Sucrose Production as Affected by Root Yield and Sucrose Concentration of Sugarbeets*

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INTRODUCTION

Refined sugar production of sugarbeets (*Beta vulgaris* L.) is based on the product of root yield and extractable sucrose concentration. Conditions that affect either of these components may either increase or decrease refined sugar yield. Therefore, it is of prime importance to use practices and conditions that provide adequate top and root growth while maintaining sufficiently high sucrose concentration and purity for profitable sucrose extraction and yield.

An inherent inverse relationship exists between sugarbeet root yield and wet root sucrose concentration (9,10,15). Increasing root yields by plant breeding, genetic selection, nitrogen (N) fertilization, agronomic practices, and environmental conditions will generally decrease sucrose concentration (5,14). Milford (13) and Doney (7,8) have both reported an inverse relationship between root cell size and sucrose concentration, and have suggested that the negative correlation results from the opposite effects of cell size on root yield and sucrose concentration. Large cells produce large roots with high root yields and low sucrose concentration; whereas small cells produce small roots with low root yields and high sucrose concentration.

Recently reported experimental results showed that N uptake and the proportion and amounts of potassium (K) and sodium (Na) have a major influence on sucrose concentration and root quality (2,3). Increased N uptake reduces

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sucrose concentration by making the tops the dominant photosynthate sink at the expense of the roots, and by changing the concentration and proportion of root K and Na. Increasing the Na concentration or decreasing the K:Na ratio by increased N uptake, increases the root water concentration with a reduction in sucrose concentration. Variations in Na concentrations and K:Na ratios for sugarbeets grown at different locations the same year, between years, and between different genotypes also results in water and sucrose concentration changes. These variations in water concentration between treatments and genotypes indicate that root Na concentrations and/or K:Na ratios may be involved in the inverse relationship between root yield and sucrose concentration. Therefore, the objective of this investigation was to evaluate sucrose production as affected by root yield, wet and dry sucrose concentrations, and dry matter and water concentrations of widely different *Beta vulgaris* genotypes grown at different N uptake levels, field locations, climatic conditions, and years.

MATERIALS AND METHODS

Eleven experiments on sugarbeets have been conducted since 1967 by scientists located at Kimberly, with experimental plots at 36 locations in southern Idaho. References to and specific procedures used in these experiments have been published (2,3). These experiments were conducted on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) with the exception of some of the plot areas in the 1971 and 1972 studies. The majority of soils in southern Idaho have a weakly cemented hardpan at the 0.5- to 0.6-m depth that has little effect on water movement but may restrict some root penetration.

Soil samples were taken from each experiment in early spring before fertilizer application by 0.15-m depth increments to the 0.6-m depth or to the hardpan. The soil samples were air dried, ground, and stored until analyzed. The potentially available soil N was determined on all samples (5).

Most of the agronomic practices such as planting date, cultivation, and harvest date were rather uniform among years. However, variations in these practices that cause changes in the sugarbeet growth and yield components are given in this section, tables, figures, or in the discussion of this information.

The sugarbeets [Amalgamated AH-10 (1967 to 1980), WS-76 (1982), WS-76 and WS-88 (1983), and *Beta vulgaris* genotypes (4) with the common name of GWD2, AH-10 (commercial hybrids); LHY-1, LHS-1 (Experimental hybrids); Monorosa, Monoblanc (Fodder beet hybrids); Pajbjerg Korsroe, and Rota (Fodder beets) (1980)] were planted in early to mid-April in either 0.56 or 0.61 m rows and thinned to a 0.23 to 0.30 m within row spacing in early June.[1/]

Nitrogen, as ammonium nitrate, was applied preplant and in mid-June by broadcast or sidedress applications. Later N applications were broadcast as urea and moved into the soil with sprinkler irrigation. All experimental plot areas were adequately supplied with phosphorus (16).

Alternate furrow (every other furrow and alternating furrows at each irrigation) or sprinkler irrigations were used. Experimental areas were adequately irrigated based on previous irrigation experiments except where deficit irrigation was intentionally imposed.

