Potassium Fertilization of Sugar Beets in Central Washington[1]

D. W. JAMES, D. C. KIDMAN, W. H. WEAVER, R. L. REEDER[2]

Received for publication July 5, 1967

Potassium fertilization of sugar beets in the arid and semi-arid western U. S. has not been reported often. One known case of beet response to potassium fertilization was reported from California (18)[3]. On the other hand, potassium fertilizer responses in sugar beets are often reported from the sub-humid areas of the U. S. and Europe (1, 3, 4, 16). The lack of concern with K requirements of sugar beets in the western U. S. is undoubtedly due to a general abundance of K in soils in this region. Another reason for lack of interest is the presence of appreciable quantities of available sodium in these same soils.

The sugar beet is a notable example from a certain group of economic plants which is known to absorb large amounts of Na from the soil when it is readily available. Although the role of Na in these plants is not clear, it appears certain that Na replaces K to a considerable extent in their metabolic processes.

Two theories have been set forth regarding the specific function of Na in plant metabolism. One states that Na serves the same function as K (4,5). In this sense Na simply substitutes for some of the K nutritional requirements when K availability is limiting. The other theory states that Na is an essential (major) plant nutrient element in those plants that have a striking affinity for it (2, 9, 10, 13). That is, growth increases when Na is added to a system already well supplied with K.

While the idea of a unique role for Na as a major plant nutrient is in dispute, apparently Na does have some real significance as a minor nutrient element in some plants (12). Uptake of Na and K by beets seems to be a reciprocal function of their relative availability in the nutrient media. In recognition of this, Ulrich et al. (18) discuss different critical levels of K for sugar beets depending on the amount of Na present in the plant.

[1] Scientific paper No. 2995. College of Agriculture, Washington State University, Pullman, Project No. 1607.

[2] Associate Soil Scientist, Washington State University, Irrigated Agriculture Research and Extension Center, Prosser, Washington; Research Agronomist, Utah-Idaho Sugar Company, Toppenish, Washington; Senior Experimental Aide and Experimental Aide, WSU, Prosser, respectively.

[3] Numbers in parentheses refer to literature cited

The reciprocal relationship of Na and K, from the point of view of availability to plants in the soil, has often been overlooked in studies on K nutrition of beets. In a field survey, Ulrich and Hills (7) showed that beet petioles with the highest K content had the lowest Na content and vice versa. They indicated, however, that the relationship was not consistent. Petioles with some of the highest K levels also had some of the highest levels of Na. They did not try to estimate the relative availability of K and Na in the soil.

Geneticists have studied the effect of Na on the processing quality of beets. It has been shown repeatedly that Na uptake can be altered by plant breeding. However, most workers either did not consider the reciprocal relationship between Na and K in the plant or the effect of different amounts of these elements in the soil (6, 7, 8, 19).

Experiences in Washington

A series of experiments established in 1961 in central Washington in commercial sugar beet fields involved several rates of K and replications at 33 locations. The fields were selected to provide a wide range in soil K availability according to the soil test criteria established by Washington State University for other crops. The main item of interest arising from this program was a weak but significant correlation ($r = 0.63$) between leaf K as percent dry matter and root sucrose percent across all sites. The linear regression equation indicated that sucrose content increased by 0.83% for each increase of 1% in leaf K. The leaf K ranged from 2% to 6% (0.51 to 1.54 meq/g). Potassium uptake at each site was influenced by sodium, the latter varying independently of K between sites. There was no relationship between plant K and soil test K nor was there any indication of response in terms of root yield[4].

In subsequent seasons, K variables were included in routine fertility investigations (involving N, P, B, etc.) in an attempt to evaluate the plant-soil relationships of K in beets. No bona fide root yield response to K was observed in any season but in every season there was a hint of response to K in terms of increased sugar accumulation. Some examples of these results are in Table 1. In most cases, the change in percent sucrose was not statistically significant. The F-test (analysis of variance) indicated significance in the 1965 *a* and *b* results. The results in Table 1, taken individually, would not merit very serious

[4] Unpublished data. These results were discussed at the Thirteenth General Meeting of the American Society of Sugar Beet Technologists, San Francisco, February, 1964.

consideration. But taken collectively and with the results in 1961, there appears to be some underlying connection between sucrose accumulation and K uptake.

