

Potassium and Sodium Uptake by Sugarbeets as Affected by Nitrogen Fertilization Rate, Location, and Year *

J. N. Carter

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INTRODUCTION

Fertilization of sugarbeets (*Beta vulgaris* L.) with potassium (K) is generally not recommended in the intermountain areas of the western United States. This is attributable to the general abundance of available K and sodium (Na) in the soils of this region, irrigation water often containing significant K and Na concentrations (7), and the lack of plant response to K fertilization in numerous unpublished field experiments.

Potassium is taken up by sugarbeets in large quantities and is an essential element for plant growth. Sodium also is taken up in large quantities, even in the presence of ample K, but is not considered essential (34). Sodium can substitute for part of the K needs of the plant, and sodium chloride has been used as a K fertilizer substitute in certain humid regions because of its lower cost (21). Positive yield responses have been noted from the addition of Na, even in the presence of ample K (25).

Potassium and Na uptake depends upon their availability in the soil (24), plant growth rate (1), and nitrate uptake (20, 25, 37). Increasing levels of either soil K or Na generally result in increased uptake of these elements. However, there appears to be a reciprocal relationship between availability and uptake of these elements. Increased K availability and uptake decreases Na uptake and vice versa (24, 27). The uptake of K and Na generally follows the crop growth pattern with the largest increases coinciding with the most rapid growth (1).

*Contribution from the U.S. Department of Agriculture, Agricultural Research Service, in cooperation with 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.

Increased nitrate uptake generally increases K and Na uptake, probably resulting from the mechanism in plants that maintains a balance between anions and cations where growth increase was not proportional to increased nitrate uptake (34, 36).

Sucrose recovery efficiency from the sugarbeet depends on the amounts and types of root and/or extracted juice impurities (3, 23). Both K and Na are impurities and their presence interferes with the crystallization process in sugar refining. Higher levels of K and Na cause a greater proportion of the sugar to be recovered as molasses with a reduction in refined sugar (6, 24, 33). 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 (% wet root) in the root (27), and a high negative correlation between Na and sucrose concentration in roots of different cultivars (5, 19, 22). However, this sucrose concentration response to K (27) may have resulted from a secondary response to K and a direct response to reduced nitrogen (N) uptake caused by the chloride-nitrate antagonism in plant N uptake when the chloride form of fertilizer is used to add the K (28).

The purpose of this paper is to report results of a study to identify and evaluate factors that affect K and Na uptake by sugarbeets.

MATERIALS AND METHODS

Eleven experiments on sugarbeets have been conducted since 1967 by scientists located at Kimberly, with experimental plots at thirty-six locations in southern Idaho. The procedures used in the experiments have been published in numerous articles since the initiation of these studies. The specific procedures used for each of these experiments can be found in the article for the year: 1967(10), 1968(11, 12), 1969(11), 1971(18), 1972(17), 1976(16), 1977(15), 1978(13), 1980(9), 1982(8), and 1983(14). 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 (11). Extractable and water soluble (extractable - soluble = exchangeable) K and Na were determined on the 1971 samples (32). A representative sampling of the extractable and soluble K and Na in Idaho soils is given in Table 1.

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); 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.^{3/}

Nitrogen was generally applied between 0 to 448 kg N ha⁻¹ in increments of 56 to 224 kg N ha⁻¹. The total amount and rates of application to each experiment depended upon the residual and mineralizable N in the soil available for plant growth (11). The N uptake efficiency of applied N fertilizer for sugarbeets grown in southern

^{3/}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.

Table 1. A representative sampling of the extractable and water soluble (extractable - soluble = exchangeable) Na and K in Idaho soils during 1971 (18).

