Nutrient Concentrations in Sugarbeet Senescing Leaves During the Season and in Six Plant Parts at Harvest

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ABSTRACT

Senescent sugarbeet leaves were collected at about two-week intervals through the growing season and analyzed for seven nutrients: Na, K, Ca, Mg, N, S, and P. These nutrients also were determined at harvest in leaves of four ages, and in crowns and roots. As the season progressed, average concentrations of Na, Ca, and Mg in senescent leaves decreased, whereas K and S remained approximately constant; N and P decreased early but increased later, probably due to increased soil availability of these nutrients. Increasing N fertilization increased N and Mg and decreased P concentrations in senescent leaves, but planting date had little effect. Nitrogen fertilization resulted in increased Na, Mg, N, and S, but decreased Ca in the six plant parts at harvest. With increasing leaf age, Ca, Mg, Na, and S concentrations increased, whereas those of N and P decreased. In general, the seven nutrients ocurred in lowest concentration in the root, in highest concentration in the leaves, and at intermediate levels in the crown. Increasing N fertilization levels resulted in increased Na, Mg, and N and decreased Ca in roots and crowns at harvest. Relative to total crop uptake, leaf senescence resulted in greater proportional loss of the less mobile nutrients (Na, Ca, Mg, S) than of the more mobile N and P, or of K, which was relatively uniformly distributed in leaves of each age.

Additional Key Words: *Beta vulgaris*, sodium, potassium, calcium, magnesium, nitrogen, sulfur, phosphorus, root, crown, nitrogen fertilization, planting date, nutrient mobility

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Field studies by Follett et al. (1970), Storer et al. (1973), and Dillon (1970) in Colorado have shown that the number of living leaves increases to a maximum of about 30 per plant in mid August to early September, then decreases to harvest. Leaf loss through senescence begins in June and continues throughout the season at an increasing rate until the accumulated number of senesced leaves equals the living leaves on the plant by about September first (Lee and Schmehl, 1988). The senescent leaves fall to the soil, dry matter is lost, and the nutrients contained therein are released to the soil. After decomposition of the leaf tissue, the nutrients become available to the plant. There are reports of translocation of nutrients from the aging leaves before abscission for some plants (Mengel and Kirkby, 1978), but there is little information on translocation from aging sugarbeet leaves or on the loss of nutrients through leaf senescence. Houba (1973), in a study with sugarbeet in the Netherlands found considerable loss of minerals and dry matter due to leaf senescence during the growing season. He reported that nutrient loss was greater for those elements that have the higher concentrations in older laminae and petioles. Watson and Petrie (1940) found that translocation of mineral elements from the leaf may also occur during senescence. According to Leopold (1961), the leaf senescence process has two primary effects: 1) it results in recycling of nutrients within the plant by translocation and recycling to the soil by leaf senescence, and 2) it brings about shedding of leaves photosynthetically ineffective because of self-shading.

The research presented in this paper complements a companion study in which dry matter loss from leaf senescence was determined to develop a sugarbeet growth model (Lee et al., 1987). The leaf fall data provided an opportunity to determine nutrients returning to the soil during the season through leaf senescence. The objective of this study was to determine the concentrations of seven nutrients (N, P, K, S, Ca, Mg, Na) in the senescing leaves and the quantities of these nutrients returned to the soil. The concentrations of the same nutrients in various plant parts at harvest were also measured. The results of this study provide baseline information useful for assessing the nutrient requirements of sugarbeets, and for modeling seasonal sugarbeet nutrition and growth.

METHODS AND MATERIALS

A field experiment was conducted at the Colorado State University Agronomy Research Center near Fort Collins, Colorado to obtain data for growth study (Lee et al., 1987). Great Western Mono Hy A2 was grown in the calcareous Nunn silty clay loam under furrow irrigation. The fertility analysis of a composite surface soil sample (0-8 inches) from the experimental area given in Table 1 indicated that N was the only deficient

nutrient. The experiment was designed as a split-plot with planting date as the main plot, and split for three levels of N fertilization. Planting dates were April 22 and May 27, and N fertilizer rates were 1) check, no N applied, 2) 100 lbs N/A and 3) 300 lbs N/A. The six treatments were replicated four times to give a total of 24 plots. A detailed description of the site and cultural practices for the experiment are given by Lee et al. (1987).

