

# Potassium and Sodium Uptake Effects on Sucrose Concentration and Quality of Sugarbeet Roots\*

J. N. Carter

Received for Publication November 11, 1985

## INTRODUCTION

Sugarbeet (*Beta vulgaris* L.) root quality has decreased since the early 1950's in most sugarbeet-growing areas (2). This decrease is generally associated with increased nitrogen (N) fertilizer use which results in decreased sucrose concentration and increased impurities in the roots (13). Decreased root sucrose concentration with N application is generally attributed to the tops becoming the dominant photosynthate sink at the expense of the roots (12). Increased impurities may result from many factors, but are generally associated with higher N uptake that increases the nonsucrose, soluble solids (2, 17).

Potassium (K) fertilization of sugarbeets is generally not recommended in the intermountain areas of the western United States because of the general K abundance in the soils and irrigation water (6,8) and the lack of plant response to K fertilizer in numerous unpublished field experiments. Both K, an essential element for plant growth, and sodium (Na), a non-essential element (28), are taken up in large quantities by sugarbeets. The uptake rate and total uptake of these elements depends upon N uptake, plant growth, availability of these elements, year, and genotype grown (1,8,15,17,30).

Sucrose recovery efficiency in sugar refining depends upon the amount and types of root and/or extracted juice impurities (2). Both K and Na are impurities and their

---

\*Contribution from the U.S. Department of Agriculture, Agricultural Research Service, in cooperation with the University of Idaho College of Agriculture Research and Extension Center, Kimberly, Idaho. The author is a Soil Scientist, USDA-ARS, Snake River Conservation Research Center, Kimberly, Idaho 83341.

presence interferes with the crystallization process, which causes a greater proportion of the sugars to be recovered as molasses with a reduction in refined sugar (5,17,27).

The proportion and amount of K and Na in the sugarbeet plant may also be important because of a positive correlation between K fertilization and sucrose concentration (19), and a high negative correlation between Na and sucrose concentration in the sugarbeet roots of different cultivars (4,14,16). This sucrose concentration response to K may result from a secondary response to K and a direct response to reduced N uptake caused by the chloride-nitrate antagonism in plant N uptake when the chloride form of K fertilizer is used (20). However, this reduced N uptake caused by the chloride-nitrate antagonism was not demonstrated in recent experiments (8,23).

Sucrose concentration and root quality at harvest generally decrease linearly with increased N uptake at one field location during any one year. If these same parameters are compared using data from different locations during the same year, or at the same location during different years, linear correlations were not as good (7), indicating location and seasonal variations. Some of these differences in root quality between years and field locations may be attributed to climatic factors (22). However, within seasons between adjacent fields, different sucrose concentrations have been measured when N uptake, irrigation levels, and agronomic factors have been similar. This would indicate that a factor or factors other than N uptake, climatic factors, or irrigation levels were contributing to these differences in sucrose concentration and root quality.

Recent studies indicate that root Na concentration and/or K:Na ratios are affecting the sucrose concentration that may result from an increased water or decreased dry matter concentration (8). This change in root water concentration with varying Na concentrations and/or K:Na ratios may be a major cause of differences or changes in

sucrose concentrations between different field locations and years.

The objective of this study was to evaluate the effect of K and Na uptake, concentrations, and the K:Na ratios in the root on sucrose concentration and root quality of sugarbeets grown at many 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, Idaho, with experimental plots at thirty-six locations in southern Idaho. References to the specific procedures used in these experiments have been published (8). 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 (10). Extractable and water soluble (extractable - soluble = exchangeable) K and Na were determined on the 1971 samples (26).

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 (9) with the common name of GWD2, AH-10 (commercial hybrids); LHY-1, LHS-1 (Experimental hybrids); Mono-

rosa, 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.<sup>1/</sup>

Nitrogen was generally applied between 0 to 448 kg N ha<sup>-1</sup> in increments of 56 to 224 kg N ha<sup>-1</sup>. The total amount and rates of application to each experiment depended upon the residual and mineralizable N in the soil available for plant growth (10). The N uptake efficiency of applied N fertilizer for sugarbeets grown in southern Idaho ranges from 50 to 70% and averages 65%. The efficiency depended upon time and rate of N application, soil type, and management practices (10,13).