The sugarbeets were harvested in October by taking top and root samples from three to six 3-m row lengths or by mechanically harvesting the roots from a larger area of each plot at final harvest in October. All beet roots were horizontally sectioned at the lowest leaf scar into harvested root and crown tissue before taking duplicate or triplicate root (16 to 18 roots per sample) and crown samples. The sucrose concentration in the beet roots and crowns was determined by the Amalgamated Sugar Company using the Sachs-le Docte cold digestion procedure as outlined by McGinnis (12).

[1/] Mention of trade names or companies is for the benefit of the reader and does not imply endorsement by the U.S. Department of Agriculture.

Moisture content and dry weights were determined in beet top, root, and crown samples dried at 65°C. The dried samples were ground and total N was determined by the macro, or semimicro, Kjeldahl procedure modified to include nitrate (1). The N uptake was estimated by assuming that the element concentration was the same in both the fibrous and storage roots (root + crown) and the weight of the unharvested fibrous roots was equal to 25% of the total harvested storage root weight (11).

Dry matter and water yields were calculated by multiplying their concentrations in the roots by the root yield. The root yield gains attributed to changes in dry matter and water concentrations were calculated by subtracting the dry matter or water yields of the check or reference treatment from the dry matter or water yields of the adjusted or higher yielding treatment.

The decrease in sucrose concentration of the wet root attributed to increases in the water concentration was calculated by using either of the following equations:

$$S_L = S_c - [SY_c/(DMY_c/(100-W_T))]$$

or

$$S_L = S_c - [(DM_T \times S_c)/(100 - W_c)]$$

where S_L is the percent unit sucrose decrease resulting from root water gain, S_c is the percent wet root sucrose of the check or reference treatment, SY_c is the sucrose yield of the check or reference treatment, DMY_c is the dry matter yield of the check or reference treatment, W_T is the percent root water of the adjusted treatment, DM_T is the percent root dry matter of the adjusted treatment, and W_c is the percent root water of the check or reference treatment.

The decrease in sucrose concentration resulting from decreases in the percent sucrose of the dry matter was calculated by differences between that attributed to water gain and the total percent sucrose decrease of the wet roots.

The change in sucrose yield between treatments, years, or genotypes attributed to percent sucrose of the dry

matter (PSDM) and dry matter changes was calculated using the following equations:

$$S_{PSDM} = SWt_2 - SWt_{1\&2}$$

and

$$S_{DM} = SWt_{1\&2} - SWt_1$$

where S_{PSDM} is the sucrose yield change attributed to PSDM, S_{DM} is the sucrose yield change attributed to dry matter, $SWt_1 = (PSDM_1/100) \times DM\ yd_1$, $SWt_2 = (PSDM_2/100) \times DM\ yd_2$, $SWt_{1\&2} = (PSDM_1/100) \times DM\ yd_2$, DM yd is the dry matter yield, subscript 1 is the lower sucrose yield treatment, and subscript 2 is the higher sucrose yield treatment.

RESULTS AND DISCUSSION

The *Beta vulgaris* genotypes varied widely in their root yield, sucrose and water concentrations (Table 1). When the genotype with the lowest root yield and highest sucrose concentration (LHS-1) was compared with the other genotypes, the proportion of the root yield increase attributed to water and dry matter varied with genotype. The proportion of the root yield increase attributed to water varied from 86 to 102% and averaged 95% of the total increase. The remaining increase in root yield of -2 to 14% was attributed to dry matter increase. The sucrose concentration (% wet root) decrease resulting from water increase varied among the genotypes from 68 to 95% and averaged 89% of the total decrease. Whereas, sucrose concentration decrease resulting from a decrease in the percent sucrose of the dry matter (PSDM) varied from 5 to 32% and averaged 11% of the total. Total sucrose yield is the product of PSDM and dry matter production. Genotypes, treatments, or conditions that affect either or both of these yield factors usually change sucrose yield. The sucrose yield changes among genotypes resulted from both a change in PSDM and dry matter production (Table 1). However, the major cause of sucrose yield change was, in most cases, attributed to dry matter production. Sucrose production generally followed the proportion of dry matter to water that increased root yield. Higher sucrose produc-

Table 1. Changes in root and sucrose yields, and sucrose concentration between *Beta vulgaris* genotypes attributed (attr.) to percent sucrose of the dry matter (PDSM), dry matter (DM), and water in the roots during 1980.