Table 1. Soil fertility analysis[1] of a composite surface sample (0-8 in) from the experimental area.

pH (saturated paste)	7.9
Conductivity (saturation extract)	0.8 dS m^{-1}
Water soluble cations (saturation extract)	
Na	1.2 me l^{-1}
Ca	3.2 me l^{-1}
Mg	1.4 me l^{-1}
Sodium adsorption ratio (SAR) (saturation extract)	0.8 (me l^{-1})½
Soil organic matter	1.6%
Nitrate-N (water extraction)	12 ppm
Available P ($NaHCO_3$ soluble)	32 ppm
Available K (NH_4Ac soluble)	300 ppm
Available Zn (DTPA extraction)	0.6 ppm
Available Fe (DPTA extraction)	16.0 ppm
Available Cu (DPTA extraction)	1.2 ppm
Available Mn (DPTA extraction)	7.4 ppm
Lime (qualitatively)	high

[1]Colo. State Univ. Soil Testing Lab (Soltanpour et al., 1978)

The plot size was twelve 22-in rows wide and 33 ft long. For this study, five consecutive plants at 10-in spacings in row three of each plot, a total of 120 plants, were selected for observation during the season (Lee and Schmehl, 1988). The emerging leaves of each plant were tagged, and as the leaves senesced, they were removed by hand and collected in separate paper bags at approximately biweekly intervals from June 25 to September 30. The average date for each sampling of senescent leaves[2] was June 25, July 9 and 19, August 4, 13, and 30, September 15 and 30 and October 18. Leaf senescence in this study was determined as the point when the green color disappeared from the leaf but before leaf disintegration.

At the end of the season (October 18) leaf[2], crown, and root sections of all 120 plants were harvested. The leaves were separated into four ages (young, recently matured, old, senescent), and the six plants parts (four leaf ages, crown, and root) for each plant were placed in separate paper bags. Leaves designated as "old" were on the plant for more than 78 days, "recently matured" leaves for 47-78 days, and "young" leaves for less than 47 days. Yield and quality of the harvested root were determined by procedures described by Lee et al. (1987).

[2]The harvested leaf included blade and petiole.

The plant samples were dried in paper bags at 65 C in a forced-air oven, then weighed. Treatment replicates were composited for each sampling date to reduce the number of samples for chemical analysis. This gave six leaf samples (one per treatment) for each of the nine sampling dates through October 18. At the end of the season a total of 144 plant samples were analyzed (four replications of a composite of six plant parts per plot and six treatments). All plant samples were ground in a stainless steel Wiley mill to pass a 20-mesh sieve for chemical analysis. The ground samples were stored in plastic bottles with tightly closed lids to prevent absorption of moisture.

A wet digestion procedure (nitric-perchloric-sulfuric acid mixture) was used for extraction of total P, K, Na, Ca, and Mg (Greweling, 1976). The metal ions were determined by atomic absorption spectrophotometry. Phosphorus was analyzed colorimetrically using the molybdovanadophosphoric acid procedure (Greweling, 1976). The modified Kjeldahl method (salicylic-sulfuric acid) was used to determine total N (AOAC, 1965). A dry ash procedure was used to prepare the plant materials for total S analysis, and total S was determined turbidimetrically as $BaSO_4$ (Greweling, 1976).

RESULTS AND DISCUSSION

The yield and quality for the root harvest on October 18 are summarized in Table 2. The results presented are the average for the growth and the leaf senescence studies (Lee, et al., 1987). They are reviewed briefly to show the level of production for the experiment.

Table 2. Effect of planting date and nitrogen level on sugarbeet yield and quality at harvest, October 18.

N level lb/A	Root yield (T/A) Planting date April 22	May 27	Mean **	Sucrose(%) Mean **	Purity(%) Mean **	Recoverable sucrose T/A[1]
0	18.5	12.2	15.4	19.2	98.0	3.26
100	27.7	15.5	21.6	18.5	97.3	4.51
300	27.6	17.3	22.5	17.0	95.2	4.20
mean**	24.6	15.0	19.8	18.2	96.8	

** Nitrogen level means for yield, percentage sucrose and percentage purity, and planting date means for yield were significant at the 0.01 probability level. Planting date x N interactions and planting date means for sucrose and purity were not significant at the 0.05 level.

[1] Recoverable sucrose (Dexter, et al., 1967) calculated for the April 22 planting.

Both date of planting and N fertilization significantly[3] affected the yield (Table 2). Typically, the mean yields were consistently higher at each N level for the early planting (April 22)

[3]Significant effects refer to probability levels of 0.05 or greater.

than for the late planting (May 27). For the April planting, the leaf canopy developed earlier in the growing season and provided a larger active photosynthetic area for dry matter production over a longer period of time. Planting date had no effect on either percentage sucrose in the root or purity of the extracted juice.