Nitrogen, as ammonium nitrate, was applied preplant by broadcast applications. All experimental plot areas were adequately supplied with phosphorus (29).

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. All beet roots were horizontally sectioned at the lowest leaf scar into harvested root and crown tissues before taking duplicate or triplicate root (16 to 18 roots per sample) and crown samples for sucrose analysis. 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 (24).

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

<sup>1/</sup>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.

the macro, or semimicro, Kjeldahl procedure modified to include nitrate (3). Potassium and Na were determined by atomic absorption spectroscopy from samples previously digested in a 3:1 mixture of nitric:perchloric acid (18) and appropriately diluted. The N, K, and Na 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 (21).

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

$$S_L = S_C - [S_{YC}/(DM_{YC}/(100-W_T))] \quad [1a]$$

or

$$S_L = S_C - (DM_T \times S_C) / (100 - W_C) \quad [1b]$$

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,  $S_{YC}$  is the sucrose yield of the check or reference treatment,  $DM_{YC}$  is the dry matter yield of the check or reference treatment,  $DM_T$  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.

#### RESULTS AND DISCUSSION

There was a high positive correlation between dry matter and sucrose concentrations (% wet root) in the roots at different locations during the same year (Table 1B) and at the same location during different years (Table 1A) on the zero N treatments and at maximum sucrose yield. The slopes of the regression lines were essentially the same in all but one treatment (Check or zero N, 1972).



change in the water concentration within the roots that may have resulted from changes in root Na concentration and/or K:Na ratio.

This relationship between root Na concentration and K:Na ratio to decreased sucrose concentration resulting from increased water concentration between *Beta vulgaris* genotypes, as compared with the genotype with the highest sucrose concentration (LHS-1), is further evaluated in Figure 2A. High linear correlation again existed between Na concentration and K:Na ratio in the roots as compared with the sucrose concentration decrease resulting from water increase (calculated using Eq. [1a,b]). The sucrose concentration decrease resulting from root water increase varied between the eight genotypes from 68 to 95% and averaged 89% of the total decrease. Whereas, sucrose concentration decrease resulting from a decrease in the PSDM varied from 5 to 32% and averaged 11% of the total decrease. The decrease in sucrose concentration resulted from increased root water concentration was attributed to the increased Na concentration and/or decreased K:Na ratio

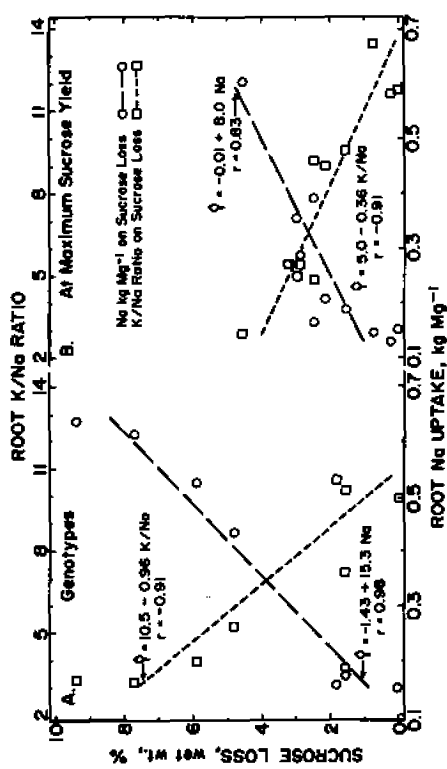


Figure 2. Effect of root Na concentration and K:Na ratio on sucrose decrease (loss)† attributable to water gain: (A) *Beta vulgaris* genotypes during 1980, (B) at maximum sucrose yield during different years. †Calculated using Eq. [1a,b]. Root Na uptake, kg Mg<sup>-1</sup> = kg root Na per Mg wet root.

in the roots; whereas, the decrease in sucrose concentration resulting from changes in the PSDM was attributed to the differences between genotypes.