Idaho location	Soil		Analysis 0 to:	Extractable		Soluble	
	Series	Classification		Na	K	Na	K
			m	-----mg kg ⁻¹ -----			
Southwestern	Scism	Haploretollic Durorthid [†]	0.45	214	141	108	4
	Elijah	Mollic Durargid [‡]	0.30	345	309	124	8
	Power	Xerollic Haplargid [‡]	0.30	81	192	32	8
South central	Delco	Xerollic Calciorthid [§]	0.45	237	172	120	8
	Portneuf	Durixerollic Calciorthid [†]	0.60	69	266	25	12
	Kimama	Aridic Calcic Aryixeroll [‡]	0.60	260	371	28	8
Southeastern	Neeley	Calciorthidic Haploxeroll [†]	0.60	196	590	74	35
	Ammon	Calciorthidic Haploxeroll [†]	0.60	46	297	14	16
	Bannock	Aridic Calcixeroll [#]	0.60	53	129	16	8

[†]Coarse-silty, mixed, mesic. [‡]Fine-silty, mixed mesic. [§]Coarse-loamy, mixed mesic. [¶]Coarse-silty, mixed frigid. [#]Coarse-loamy oversand or sandy skeletal, mixed, frigid.

Idaho ranges from 50% to 70% and averages 65%. The efficiency depended upon time and rate of N application, soil type, and management practices (11, 17).

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 (35).

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

The sugarbeets were harvested during the season and 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 samples (16 to 18 roots per sample) and crown samples, on selected treatments from experiments conducted during 1977 to 1983, were taken for sucrose analysis. The sucrose concentration in the beet roots and crown was determined by The Amalgamated Sugar Company using the Sachs-le Docte cold digestion procedure as outlined by McGinnis (30).

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 (4). Potassium and Na were determined by atomic absorption spectroscopy from samples previously digested in a 3:1 mixture of nitric:perchloric acid (26) 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 (29).

One additional experiment was conducted in 1982 that has not been previously reported. This experiment had three replications in a randomized block design, using three N fertilizer rates of 0 (three plots only), 224, and 448 kg N ha⁻¹ and two K or Na rates of 0 and 448 kg ha⁻¹ applied only to the 224 and 448 N rates. One additional treatment of 672 kg K ha⁻¹ was applied to a N application of 448 kg ha⁻¹. The N, K, and Na were applied as a pre-plant broadcast application as ammonium nitrate, potassium chloride, and sodium chloride, respectively. Concentrated superphosphate was applied at 56 kg P ha⁻¹ and all fertilizer incorporated into the upper 0.1 m of soil. The planting, irrigation, and harvesting of the sugarbeets were as previously described.

RESULTS AND DISCUSSION

Total K and Na uptake (top + root + crown) followed a rather typical N uptake and growth pattern (15) for sugarbeets throughout the season when N was applied preplant during the four years (Figure 1 A, B). Judging from the line slopes, uptake rates were highest from late June until early August during most rapid plant growth periods (15). From early August until harvest in October, both the plant growth rate and uptake of these elements were greatly reduced. Although the values given were all at the highest sucrose yield and the sugarbeets grown under similar soil and agronomic conditions, the total element uptake and the proportion of K to Na varied widely among years. Increasing the available N to the plant by the addition of N fertilizer at planting increased the plant growth rates and the uptake of both K and Na during all plant growth stages (Figure 1 C, D). Increasing the available N also increases the Na uptake more in proportion to K at all plant growth stages. However, total K uptake was always greater than total Na uptake during these experiments.

