Factors Affecting Chloride Uptake and Implications of the Chloride-Nitrate Antagonism in Sugarbeet Mineral Nutrition[1]

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Chloride has been identified as an essential plant nutrient element for sugarbeets and other plants (7,11).[3] Ulrich and Ohki (11) reported that Cl concentrations in sugarbeet petioles of 0.2 milliequivalents per gram (meq/g) were associated with healthy plants but that Cl concentrations approximating 0.005 meq/g were indicative of extreme Cl deficiency and growth retardation.

When Cl is readily available the amounts absorbed by plants greatly exceed the growth-limiting levels. Kretchmer *et al.* (9) state that increasing levels of Cl in the substrate resulted in linear increases in Cl content of 10 different plant species. This effect was independent of type of substrate or plant species. They reported dry-weight Cl concentrations up to about 1.2 meq/g of plant tissue.

Another aspect of Cl nutrition is that increasing levels of Cl in plants are associated with decreasing levels of NO_3-N and vice versa (1,2,6,9,10,12,13). Thus, there is an antagonism or negative interaction between these two ions in nutrient absorption.

These kinds of observations prompted an investigation into the role of Cl in central Washington-grown sugarbeets. Field experiments have been under way for several years which were not initially designed with the study of Cl in mind. Cl analyses proved to be very useful, however, in explaining some apparently anomalous results. In an earlier report (5), for example, it was shown that increasing rates of K fertilizer (as KCl) resulted in increasing levels of sucrose in the beet roots. Also, NO_3 in the petioles decreased with the K rates. The analytical results for petiole Cl (not reported earlier) are presented here in Figure 1. The results for K uptake are repeated for comparison. Figure 1 indicates that Cl concentration increased from below 0.2 meq/g to more than 1.2 meq/g. There is no indication in these results of an upper limit of Cl absorption. It is apparent also that K and Cl uptake are independent of each other.

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[3] Numbers in parentheses refer to literature cited.

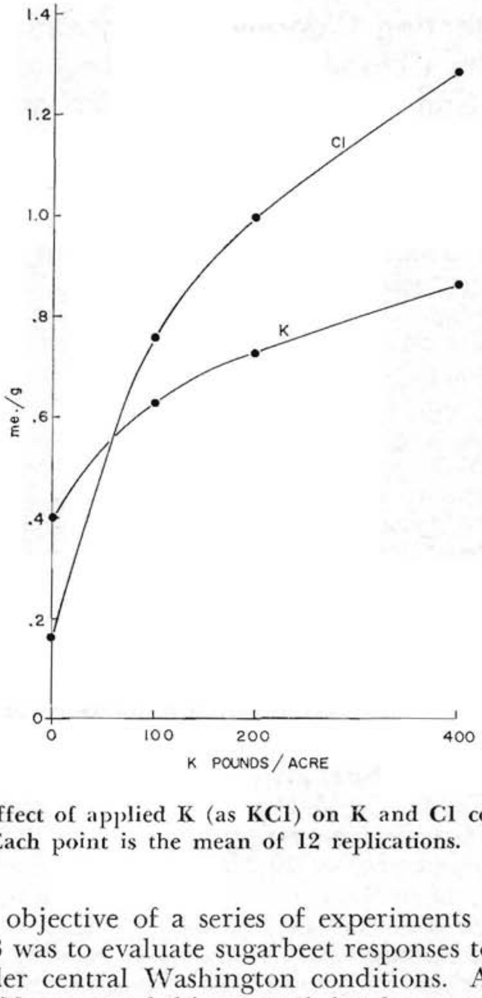

Figure 1.—Effect of applied K (as KCl) on K and Cl content of sugarbeet petioles. Each point is the mean of 12 replications. For further details see (5).

The basic objective of a series of experiments conducted in 1967 and 1968 was to evaluate sugarbeet responses to N, P and K fertilizers under central Washington conditions. A preliminary report on the N aspects of this research has been made (4). The purpose of this report is to present the results of Cl analyses from these experiments. Factors affecting Cl availability and the implications of the Cl-NO_3 interaction are discussed.