There was a medium to high linear correlation between Na concentration in the roots as well as their K:Na ratios and root water concentration of commercial hybrids during each of the four years (Figure 3A,B). There was also a high linear or curvilinear correlation between Na concentration or K:Na ratio in the roots and water concentration at maximum sucrose yield between years (Figure 3C,D). The

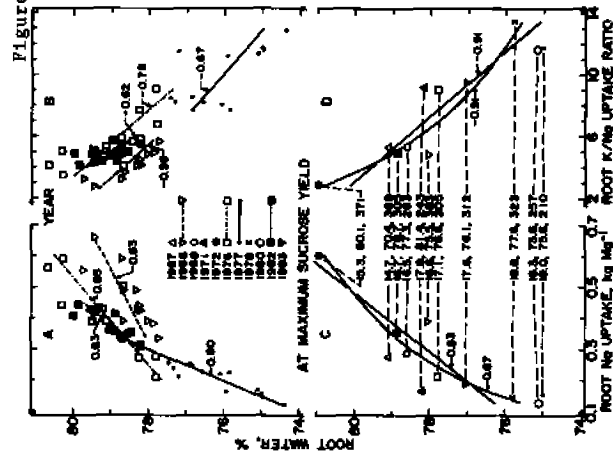


Figure 3. Effect of root: (A) Na concentration on water concentration and (B) K:Na ratio on water concentration during different years, (C) Na concentration on water concentration and (D) K:Na ratio on water concentration at maximum sucrose yield during different years. Values given between C and D are percent sucrose of the wet root, percent sucrose of the dry matter, and N uptake, respectively. Numbers beside regression lines = r. Root Na uptake, kg Mg<sup>-1</sup> = kg root Na per Mg wet root.

root water concentration increased with higher Na concentrations and decreased with higher K:Na ratios during each of the four years and at maximum sucrose yield during different years. High sucrose concentration in the wet roots was always obtained with low Na concentration, high K:Na ratio, and low water concentration; whereas, lower sucrose concentration was obtained with higher Na concentration, lower K:Na ratio, and higher water concentration in the roots. These relationships were obtained even with considerable variation in the PSDM and the total N uptake

by the sugarbeet.

This relationship between Na concentration or K:Na ratio and root water concentration of commercial sugarbeet hybrids is further verified by a positive correlation between Na concentration and sucrose decrease and a negative correlation between K:Na ratio and sucrose decrease resulting from increased water concentration (calculated using Eq. [1a,b] at maximum sucrose yield during different years as compared with the year (1977) having the highest sucrose concentration (Figure 2B). In 7 of the 10 comparisons included in this analysis, 100% of the decrease in sucrose concentration of the wet roots occurred because of the increased water concentration. The 3 remaining years, 99, 74, and 30% of the total decrease occurred because of increased root water concentration.

During any one experiment with increased N application and uptake, there is generally a high linear increased Na concentration, decreased K:Na ratio, increased water concentration, decreased PSDM, and decreased sucrose concentration of the fresh roots. However, between experiments, location, years, and genotypes, these linear relationships between N uptake and root composition change, provide an opportunity to separate those effects resulting from increased N uptake and those attributable to associated changes such as Na concentration and K:Na ratio. These changes in root composition with N uptake between experiments, locations, years, and genotypes are evaluated in Figures 4, 5, 6, and Table 2.

The *Beta vulgaris* genotypes varied widely in their sucrose concentration in the wet and dry roots as well as Na concentration, K:Na ratio, and water concentration at both N levels (Figure 4). In every case, the water concentration of the roots varied with the change in Na concentration or K:Na ratio within genotypes between N levels and between genotypes. Higher water concentration with lower sucrose concentration in the roots was produced with high Na levels and low K:Na ratios and vice versa. Between genotypes, an average 89% of the total sucrose

Table 2. Effect Na concentration and K:Na ratio on water concentration in the roots and differences in sucrose concentration resulting from changes in the percent sucrose of the dry matter (PSDM) and water concentration: (A) same location, different years, (B) different sites, same year and climatic conditions, (C) different sites, same year but widely different climatic conditions.

