Sugarbeet Yield and Quality Response to Irrigation, Row Width, and Stand Density[1]

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ABSTRACT

With reduced irrigation, many producers feel that wide rows and thin stands may not be detrimental or may even benefit production of sugarbeets (*Beta vulgaris* L.). Field research was conducted to define sugarbeet response to irrigation and to determine if row width or stand density should be adjusted for irrigation amount. Treatments were a factorial combination of three levels of irrigation (0, 8.4, and 17.9 inches mean seasonal applied water) with 30 and 40 inch rows at 17,400 and 34,800 plants/A during 4 years on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) at Bushland, TX. The only significant interaction was irrigation level by row width for root yield. The advantage of 30-inch rows over 40-inch rows was 0.7, 2.3, and 3.6 T/A with 0, 8.4, and 17.9 inches seasonal irrigation, respectively. Each inch of seasonal irrigation increased root yield 0.8 T/A and brei Na 6.5 ppm and decreased K 10 ppm, amino-N 6.4 ppm, and loss to molasses 0.012%. Sugarbeets in narrow rows with thick stands produced higher yields and better purity at all irrigation levels all years; therefore, row width and stand density need not be adjusted if seasonal irrigation is reduced.

Additional index words: *Beta vulgaris* L., molasses, sugar, sucrose, sodium, potassium, amino-nitrogen, water stress.

Sugarbeets are grown with a wide range of applied irrigation water on the Texas High Plains. Annual rainfall of 18

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inches falls mostly during the 8-month growing season and, during wetter than normal periods, is a significant source of water. Since winter and spring are ordinarily dry, irrigation is essential for consistent stand establishment. Typical irrigation after stand establishment is four "seasonal" furrow irrigations applied between mid June and mid September. In average or dry years, six to eight furrow irrigations are required to produce near maximum yield. A significant acreage of sugarbeets is produced with only one to three seasonal irrigations due to expensive and/or limited water supply. Many growers use 40-inch rows for compatibility with rotation crops especially in areas short of water. The feeling is that with limited water, row spacing will not significantly affect yield. Some growers with limited water and others with adequate water, prefer beets spaced 12 inches apart in 30-inch rows even though research indicates a 6-inch spacing gives higher root yield and sugar content with adequate irrigation (7, 16).

Sugarbeets are reasonably drought tolerant with yield roughly proportional to total water use (2, 11, 12, 15). Irrigation effects on purity or % sugar are more complicated and are frequently difficult to separate from nitrogen (N) effects. Percent sugar may be improved where excess water leaches N from the soil early in the growing season (4). Purity is not usually improved by water stress (10, 13) although fresh weight sugar % may increase due to root dehydration (1, 2, 10). Wide rows and thin stands reduce yield and % sugar of adequately watered sugarbeets (3, 6, 7, 14).

This research was conducted to further define sugarbeet yield and quality response to irrigation over a range of environments and to determine if row width and stand density should be adjusted for differences in irrigation level.

MATERIALS AND METHODS

Sugarbeets, 'Mono-Hy TX 9', were grown in level basins on Pullman clay loam soil (fine, mixed, thermic, Torrertic Paleustoll) at Bushland, Texas, elevation 3,700 ft, in 1982, 1984, 1985, and 1986. Soil samples taken to 10-ft depth and irrigation water analyses indicated non-saline soil with very high K fertility and high quality irrigation water. Total salinity was low in the 0- to 2-ft depth at 600 ppm, increased to 1,600 ppm in the 2- to 4-ft depth, and then declined to 800 ppm at 10 ft. Potassium was 410 ppm in the 0- to 2-ft depth and about 260 ppm at greater depths. Sodium was 160 ppm in the 0- to 2-ft zone and 280 to 400 ppm below 2 ft. Irrigation water was low in all salts with 33, 5, and 304 ppm Na, K, and total dissolved solids, respectively. Treatments were a factorial combination of three irrigation levels (none, limited, and adequate seasonal irrigation), two row widths (30 and 40 inch rows), and two stand densities (17,400

Table 1. Water use by sugarbeets from precipitation, irrigation, and the soil during 4 years of research at Bushland, TX.

