were removed from each root and tops and roots from all beets were weighed to obtain fresh weight data. Weights for each plot were adjusted to the same size land area. A random sample of 10 beets for each plot was selected for sucrose and clear juice purity (CJP) determinations. These determinations were made by Michigan Sugar, Carrollton, MI, by standard clear juice methods (Association of Official Agricultural Chemists, 1955). Three tops and a sample of root brei from each plot were dried in an oven for 72 hours at 30 C (85 F) to determine the dry matter percentage and calculate the dry matter produced by each genotype in each spacing treatment.

Data were analyzed using the Michigan State University MSTAT statistical program.

Experiment 2. In a second experiment, we compared SR 87 and MH E-4 at six plant densities in 1989 and at eight plant densities in 1990. Between and within row spacing and the approximate number of plants ha^{-1} or $acre^{-1}$ are shown in Table 1. Individual plots were 9 m (30 ft.) in length and were planted between tractor wheels spaced 2.13 m (84 in.) apart. There were three rows per plot in the 71 cm row spacing, and four rows per plot in the 56 cm, 51 cm, or 46 cm spacings. Plantings were made in a split plot randomized design with six replications in 1989 and three replications in 1990. Randomization in the 1990 experiment, but not in 1989, was restricted with the same row widths across the field so the experiment could be machine harvested. Within row treatments were established by thinning 5-week old plants to either 15 or 30 cm (6 or 12 in.) between plants.

The center row(s) of each plot of experiment 2 were harvested on October 11, 1989, and soil was cleaned from the roots by hand. Roots less than 4.5 cm (1.5 in.) diameter were removed from the sample before weighing, since they would be too small to be picked up or retained by a mechanical harvester. In 1990, experiment 2 was machine harvested by adjusting the puller wheels of our harvester to match the row widths. A 15 beet sample was taken from each plot each year for laboratory analyses of sucrose and purity. Root weights were corrected to equalize land area and all data were analyzed using MSTAT statistical programs.

RESULTS

The natural environments during each of the three growing seasons were extremely different. The 1988 season was abnormally hot and dry with little precipitation in May and June. Good seedling emergence occurred, but the lack of moisture in the early spring resulted in cracking of the soil and increased incidence of Rhizoctonia root rot in comparison with the other years. An estimate of stand was made just prior to harvest in 1988 and plot row length was adjusted to correct yield from bias due to diseased plants. An excellent stand was observed in the 1989 experiments. This year was marked by heavy spring rains which delayed thinning for two weeks, and good moisture during the balance of the growing season. The year 1990 was an excellent growing season with moisture similar to that of 1989 except lacking the heavy spring rains.

Table 1. Approximate population densities of sugarbeets with different between and within row spacings.

Spacing (cm)		Approximate No.	
Between Rows	Within Rows	Plants ha^{-1}	Plants $Acre^{-1}$
71	30	43,130	17,450
56	30	58,710	23,750
51	30	64,580	26,130
46	30	71,760	29,040
71	15	92,260	37,330
56	15	117,420	47,520
51	15	129,170	52,270
46	15	143,510	58,080

Experiment 1. Comparative performance of the four genotypes and their interactions with row spacings are shown in Table 2. MH E-4 and ACH 176 had significantly higher sugar yield and sucrose percentage than the two SR genotypes in both 1988 and 1989 except that SR87 equalled MH E-4 in sugar yield ha^{-1} in 1989. SR 87 was consistently highest in root weight and lowest in sucrose percentage and CJP percentage for both years. Hybrid commercial cultivars also produced larger plants as evidenced by both the top and root dry matter.

The three row spacings summed over genotypes showed no significant differences for any of the characteristics measured in 1988. In 1989, the 56 cm row spacing gave significantly higher root yield than the 71 cm row spacing. The 46 cm spacing produced less top dry matter than the 56 or 71 cm spacing that year.