Procedure

Sugarbeets were studied at 40 different locations in 2 years. Data obtained included soil and petiole analyses and yield results. Experiments at 26 locations were carried to completion. Some information was recovered from several locations which were not carried to completion. Each experimental site consisted of approximately 1 acre in a larger commercial field of sugarbeets. Fields were selected which had not received any fertilizer since the beginning of the previous growing season. Before crop establishment, the soil was sampled according to a standard procedure which takes into account the wide horizontal and vertical variations in soluble soil constituents which commonly occur in irrigated soils (3). Each experimental area was separated into 0.034 acre size plots and fertilizer treatments were applied according to the schedule given in Table 1. Phosphate fertilizer was used where necessary so that P was not a limiting factor in the growth of beets. In most instances the fertilizer was applied broadcast-plowdown. In a few cases the fertilizer was applied as sidedress after thinning. The fertilizer treatments were organized in a randomized complete block design in four replications. Planting and all cultural practices were done by the grower-cooperator.

Table 1.—Treatment combinations of nitrogen, and potassium fertilizer.

Treatment No.	Element rate—pounds per acre[1]	
	N	K[2]
1	0	0
2	100	0
3	200	0
4	200	200

[1] The element forms were: N, ammonium nitrate, and K, muriate of potash.

[2] When the preliminary soil test indicated a probable K deficiency, treatments 1, 2 and 3 received K, and it was then omitted in treatment 4. Thus, treatment 4 was either a positive or negative check treatment, depending on the location.

The sampling and NO_3 analytical procedures for petioles have been described (5).

Cl was measured in distilled water extracts of soil and plant samples by an adaptation of the method given by Johnson and Ulrich (8). Petiole NO_3 and Cl are reported in terms of meq/g dry weight. Soil NO_3 and Cl are reported in terms of soil test indexes. Each index is the sum of the element ppm in all one-foot increments of soil through the zone sampled.

Results and Discussion

Petiole Cl *versus Soil Test* Cl

Petiole Cl concentrations from the zero-K treatment at the respective experiments are presented in Figure 2 as a function of soil test Cl. The results follow the same pattern for both years. In general, as soil test Cl goes up the Cl content of petiole goes up. The (o) data points are from an area that is irrigated by return-flow water. This water contains 18 ppm of Cl. Seasonal fluctuations in this Cl load are quite small. All other data points are from experiments that are irrigated with water directly from the Yakima and Columbia rivers. These waters have Cl concentrations of 2.0 and 0.6 ppm, respectively.

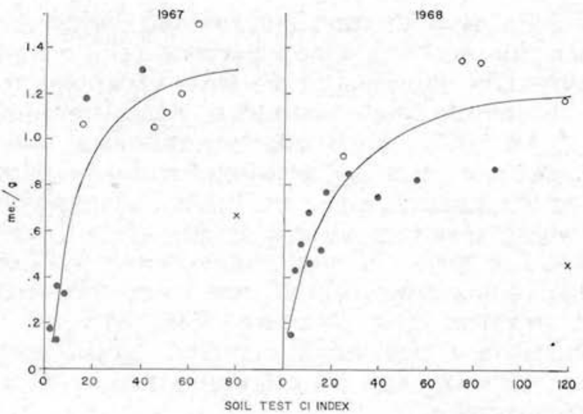

Figure 2.—The relationship between Cl concentration of sugarbeet petioles and the soil test Cl index is 2 years. Each point is the mean of four replications of treatment No. 1 from different experiments. See text for explanation of different symbols.

Some of the fields receiving low-Cl water have a history of KCl fertilization. A few fields have undergone some degree of salinization.

The (x) data points are from fields that had a high amount of residual fertilizer N. Estimations from soil analyses indicate that the 1967 high-N field contained 310 pounds of NO_3-N per acre in the rooting zone, and the 1968 high-N field contained 460 pounds per acre. (These conversions are based on an average soil bulk density value of 1.45.) The results from these two sites indicate the depression of Cl uptake by NO_3.