Water source	Seasonal irrigation	1982	1984	1985	1986
		inches			
Precipitation'	all levels	17.1	18.5	12.5	19.1
Emergence irrigation	all levels	9.1	12.9	11.5	13.6
Net soil water depletion, 0 to 10 ft	none	2.3	4.4	3.0	6.1
	limited	2.2	4.0	2.0	5.9
	adequate	1.6	2.3	1.0	3.6
Seasonal irrigation	none	0.0	0.0	0.0	0.0
	limited	3.4	8.0	12.0	10.3
	adequate	10.9	16.0	27.0	17.6
Total water use	none	28.5	35.8	27.0	38.8
	limited	31.8	43.4	38.0	48.9
	adequate	38.7	49.7	52.0	53.9

' Precipitation from planting in March to harvest in November. The 47-yr average precipitation, April 1 to October 31, is 15.5 inches.

and 34,800 plants/A). Flood irrigations applied to diked, level basins were measured with an in-line flow meter. Preplant and emergence irrigation was uniform on all treatments (Table 1). The driest treatment received no seasonal irrigation. Limited irrigation was 4 to 5 inches at one month intervals from 15 June to 15 August except during rainy periods when the irrigation was delayed or skipped. Adequate irrigation received 3 to 4 inches at 10 to 14 day intervals from 10 June to 15 September except when delayed by rain. Precipitation plus irrigation applied to the adequate treatment was 80% of evaporation from a Young 2 ft screened pan in 1982 and 100% the other years. To facilitate harvest, no irrigation was applied after 15 September. Soil water was measured gravimetrically by coring to 10-ft depth prior to preplant irrigation and after harvest. Irrigation treatments were main plots (20 x 60 ft), row widths were sub plots (10 x 60 ft), and stand densities were sub-sub plots (10 x 30 ft) in a randomized complete block design with three replications except in 1986 when there were six replications.

The sugarbeets were planted in March at 8 to 12 seeds/ft of row on 6-inch-high beds spaced 30 or 40 inches between furrows and hand thinned to the desired stands at the eight-leaf stage of growth. The center row of three 40-inch rows and the center two rows of four 30-inch rows were lifted with a commercial harvester in November. At harvest, two 30-lb samples were collected from each plot (four samples/plot in 1986) for tare, sugar, and purity analysis. Brei samples (finely chopped roots) were analyzed for Na and K with a flame photometer and for amino-N using the ninhydrin procedure. The following formulas developed by American Crystal Sugar Company, Moorhead, MN, were used to calculate yield and purity values:

Gross sugar, lb/A = (t/A) (% sugar) (20)

$$\text{Recoverable sugar, lb/A} = \frac{(\text{Gross sugar, lb/A}) \quad (\text{Recoverable sugar \%})}{100}$$

$$\text{Loss to molasses} = \frac{(\text{impurity})}{11{,}000} \quad (1.5)$$

$$\text{Impurity} = (3.5)\,(\text{ppm Na}) + (2.5)\,(\text{ppm K}) + (9.5)\,(\text{ppm Amino-N})$$

$$\text{Recoverable sugar \%} = (100)\ \frac{(\text{Sugar \% - 0.60 - loss to molasses})}{\text{Sugar \%}}$$

Soil samples taken to 6-ft depth before planting indicated residual nitrate nitrogen of 223, 186, 180, and 86 lbs/A in 1982, 1984, 1985, and 1986, respectively. No additional nitrogen was applied to any plots in 1982 and 1985. In 1984, N was applied at 0, 50, and 100 lb/A to all plots receiving none, limited, and adequate irrigation, respectively. In 1986, due to low residual N, 60, 120, and 150 lb/A was applied to none, limited, and adequate irrigation plots, respectively.

The data were analyzed as a split-split-plot using analysis of variance procedures (9). In addition, linear regressions were run for yield and quality factors using seasonal irrigation amount in inches as the independent variable. Differences discussed are significant at P = 0.05 or less.

RESULTS AND DISCUSSION

Total water use ranged from 27.0 inches with no seasonal irrigation in 1985, a dry year, to 53.9 inches with adequate irrigation in 1986, a wet year. Three years, 1982, 1984, and 1986, had above average precipitation (Table 1). The limited and no seasonal irrigation treatments resulted in moderate to severe water stress for periods as long as 120 days beginning in early June.