Year	Site No.	N Uptake, 300 kg ha <sup>-1</sup> †				Sucrose ‡		Loss, Change in: PSDM Water	K/Na	Ratio	----- % -----
		Sucrose Wet	Sucrose Dry	Root Na	Root K/Na	PSDM	Water				
<b>A</b>											
1968	----	16.6	75.5	78.0	0.346	5.2	0	100			
1976	----	16.7	76.1	78.3	0.302	6.9	0	100			
1977 †	----	18.0	73.5	75.8	0.193	9.7	----	----			
1982	----	16.6	77.3	78.6	0.354	5.0	0	100			
<b>B</b>											
6		16.9	75.0	77.6	0.120	7.3	100	0			
1971	7 †	17.0	78.3	78.3	0.230	5.8	----	----			
8		16.1	75.8	78.8	0.564	2.8	57	43			
<b>C</b>											
20 †		17.3	80.3	78.5	0.258	6.4	----	----			
1972	111	15.7	78.9	80.2	0.456	4.1	15	85			
220		16.4	75.7	78.4	0.262	9.8	100	0			

† Reference.

‡ Values from regression lines.

§ Calculated using Eq. [1a, b].

¶ kg root Na per Mg wet root.

concentration change was the result of water concentration change of the roots as compared with the genotype with the highest sucrose concentration (LHS-1). Within genotypes, between N levels or uptake, the change in sucrose concentration attributable to root water change was 69, 131, 101, 58, and 22% of the total for the AH-10, LHY-1, LHS-1, Monorosa, and Pajbjerg Korsroe, respectively. The remaining change in sucrose concentration resulted from a change in the PSDM.

The two experimental genotypes, LHY-1 and LHS-1, were developed for their high root yield and high sucrose concentration, respectively. When LHS-1 was compared with LHY-1, 90% of the total decrease in sucrose concentration of the wet root was attributable to the increased water concentration, and the remaining 10% to the decrease in PSDM (Figure 4B, C). The Na concentration was higher and

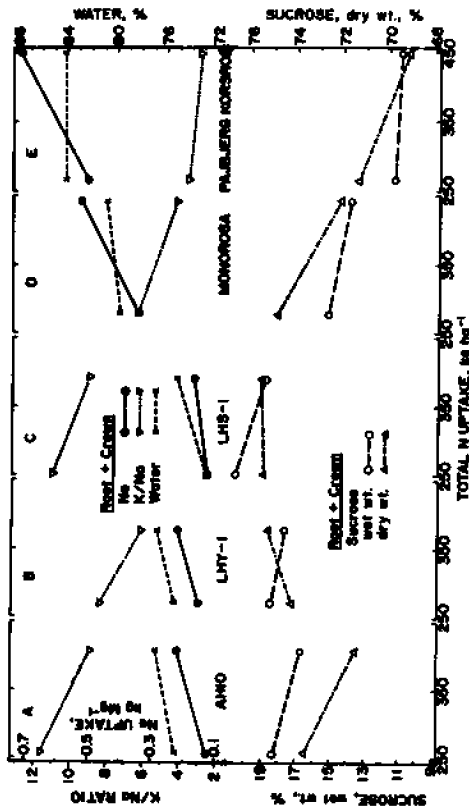


Figure 4. Effect of total N uptake and *Beta vulgaris* genotypes on Na concentration, K:Na ratio, water concentration, wet sucrose concentration, and percent sucrose of the dry matter (PSDM) of the roots during 1980. Root Na uptake,  $\text{kg Mg}^{-1}$  =  $\text{kg root Na per Mg wet root}$ .

the K:Na ratio lower in the LHY-1, which again indicates that Na concentrations and K:Na ratios were having a major impact on both the water and sucrose concentrations in the wet roots.