		ROOT + CROWN†											
		Root yield				Sucrose Concentration					Sucrose Yield		
			Change. attr. to:				Change. attr. to:					Change. attr. to:	
Beta vulgaris genotypes	Total N uptake	Total	DM	--- Water ---		Wet wt.	PSDM	--- Water ---		Dry wt.	Total	PSDM	DM
	kg ha^{-1}	----- Mg ha^{-1} -----			% §	%	-% units -¶		%§	%	----- Mg ha^{-1} -----		
LHS-1‡	322	73.0				19.7				75.4	14.32		
AH-10	332	79.8	+0.2	+6.6	+97	17.5	-0.7	-1.5	-68	72.5	13.91	-0.56	+0.15
GWD2	339	86.0	+1.4	+11.6	+89	17.7	-0.1	-1.9	-94	74.8	15.24	-0.12	+1.04
LHY-1	324	87.0	+1.9	+12.1	+86	18.0	-0.2	-1.5	-90	74.7	15.62	-0.15	+1.45
Monorosa	360	98.5	+0.4	+25.1	+98	14.5	-0.4	-4.8	-93	73.5	14.26	-0.37	+0.31
Monoblanc	343	112.0	+1.5	+37.5	+96	13.5	-0.3	-5.9	-95	73.8	15.11	-0.33	+1.12
Rota	318	130.2	-1.2	+58.4	>+100	9.5	-0.8	-9.4	-92	69.6	12.37	-1.10	-0.85
Pajbjerg K.	357	131.8	+1.9	+56.9	+97	11.2	-0.8	-7.7	-90	70.3	14.68	-1.08	+1.44

† Avg. of 196 and 392 kg N ha^{-1} applied N treatments.
‡ Lowest root yield and highest wet root sucrose concentration.
§ Percent of total gain or decrease.
¶ Actual % sucrose units, wet weight.

tion was obtained when the increase in dry matter in relation to water was highest while maintaining a reasonably high PSDM and vice versa.

High negative linear correlations existed between the root water and sucrose concentrations of the different genotypes at each of the two N levels (Figure 1A). There also was a high negative linear correlation between root or water yields and sucrose concentration at the two N levels (Figure 1B). The slopes of the regression lines

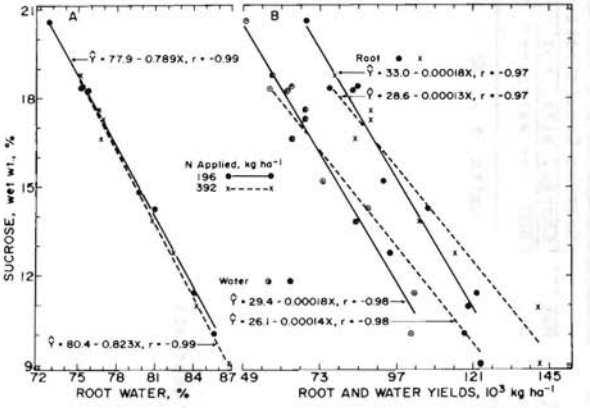

Figure 1. Effect of root: (A) water concentration on sucrose concentration, and (B) water and root yields on sucrose concentration of different *Beta vulgaris* genotypes during 1980. All correlation coefficients highly significant at the 1% level.

were also essentially the same for root and water yields when compared with sucrose concentration at the two N levels. These relationships indicate that the inverse relationship between root yield and sucrose concentration of different genotypes resulted mainly from the increased proportion of water to dry matter in the roots with higher root yields. However, PSDM level does contribute to this inverse relationship that varies among genotypes and may contribute up to 32% of the change in sucrose concentration. This increase in root water among genotypes was associated with an increase in the Na concentration and/or a decrease in the K:Na ratio of the root (3).