The only significant interaction was irrigation level by row width for root yield in 1985 and in the combined analysis over years. The advantage of 30-inch rows over 40-inch rows was 0.7, 2.3, and 3.6 T/A with 0, 8.4, and 17.9 inches seasonal irrigation, respectively. As seasonal irrigation decreased, the advantage of 30 inch rows over 40 inch rows decreased. Apparently, with prolonged water stress, as occurred in the driest treatment, yield was limited mainly by water. Because of the general lack of significant interactions, it is valid to look at mean treatment effects as presented in Table 2.

When considering the results of these experiments, remember that N was confounded with water in 1984 and 1986. The effects that might be attributed solely to irrigation in 1984 and 1986 are really due to systems of production that consisted of the agronomically correct N rate for each irrigation level. Nitrogen was confounded with water in order to obtain valid results from the row spacing and stand density treatments. In 1982 and 1985, residual N was adequate to avoid serious N deficiency at all irrigation levels so no N was applied to any treatment. Thus, the 1982 and 1985 data allow study of unconfounded effects of irrigation level. In actuality, results of these studies, as will be discussed in the following sections, were largely unaffected by N and were basically the same every year.

Table 2. Four-year-average effects of seasonal irrigation, row width, and stand density on sugarbeet yield and quality factors at Bushland, TX.

Factor	Level	Root yield	Sugar	Na	K	Amino-N	Loss to molasses	Recoverable sugar	
		T/A	%	ppm			%	%	lb/A
Seasonal irrigation	inches								
	0	23.1 c'	14.84 a	629 a	2580 a	517 a	1.84 a	83.67 a	6080 c
	8.4	31.6 b	14.57 ab	655 a	2490 ab	458 b	1.76 b	83.83 a	8000 b
	17.9	37.4 a	14.16 b	671 a	2400 b	403 c	1.67 c	84.04 a	9040 a
Row width	inches								
	30	31.5	14.63	641	2490	446	1.73	84.11	8030
	40	29.9	14.42	663	2490	472	1.78	83.59	7390
Stand density	plants/A								
	17,400	29.6	14.42	661	2540	468	1.79	83.51	7340
	34,800	31.8	14.62	643	2440	450	1.72	84.18	8070
F values									
Irrigation		382**	17.7**	2.6NS	12.0**	19.9**	10.2**	1.7NS	179**
Row width		25**	9.1**	1.3NS	0.4NS	8.3**	4.5*	6.4*	28**
Stand density		47**	8.2**	1.5NS	21.3**	4.7*	15.7**	16.6**	62**
CV (%)		6.9	3.2	13.9	5.4	11.7	6.0	1.2	7.7

*, ** Significant at the 0.05 and 0.01 probability levels, respectively. NS = not significant.
' Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 3. Linear regression relationships to predict root yield, sugar, gross sugar (GS), and recoverable sugar (RS) based upon the inches of seasonal irrigation applied during 4 years at Bushland, TX.

Parameter	1982	1984	1985	1986	Combined
			SLOPE		
Root yield, T/A	0.836 **	0.696 **	0.769 **	0.926 **	0.845 **
Sugar, %	NS	NS	NS	-0.081 **	-0.058 **
GS, lb/A	263 **	194 **	219 **	199 **	204 **
RS, lb/A	232 **	165 **	187 **	164 **	173 **
			INTERCEPT		
Root yield, T/A	19.8 **	22.6 **	12.9 **	31.0 **	24.6 **
Sugar, %	NS	NS	NS	14.84 **	15.10 **
GS, lb/A	6080 **	6970 **	3580 **	9240 **	7450 **
RS, lb/A	5080 **	5660 **	2940 **	7890 **	6250 **
			r^2		
Root yield, T/A	0.78 **	0.60 **	0.98 **	0.81 **	0.41 **
Sugar, %	NS	NS	NS	0.54 **	0.21 **
GS, lb/A	0.70 **	0.51 **	0.96 **	0.65 **	0.36 **
RS, lb/A	0.67 **	0.49 **	0.95 **	0.61 **	0.34 **
n	36	36	36	72	180

*, ** Significant at the 0.05 and 0.01 probability levels, respectively. NS = not significant.

Irrigation effects

Greater seasonal irrigation increased root yield and improved processing quality (Table 2) although % sugar, fresh weight basis, was reduced in 1986 (Table 3). The dry treatments resulted in greater loss of sugar to molasses because K and amino-N in the root at harvest were increased compared to the adequate water level.