It is apparent from Figure 2 that water-soluble Cl in the soil is a good indicator of Cl availability. It is apparent also that Cl availability at a given site can be predicted only after considering irrigation water input and the background of residual NO_3. The latter point will become more evident with subsequent discussions.

A very pertinent question arises from Figures 1 and 2. This has to do with the likelihood of having Cl-deficient sugarbeets where both soil and water are very low in Cl content. This question is being pursued.

The Cl-NO_3 *Negative Interaction*

It has been shown that the soil test N index is a fair indicator of N availability for sugarbeets in central Washington (4). In light of this and the foregoing data on Cl uptake, the background on which the fertilizer treatments were superimposed should be considered in interpreting the treatment effects. Sugarbeet responses to the fertilizer treatments, in terms of petiole Cl and NO_3 concentrations, are given in Figures 3, 4 and 5 for seven selected sites. The soil test indexes for these sites are given in Table 2. The selections were made to show the different ways in which the Cl-NO_3 uptake interaction manifested itself.

Table 2.—Soil test indexes for NO_3-N and Cl[1] (background data for Figures 3, 4 and 5).

Soil test index	Figure 3*a*	3*b*	4*a*	4*b*	4*c*	5*a*	5*b*
N	36	69	8	26	13	13	78
Cl	62	17	6	29	2	50	80

[1] Soil test index is the sum of the element ppm in all one-foot increments sampled. Sampling depths varied from 14 to 72 inches, depending on the depth of the rooting zone. The limiting soil layer was caliche.

Figure 3 shows two sets of results where 200 pounds of K per acre were applied with treatments 1, 2 and 3 (Table 1). The K rate was omitted with treatment 4. In Figure 3, as the N rate goes up the petiole NO_3 goes up and petiole Cl goes down. With treatment 4, Cl content drops and NO_3 increases. Note that without added KCl, there is more petiole Cl than NO_3 in Figure 3*a* and less Cl than NO_3 in Figure 3*b*. This shift is in agreement with the soil test indexes, Table 2.

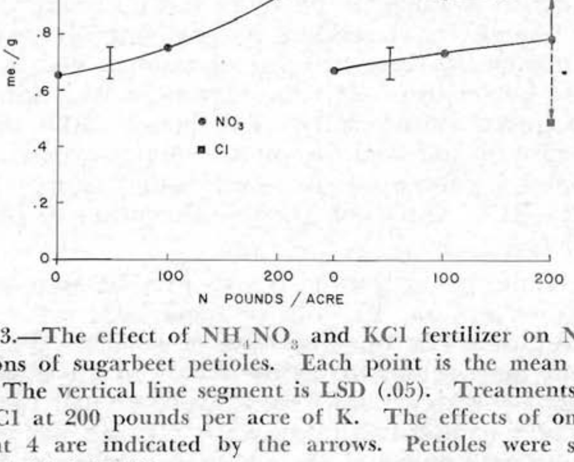

Figure 3.—The effect of NH_4NO_3 and KCl fertilizer on NO_3 and Cl concentrations of sugarbeet petioles. Each point is the mean of four replications. The vertical line segment is LSD (.05). Treatments 1, 2 and 3 included KCl at 200 pounds per acre of K. The effects of omitting KCl at treatment 4 are indicated by the arrows. Petioles were sampled (a) 6/22/67 and (b) 6/28/67.

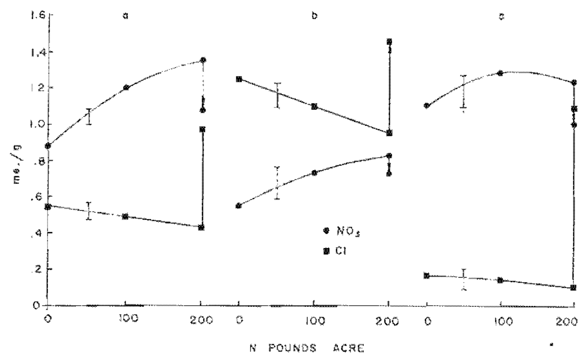

Figure 4.—Effect of NH_4NO_3 and KCl fertilizer on NO_3 and Cl concentrations in sugarbeet petioles. KCl fertilizer was introduced only with treatment 4. Petioles were sampled (a) 6/18/68, (b) 6/21/68, and (c) 6/4/68.