The application of N increased root yield but decreased sucrose percentage and purity. Both the yield and quality of roots for the early planting were above average for the Fort Collins location. Recoverable sucrose, calculated using the procedure of Dexter et al. (1967), was highest for the 100-lb N rate and the April planting (Table 2). Since production was at a high level, this study provides growth data that typifies a good production environment.

Seasonal nutrient concentration of senescent leaves

The concentration of nutrients is reported as percentage in the plant on a dry matter basis. The data were analyzed statistically as a factorial arrangement of treatments in a split-plot design without replication. The main effect of sampling date (D_s) was significant for all seven nutrient elements in the senesced leaves (Table 3), while the main effects of N fertilization (N) were significant for Mg, N, and P (Table 4) but not for the other nutrient elements. The main effect of planting date (D_p) was significant for Mg and S. The only significant first order interactions were D_p x D_s for K, Mg, and P.

Table 3. Average concentration of seven nutrient elements in senescent sugarbeet leaves on a dry matter basis for each sampling date during the growing season.

Nutrient Element	Sampling date (D_s)*									Tukey HSD	
	June 25	July 9	July 19	Aug 4	Aug 13	Aug 30	Sept 15	Sept 30	Oct 18	0.05	0.01
K	2.28	3.68	3.04	2.19	2.19	2.63	2.54	2.97	2.61	0.70	0.83
Na	6.84	7.74	8.45	7.40	6.55	5.70	4.37	4.21	3.18	1.63	1.93
Ca	2.31	1.99	2.08	2.20	2.23	1.80	1.78	1.44	1.04	0.46	0.54
Mg	2.07	1.75	1.86	1.68	1.74	1.23	0.94	0.77	0.58	0.42	0.49
N	1.89	1.67	1.55	1.33	1.31	1.41	1.26	1.35	1.73	0.59	NS
S	0.52	0.61	0.64	0.56	0.59	0.66	0.56	0.64	0.56	0.12	NS
P	0.14	0.11	0.08	0.09	0.08	0.09	0.11	0.12	0.19	0.04	0.05

*Each value is the average of three N levels and two planting dates.

The seasonal nutrient concentrations of Na, Ca, Mg, P, and N (Table 3) in the senesced leaves generally decreased as the season progressed to about September 15, thereafter N and P increased ($P = 0.10$). Sulfur concentrations tended to remain constant throughout the growing season. Similar changes in seasonal nutrient concentrations were observed by Bravo (1979) for the living leaves in the growth study. According to Houba (1973) a decrease in nutrient concentration of the plant as the season advances occurs in a given plant organ when the dry matter

production exceeds the rate of nutrient intake (dilution-effect), or because of translocation of nutrients to other organs in the plant.

Potassium and sodium – Although the K and Na concentrations in the senescent leaves varied during the season (sampling date effect, Table 3), neither date of planting nor N fertilization had an effect on the average concentrations for the season. The K concentration in the senescing leaves was highest in early July, with a minimum in early August followed by a slight increasing trend to the end of the season. Possibly, heavy rains that came late in July not only washed K from the leaves, but also leached nitrate from the soil. Both effects could reduce K in the plant during this period. The concentration of K was lower than for Na throughout the season but generally higher than Ca or Mg. The Na concentration was the highest among the seven nutrient elements analyzed in the senesced leaves for all harvest dates.

Both K and Na concentrations in the senesced leaves increased early in the growing season, possibly because the high level of available soil N early in the season tended to increase the uptake of these cations. For example, Wadleigh (1952) reported that high nitrate uptake increases the uptake of positively charged ions such as K and Na. This appears to be an important mechanism in sugarbeet that maintains electrical balance of cations and anions. Also, Sutcliffe (1957) in an experiment with red beets, found that an increase in the absorption of nitrate resulted in greater Na uptake.

Calcium and magnesium – Both Ca and Mg concentrations in the senescent leaves decreased progressively as the season advanced (Table 3). Throughout the growing season the concentration of Ca was higher than Mg, lower than Na, and generally lower than K.

Increasing the rate of N fertilization increased Mg concentrations in the senesced leaves (Table 4), possibly because of the cation-anion balance effect. Sutcliffe (1957) reported that as anion uptake increases, it tends to enhance the uptake of cations to maintain an electrostatic balance in the plant. Although this interdependence appears mostly with monovalent ions, it also is possible with divalent ions.