The commercial hybrids used in 1968, 1976, 1977, and 1982 showed the same relationships between Na concentration, K:Na ratio, water and sucrose concentrations in the wet roots as demonstrated for the different genotypes (Figure 5). Highest sucrose concentration of the wet roots was obtained during the years with the lowest Na and water concentrations, and the highest K:Na ratios. Between years at maximum sucrose yield, over 100% of the change in sucrose concentration of the wet roots was the result of a change in the water concentration when the hybrids for different years were compared with the year having the highest sucrose concentration (1977). The values in excess of 100% resulted from the hybrid having the highest sucrose concentration of the wet roots also had the lowest PSDM. These differences in water concen-

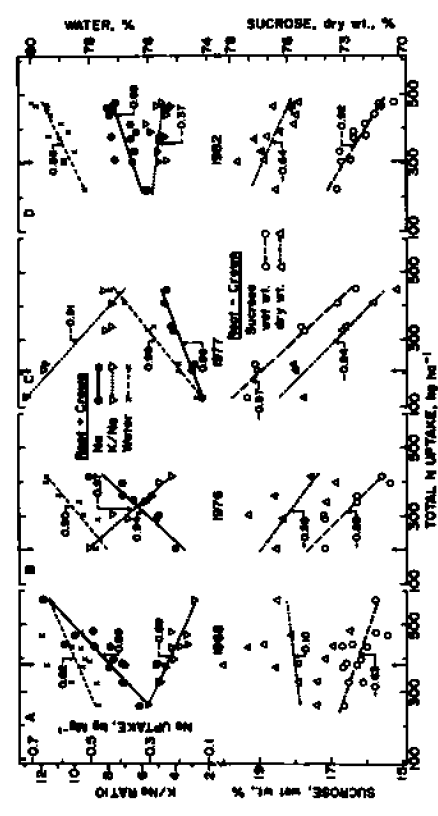


Figure 5. Effect of total N uptake, year, and same location on Na concentration, K:Na ratio, water concentration, wet sucrose concentration, and percent sucrose of the dry matter (PSDM) of the roots. Arrows indicate N uptake for maximum sucrose yield. Numbers beside regression lines =  $\frac{r}{r}$ . Root Na uptake,  $\text{kg Mg}^{-1}$  =  $\text{kg root Na per Mg wet root}$ .

tration attributable to Na concentration or K:Na ratio of the roots occurred even when the N uptake levels were equalized at  $300 \text{ kg ha}^{-1}$  by regression techniques (Table 2A) and all sugarbeets for the different years were irrigated adequately throughout the growing season. This, again, indicates that Na concentrations and/or K:Na ratios of the roots were the primary cause of water concentration differences in the roots between seasons and during the same year.

This effect of root Na concentration or K:Na ratio on water and sucrose concentrations is further evaluated using sugarbeets grown in the same general area under similar irrigation levels and climatic conditions in southwestern Idaho during 1971 (Figure 6). Two of the sites, 6 and 8, had similar total N uptake values; whereas on Site 7, the total N uptake was lower. The PSDM was much higher on Site 7. Under these conditions, between sites at maximum sucrose yield, over 100% for Site 6 and 55% for Site 8 of the sucrose concentration change of the wet roots resulted from a PSDM change as compared with