Midseason N application has been shown to generally increase the efficiency and amount of N uptake by the plant as compared with similar amounts applied preplant

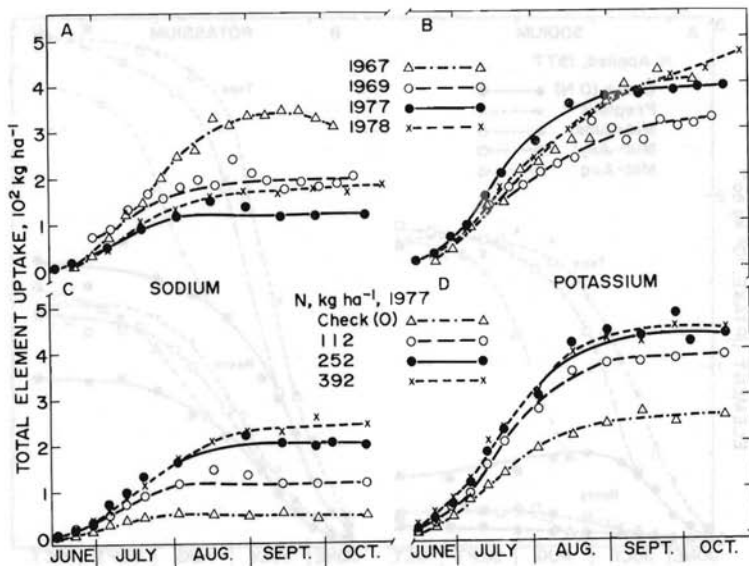


Figure 1. Total K and Na uptake (top + root + crown) as affected by time of sampling during the season, year of sampling at maximum sucrose yield (A, B), and N fertilizer level (C, D).

(15). This probably resulted from minimizing the time between N application and uptake which allowed less opportunity for N to be leached out of the root zone, denitrified, or incorporated into the soil microorganisms and their byproducts. This midseason increase in N uptake and use efficiency from the time of N application caused a large increase in plant growth (15) and increased K and Na uptake in the tops, roots (root + crown), and in the total plant (Figure 2 A, B). The maximum K and Na uptake rates were later in the season with each delay in N application. The majority of the K and Na uptake by the sugarbeet was in the tops at all stages of plant growth.

Total K and Na uptake by the plant at final harvest increased with each increase in total N uptake during the four years (Figure 3 A, B). High linear correlation existed between N and Na uptake during each of the years, but correlations were lower between N and K. A medium

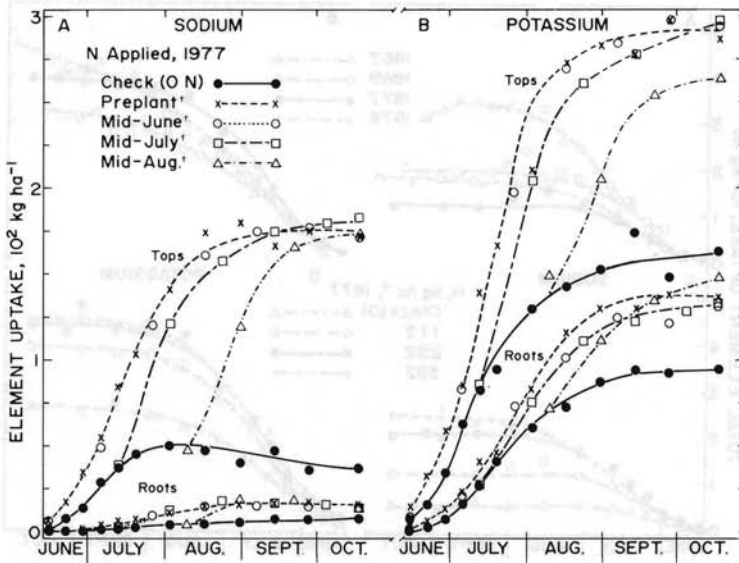


Figure 2. Potassium and Na uptake by the tops and roots (root + crown) as affected by time of sampling and time of N application. † avg. of 112, 252, 392 kg N ha⁻¹.