The effect of planting date on Mg concentration is shown by the $D_p \times D_s$ interaction (Figure 1). The Mg concentration for both planting dates decreased as the season progressed, but the rate of decrease was more rapid for the May 27 planting to about the end of August, thereafter Mg concentrations were about the same for both dates of planting.

Nitrogen – The total N concentration of senesced leaves was affected by date of sampling as well as by N fertilization (Tables 3 and 4). The N concentration in the senesced leaves was high early in the growing season (Table 3) because of the high level of

available N; then it decreased progressively to mid-September when it increased unexpectedly by the October 18 harvest. According to Haddock (1958), the amount of nitrate in living sugarbeet petioles usually decreases rapidly from June to the end of July; thereafter it declines only gradually until it reaches a minimum in October. The increase in N in the senesced leaves late in the season could have resulted from root contact with deep soil N (probably nitrate) as the roots extended into subsoil. Alternatively, new growth was slowing late in the season while the rate of senescence was increasing, thereby lowering the rate of redistribution.

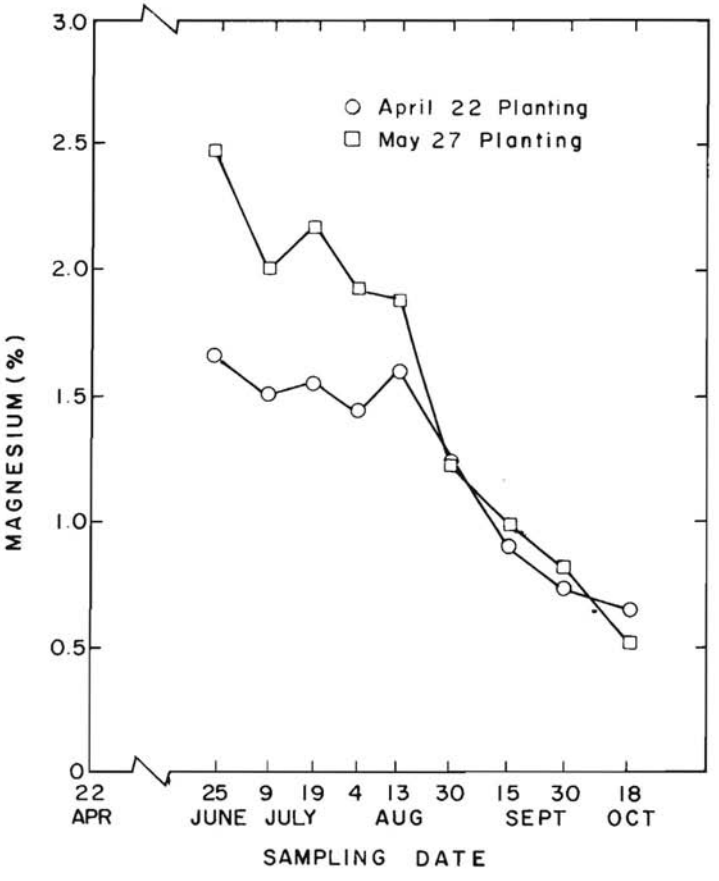

Figure 1. The seasonal effect of planting date on Mg concentrations in senescent sugarbeet leaves.

The application of N fertilizer increased the seasonal average N concentration (Table 4). At all nine harvest dates the concentration of total N was higher than S or P (Table 3). The seasonal

trend with N was similar to that for P, but at a higher level.

Sulfur – Although sampling date was significant for the S concentration in the senesced leaves (Table 3), the effects were quite variable. The slope of a linear regression model fitted to the seasonal data points did not differ from zero indicating little change in S concentration during the season. Significance for planting date was the result of about 10 percent higher total S for the first planting (April 22). The concentration of S was less than N and more than P for all nine sampling dates (Table 3).

Phosphorus – Sampling date and N fertilization caused changes in the P concentration of senescent leaves. As with total N, the P concentration decreased as the season progressed to the end of September, then increased (Table 3). Normally, the P concentration would be expected to decrease slowly as the season advanced. In another experiment on the Agronomy Research Center, the petiole phosphate concentration decreased to a minimum in midseason, then increased in September. Since the analysis of available soil P had shown a threefold increase at a depth of about five feet (Trierweiler, 1962), Romsdal[4] attributed the increase in petiole P to root extension into the five-foot depth early in September. The P concentration in senescent leaves may have been affected similarly.