One factor should be considered in connection with the soils involved in the experiments in Table 1. Potassium fixation in these soils ranges from 0.4 to 1.3 meq/100 g between experiments shown. Fixation does not necessarily connote nonavailability of fixed fertilizer K, but it does mean that higher rates of K must be applied to achieve the same result as where fixation does not occur.

The purpose of this report is to present the detailed results from a 1966 field experiment with K in sugar beets.

Table 1.—Association between K fertilization and sucrose content of sugar beets grown in Washington by years.[1]

K rate lb/acre	Percent sucrose				
	1963	1964	1965		1966
			a	b	
0	15.3	16.0	14.8	15.6	16.2
50	15.4				
100	15.5	15.9	14.2	15.3	16.1
200	15.8	16.1	15.1	15.9	16.4
300					16.4
400		16.2	15.2	15.7	16.5
800	15.8	16.3			

[1] The number of replications for the respective experiments was 5, 4, 3, 4 and 4. Sucrose percentages are replication means. Three or four subsamples of roots were taken from each plot at harvest. Each experiment was in a different area. Nitrogen and phosphorus were applied uniformly with the indicated K rates. There was some variation in nitrogen availability because of residual fertilizer.

Procedure

An experiment was established in a specially selected field shown to be low in K and Na by soil test. Close inspection disclosed a slightly decreasing gradient of K and a sharply increasing gradient of Na between replications down the field. Table 2

Table 2.—Some soil chemical characteristics of the experimental field on which sugar beets were grown.

	Replication			
	1	2	3	4
Soil test K index[1]	107	99	102	82
Exchangeable K meq/100 g[2]	0.20	0.20	0.16	0.16
Exchangeable Na meq/100 g[2]	0.16	0.16	0.33	1.18

[1] Literally parts of K per two million parts of soil in a single extraction with 0.5 normal $NaHCO_3$; soil-solution ration of 1:10. Values are means of plot samples taken before fertilization. Using this procedure K fertilizer is recommended for potatoes when the soil test index is below 400, and for most other crops when the soil test is below 200.

[2] Composite soil sample results from each replication. Exchangeable ions determined in three extractions of soil with neutral, normal ammonium acetate.

shows some analytical data for the site. The soil is a silt loam with about 1% free calcium carbonate equivalent in the surface-foot and a cation-exchange capacity of about 12 meq/100 g. This soil fixes K to the extent of 0.8 meq/100 g in the surface and 1.2 meq/100 g in the subsoil. Selection of this site was somewhat unfortunate from the point of view of N residues. This field, which had grown mint previously, had a high N carryover. This is reflected in the results.

The experimental variables were rate and method of fertilizer K application. Potassium was banded at rates of zero, 100, 200 and 400 pounds K/acre as KCl on June 1, after thinning. The material was placed six inches to the side on both sides of the row and four inches deep. In complete factorial combination with the banded rates of K were three frequencies of foliar applications of K, zero, 1 and 2. Frequency 1 involved foliage applications at four-week intervals, beginning on July 7 (after complete development of the canopy) for a total of three applications. Frequency 2 was on two-week intervals beginning at the same time for a total of six applications. Each foliar treatment consisted of 20 lb K/acre as KCl in about 60 gallons of water. The solution was applied to the middle four rows of the six-row plots. With a surfactant, this rate of solution application provided fair coverage on the leaves with essentially no runoff. There were four replications of the twelve treatments. Ammonium nitrate at 150 lb N/acre and concentrated superphosphate at 35 lb P/acre were applied uniformly with the banded K. Individual plots were 40 feet long. Irrigation was in every row; no known moisture stress occurred during the season.