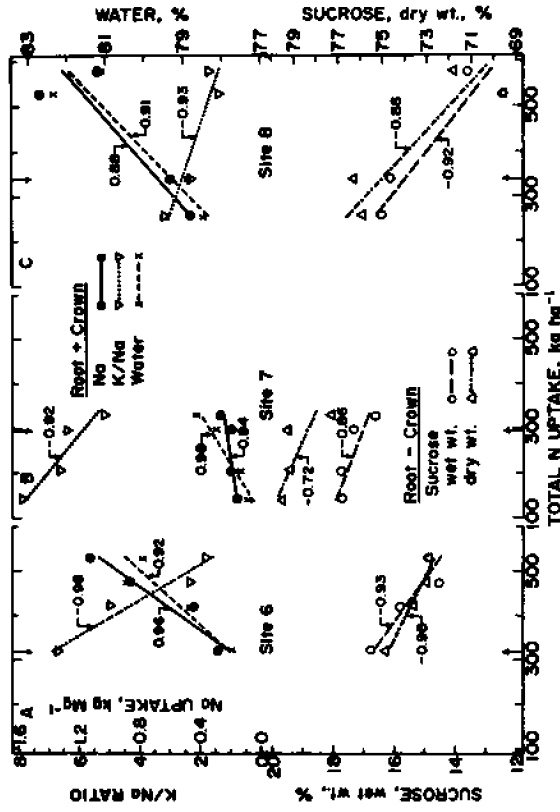


Figure 6. Effect of total N uptake, site location, and same year (1971) under similar climatic conditions on Na concentration, K:Na ratio, water concentration, wet sucrose concentration, and percent sucrose of the dry matter (PSDM) of the roots. Arrows indicate N uptake for maximum sucrose yield. Numbers beside regression lines =  $r$ , Root Na uptake, kg Mg<sup>-1</sup> = kg root Na per Mg wet root.

Site 7. However, at maximum N uptake, 52% for Site 6 and 33% for Site 8 of the change resulted from the change in PSDM. When the N uptake levels are equalized at 300 kg Na<sup>-1</sup> by regression techniques, 100% for Site 6 and 57% for Site 8 of the sucrose concentration change of the wet roots resulted from a change in the PSDM as compared with Site 7 (Table 2B). A much higher Na concentration and lower K:Na ratio along with a higher water concentration in the wet roots was found at Site 8 than at the other sites. These results indicate that extremely low sucrose concentrations result from high plant N uptake along with high Na concentrations and/or low K:Na ratios. The high plant N uptake reduced the PSDM and the high Na concentration and/or low K:Na ratio increased the water concentration. The two different effects occurring together reduce

sucrose concentration in the wet roots to low values.

Three experimental sites located in southwestern (Site 20), southcentral (Site 111), and southeastern (Site 220), Idaho, were used to further evaluate these effects under similar irrigation levels but widely different soil and climatic conditions during 1972. When N uptake was equalized at 300 kg ha<sup>-1</sup> by regression techniques, 100% of the sucrose concentration change resulted from the change in PSDM between Sites 20 (highest sucrose concentration) and 220 with approximately equal Na concentration values (Table 2C). However, 85% of the total change between Sites 20 and 111 resulted from a change in root water concentration with increased Na concentration and a lower K:Na ratio. This, again, indicates that Na concentration and/or K:Na ratio in the roots was the primary cause of the differences in water concentration and can cause major changes in the sucrose concentration in the wet roots.

The reason for the increased water in the roots with an increase in the Na concentration and/or a decreased K:Na ratio in the roots is yet to be determined. However, it has been frequently reported in the literature that K has an effect on the water uptake, turgor pressure, and water relation associated with the stomatal opening (25). Sodium can substitute for K in certain plants including sugarbeets. However, the effect of Na substitution for K on water relations of the plants are not yet known or understood.

#### CONCLUSIONS

The results of this investigation indicate that N uptake and the proportion and amount of K and Na have a major influence on the sucrose concentration in sugarbeet roots. Sucrose concentration is controlled by the percent sucrose in the dry matter (PSDM) and the dry matter or water concentration within the root. Nitrogen application and N uptake increases the photosynthate translocated to the roots under deficient to adequate N levels, but may reduce these amounts when N uptake is in excess to that needed for maximum sucrose yield (12). Nitrogen, when



taken up in excess of that needed, generally decreases the PSDM. Increasing N uptake also increases the Na concentration and decreases the K:Na ratio in the roots. Both are associated with decreased dry matter or increased water concentrations of the roots. Throughout this investigation, high sucrose concentrations in commercial hybrids were generally associated with low to moderate N uptake with low Na concentration, high K:Na ratio, and low water concentration and vice versa. Between *Beta vulgaris* genotypes in these experiments, high sucrose concentration was always associated with low Na concentration, high K:Na ratio, and low water concentration in the roots.