Mean root yield increased from 23.1 T/A with no seasonal irrigation to 37.4 T/A with 17.9 inches seasonal irrigation (Table 2). Response to water averaged 0.80 T/A-inch with a range from 0.70 to 0.93 T/A-inch (Table 3). This response to water compares favorably to responses reported in the literature (8) and reflects the good growth achieved in these studies. Sugar % on a fresh weight basis was increased in 1986 by reduced seasonal irrigation. This response is believed to be a root dehydration effect that has frequently been discussed in the literature (1, 2, 10). In other years, seasonal irrigation did not affect % sugar at harvest. The lack of effect most years may be related to the fact that irrigation cutoff was usually about 60 days prior to harvest. The early irrigation cutoff allows sugarbeets in all irrigation regimes to reach similar hydration by harvest in most years. Early cutoff is practiced to facilitate harvest and because sugar yield is usually not reduced as has been noted elsewhere (2).

Irrigation effects on impurities in the root at harvest are presented in Table 4 in the form of slopes and intercepts of linear regressions. Greater irrigation decreased Na in 1982 but increased it the other 3 years. The 1982 effect is probably anomalous since a consistent increase in Na occurred the last 3 years with an average of + 6.5 ppm Na/inch seasonal irrigation (Table 4). In contrast, K, amino-N, and sugar loss to molasses declined with greater seasonal irrigation. While the regressions of K and amino-N against irrigation were sometimes not significant, when significant, the slopes were negative (Table 4) and main effects of irrigation for the 4-year combined analyses were significant (Table 2). The combined regression analyses for K and amino-N were not satisfactory but responses can be estimated from yearly regressions and from main effects in Table 2. The approximate responses of K, amino-N, and molasses loss to seasonal irrigation were: -10 ppm, -6.4 ppm, and -0.012%, respectively, per inch of seasonal irrigation.

Nitrogen fertilization did not alter the basic relationships between impurities and irrigation level. More irrigation lowered total impurities (decreased loss to molasses) in the roots at harvest even in 1984 and 1986 (Table 4) when more N was applied to the higher water levels. In 1982 and 1985, when all water levels received the same N, sugar loss to molasses declined an average of 0.0147% for each additional inch of seasonal irrigation. In 1984 and 1986, sugar loss to molasses declined an average of 0.0102% for each additional inch of seasonal irrigation. Thus, applying

Table 4. Linear regression relationships to predict Na, K, and amino-N in the root at harvest, sugar loss to molasses, and recoverable sugar (RS) percent based upon the inches of seasonal irrigation applied during 4 years at Bushland, TX.

Parameter	1982	1984	1985	1986	Combined
			SLOPE		
Na, ppm	-12.0 *	6.4 *	5.8 **	7.3 **	NS
K, ppm	-28.2 **	NS	NS	-8.4 **	-23.8 **
Amino-N, ppm	NS	-11.8 **	-7.3 **	-5.0 **	NS
Molasses, %	-0.021 **	-0.0146 *	-0.0083 *	-0.0058 **	-0.0120 **
RS, %	0.146 **	NS	NS	-0.046 **	NS
			INTERCEPT		
Na, ppm	813 **	567 **	506 **	566 **	NS
K, ppm	3230 **	NS	NS	2290 **	2690 **
Amino-N, ppm	NS	818 **	707 **	406 **	NS
Molasses, %	1.927 **	2.270 **	1.847 **	1.577 **	1.855 **
RS, %	83.5 **	NS	NS	85.3 **	NS
			r^2		
Na, ppm	0.14 *	0.12 *	0.57 **	0.21 **	NS
K, ppm	0.22 **	NS	NS	0.23 **	0.17 **
Amino-N, ppm	NS	0.34 **	0.53 **	0.31 **	NS
Molasses, %	0.25 **	0.17 *	0.32 **	0.12 **	0.09 **
RS, %	0.14 *	NS	NS	0.07 *	NS
n	36	36	36	72	180

*, ** Significant at the 0.05 and 0.01 probability levels, respectively. NS = not significant.

the agronomically correct N rates in 1984 and 1986 reduced by one third the improvement in quality attributed to water in 1982 and 1985. The effect that N confounding may have had on Na, K, and amino-N cannot be accurately determined because the regression equations were not significant every year (Table 4).