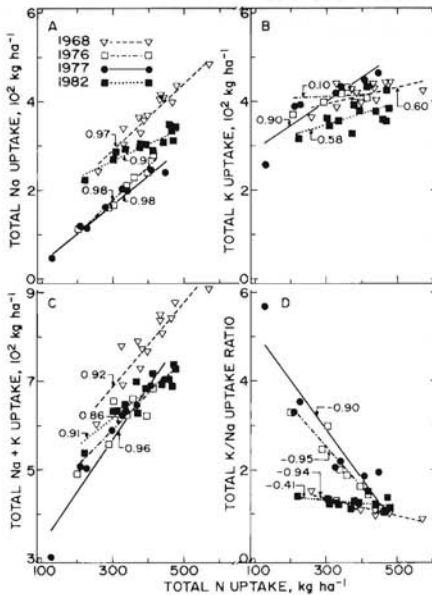


Figure 3. Effect of total N uptake on: (A) total Na uptake (top + root + crown), (B) total K uptake, (C) total Na + K uptake, and (D) total K:Na uptake ratio in sugarbeets during four years. Numbers beside regression lines = r.

correlation generally existed between N and K + Na uptake, resulting principally from the N and Na correlation, in each of the four years (Figure 3 C). Sodium uptake increased more in proportion to K uptake with increased N uptake. The K:Na ratio was reduced during each of the four years as N uptake increased (Figure 3 D). However, the extent and rate of change varied widely among years. The uptake of these elements was primarily related to total N uptake, amount of plant growth, and the year of the study.

The K and Na uptake by the root (root + crown) as a function of total N uptake showed about the same relationships as those of the element uptake by the entire sugarbeet plant (data not shown). High positive linear correlation existed at final harvest between N and Na uptake by the roots during each of the four years. Potassium uptake also increased with N uptake, but the linear correlations were much smaller. This generally resulted in a medium correlation between N and K + Na uptake by the roots during each of the years. Again, the Na uptake increased more in proportion to K uptake with increased N uptake which reduced the K:Na ratios in the roots during each of the four years. The Na, K, Na + K uptake, and the K:Na ratio by the roots varied widely among years when grown under similar agronomic conditions.

Total K and Na uptake at final harvest usually increased with each increase in total N uptake at different locations within southern Idaho in 1971 (data not shown) and in 1972 (Figure 4). Linear correlations between N and K or Na uptake were generally medium to high at each of the different locations for two years. The total uptake of K and Na varied widely between different locations, even when the N uptake at the different locations was similar.

Low relationships existed between K and Na concentrations (mg kg^{-1}) in the soil (Table 1) and their uptake by the sugarbeet plants in 1971. This low relationship existed even when K and Na uptake was approximated at equal N

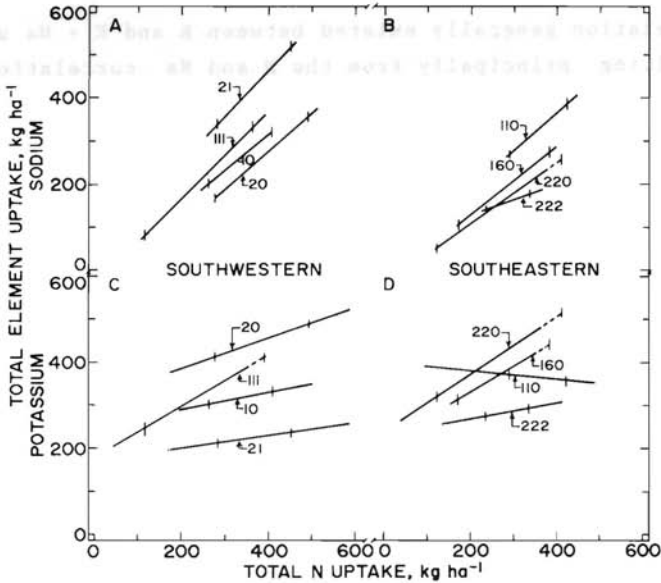


Figure 4. Effect of total N uptake and field location on total (top + root + crown) Na (A, B), and K (C, D) uptake in sugarbeets during 1972 (solid lines = K or Na uptake for nine N fertilizer treatments, short vertical lines = limits of N uptake, number = Exp. Site no.).

uptake values when evaluated by regression analysis techniques. The uptake of K and Na was more closely associated to N uptake than from their concentrations in the soil above the hardlayer. This lack of correlation between concentration in the soil and plant uptake was probably attributable to three factors: 1) K and Na within and below the hardlayer that is available and taken up by the plant was not measured in the soil test, 2) both elements were added in the irrigation water at concentrations varying over a wide range with different water sources (7), and 3) sugarbeet growth differences caused by climatic change between sites.