Total sucrose yield is the product of sucrose concentration and total root yield. Sucrose concentration is not important for total sucrose yield if increases in root yield with treatment more than compensates for the reduction in sucrose concentration. However, only the sucrose that can be crystallized by the manufacturer can be used as refined sugar. Sucrose concentration is generally an excellent indicator of the impurities present that interfere with sugar crystallization. High sucrose concentration generally means low impurities and high crystallizable sugar and vice versa.

The decrease in root quality that has occurred over the past three decades, which is generally related to increased N use, could also be associated with the changing amounts and proportion of K and Na in the soils and irrigation water. Potassium has been depleted by removing harvested crops with only minor additions from fertilizer use. The increased land placed under irrigated agricultural production, and the increased reuse of the irrigation water, may also favor the buildup of Na in relation to K in our soils. The increased availability and use of Na in relation to K by sugarbeets may account for part of the decrease in sucrose concentration as well as increased impurities in the roots that have occurred over the past 30 years.

The methods that are presently available to increase

root quality within genotypes is to use good agronomic practices and to select fields for their low residual soil N and Na content and apply the necessary N and K fertilizers based on a soil test for maximum extractable sucrose production. Research is needed to determine additional procedures for controlling the amount and proportion of K and Na in sugarbeets.

#### SUMMARY

Sugarbeet (*Beta vulgaris* L.) root quality has decreased since the early 1950's in most sugarbeet-growing areas with decreased sucrose concentrations and increased nonsucrose, soluble solids. Potassium (K) and sodium (Na) are both impurities in the harvested roots processed for refined sugar and both have been associated with changes in sucrose concentrations. Data collected at several field locations in southern Idaho since 1967, mainly on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic), were used to identify and evaluate the effect of K and Na uptake, concentration, and ratios in the roots on sucrose concentration and root quality. Results showed that nitrogen (N) uptake and the proportion and amounts of K and Na have a major influence on the sucrose concentration and root quality. Excess N uptake reduces the sucrose concentration by making the tops the dominant photosynthate sink at the expense of the roots as shown in previous studies, 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, or by other means, increases the root water concentration and reduces the sucrose concentration. High sucrose concentration and root quality were generally associated with low to moderate N uptake and low Na concentration, high K:Na ratio, and low water concentration in the roots and vice versa. The decreased root quality that has occurred over the past three decades, which is generally related to increased N use, could also be associated with the changing amounts, proportion, and availability of K and Na in the soils and ir-

rigation water by K removal in plant harvest and increased reuse of irrigation water. The methods that are presently available to increase root quality within genotypes is to use good agronomic practices and to select field for their low residual soil N and Na content and to apply the necessary N and K fertilizers based on a soil test for maximum extractable sucrose production.

#### LITERATURE CITED

1. Adams, S. N. 1961. The effect of sodium and potassium fertilizer on the mineral composition of sugar beet. *J. Agr. Sci.* 56:383-388.
2. Alexander, J. T. 1971. Factors affecting quality. P. 371-381. *In* R. T. Johnson, J. T. Alexander, G. E. Rush, and G. R. Hawkes (eds.) *Advances in sugarbeet production: Principles and practices*. The Iowa State Univ. Press, Ames, IA.
3. Bremner, J. M. 1965. Inorganic forms of nitrogen. P. 1179-1237 *In* C. A. Black (ed.) *Methods of soil analyses*. Part 2. American Society of Agronomy, Madison, WI.
4. Brown, R. J., and R. R. Wood. 1952. Improvement of processing quality of sugar beets by breeding methods. *Proc. Am. Soc. Sugar Beet Technol.* 7:314-318.
5. Carruthers, A., J. P. T. Oldfield, and H. J. Teague. 1962. Assessment of beet quality. p. 1-28. *In* 15th Ann. Tech. Conf. of the British Sugar Corp., Ltd., Nottingham, England.
6. Carter, D. L., C. W. Robbins, and J. A. Bondurant. 1973. Total salt, specific ion, and fertilizer element concentrations and balances in the irrigation and drainage waters of the Twin Falls tract in southern Idaho. USDA, ARS-W-4.
7. 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.
8. 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.* *J. Am. Soc. Sugar Beet Technol.* 23:121-141.