Increasing N applications and N uptake by commercial

sugarbeet varieties on low N soils, generally increase root and sucrose yields but may decrease both wet and dry sucrose concentrations during each of several years when compared with the zero N treatment (Table 2). The root yield increase consists of both dry matter and water. However, the proportion of water to dry matter increases with increasing N uptake. The decrease in sucrose concentration of the wet roots with increased N uptake was caused by both a decrease in the PSDM and a decreased dry matter or increased water concentrations. However, the greatest amount of sucrose concentration decrease was caused by the increased proportion of water to dry matter in the roots. High linear correlations generally existed between root dry matter or water (WC) and sucrose concentrations (y) during each of the years (1968: $\hat{y} = 46.9 - 0.39$ WC, $r = -0.61^{*}$; 1977: $\hat{y} = 113.3 - 1.26$ WC, $r = -0.99^{**}$; 1982: $\hat{y} = 89.1 - 0.92$ WC, $r = -0.97^{**}$). This indicates that the inverse relationship between root yield and sucrose concentration within genotypes with increased N uptake resulted mainly from the increased proportion of water to dry matter with a lesser but important amount that can be attributed to a decrease in the PSDM. This increase in root water with increased N uptake has also been associated with an increase in the Na concentration and/or a decrease in the K:Na ratio (3).

Sucrose yield increased above the zero N treatment with increased N uptake during each of the years with the exception of the highest N uptake in 1977 (Table 2). Sucrose yield change with increased N uptake resulted from a change in both PSDM and dry matter yield. However, the majority of the yield differences was attributed to a change in dry matter yield with a smaller change attributed to the PSDM. Maximum sucrose yield was generally obtained when the increase in root yield was highest for dry matter rather than as water while maintaining a reasonably high PSDM.

Increasing N applications and N uptake by sugarbeets grown throughout southern Idaho with varying soil and cli-

Table 2. Changes in root and sucrose yields, and sucrose concentration between N uptake levels and year of plant growth at one location attributed (attr.) to percent sucrose of the dry matter (PSDM), dry matter (DM), and water in the roots.

Year	R + C Total N uptake	ROOT - CROWN (R - C)											
		Root yield				Sucrose Concentration					Sucrose Yield		
			Change. attr. to:			Wet wt.	Change. attr. to:			Dry wt.		Change. attr. to:	
		Total	DM	--- Water ---			PSDM	--- Water ---			Total	PSDM	DM
	kg ha^{-1}	----- Mg ha^{-1} -----			%‡	%	-% units -§		%‡	%	----- Mg ha^{-1} ------		
	258†	46.1				16.6				74.5	7.65		
1968	380	52.5	+1.0	+5.4	+87	16.2	+0.2	-0.6	>-100	75.5	8.48	+0.11	+0.72
	416	56.9	+1.8	+9.0	+83	16.3	+0.4	-0.7	>-100	76.3	9.25	+0.22	+1.38
	459	55.4	+1.6	+7.7	+83	16.1	+0.2	-0.7	>-100	75.6	8.94	+0.13	+1.16
	130†	46.1				19.3				75.2	8.89		
1977	210	52.1	+1.3	+4.7	+79	19.0	+0.1	-0.4	>-100	75.6	9.92	+0.06	+0.97
	338	54.2	+1.4	+6.7	+83	17.8	-0.6	-0.9	-63	72.9	9.66	-0.30	+1.07
	407	51.4	+0.2	+5.1	+96	16.8	-0.9	-1.6	-66	71.5	8.62	-0.43	+0.16
	222‡	65.1				16.8				76.7	10.95		
	321	71.8	+1.1	+5.6	+84	16.6	+0.2	-0.4	>-100	77.8	11.92	+0.16	+0.81
1982	376	73.8	+1.3	+7.4	+87	16.2	+0.1	-0.7	>-100	77.1	11.96	+0.06	+0.95
	436	74.2	+1.2	+7.9	+87	15.8	-0.2	-0.8	-80	75.7	11.74	-0.15	+0.94
	468	74.4	+0.9	+8.4	+92	15.5	-0.1	-1.2	-88	75.9	11.49	-0.11	+0.65

† Lowest root yield and highest wet root sucrose concentration.
‡ Percent of total gain or decrease.
§ Actual % sucrose units, wet weight.

matic conditions showed essentially the same trends (data not shown). Root yields may or may not increase depending upon the N status of the soil. On sites where there was a root yield increase, both dry matter and water changes contributed to these yield differences. The root yield changes resulting from changes in water content generally increased with increasing N uptake. However, with increased N uptake and water concentration, there was a reduction in both wet and dry sucrose concentrations. Sucrose concentration of the wet root generally followed the dry matter concentration as previously shown which indicates root water change was the major contributing factor in the decline of sucrose concentration with increased N uptake at each of the different locations. Maximum sucrose production again occurred when the proportion of dry matter to water that increased root yield was highest with a maximum increase or a minimum decrease in PSDM.