Plant tissue samples consisting of 25 petioles from the youngest fully developed leaves were obtained from each plot on June 29 and October 27. This material was analyzed for NO_3-N (18) and for total K and Na. Tissue analyses are reported as parts per million (ppm) NO_3-N and milliequivalents per 100 grams (meq/100 g) of Na and K.

Yield was estimated on October 10 by subsampling the plots. Each subsample consisted of all the roots in 15 feet of row. Roots were obtained where the stand of beets was nearly ideal in the sample row and in the two adjacent rows. Attempts were made to obtain three subsamples from each plot but where the stand was limiting, less than three subsamples were taken. The beet samples were washed, weighed, and put through the Spreckels saw for pulp samples and sucrose analysis. The subsamples were averaged for yield and percent sucrose for each plot. In two plots, no subsamples were obtained. The missing values for yield and percent sucrose were estimated. using standard formulas with corresponding adjustment of the treatment and error variances in the statistical analysis (15). Statistical significance is shown by vertical line segments in the figures. Significance did not occur where it is not indicated.

No attempt was made at determining the processing quality of the beet roots (e.g. K and Na in the thin juice).

Results

In analyzing the various nutrient uptake and growth parameters, the field location or replication effects were shown to be highly significant in several instances. The location effects are quite informative, since they reflect the gradients of K and Na in the field. Therefore, replication means are presented in Table 3 for comparison.

Table 3.—Replication means for various nutrient uptake and yield parameters of the experimental sugar beets.

Item		Date sampled	Replication 1	2	3	4	Overall experimental coefficient of variation - %
Petiole-K	meq/g	6-29-66	.74	.71	.62	.56	12.3
Petiole-Na	meq/g	6-29-66	1.27	1.39	1.46	1.79	44.3
Petiole-NO_3-N	ppm	6-29-66	11200.	9500.	10100.	12000.	15.3
Petiole-K	meq/g	10-7-66	.29	.27	.24	.22	31.0
Petiole-Na	meq/g	10-7-66	.94	.94	1.01	1.20	6.0
Petiole-Na/K	ratio		4.75	4.92	6.22	8.62	50.0
Petiole-NO_3-N	ppm	10-7-66	3090.	2710.	2720.	2220.	28.0
Root yield	Tons/acre		24.0	23.4	25.3	24.4	10.0
Sucrose percent			13.4	13.5	13.4	13.2	3.0

Results for petiole content of K and Na for the first sampling are in Figure 1. Foliar treatment effects are not included, since spray treatments had not been initiated at that time. There was a sharp and continuous increase in K uptake with K rates. The increase in petiole K with the first fertilizer increment was statistically significant from the check. In the check plots, petioles contained nearly four times as much Na as K. Sodium decreased slightly with fertilizer K increments but the effect was not statistically significant. The location effects were significant; the K and Na contents of petioles follow the same gradients as the soil tests in the field. The sum Na+K in petioles increased slightly with K treatment and sharply with consecutive replications down-field.

Figure 2 shows the petiole content of NO_3-N for two dates of sampling. Potassium fertilization appears to have markedly depressed N uptake at the time of the first sampling. Replication means for N content indicate that residual soil N varied randomly down the field.

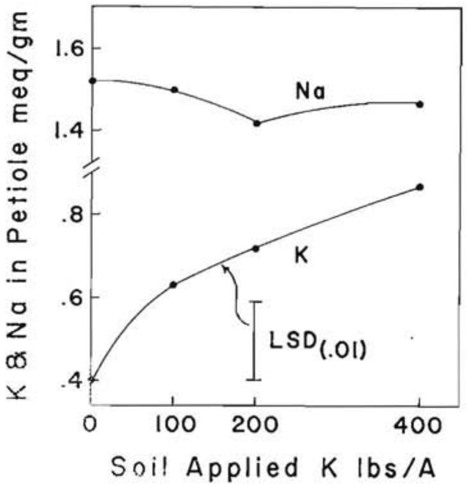

Figure 1.—Effect of K applied to soil on K and Na in petioles of sugar beet. Petioles sampled on June 29. Each point is mean of 12 replications (foliar K treatments not yet initiated).