9. 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.
10. 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.
11. 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.
12. Carter, J. N., and D. J. Traveller. 1981. Effect of time and amount of nitrogen uptake on sugarbeet growth and yield. *Agron. J.* 73:665-671.
13. Carter, J. N., D. T. Westermann, and M. E. Jensen. 1976. Sugarbeet yield and quality as affected by nitrogen level. *Agron. J.* 68:49-55.
14. Dostator, C. W., and F. R. Calton. 1950. Sodium and potassium content of sugar beet varieties in some western beet growing areas. *Proc. Am. Soc. Sugar Beet Technol.* 6:144-151.
15. Dostator, C. W., R. E. Finkner, R. H. Helmerick, and P. C. Hanzas. 1965. The performance of sugar beet selections made for purity and chloride at three levels of nitrogen fertility. *J. Am. Soc. Sugar Beet Technol.* 13:362-369.
16. Finkner, R. E., and H. M. Bauserman. 1956. Breeding of sugar beets with reference to sodium, sucrose, and raffinose content. *J. Am. Soc. Sugar Beet Technol.* 9:170-177.
17. Hilde, D. J., S. Bass, R. W. Levos, and R. L. Ellingson. 1983. Grower practices system promotes beet quality improvement in the Red River Valley. *J. Am. Soc. Sugar Beet Technol.* 22:73-88.
18. Isaac, R. A., and J. D. Kerber. 1972. Atomic absorption and flame photometry: Techniques and uses in soil, plant, and water analysis. p. 17-27. *In* L. M. Walsh (ed.) *Instrumental methods for analysis of soils and plant tissues*. Soil Science Society of America, Madison, WI.
19. James, D. W., D. C. Kidman, W. H. Weaver, and R. L. Reeder. 1968. Potassium fertilization of sugar beets in central Washington. *J. Am. Soc. Sugar Beet Technol.* 14:682-694.

20. James, D. W., D. C. Kidman, W. H. Weaver, and R. L. Reeder. 1970. Factors affecting chloride uptake and implications of the chloride-nitrate antagonism in sugarbeet mineral nutrition. *J. Am. Soc. Sugar Beet Technol.* 15:647-656.
21. 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.
22. Loomis, R. S., A. Ulrich, and N. Terry. 1971. Environmental factors. p. 19-48. *In* R. T. Johnson, J. T. Alexander, G. E. Rush and G. R. Hawkes (eds.). *Advances in sugarbeet production: Principles and practices.* The Iowa State Univ. Press, Ames, IA.
23. Ludwick, A. E., W. A. Gilbert, and D. G. Westfall. 1980. Sugarbeet quality as related to KCl fertilization. *Agron. J.* 72:453-456.
24. 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.
25. Mengel, K., and E. A. Kirkby. 1980. Potassium in crop production. *Adv. Agron.* 33:59-110.
26. Pratt, P. F. 1965. Potassium. p. 1022-1030. Sodium. p. 1031-1034. *In* C. A. Black (ed.) *Methods of soil analysis.* Part 2. American Society of Agronomy, Madison, WI.
27. Rorabaugh, G., and L. W. Norman. 1956. The effect of various impurities on the crystallization of sucrose. *J. Am. Soc. Sugar Beet Technol.* 9:238-252.
28. Schmehl, W. R., and D. W. James. 1971. Phosphorus and potassium nutrition. p. 137-169. *In* R. T. Johnson, J. T. Alexander, G. E. Rush, and G. R. Hawkes (eds.). *Advances in sugarbeet production: Principles and practices.* The Iowa State Univ. Press, Ames, IA.
29. Westermann, D. T., G. E. Leggett, and J. N. Carter. 1977. Phosphorus fertilization of sugarbeets. *J. Am. Soc. Sugar Beet Technol.* 19:262-269.
30. Zielke, R. C., and F. W. Snyder. 1974. Impurities in sugarbeet crown and root. *J. Am. Soc. Sugar Beet Technol.* 18:60-75.