There were some significant spacing x genotype differences observed, but there was no consistency from year to year. MH E-4 in 1989 produced higher sugar yield ha^{-1} at 56 cm row spacing. In 1988, ACH 176 had significantly higher sugar yield ha^{-1} in 46 cm spaced plots. There were no significant differences for genotype x spacing interactions for sugar yield t^{-1}. In 1988, variety ACH 176 in 46 cm row widths significantly exceeded the root weight of plots spaced 71 cm and 56 cm between rows. None of the four genotypes showed significant differences for interaction with row spacing for sucrose percentage for either year of the study. SR 87 and 87H1-00 showed better CJP with 46 cm row width than with 71 cm spacing in 1988. Top and root dry matter were relatively consistent within year, but not between years: i.e., ACH 176 had significantly greater dry matter of both tops and roots in 46 cm spaced plots in 1988, but in 1989 the 56 cm spacing had the highest top and root dry matter. In 1989, top dry matter of MH E-4 produced at the 46 cm row width was significantly less than that for this variety grown in plots with 71 or 56 cm row widths.

Experiment 2. Mean sugar yield, root yield, sucrose percentage, and clear juice purity percentage at three row widths in 1989 and four row widths in 1990, summed across genotypes, are shown in Table 3. In general, performance at the 56 cm and 51 cm row widths was significantly better than for plots with 71 cm row widths for most of the measured characteristics.

Variety x plant density interactions are shown in Table 4. The between and within row spacings are listed under each variety in order of increasing plant density (See Table 1). Sugar yield was often improved when plant density was increased over the standard practice of 71 cm row width. For MH E-4, the 56 x 30 cm, 46 x 30 cm and 56 x 15 cm row spacings had the greatest sugar yield ha^{-1} in 1989. SR 87 at 46 x 30 cm

Table 2. Genotype x spacing means for smooth root lines and commercial hybrid cultivars.

Variety	Between Row Spacing 1988			1989		
	71 cm	56 cm	46 cm	71 cm	56 cm	46 cm
			SUGAR YIELD (Mg ha^{-1})			
MH E-4	7.02ab†	7.20ab	7.13ab	7.15cde	7.68abc	7.17cde
ACH 176	6.74b	7.02ab	7.64a	7.63abc	7.96a	7.77ab
SR 87	6.73b	6.45b	6.72b	7.18cde	7.55abcd	7.32bcd
87H1-00	6.63b	6.79b	6.44b	6.60f	7.06def	6.73ef
Mean	6.78	6.86	6.98	7.14	7.56	7.24
			SUGAR YIELD (kg t^{-1})			
MH E-4	122.9c	125.4bc	122.8c	103.8cd	106.6bc	105.0cd
ACH 176	129.2ab	132.4a	128.6ab	114.0a	111.1ab	110.8ab
SR 87	102.3e	105.7de	106.7de	91.8f	95.5ef	91.2f
87H1-00	110.2d	110.8d	109.9d	100.0de	97.6e	95.5ef
Mean	116.1	118.5	117.0	102.4	102.7	100.6
			ROOT WEIGHT (t ha^{-1})			
MH E-4	47.75bc	47.98bc	48.65bc	57.62bcd	60.31b	57.17bcd
ACH 176	43.49c	44.39c	50.00b	56.05cd	59.86bc	58.52bcd
SR 87	54.93a	50.89ab	52.91ab	65.47a	66.59a	67.04a
87H1-00	50.45ab	50.78ab	49.32b	55.38d	60.53b	58.96bcd
Mean	49.15	48.51	50.22	58.63	61.82	60.42
			SUGAR PERCENTAGE			
MH E-4	17.63a	17.91bc	17.65c	14.77cd	15.19bc	14.92cd
ACH 176	18.47ab	18.66a	18.28abc	16.11a	15.80ab	15.73ab
SR 87	15.18e	15.48de	15.52de	13.40f	13.81ef	13.36f
87H1-00	15.96d	16.01d	15.66de	14.36de	13.97ef	13.81ef
Mean	16.81	17.01	16.78	14.66	14.69	14.45
			CLEAR JUICE PURITY PERCENTAGE			
MH E-4	93.71bcde	93.91abcd	93.62bcde	94.59ab	94.38ab	94.59ab
ACH 176	93.78abcd	94.50a	94.07abc	94.70a	94.40ab	94.52ab
SR 87	92.36f	92.96ef	93.26de	93.48cd	93.88bcd	93.38d
87H1-00	93.45de	93.58bcde	94.28ab	94.13abc	94.41ab	93.90bcd
Mean	93.32	93.73	93.81	94.22	94.26	94.10
			TOP DRY MATTER (kg)			
MH E-4	3.38b	3.40b	3.34b	3.27ab	3.31ab	2.77cd
ACH 176	3.23b	3.26b	3.82a	3.22ab	3.41a	3.04bc
SR 87	2.80cd	2.60d	2.87cd	2.81cd	2.81cd	2.59d
87H1-00	3.07bc	2.79cd	3.05bc	2.63d	2.91cd	2.63d
Mean	3.12	3.01	3.27	2.98	3.11	2.75
			ROOT DRY MATTER (kg)			
MH E-4	10.49abc	10.78ab	10.73ab	6.95ab	7.35ab	6.86bc
ACH 176	9.90bc	10.08bc	11.33a	7.13ab	7.49a	7.26ab
SR 87	9.96bc	9.67bc	9.77bc	6.76bcd	7.13ab	7.04ab
87H1-00	9.77bc	9.95bc	9.44c	6.27d	6.36cd	6.27d
Mean	10.03	10.12	10.32	6.77	7.08	6.86