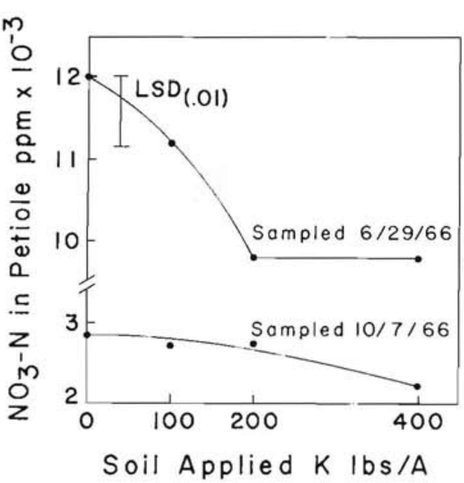

Figure 2.—Treatment effects on NO_3-N in petioles of sugar beets.

The results for petiole analysis, yield of roots and percent sucrose at harvest are in Figures 3 through 6. The data are presented as means of the main effects from the 3×4 factorial experiment except for percent sucrose, which is graphed to show the interaction between methods of K application.

As would be expected, K and Na contents at harvest were lower than at the June 29 sampling. The time of late sampling was selected so as to provide a full measure of the foliar treatment effects on cation content. Figure 3 shows that K in the plant was increased significantly by both methods of K application. In the individual treatment effects, there was a five-fold increase in plant K (0.08 meq/g to 0.41 meq/g) between the check treatment and a combination of higher rates of banded and foliage applied K. The lack of interaction between methods indicates that the increase in K content was additive for the two procedures. Again, the replication means reflected the field gradient of soil test K and Na.

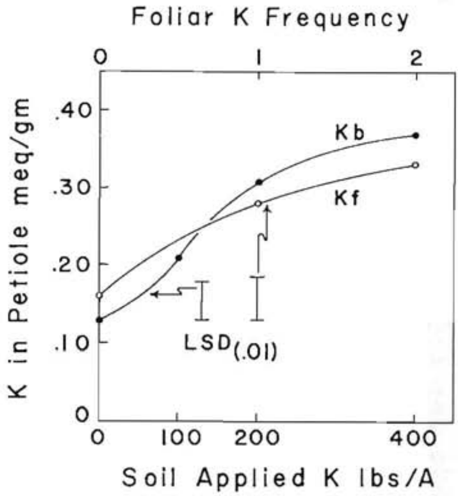

Figure 3.—Treatment main effects on K in petioles of sugar beets at harvest time. Kb refers to band-applied K and Kf refers to foliar-applied K. Frequency 1 and 2 refer to 3 and 6 foliar applications respectively.

Figure 4 shows the effect of K treatment on Na content. Sodium uptake was significantly reduced by both K application methods with no interaction. It is apparent that absorption of elements through the leaves has a direct impact on root absorption from the soil. The replication means for Na content of petioles increase in the same direction as soil test data but not proportionately.

The sum of Na+K was not affected by K treatments. The sum averaged 1.28 meq/g. There was a significant effect of location in the field, the sum increasing down-field. In the individual treatment means, Na/K decreased from a relative value of 16.1 on the check treatment to about 2.0 with a combination of treatments at the heavier applications of K. The treatment main

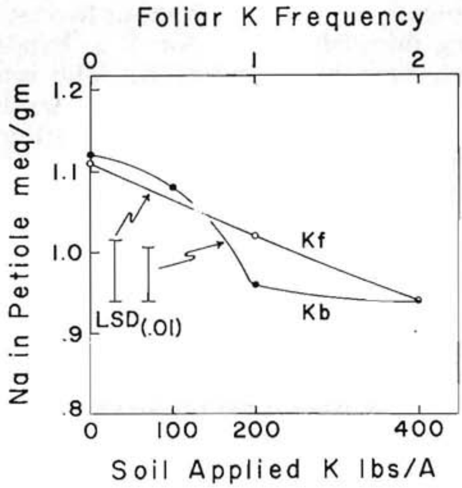

Figure 4.—Treatment main effects on Na in petioles of sugar beets at harvest time.

effects of Na/K are shown in Figure 5. The location effect on Na/K ratio in the plant followed the soil test ratio gradient in the field.