Commercial varieties grown during different years varied widely, at maximum sucrose yield, in their root yield, sucrose concentration, and sucrose yield (Table 3). When the year with the lowest root yield and highest sucrose concentration (1977) was compared with the other years, the proportion of the root yield increase attributed to water and dry matter varied with the year. The majority of the root yield increase between years resulted from increased water with smaller, but important increases during certain years, attributed to dry matter. The sucrose concentration decrease resulted from a change in the PSDM and the increased proportion of water to dry matter in the roots. However, most of the decrease in sucrose concentration between years resulted from an increased root water concentration. High linear correlations existed between root water (WC) or dry matter and sucrose concentrations (y) indicating again that the inverse relationship between root yield and sucrose concentration resulted mainly from the increased proportion of water to dry matter in the roots ($\hat{y} = 68.7 - 0.66$ WC, $r = -0.89^{**}$). Sucrose production again followed the propor-

Table 3. Changes in root and sucrose yields, and sucrose concentration between years of plant growth at maximum sucrose yield and one location attributed (attr.) to percent sucrose of the dry matter (PSDM), dry matter (DM), and water in the roots.

Year	R & C Total N uptake	ROOT - CROWN (R - C)†											
		Root yield				Sucrose Concentration					Sucrose Yield		
			Change. attr. to:			Wet wt.	Change. attr. to:			Dry wt.		Change. attr. to:	
		Total	DM	--- Water ---			PSDM	--- Water ---			Total	PSDM	DM
	kg ha^{-1}	----- Mg ha^{-1} -----			%§	%	-% units -¶		%§	%	----- Mg ha^{-1} -----		
1977‡	210	52.1				19.0				75.6	9.92		
1976	205	53.4	-1.1	+2.4	>+100	17.1	+0.2	-2.1	>-100	76.6	9.15	+0.13	-0.90
1967	389	56.7	-1.2	+5.8	>+100	14.7	-1.1	-3.2	-74	70.4	8.35	-0.69	-0.88
1968	416	56.9	-1.0	+5.8	>+100	16.3	+0.2	-2.9	>-100	76.3	9.25	+0.09	-0.76
1971	243	61.0	+0.2	+8.7	+97	17.8	+1.3	-2.5	>-100	81.4	10.88	+0.77	+0.19
1969	263	61.3	0	+9.2	+100	16.5	+0.3	-2.8	>-100	77.3	10.14	+0.21	+0.01
1972	371	63.9	-0.9	+12.7	>+100	15.3	+0.9	-4.6	>-100	80.1	9.79	+0.58	-0.71
1978	323	70.9	+4.1	+14.7	+78	18.8	+0.5	-0.7	>-100	77.6	13.34	+0.33	+3.09
1982	321	71.8	+2.3	+17.4	+89	16.8	+0.6	-2.8	>-100	77.8	11.92	+0.32	+1.68
1983	312	75.5	+4.3	+19.1	+81	17.6	+0.1	-1.5	>-100	76.1	13.34	+0.09	+3.33
1980	257	76.0	+5.8	+18.1	+76	18.3	-0.5	-0.2	-30	73.6	13.90	-0.39	+4.37

†At maximum sucrose yield.
‡Lowest root yield and highest wet root sucrose concentration.
§Percent of total gain or decrease.
¶Actual % sucrose units, wet weight.

tion of dry matter to water that increased root yield. Highest sucrose production was obtained when the proportion of dry matter to water for the root yield increase was highest while maintaining a reasonably high PSDM.