There was no indication that K or Na application in the chloride form caused any decrease in the N uptake (Figure 5 A) brought on by chloride-nitrate antagonism previously reported by James (28). The only consistent change in N uptake was an increase caused by N fertilizer

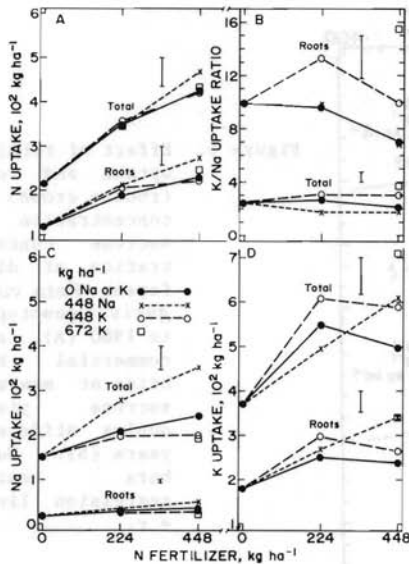


Figure 5. Effect of added N, K, and Na fertilizer on: (A) total (top + root + crown) and root (root + crown) N uptake, (B) total and root K:Na uptake ratio, (C) total and root Na uptake, and (D) total and root K uptake in 1982 (bars = LSD 5%).

application. Applying Na fertilizer increased the Na uptake in the root and total plant at both N levels (Figure 5 C). Applying K fertilizer increased the K uptake by the plant only at the higher N application level (Figure 5 D). The one anomaly was the large K uptake increase in the root and total plant at the higher N level with the application of Na fertilizer. The changes in both K and Na uptake caused by their applications resulted in changes in the K:Na ratios in the plant (Figure 5 B). The application of K consistently increased the K:Na ratio in both the total plant and root uptake; whereas, Na application decreased these ratios in the roots only at 224 kg N ha⁻¹. This indicated that two factors that affect uptake of these elements were their concentration in the soil as well as the availability and uptake of N that affects the rate and total growth of sugarbeets.

Eight *Beta vulgaris* genotypes and commercial hybrids at maximum sucrose yield during eleven years varied widely in both their K and Na root concentrations (Figure 6) and K:Na ratios (Figure 7) as well as their sucrose concentration (% wet root). There was a high linear correlation

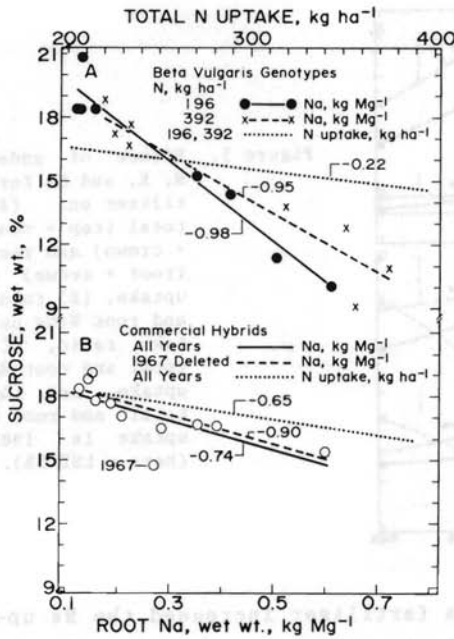


Figure 6. Effect of total N uptake and root (root + crown) Na concentration on sucrose concentration of different *Beta vulgaris* genotypes in 1980 (A), and commercial hybrids at maximum sucrose yield during different years (B). Numbers beside regression lines = r.