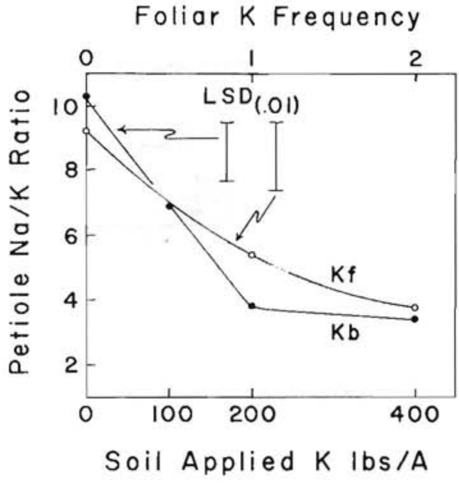

Figure 5.—Treatment main effects on Na/K ratio in petioles of sugar beets at harvest time.

Data on NO_3-N in petioles at harvest given in Figure 2 show that N was quite excessive, although the large supply of soil N was not indicated by the earlier petiole samples. Treatment effects on N content were not significant at harvest. But, whereas there is a strong decreasing trend for N as banded K goes up, no effect is seen from foliar-applied K. The replication effect on N content is significant; however, the N levels in the plant do not follow the same pattern as in the earlier sampling for either treatment effects or location effects.

Figure 6a shows treatment effects on sucrose content. Individual treatment combinations produced a range in sucrose from 12.7% to 14.0%. Foliar K treatments had no significant main effect but showed a weak positive trend. The main effect of banded K (means of f_0, f_1, f_2 in figure 6a) gave a significant difference in sucrose content, increasing from 13.0% at zero K to 13.6% with 200 lb K/A. There was a significant interaction between methods of K application on sucrose accumulation. This is shown in Figure 6a as increased percent sucrose with f_2 at zero banded K; while at 400 lb K/A banded, f_2 decreased percent

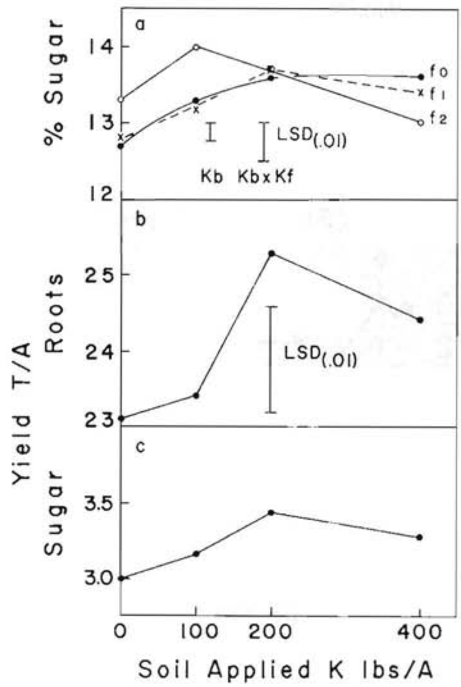

Figure 6.—a.—Relationship between sucrose content of sugar beet roots and soil and foliar-applied K. Data are plotted to show significant interaction between methods of application. *f* refers to frequency and 0, 1 and 2 refer to zero, 3 and 6 applications, respectively. Each foliar application consisted of 20 lbs. K per acre in about 60 gallons of water. b.—Treatment main effect of banded K on root yield. c.—Treatment main effect of banded K on total sucrose accumulation.

sucrose. The replication effects showed a decreasing but nonsignificant down-field trend in sucrose content. Statistical control of sucrose variability was better than for any other parameter measured (CV = 3%).

The amount of sucrose in the root was low. This is a direct result of the excessive N. The changes in sucrose content correlated (negatively) with the petiole nitrogen at the first sampling but there was very little association between N and sucrose in the harvest-time petiole samples.