In contrast with N and Mg, the concentration of P in the senescent leaves decreased when N fertilizer was applied (Table 4). Follett et al. (1964) also found that increasing petiole N was negatively correlated with petiole P, but Dubetz and Russell (1964), and Soine (1968) reported that the application of N increased the P concentration of sugarbeet leaf blades.

Although the date of planting (D_p) had little effect on the average P concentration, there was a $D_p \times D_s$ interaction. This was caused primarily by variation between planting dates early in the season when total P was typically higher for the second planting date, possibly because the tissue, though senescent, represented younger plants.

Seasonal recycling of nutrients through leaf senescence

The accumulated loss of nutrients at montly intervals to September 30 and at final harvest was calculated from dry matter loss by leaf senescence (Lee et al., 1987) and the mean concentrations of nutrients in the senesced leaves for each time interval. The values in Table 5 are averages for the three N rates for the April 22 planting. Average dry matter loss by leaf senescence for the three N rates was approximately the same as the loss by the 100 lb. N rate.

[4] Romsdal (1963), Department of Agronomy, Colo. State University – Unpublished data

Table 4. Effect of N fertilization on Mg, P, and N concentrations in senescent leaves on a dry matter basis (season average).

Nitrogen level (N)	Nutrient Mg**	P*	N**
	%		
N_0 (0 lb N/A)	1.24	0.13	1.26
N_1 (100 lb N/A)	1.30	0.10	1.35
N_3 (300 lb N/A)	1.66	0.11	1.88
Mean	1.40	0.11	1.50

*Significant at 5% level of probability.
**Significant at 1% level of probability.

Table 5. Accumulated loss of plant nutrients by leaf senescence at monthly intervals to September 30 and at harvest (October 18).

Nutrient	Accumulated nutrient loss to each date* June 28	July 28	August 30	Sept. 30	Oct. 18
			lb/A		
Na	2.1	38	91	159	198
Ca	0.6	9.9	28	52	65
Mg	0.4	7.6	19	32	39
S	0.1	3.1	10	21	26
K	0.8	12	36	81	113
N	0.4	7.6	20	41	61
P	<0.1	0.5	1.4	3.4	5.7

*April 22 planting and average of three N rates (24.6 T/A yield).

The return of nutrients to the soil by leaf senescence by October 18 ranged from 5.7 lb/A for P, to 198 lb/A for Na (Table 5). Nutrient recycling by leaf senescence can also be expressed as the loss in relation to total nutrient uptake. Since a good yield of beets grown under Colorado conditions is about 25 T/A (Storer et al., 1973, and Lee et al., 1987), this yield level was used to calculate the loss of each of the seven plant nutrients in relation to the total uptake by the crop. Total plant uptake is the sum of the plant nutrients in the harvested crop plus nutrients lost by leaf senescence and by loss of fibrous roots during harvest. The loss of fibrous roots was assumed to be 25% of the harvested root (Kelley and Ulrich, 1966).

The data (Table 6, column 3) show that nutrient loss by leaf senescence to October 18 ranged from 50 to 55% of total plant uptake for Na, Ca and S to 10 to 15% for P. Losses of the other plant nutrients were intermediate. It should be noted that Na has a unique role in sugarbeet and may be considered as a plant nutrient (Schmehl and James, 1971). The plant requirement for Na generally is assumed to be less than that for K (Draycott, 1972). Uptake of Na under Colorado conditions is primarily a reflection of the amount of exchangeable and water soluble Na in the soil (Table 1) rather than plant requirement.

The results show that recycling of plant nutrients by leaf senescence should have little influence on sugarbeet fertilizer

recommendations in Colorado. Nitrogen and P are the two fertilizer nutrients generally applied. The data in Tables 5 and 6 show that only about 3% of the total uptake of P and 6% of the total uptake of N were returned to the soil by August 30, the time when the N supply should be low to promote an increase in sucrose in the root at harvest. About 10% of the total K uptake was returned to the soil by leaf senescence by August 30.

Table 6. Calculated nutrient loss by leaf senescence to October 18 in relation to total crop uptake.

Nutrient	Nutrient loss in lb/A*	Loss in proportion to total crop uptake (%)**	Nutrient concentration in leaves (%)	
			Young	Senesced
Na	201	50-55	1.26	3.18
Ca	66	50-55	0.43	1.04
Mg	40	40-45	0.30	0.58
S	26	50-55	0.41	0.56
K	115	30-35	2.64	2.61
N	62	15-20	3.57	1.73
P	5.8	10-15	0.45	0.19

*Calculated from Table 5 for 25 T/A yield.
**Total crop uptake includes nutrients in the harvested crop plus those lost by leaf senescence and by fibrous root loss during harvest.