Most of the agronomic and fertilization practices among years were similar with two major exceptions. Starting in 1978, aldicarb at a rate of 2.24 kg of active ingredients per hectare, was applied preplant to all sugarbeets grown in succeeding years. Starting in 1982, Amalgamated WS-76 and WS-88 varieties were used replacing the previous variety, AH-10. From 1978, an increasing proportion of the root yield increase, when compared with the year 1977, was as dry matter, rather than as water (Table 3). This increase in dry matter, while maintaining a reasonably high PSDM, increased sucrose production substantially above that previously received. This would indicate that root, dry matter, and sucrose yields during 1967 to 1977 were being reduced by undetected insect damage which was controlled by aldicarb application from 1978 to 1983. However, the newer high yielding varieties used during the 1982-83 season undoubtedly contributed to these yield changes.

Nitrogen fertilizer applied preplant and during the growing season to N deficient soil generally increased root yields and reduced both wet and dry sucrose concentrations (Table 4A). Delaying N application beyond preplant delayed N uptake and plant growth that further reduced sucrose concentration with a resulting sucrose yield reduction below those received from zero N or that applied preplant. When the treatment with the lowest root yield and highest sucrose concentration (zero N) was compared with the other treatments, the proportion of the root yield increase attributed to water and dry matter varied with the treatment. The root yield change resulting from water increased with each delay in N application. The decrease in wet root sucrose concentration caused by delayed N application resulted from both a decrease in the PSDM and a decreased dry matter or increased water concentra-

Table 4. Changes in root and sucrose yields, and sucrose concentration between: (A) time of N applications, and (B) irrigation treatments at one location attributed (attr.) to percent sucrose of the dry matter (PSDM), dry matter (DM), and water in roots.

A-Time N applied B-Irrig. treatment	R + C Total N uptake	ROOT - CROWN (R - C)											
		Root yield				Sucrose Concentration					Sucrose Yield		
			Change. attr. to:				Change. attr. to:					Change. attr. to:	
		Total	DM	--- Water ---		Wet wt.	PSDM	--- Water ---		Dry wt.	Total	PSDM	DM
A†	kg ha^{-1}	----- Mg ha^{-1} -----			%¶	%	-% units -#		%¶	%	----- Mg ha^{-1} -----		
Check §	130	46.1				19.3				75.2	8.89		
Preplant	318	52.6	+1.0	+5.5	+85	17.9	-0.4	-1.0	-70	73.3	9.40	-0.23	+0.74
Mid-June	335	50.0	+0.3	+3.6	+93	17.7	-0.5	-1.1	-69	73.0	8.86	-0.25	+0.22
Mid-July	337	47.6	-0.3	+1.8	>+100	17.5	-0.6	-1.2	-65	72.5	8.34	-0.31	-0.24
Mid-August	317	49.5	-0.3	+3.7	>+100	17.0	-0.5	-1.8	-80	73.1	8.45	-0.23	-0.21
B‡													
M_1 §	338	54.2				17.8				72.9	9.66		
M_3	278	50.2	+0.1	-4.1	>-100	18.9	-0.4	+1.5	>+100	71.3	9.49	-0.21	+0.04
M_4	237	44.5	-1.2	-8.5	-88	19.7	0	+1.9	>+100	72.8	8.77	0	-0.89

† Avg. of 112, 252, and 392 kg N ha^{-1} applied N treatments.
‡ Adequately irrigated (M_1), no irrigation after 1 August (M_3), and no irrigation after 15 July 1977 (M_4), respectively (6).
§ Check or reference treatment
¶ Percent of total gain or decrease.
# Actual % sucrose units, wet weight.

tion (WC). However, the largest amount of sucrose concentration (y) decrease was caused by the increased proportion of water to dry matter in the roots with each delay in N application ($\hat{y}$ = 91.7 - 0.98 WC, r = -0.99**). The sucrose yield change resulted from a change in both PSDM and dry matter production. The sucrose yield change with delayed N application beyond mid-June was attributed about equally to a reduction in PSDM and dry matter production. Maximum sucrose yield was obtained with N applied preplant when the increase in root yield was highest for dry matter rather than as water while maintaining a reasonably high PSDM.