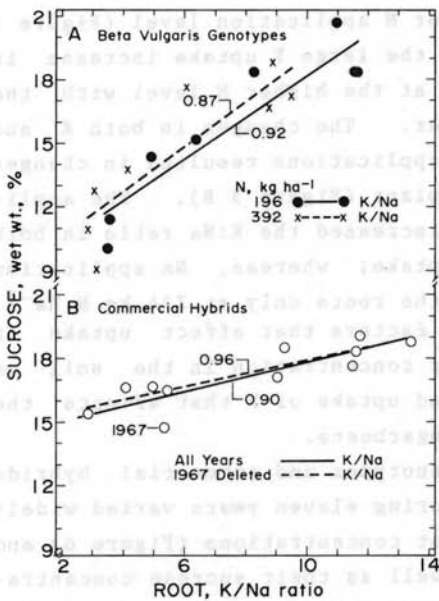


Figure 7. Effect of root (root + crown) K:Na uptake ratio of sucrose concentration of different *Beta vulgaris* genotypes in 1980 (A), and commercial hybrids at maximum sucrose yield during different years (B). Numbers beside regression lines = r.

between the concentration of Na in the roots as well as the K:Na ratios and sucrose concentrations. A low concentration of Na ($<0.2 \text{ kg Mg}^{-1}$) in the roots and a high K:Na ratio (>9) resulted in roots with high sucrose concentration; whereas, high Na concentration (>0.4) and low K:Na ratios (<5) resulted in roots with low sucrose concentration. These relationships between Na concentration or K:Na ratio and sucrose concentration were more closely associated than the commonly used total N uptake as shown in Figures 6A and B.

Most of the K and Na taken up by the sugarbeet at final harvest was located in the tops with lesser but important amounts in the harvested roots and crowns (Table 2). Total K and Na uptake and concentration (kg Mg^{-1}) in the wet and dry roots were increased with each increase in N uptake by the plants. Although the concentration of Na was increasing in the tops with N uptake, there was a steady reduction in the K concentrations. The tops and crowns, containing the higher concentrations of these elements, are removed from the harvested root and left in the field.

The increased N application rates resulted in an increase in the amount and concentration of N, K, and Na in the harvested root. Along with the increases of these elements, there was a steady decrease in the sucrose concentration in the wet and dry roots (Table 2). It has been presumed by most investigators (15, 31) that the decreasing sucrose concentration of the wet root with increasing N is caused by the tops becoming the dominant sink for the photosynthate, thereby reducing the amount and concentration of sucrose in the roots. Excellent correlation generally existed between N uptake and wet root sucrose concentration during any one year at the same location (15). However, between locations and years the correlations between N uptake and sucrose concentration were lower (17). This would indicate that a factor or factors other than N level and uptake by the plant could be major contributing factors to the differences in wet

Table 2. Potassium and Na concentrations and uptake by the different plant parts as affected by fertilizer and N uptake and its effect on sucrose concentration in the wet and dry roots during 1977; H. root = harvested root (root-crown).