Nutrient Concentrations in the Plant at Harvest

On October 18, four leaf ages (young, recently matured, old, senescent), and crowns and roots of 120 individual sugarbeet plants were sampled. The five plants in each plot were composited by plant part to give 144 samples for the determination of K, Na, Ca, Mg, N, S, and P. Concentrations of the seven nutrient elements were analyzed statistically as a factorial arrangement (six plant parts, four replications, six treatments).

An overview of the effect of treatment on total nutrient concentrations in the plant at the time of harvest is shown by an analysis of variance of the six plants parts (Table 7). The main effect of planting date (D_p) was not significant for any nutrient. Nitrogen fertilization (N) as a main effect influenced Na, Ca, Mg, N, and S contents but not K and P. All seven nutrient concentrations differed among plant parts (PP) at harvest. The D_p x PP interaction was significant for Mg and P, and the N x PP interaction was significant for Na, Ca, Mg, and S. Neither the D_p x N interaction nor the three-way interaction (D_p x N x PP) was significant for any plant nutrient.

Potassium and sodium – The K concentration in the leaves was about three and one half times higher than that of the crown and root (Table 8). There was little difference in K concentration among the four leaf ages or between the crown and root. Neither the application of N fertilizer nor date of planting affected the K concentration in the plant at harvest.

The average concentration of Na differed widely among plant parts (Table 8). It was highest in the senesced leaves and

decreased in order from the senesced and old leaves to the recently matured and to the young leaves. There was only a small difference in the Na concentration of senescent and old leaves, but the younger leaves were much lower. Sodium was four to nine times higher in leaves than in crowns and eight to twenty times higher than in the roots, with about a two-fold difference between crown and root Na.

Table 7. Summary of analysis of variance for the concentrations (%) of seven nutrient elements in six sugarbeet plant parts at harvest, October 18.

Source of Variation	df	Nutrient K	Na	Ca	Mg	N	S	P
Planting Date (D_p)	1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Nitrogen (N)	2	N.S.	**	*	**	**	**	N.S.
Plant Part (PP)	5	**	**	**	**	**	**	**
D_p x N	2	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
D_p x PP	5	N.S.	N.S.	N.S.	**	N.S.	N.S.	**
N x PP	10	N.S.	**	*	**	N.S.	**	N.S.
D_p x N x PP	10	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. Not significant at 5% level of probability
* Significant at 5% level of probability
** Significant at 1% level of probability

Table 8. Average concentration of seven nutrients on a dry matter basis in six sugarbeet plant parts at harvest, October 18.

Nutrient element	Sugarbeet organ (PP)* Young leaves	Recently matured leaves	Old leaves	Senescent leaves	Crowns	Roots
	%					
K	2.64	2.70	2.45	2.61	0.90	0.59
Na	1.26	1.93	2.97	3.18	0.34	0.15
Ca	0.43	0.66	0.91	1.04	0.37	0.14
Mg	0.30	0.35	0.50	0.58	0.23	0.17
N	3.57	2.66	1.97	1.73	1.27	0.78
S	0.41	0.49	0.56	0.56	0.06	0.03
P	0.45	0.39	0.24	0.19	0.29	0.23

*Each value is the average of three N levels and two planting dates; main effect of PP significant at 1% level.

Except for the young leaves, increasing N fertilizer increased the Na concentration in the plant parts, most markedly the 300 lb N rate for the old and senesced leaves (Figure 2). The first order N x PP interaction resulted because the high level of N fertilizer had a large effect on the Na concentrations of the recently matured, old, and senescent leaves but had only a small effect on young leaves, crown and root (Figure 2).

As previously noted, and in contrast with Na, the K concentration was about the same for the four leaf ages (Figure 3). The difference can be explained by the extensive recycling of K in the plant. Since Na is considered to be a relatively immobile

element in the phloem, it accumulates in older leaves, therefore, the higher concentration is in senesced and old leaves. For example, Pate et al. (1975) compared the phloem and xylem sap, in two species of legumes. Potassium (the most mobile element in phloem) was present at many times the concentration in phloem than in xylem sap, whereas Na concentration in the phloem was only about twice that in xylem sap.