†Duncan's Multiple Range Test - means within years with the same letter are not significantly different at the 0.05 level.

spacing (71,760 plants ha^{-1}) was significantly higher in sugar yield ha^{-1} than at other spacings in 1989. In 1990 there was little difference in the sugar yield ha^{-1} at the eight plant densities for both varieties, with the exception that the standard 71 x 30 cm spacing for SR 87 yielded significantly less than was obtained at all other plant densities.

MH E-4 grown in 56 x 15 cm row width produced the highest sugar yield t^{-1} for both years. The 71 x 30 spacing for MH E-4 was significantly lower than for all other row spacings in 1990. Sugar yield t^{-1} for SR 87 was highest for the 46 x 30 row spacing and lowest for 56 x 30 cm row spacing in 1989. In 1990, 51 x 15 cm, 46 x 30, and 46 x 15 row spacings were highest in sugar yield t^{-1} and the 71 x 30 cm spacing was significantly lower in sugar yield t^{-1} than all other row spacings for both varieties. The high density 46 x 15 cm spacing for the MH E-4 cultivar gave significantly the lowest root yield of all the different row spacings in 1989, while there were few significant differences among the plant densities for root yield of MH E-4 in 1990. SR 87 produced highest root yields in 46 x 30 cm spacing (71,760 plants ha^{-1}) in 1989 and in 56 x 15 cm spacing (117,420 plants ha^{-1}) in 1990. The standard 71 x 30 cm row spacing gave low root yield for SR 87 each year. Within

Table 3. Mean sugar yield, root yield, sucrose percentage, and clear juice purity percentage for sugarbeets grown in 71, 56, 51, and 46 cm row widths averaged over genotypes (MH E-4, SR 87).

Row Width	Sugar Yield		Root Wt.	Sucrose	CJP
cm	Mg ha^{-1}	kg t^{-1}	t ha^{-1}	%	%
1989					
71	6.54b†	107.5a	51.12b	15.43a	93.94b
56	6.98a	107.6a	54.70a	15.42a	94.03b
46	6.91a	109.8a	53.14ab	15.63a	94.33a
1990					
71	5.94bc	111.6b	44.62ab	18.01b	95.12b
56	6.47a	115.2a	47.53a	18.41a	95.53a
51	6.29ab	115.0a	46.19a	18.34a	95.64a
46	5.90c	115.4a	43.05b	18.41a	95.62a

† Duncan's Multiple Range Test - means in columns within years with the same letter are not significantly different at the 0.05 level.

Table 4. Mean sugar yield, root yield, sucrose percentage and clear juice purity percentage for SR 87 smooth root line versus MH E-4 commercial variety grown at different plant densities.