N Applied	Plant Part	Element concentration and uptake										Sucrose	
		N	Na				K				Dry	Wet	
kg ha ⁻¹		kg ha ⁻¹	Dry †	Wet ‡	kg ha ⁻¹	% of total	Dry †	Wet ‡	kg ha ⁻¹	% of total	---- %	----	
			%†	kgMg ⁻¹ ±			%†	kgMg ⁻¹ ±					
0	TOP	54	0.95	1.74	37.8	84	4.08	7.48	162.8	63	----	----	
	H. ROOT	64	0.04	0.11	6.4	14	0.55	1.41	81.1	32	75.2	19.3	
	CROWN	12	0.08	0.20	0.9	2	1.13	2.84	12.8	5	58.0	14.6	
112	TOP	94	1.64	2.57	107.7	91	3.96	6.17	258.7	67	----	----	
	H. ROOT	92	0.05	0.14	8.8	7	0.66	1.65	107.4	28	75.6	19.0	
	CROWN	24	0.12	0.28	2.2	2	1.20	2.84	22.0	6	59.8	14.1	
252	TOP	174	2.10	3.10	181.1	91	3.44	5.08	296.7	69	----	----	
	H. ROOT	123	0.08	0.20	13.3	7	0.64	1.57	106.1	25	72.9	17.8	
	CROWN	41	0.19	0.42	4.4	2	1.27	2.86	30.0	7	58.6	13.2	
392	TOP	216	2.44	3.14	222.5	92	3.30	4.25	301.2	68	----	----	
	H. ROOT	147	0.09	0.22	14.1	6	0.76	1.78	114.5	26	71.5	16.8	
	CROWN	44	0.19	0.42	4.7	2	1.25	2.68	29.9	7	58.0	12.5	
Avg.	TOP	134	1.78	2.64	137.3	90	3.70	5.75	254.9	67	----	----	
	H. ROOT	107	0.07	0.17	10.7	9	0.65	1.60	102.3	28	73.8	18.2	
	CROWN	30	0.15	0.33	3.1	2	1.21	2.80	23.7	6	58.6	13.6	

†% of plant part (top, H. root, or crown), dry wt.
 ± kg Mg⁻¹ of plant part, wet wt.

root sucrose concentration at different field locations and years. Yearly and location differences in sucrose concentration may be affected by the soil water level during harvest, average minimum August and September temperatures, and the date of first killing frost (-4.4°C) in the fall (2). The change in the amount, concentration, and proportion of K and Na with changes in N uptake may also be having an effect on sucrose concentration of the wet roots that has gone unnoticed by investigators because during any one experiment the changes in sucrose concentration are rather uniform with N uptake. However, between experiments there can be extreme differences in the amount and proportion of K and Na uptake as well as sucrose concentrations in the beet root.

The total and root uptake of N, K, Na, and the proportion of K to Na uptake varied widely at one location among years for both the total plant and that located in the roots (root + crown) at maximum sucrose yield (Figure 8 A,B). Generally, there was a high correlation between N and Na uptake with a reduced correlation between N and K uptake by both the total plant and roots. This would again indicate that N availability and uptake were having a major impact on Na uptake. However, other factors such as availability of both K and Na were probably contributing to the Na uptake. The most noticeable factor in Figure 8 was the relationship between root K:Na ratio and the wet root sucrose concentration. In every case, where the root ratio was greater than 9, sucrose concentration in the roots exceeded 17 and averaged 18.1 %; whereas, when the ratio was less than 9, sucrose concentration was less than 17 and averaged 15.9%. The increased amount of N taken up by sugarbeets having a K:Na ratio less than 9 (avg. 342 vs 260 kg N ha⁻¹) undoubtedly contributed to this decreased sucrose concentration.

CONCLUSIONS

The results of these experiments showed that K and Na uptake is controlled by N uptake, plant growth, availability of K and Na to the plant, year, and genotype grown.