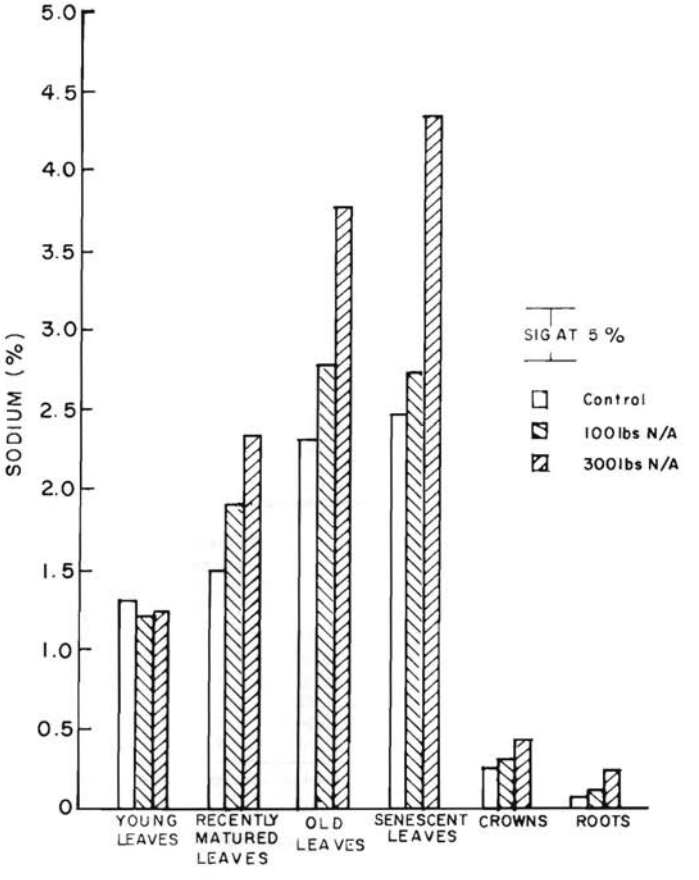

Figure 2. The effect of N fertilization on the Na concentration of six sugarbeet plant parts, October 18 harvest.

Another difference between Na and K is that N fertilization increased the Na concentration in the plant but had little effect on K. Bravo (1979) found a similar enhancing effect of N fertilizer on total Na but not on K in sugarbeet. Wadleigh (1952) found that a high level of nitrate will increase the uptake of Na and K by sugarbeet and maintain a cation-anion electrostatic balance

in the roots. Finkner et al. (1958) also noted that N fertilization increased Na concentrations in sugarbeet roots.

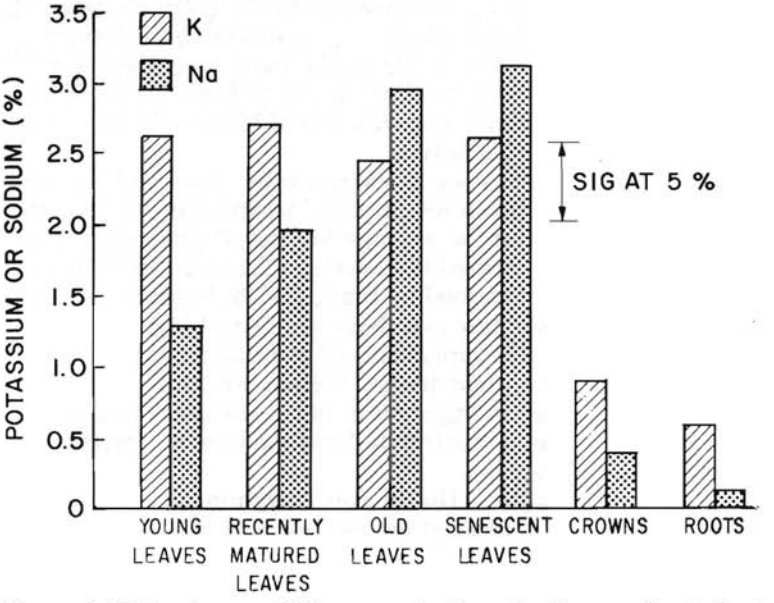

Figure 3. Potassium and Na concentrations in six sugarbeet plant parts for the October 18 harvest.

Calcium and magnesium – The main effects of treatment on Ca and Mg concentrations in the plant for the October 18 harvest were similar. The D_p x PP interaction was significant only for Mg but the N x PP interaction was significant for both Ca and Mg (Table 7).

The average Ca concentration in four leaf ages in decreasing order were: senescent > old > recently matured > young (Table 8). The concentration of Ca in the crown was higher than in the root but both root and crown were lower in Ca than the leaves. Increasing rates of N fertilizer decreased Ca concentration in the plant tissue except for the senescent and old leaves. This caused the N x PP interaction.