Row width and stand density effects

Wide rows and thin stands reduced root yield, sugar %, recoverable sugar %, and recoverable sugar per acre at all irrigation levels. Results were consistent over years (data for individual years not shown). Because of the lack of significant interactions, as discussed earlier, and the consistent results over years, the most accurate comparisions of row widths and stand densities are the means over other treatments and years presented in Table 2. The yield responses to row width and stand density at all irrigation levels are similiar to those previously reported for adequately irrigated conditions (3, 5, 6, 7, 14). The detrimental effects of wide rows and thin stand on processing quality were due to increased amino-N that resulted in increased sugar loss to molasses (Table 2).

Row width and stand density had similiar effects on yield and quality. This is not suprising since both affect the geometry of plant spacing. The one factor where row width and stand density produced different effects was on brei K. Row width had no effect on K whereas thin stands increased K compared to thick stands (Table 2).

Row width and stand density do not need to be adjusted if seasonal irrigation is reduced. Narrow rows and thick stands increased yield and reduced sugar loss to molasses even where water stress was severe enough to reduce root yield from about 37 T/A to 23 T/A.

LITERATURE CITED

1. Carter, J. N. 1982. Effect of nitrogen and irrigation levels, location and year on sucrose concentration of sugarbeets in Southern Idaho. J. Am. Soc. Sugar Beet Technol. 21:286-306.
2. Carter, J. N., M. E. Jensen, and D. J. Traveller. 1980. Effect of mid-to-late-season water stress on sugarbeet growth and yield. Agron. J. 72:806-815.
3. Dillon, M. A., and W. R. Schmehl. 1971. Sugarbeet as influenced by row width, nitrogen fertilizer, and planting date. J. Am. Soc. Sugar Beet Technol. 16:585-594.
4. Haddock, J. L. 1959. Yield, quality and nutrient content of sugar beets as affected by irrigation regime and fertilizers. J. Am. Soc. Sugar Beet Technol. 10:344-355.
5. Haddock, J. L., P. B. Smith, A. R. Downie, J. T. Alexander, B. E. Easton, and V. Jensen. 1959. The influence of cultural practices on the quality of sugar beets. J. Am. Soc. Sugar Beet Technol. 10:290-301.
6. Herron, G. M., D. W. Grimes, and R. E. Finkner. 1964. Effect of plant spacing and ferilizer on yield, purity and chemical constituents and evapotrapiration of sugar beets in Kansas. I. Yield of roots, purity, percent sucrose and evapotranspiration. J. Am. Soc. Sugar Beet Technol. 12:686-698.
7. Hills, F. J. 1973. Effects of spacing on sugar beets in 30 inch and 14-26 inch rows. J. Am. Soc. Sugar Beet Technol. 17:300-308.
8. Jensen, M. E., and L. J. Erie. 1971. Irrigation and water management. *In Advances in Sugarbeet Production: Principles and Practices.* R. T. Johnson, J. T. Alexander, G. E. Rush, and G. R. Hawkes eds. The Iowa State Univ. Press, Ames, Iowa USA. pp. 189-222.
9. Little, T. M., and F. J. Hills. 1978. Agricultural experimention. John Wiley and Sons. New York.
10. Loomis, R. S., and G. F. Worker, Jr. 1963. Responses of the sugar beet to low soil moisture at two levels of nitrogen nutrition. Agron. J. 55:509-515.
11. Miller, D. E., and J. S. Aarstad. 1976. Yield and sugar content of sugarbeets as affected by deficit high-frequency irrigation. Agron. J. 68:231-234.
12. Nicholson, M. R., T. Kibreab, R. E. Danielson, and R. A. Young. 1974. Yield and economic implications of sugarbeet production as influenced by irrigation and nitrogen fertilizer. J. Am. Soc. Sugar Beet Technol. 18:34-44.
13. Reichman, G. A., E. J. Doering, L. C. Benz, and R. F. Follett. 1977. Effects of water-table depth and irrigation on sugarbeet yield and quality. J. Am. Soc. Sugar Beet Technol. 19:275-287.
14. Robinson, F. E., and G. F. Worker, Jr. 1969. Plant density and yield of sugar beets in an arid environment. Agron. J. 61:441-443.
15. Winter, S. R. 1980. Suitability of sugarbeets for limited irrigation in a semi-arid climate. Agron. J. 72:118-123.
16. Winter, S. R. 1980. Planting sugarbeets to stand when establishment is erratic. Agron. J. 72:654-656.