There was a difference of 2.2 tons of roots per acre between the check treatment and 200 lb K/A (Figure 6b). There was no effect on root yield from foliar K nor was there any interaction between methods of K application.

The yield of sugar (Figure 6c) results from combining the data in Figures 6a and 6b. The main effects from banded K show a net increase of 0.44 tons sucrose per acre with the 200 lb K/A treatment. Yield of sucrose was not analyzed statistically but the increase of 0.44 tons per acre is assumed to be real since both percent sucrose and yield of roots were significant. The 0.44 ton gain in sucrose may have been offset by a decrease in root quality. It would depend on whether the increase in K in the thin juice would offset the lower N content.

Discussion

The positive relationship between fertilizer K and percent sucrose in the root confirms the previous observations in central Washington (Table 1). It would appear, however, in view of the association between N content and K fertilization, that increasing sucrose content may possibly be a secondary response to K and a direct response to the reduced N uptake. Sucrose accumulation is known to be very sensitive to excessive N in the plant. The soil-applied KCl seems to have affected N uptake, and the differential N uptake is negatively reflected in the level of sucrose in the roots. Previous experimentation here has also provided hints of such interlocking associations.[5] Overall, percent sucrose in the beets was low. This is obviously a result of the excessive N. It is of interest that the magnitude of increase in sucrose, as associated with K fertilization, is the same as in other experiments where N levels were more conducive to sucrose accumulation (Table 1).

In comparing both the banded K treatment effects and replication effects, percent sucrose followed N content of early sampled petioles fairly closely. In contrast, there was little relationship between N content and percent sucrose at harvest

[5] Unpublished data.

time. This is reasonable, since early petiole samples would provide a better measure of total N uptake by the plant than would samples taken at the season's end.

If the effect of soil-applied K on N uptake is real, it can probably be explained in terms of competition or antagonism in ion uptake by the roots. The fact that foliar-applied K had a considerable impact on both K and Na contents of the petiole, but not N content, supports this idea. The chloride ion naturally comes into consideration on this point, but the fact that there was no treatment difference in uptake of N between 200-K and 400-K confuses this thought. The null effect of foliar treatments on N uptake may have been due to delayed application.

The effects of band K and foliar K on Na and K content of petioles were additive. Therefore, the negative interaction between methods of K application on sucrose content of the roots may have been an artifact, especially in view of the fact that foliar K did not affect N content.

Reports of notable increases in root yield and percent sucrose from foliar-applied plant nutrients are quite common in European literature (e.g., Milica, 14). It is likely that soil fertility is quite limiting where these kinds of responses are obtained.

With regard to K nutrition per se, it appears that K levels in the plant at the zero fertilizer rate were limiting to maximum development of the crop. Using the criteria of Ulrich et al. (18) there must be more than 0.26 meq/g of K where Na exceeds 0.65 meq/g in the petiole. These numbers compare with 0.40 and 1.52 meq/g, respectively, for K and Na in the petioles from the zero-K plots for the first sampling. The results from the final petiole sampling are not considered to be too meaningful from the point of view of "critical" levels. It is apparent that K is absorbed from the soil against a much greater concentration gradient than is Na. Kaudy et al. (11), using nutrient solution culture techniques, observed the same relative differences between K and Na in the plant and the rooting medium.

From the results presented here it appears that K fertilization under arid and semi-arid conditions may have two distinctly different effects on beet sugar production. These are [1] limitation on uptake of N (and the concomitant effect on sucrose accumulation) and [2] stimulation of root growth where K is limiting.

The soil test K index is lower in many soil situations in central Washington than in the field represented here. It remains to be seen whether a combined soil test for K and Na can be made meaningful for sugar beets on these soils.