Magnesium concentrations varied with plant part (Table 8). As with the Ca, Mg was highest in senescent leaves, then followed in decreasing order by old, recently matured, and young leaves. The crown and root were lower in Mg than the leaves. Increasing N fertilization had little effect on Mg in the roots, crowns or the young or recently matured leaves, but the 300 lb N rate increased total Mg nearly two-fold in the senescent and old leaves and caused the N x PP interaction. The 100 lb N rate had little effect on Mg for any stage of leaf development.

Brown and Irving (1942) reported a close parallel between the Ca and Mg concentrations in sugarbeet. Calcium is consi-

dered to be relatively immobile in the phloem. Cook (1954) found that Ca was not translocated from old to young tissue, therefore a continous supply of Ca is necessary for the plant, because as soon as the supply is limited, the young leaves show deficiency symptoms. The transport of Mg in the plant resembles that of Ca but has intermediate mobility in the phloem (Steucek and Koontz, 1970). As with Ca, higher levels of Mg usually are found in older than in younger leaves.

The principal difference in the response of Ca and Mg concentrations in the plant to the imposed treatments was that the 300 lb N rate increased the average Mg for all plant parts from 0.32 to 0.46% but decreased the average Ca from 0.69 to 0.53%. Similar results were obtained by Bravo (1979). Smith (1956) proposed that synergism may exist between N and Mg, and under certain conditions, the application of N fertilizer increases the Mg concentration of plant tissue. Soltanpour and Cole (1978) observed an increase in Mg content of potato stems and tubers due to N fertilization and attributed this increase to a synergistic effect of N on Mg uptake.

Nitrogen and sulfur – The N concentration was highest in young leaves and decreased as the leaf age increased with a further decrease in the crown and root (Table 8). Increasing the rate of N fertilization increased N concentrations in the plant.

The S content of sugarbeet was affected by N fertilizer and varied among the plant parts (Table 7). In contrast with N, the average S concentration was high in the senesced leaves and decreased progressively to the youngest leaves (Table 8). The amounts of S in crown and root were about the same but much below that in the leaves. The application of N fertilizer increased the S concentration of the leaves but had little effect on S in the crown or root, hence the reason for the N x PP interaction. Rehm and Caldwell (1970) reported that S in the crown was higher when nitrate rather than the ammonium form was used as a N source. The major difference between the N and S contents of leaf tissue of varying age (Table 8) was caused, apparently, by the relatively greater mobility of N than S in the phloem. Sorensen (1962) and Coic et al. (1962) reported that young expanding laminae of sugarbeet contain more organic N than the older ones.

Phosphorus – The main effect of plant part and the D_p x PP interaction were significant for P (Table 7). Phosphorus concentrations in the six plant parts in decreasing order were young leaves > recently matured leaves > crowns > old leaves and root > senescent leaves (Table 8). Phosphorus is a mobile nutrient in the phloem. Bouma (1967) reported that young clover leaves are supplied not only by phosphate taken up by the roots, but also with phosphate coming from the older leaves.

Nitrogen fertilization had little effect on the P concentration in the plant at harvest. There was a D_p x PP interaction because the early planting (April 22) resulted in an increase, relative to

the later planting, in P in the leaves and crown but a decrease in P in the root.

Relation of leaf-age concentration to nutrient loss

The nutrient loss by leaf senescence in relation to total crop uptake (Table 6, column 3) can be explained by the differences in nutrient concentrations among leaves of differing ages. Columns four and five in Table 6 compare nutrient concentrations in the youngest and senesced leaves for the October 18 sampling. The differences in concentration among leaf ages reflect the relative mobility of the nutrients in the phloem. The data show that loss of nutrients by senescence was less for nutrients that move more rapidly from the older to younger leaves, as P and N. Those nutrients that move slowly from the older leaves, as Na and Ca, were lost in relatively greater amounts. The other nutrient elements, which were intermediate in relative nutrient loss, were also intermediate in the nutrient mobility among leaves of varying ages. In general, relative loss of a nutrient by leaf senescence is a reflection of the extent of translocation to younger tissues as the leaves age. Sulfur, however, was lost in relatively larger amounts than expected when based upon translocation from the senescent leaves (Table 6). This can be explained by the relatively small proportion of this nutrient in the root and crown (about 14%), thus the relatively greater loss by leaf senescence.

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