The use of deficit water management during August, September, and October curtailed leaf growth and reduced leaf area (6), reduced N uptake from the soil, increased sucrose concentration in the wet root, and decreased fresh root yield when compared with the M_1 (normal irrigation) irrigation treatment (Table 4B). These effects on root yield and sucrose concentration were mainly caused by dehydration of the fresh roots. The majority of the root yield decrease with deficit water management resulted from decreased water with smaller, but important decreases attributed to dry matter production at the M_4 (15 July water cutoff) irrigation level. Sucrose concentration (y) increases resulted mainly from the decreased water (WC) or increased dry matter concentrations in the dehydrated root ($\hat{y}$ = 67.4 - 0.66 WC, r = -0.96**). Sucrose yield was scarcely affected by late season water management on the M_3 (1 August water cutoff) irrigation treatment because root yield decrease caused by dehydration was nearly compensated for by the increased sucrose concentration. However, sucrose yield was decreased on the M_4 irrigation treatment which can be attributed to reduced photosynthesis in the dehydrated tops causing decreased dry matter and sucrose accumulation in the beet root. These relationships again indicate that the inverse relationship between root yield and sucrose concentration was mainly controlled by the water concentration in the roots.

CONCLUSION

The results of this investigation clearly show that the inverse relationship between root yield and sucrose concentration within genotypes during different years, at different N uptake or irrigation water levels, and between genotypes may be caused, in part, by water concentration differences. Root yield changes are caused primarily by water rather than dry matter, thereby increasing or decreasing wet root sucrose concentration. However, PSDM does vary between genotypes and within genotypes during different years and between N uptake and irrigation water levels. This variation in the PSDM does contribute to this inverse relationship between sucrose concentration and root yield but generally contributes far less to this relationship than does the water or dry matter concentration and yield.

The change in water concentration in the root among genotypes and within genotypes during different years and treatments at normal irrigation levels has been associated with a change in the root Na concentration and/or K:Na ratio (3). Increasing the Na concentration or decreasing the K:Na ratio in the root by changing genotypes or treatments, increases the water concentration and root yield. The increased root water concentration dilutes both the dry matter and associated sucrose, thereby reducing the sucrose concentration of the fresh root. As an example, root yield would be increased from 52.1 (1977) to 68.7 Mg ha^{-1} with a reduction in fresh root sucrose concentration from 19.0 (1977) to 14.4% if root water concentration was increased from the level received in 1977 of 74.8 to that obtained in 1972 of 80.9% while maintaining a constant PSDM, dry matter and sucrose yields. Therefore, sucrose concentration of the fresh root is not important for total sucrose yield if increases in root yield with treatment compensates or more than compensates for the reduction in sucrose concentration. However, sucrose concentration is generally an excellent indicator of the root impurities present that interfere with sugar crystallization and

processing. High sucrose concentration of the fresh root generally means low impurities and high crystallizable sugars and vice versa.

The only way to change total sucrose yield is to increase or decrease either or both of the two yield components, dry matter yield and PSDM. Within any climatic zone, these factors are normally controlled by agronomic and fertilization practices such as, 1) weed, insect, and disease control, 2) transplanting or planting date and leaf area development, 3) plant nutrition, 4) irrigation adequacy, and 5) genotype grown. Within sugarbeet varieties and climatic zones, conditions that cause adequate early top growth for maximizing photosynthesis throughout the season should provide conditions for maximum sucrose production and yield. This can normally be achieved by using good agronomic practices and by adding adequate, but not excessive, N for maximizing partitioning of the photosynthate produced to the roots for storage as dry matter and sucrose.

SUMMARY

Increasing root yield of sugarbeets (*Beta vulgaris* L.) by plant breeding, genetic selection, nitrogen (N) fertilization, agronomic practices, and environmental conditions generally decreases sucrose concentration. Therefore, the objective of this investigation was to evaluate sucrose production as affected by root yield, wet and dry sucrose concentrations, and dry matter and water concentrations of widely different *Beta vulgaris* genotypes grown at different N uptake levels, field locations, climatic conditions, and years. Data collected at 36 field locations in southern Idaho during 11 years since 1967, mainly on Portneuf silt loam soil (Durixerollic Calciorthids, coarse-silty, mixed, mesic), were used to identify and evaluate factors and conditions affecting sucrose concentration, root and sucrose yields. The results clearly show that the inverse relationship between root yield and sucrose concentration within genotypes during different years, at different N uptake or irrigation water levels,