Summary

Various rates of K fertilizer were supplied to sugar beets in a field in Washington which tested low in available soil K. The K was supplied both as banded treatments following thinning and, later in the season, as foliar sprays. Results indicate that either method increased K in the plant and decreased Na. A significant decrease in NO_3-N in the petiole was associated with increasing rates of band-applied K. Percent sucrose at harvest was significantly increased by the banded K treatments, but the change in percent sucrose probably reflects the decrease in uptake of N. In addition, there seems to have been a root yield response to banded K. The combined effect of increased sucrose content and increased root yield gave a difference of 0.44 tons of sugar per acre between the check treatment and plots receiving 200 pounds of K per acre, as KCl banded after thinning. The lack of response to foliar-K may be attributed to the time of season it was applied.

Literature Cited

(1) ADAMS, S. N. 1961a. The effect of sodium and potassium on sugar beet on the Lincolnshire limestone soils. J. Agr. Sci. 56: 283-286.

(2) ADAMS, S. N. 1961b. The effect of sodium and potassium fertilizer on the mineral composition of sugar beet. J. Agr. Sci. 56: 383.

(3) BERGER, K. C. 1950. Sugar beet fertilization in Wisconsin. Proc. Am. Soc. of Sugar Beet Technol. 6: 440-444.

(4) COOK, R. L., and J. F. DAVIS. 1957. The residual effect of fertilizer. Advances in Agronomy 9: 205-216.

(5) DORPH-PETERSEN, K., and F. STEENBJERG. 1950. Investigations of the effect of fertilizers containing sodium. Plant and Soil 2: 282-300.

(6) DOXTATOR, 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.

(7) DUDLEY, JOHN W., and LEROY POWERS. 1960. Population genetic studies in Na and K in sugar beets. J. Am. Soc. Sugar Beet Technol. 11: 97-127.

(8) FINKNER, R. E., D. B. OGDEN, P. C. HANZES, and R. F. OLSON. 1958. II. The effect of fertilizer treatment on Ca, Na, K, raffinose, galactinol, nine amino acids, and total amino acid content of three varieties of sugar beets grown in the Red River Valley of Minnesota. J. Am. Soc. Sugar Beet Technol. 10: 272-280.

(9) HARMER, PAUL M., and ERWIN J. BENNE. 1945. Sodium as a crop nutrient. Soil Sci. 60: 137-148.

(10) HOLT, M. E., and N. J. VOLK. 1945. Sodium as a plant nutrient and substitute for potassium. J. Am. Soc. Agr. 37: 821-827.

(11) KAUDY, J. C., E. TRUOG, and K. C. BERGER. 1953. Relation of sodium uptake to that of potassium by the sugar beet. Agron. J. 45: 444-447.

(12) KRATZ, WILLIAM A., and JACK MYERS. 1955. Nutrition and growth of several blue-green algae. Am. J. Botany 42: 282-287.

(13) LEHR, J. J. 1942. The importance of sodium for plant nutrition: III. The equilibrium of cations in the beet. Soil Sci. 53: 399-411.

(14) MILICA, C. I. 1960. Contribution to the problem of supplementary extra-root nutrition of sugar beet. Soils and Fertilizers 23: 2326.

(15) OSTLE, BERNARD. 1954. Statistics in research. Iowa State College Press, Ames, Iowa.

(16) SHEPHERD, L. N., J. C. SHICKLUNA, and J. F. DAVIS. 1959. The sodium-potassium nutrition of sugar beets produced on organic soil. J. Am. Soc. Sugar Beet Technol. 10: 603-608.

(17) ULRICH, A., and F. J. HILLS. 1952. Petiole sampling of sugar beet fields in relation to their N, P, K and Na status. Proc. Am. Soc. Sugar Beet Technol. 7: 32-45.

(18) ULRICH, A., D. RIRIE, F. J. HILLS, ALAN G. GEORGE, M. D. MORSE. 1959. Plant analysis: a guide for sugar beet fertilization. Calif. Agr. Expt. Sta. Bull. 766.

(19) WOOD, R. R., H. L. BUSH, and R. K. OLDEMEYER. 1958. The sucrose-sodium relationship in selecting sugar beets. J. Am. Soc. Sugar Beet Technol. 10: 133-137.