	Row Spacing (cm)		Sugar Yield		Root Wt.	Sucrose	CJP
Variety	Between	Within	Mg ha^{-1}	kg t^{-1}	t ha^{-1}	%	%
1989							
MH E-4	71	30	6.37cd[†]	112.1b	47.53ef	16.06b	93.98de
	56	30	7.05b	113.4b	52.01de	16.11b	94.42bcd
	46	30	7.06b	115.5ab	51.12de	16.33ab	94.65abc
	71	15	6.26de	113.8b	46.19f	16.16b	94.42c
	56	15	6.71bc	118.9a	47.31ef	16.63a	95.18a
	46	15	5.68e	115.6ab	41.03g	16.29ab	94.83ab
SR 87	71	30	6.75b	101.4cde	55.83cd	14.69cde	93.60efg
	56	30	7.19b	98.4e	61.21ab	14.41e	93.11g
	46	30	7.88a	104.7c	63.00a	15.02c	94.04f
	71	15	6.81bcd	102.5c	55.60cd	14.80cd	93.77ef
	56	15	6.94bc	99.7de	58.29abc	14.52d	93.39f
	46	15	7.03b	103.3cd	56.95b	14.90cd	93.81ef
Mean			6.81	108.2	52.91	15.49	94.10
1990							
MH E-4	71	30	6.28a	118.6c	44.39cdef	18.96e	95.43d
	56	30	6.14ac	123.8a	41.48ef	19.58ab	95.87bc
	51	30	6.12a	120.8b	42.37ef	19.15de	95.82bc
	46	30	6.32a	121.7b	43.49def	19.33cd	95.69c
	71	15	6.22a	121.4b	42.82def	19.30cd	95.66c
	56	15	6.25a	125.3a	41.70ef	19.75a	96.02ab
	51	15	5.89b	123.9a	39.91ef	19.50bc	96.12a
	46	15	6.17a	123.7a	42.73def	19.45bc	96.20a
SR 87	71	30	5.40c	101.7i	44.39cdef	16.86i	94.13g
	56	30	6.64a	104.8h	52.91ab	17.08hi	94.84f
	51	30	6.65a	106.3gh	52.46ab	17.19gh	95.20e
	46	30	6.28a	108.5ef	48.43abcd	17.50f	95.26de
	71	15	5.87b	104.7h	46.86bcde	16.93i	95.26de
	56	15	6.84a	106.9fg	53.58a	17.21gh	95.41de
	51	15	6.50ab	109.1e	49.77abc	17.53f	95.43d
	46	15	6.18a	107.8efg	49.98abcd	17.38fg	95.32d
Mean			6.23	114.3	45.89	18.29	95.48

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

each of the two genotypes there were highly significant differences in sucrose percentage between some spacings each year, but there was not a widespread difference by plant densities within a genotype. Field plots having the highest sucrose percentage for both years was the 56 x 15 cm spacing for MH E-4 and the 46 x 30 cm spacing for SR 87. Higher plant densities resulted in higher clear juice purity for both varieties.

DISCUSSION

Data from these two experiments support the results of Christenson et al. (1978; personal communication) that sugarbeet yield and sucrose percentage could be increased in Michigan by planting at higher plant densities in narrower rows than the standard 71 cm row width used in commercial production today. Optimum plant density in these studies appears to be between 58,710 (56 x 30 cm row spacing) and 129,170 (51 x 15 cm row spacing) plants ha^{-1}.

Because of the differences observed between MH E-4 and SR type beets in fibrous root development (Theurer, 1993a) and in fibrous root turnover (growth vs death) observed in field minirhizotron microvideo camera studies (Smucker and Theurer, 1991, 1992), there was concern before we conducted these experiments that SR type beets might be affected more than commercial cultivars when they were subjected to more intense plant competition for nutrients and water. In these studies, no adverse effects in sugar yield, root yield, or sucrose percentage were noted when SR genotypes were subjected to increased plant competition by narrowing row widths or increasing plant density within rows. To the contrary, it appeared that SR genotypes had higher root yield and better sucrose percentage when they were grown in 46 x 30 cm to 51 x 15 cm row spacings (71,760 to 129,170 plants ha^{-1}). During a dry period in the 1991 growing season in a minirhizotron study we noted more wilting of leaves in SR 87 at a plant density of approximately 92,000 plants per hectare than in MH E-4 during afternoon full sunlight and above 27 C (80 F) degree temperatures. However, leaves of SR 87 were always turgid in the mornings. At harvest, SR 87 had the same relationship of higher root yield and lower sucrose percentage relative to MH E-4 as we have observed in this and other experiments with SR type beets (Coe and Theurer, 1987; Theurer 1989, 1993b; Theurer and Zielke, 1991). The two field experiments indicated that smooth root beet genotypes responded to plant density in different environments similarly to adapted standard root commercial cultivars. Although SR beets have a different fibrous root system than today's standard root type, we observed no adverse effect when SR sugarbeets were grown under higher plant densities than conventional 71 cm row width. If anything, SR production was enhanced when sugarbeets were grown at 71,760 plants ha^{-1} (46 x 30 cm row width).

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