and between genotypes, may be caused, in part, by water concentration differences. Root yield changes are caused primarily by water rather than dry matter, thereby increasing or decreasing wet root root sucrose concentration. Variation in the percent sucrose of the dry matter contributes to this inverse relationship, but generally contributes less than does water or dry matter concentration and yield. The change in water concentration in the root between genotypes and within genotypes during different years and treatments, has been associated in previous work with a change in root Na concentration and/or K:Na ratio. Sucrose concentration of the fresh root is not important for total sucrose yield if increases in root yield with treatment compensates or more than compensates for the reduction in sucrose concentration. The only way to change total sucrose yield is to increase or decrease either or both of the two yield components, dry matter yield and percent sucrose of the dry matter. This can normally be achieved by using good agronomic practices and by adding adequate, but not excessive, N for maximizing partitioning of the photosynthate produced to the roots for storage as dry matter and sucrose.

LITERATURE CITED

1. Bremner, J. M. 1965. Inorganic forms of nitrogen, pp. 1179-1237. *In* C. A. Black (ed.) Methods of soil analyses, Part 2. American Society of Agronomy. Madison, WI.

2. Carter, J. N. 1986. Potassium and sodium uptake by sugarbeets as affected by nitrogen fertilization rate, location, and year. J. Am. Soc. Sugar Beet Technol. In press.

3. Carter, J. N. 1986. Potassium and sodium effects on sucrose concentrations and quality of sugarbeet roots. J. Am. Soc. Sugar Beet Technol. In press.

4. Carter, J. N., D. L. Doney, and J. C. Theurer. 1982. Potential alcohol production from *Beta vulgaris* genotypes as affected by nitrogen level and water stress. J. Am. Soc. Sugar Beet Technol. 21:324-344.

5. Carter, J. N., M. E. Jensen, and S. M. Bosma. 1974. Determining nitrogen fertilizer needs for sugarbeets from residual soil nitrate and mineralizable nitrogen. Agron. J. 66:319-323.

6. 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.

7. Doney, D. L. 1984. Selection of potential sucrose concentration in 7-day-old sugarbeet seedlings. J. Am. Soc. Sugar Beet Technol. 22:205-219.

8. Doney, D. L., Wyse, R. E., and Theurer, J. C. 1981. The relationship between cell size, yield, and sucrose concentration of the sugarbeet root. Can. J. Plant Sci. 61:447-453.

9. Hecker, R. J. 1967. Evaluation of three sugarbeet breeding methods. J. Am. Soc. Sugar Beet Technol. 14:309-318.

10. James, D. W., D. L. Doney, J. C. Theurer, and R. L. Hurst. 1978. Sugarbeet genotype, N, and soil moisture availability interaction in components of beet yield and quality. Agron. J. 70:525-531.

11. Kelley, J. D., and A. Ulrich. 1966. Distribution of nitrate nitrogen in the blades and petioles of sugarbeets grown at deficient and sufficient levels of nitrogen. J. Am. Soc. Sugar Beet Technol. 14:106-116.

12. McGinnis, R. A. 1971. Analysis of sugar content. p. 78 *In* R. A. McGinnis (ed.) Beet-sugar technology. Beet Sugar Dev. Found., Ft. Collins, CO.

13. Milford, G. F. 1973. The growth and development of the storage root of sugar beet. Ann. Appl. Biol. 75:427-438.

14. Milford, G. F. and D. J. Watson. 1971. The effect of nitrogen on the growth and sugar content of sugar beet. Ann. Bot. 35:387-400.

15. Oldemeyer, R. K. 1975. Introgressive hybridization as a breeding method in *Beta vulgaris*. J. Am. Soc. Sugar Beet Technol. 18:269-273.

16. Westermann, D. T., G. E. Leggett, and J. N. Carter. 1977. Phosphorus fertilization of sugarbeets. J. Am. Soc. Sugar Beet Technol. 19:262-269.