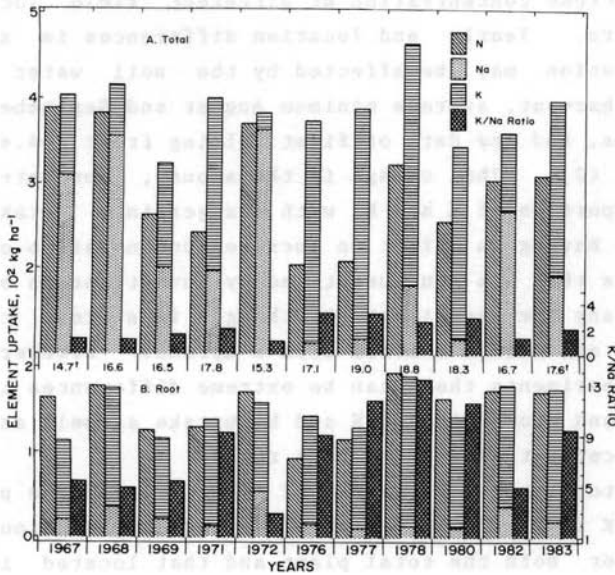


Figure 8. Nitrogen, K, and Na uptake and K:Na ratio of the total (top + root + crown) plant (A), and root (root + crown) (B) at maximum sucrose yield for different years.† Sucrose concentration, %.

The increase or decrease in the K and Na uptake affected the individual plant parts about equally. The higher concentration and larger amounts of these elements were located in the tops and crowns that are normally cut off and left in the field. Smaller, but important, concentrations are located in the harvested root used for refined sugar production. If K and Na are not normally added to the soil as a fertilizer or contaminant, then the only method presently available to limit their uptake by plants is through field selection for residual N, K, or Na content or by limiting the amount of N applied. Low available N and N uptake will generally produce roots with lower K and Na concentrations than those with higher levels of N. However, there appears to be a wide variation in the uptake of these elements at the same N uptake levels between locations and years.

The most noticeable changes resulting from K and Na

uptake on sugarbeet growth was on wet root sucrose concentration. Sucrose concentration in the fresh or wet root is the result of the percent sucrose of the dry matter and the dry matter concentration within the root. The reduced percent sucrose of the dry matter, that generally occurs with increased available N and plant uptake, undoubtedly resulted from the tops becoming the dominant photosynthate sink at the expense of the roots. However, the decreased dry matter concentration or increased water content within the fresh roots may be attributed to other factors such as the Na concentration or K:Na ratio within the roots. If this is the case, then sucrose concentration would be determined both by N uptake and the amount and proportion of K and Na uptake. Low sucrose concentration and extractable sucrose production would then be expected when both N and Na uptake are high with a low K:Na ratio in the roots, as shown in these experiments.

In the production of high quality sugarbeet roots for processing, it is desirable to have roots with high sucrose concentration and low impurities, such as amino N, K, and Na. The addition of N and increased N uptake reduces sucrose concentration and increases these impurities in the roots. However, maximum production of extractable sucrose can only be achieved by having the N level in the soil and N uptake by the plants at adequate, but not excessive, levels to maintain optimum plant growth and root production. This balance between optimum growth rates and production of high quality roots can generally only be achieved consistently by the use of an adequate soil test that takes into consideration all forms of soil N within the root zone that can become available to the plant during the season. Maintaining the N and K available to the plant at adequate, but not excessive, levels and to select sugarbeet fields for their low residual Na content, should produce roots that have high sucrose concentration with low impurities.

SUMMARY

Potassium (K) and sodium (Na) are impurities in the

sugarbeet (*Beta vulgaris* L.) root which interfere with the extraction of sucrose and may be associated with reduced sucrose concentration (% wet root) as well as refined sugar production. Data collected at thirty-six field locations in southern Idaho during eleven 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 the K and Na uptake by sugarbeets. Both K and Na uptake were affected by N uptake, plant growth, availability of K and Na, year, and genotype grown. The major concentrations of K and Na were located in the tops and crowns with smaller, but important, concentrations in the harvested root. The increased concentration and proportion of K and Na in the roots were correlated with increased N uptake and genotype grown. If K and Na are not normally added to the soil as a fertilizer or contaminant, then the only methods that are presently available to limit their presence in the roots of commercial sugarbeet hybrids are to regulate the availability of N, K, and Na for uptake by the plant through field selection for residual content of these elements, or by limiting the amount of N applied by the use of a soil test that can recommend adequate, but not excessive, amounts of N for maximum extractable sucrose.

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