In Figure 4 results are shown for three sites where KCl was introduced only with treatment 4. At each site as the N fertilizer rate increased petiole NO_3 increased and with treatment 4 petiole NO_3 decreased. Petiole Cl decreased regularly with N rates in Figures 4*a* and *b* and increased upon addition of KCl. The level of soil Cl at the site represented by Figure 4*c* was apparently too low for the N rate to have much effect on Cl uptake. When KCl was added, however, there was a very large effect on petiole Cl. Again, the variation in soil test Cl is reflected in the results of Figure 4 by the relative position of the three Cl response curves.

At the site represented by Figure 5*a* there was a large petiole NO_3 response to N rates. In 5*b* there was no response to the N fertilizer. The effects of residual N (soil test 13 versus 78) are especially notable in these two sets of results. Petiole NO_3 was not affected by fertilizer KCl in Figure 5*a*; this kind of null response occurred infrequently. The petiole NO_3 response to KCl in Figure 5*b* followed the more common pattern. In both Figure 5*a* and *b* petiole Cl decreased with fertilizer N and increased with KCl. Only one possible exception to this pattern has been noted.

Another kind of contrast in results may be seen by comparing Figures 4*c* and 5*a*. In both of these cases soil test N was identical and low. The two experiments were in different years, but the shift in positions of petiole NO_3 and Cl is evidence of the different between Cl soil tests: Figure 4*c* had very low soil Cl background (coupled with low water Cl content); and Figure 5*a* had a relatively high soil Cl (as a result of water-borne Cl).

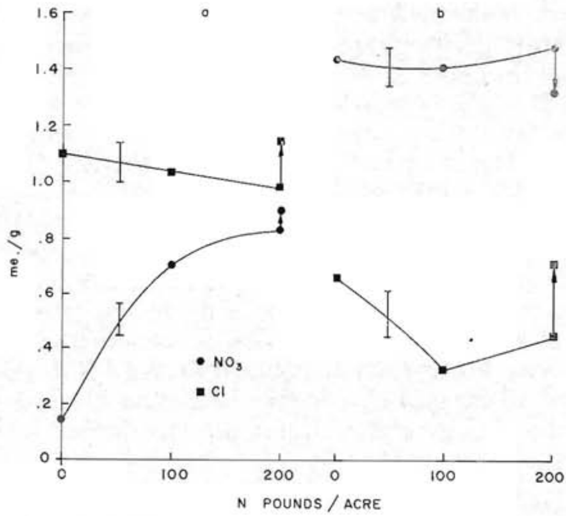

Figure 5.—Effects of NH_4NO_3 and KCl fertilizer on NO_3 and Cl concentrations of sugarbeet petioles. KCl was introduced only with treatment 5. Petioles were sampled (a) 6/22/67 and (b) 6/20/67.

The Cl-NO_3 negative interaction in plant nutrition has been investigated under solution or sand culture conditions (1,2,9, 10,12,13). From the results presented here it appears that the antagonism clearly manifests itself under field conditions too. It is apparent also that this phenomenon has important implications in assessing either soil test N as an index of N availability or petiole NO_3 as an indicator of the N nutritional status of the plant. From all the results taken from these experiments, for example, as a first approximation, optimum N fertilizer rates will be 50 pounds per acre higher in the areas irrigated with 18 ppm Cl waters compared to the areas receiving low-Cl waters.

Root Yield and Sucrose Responses

It is not the main purpose of this report to elaborate on the overall crop performance in this series of experiments. It is well to point out in passing, however, that there was one site where there was a possibility of a direct response to K *per se* as judged by petiole K and Na levels and root yields. In addition there were six sites that had a root yield response to 100 pounds of N per acre. (Among the sites represented by the figures there were significant responses to N in 4*a*, 4*c* and 5*a*.) In all cases there was a reduction in sucrose percent with added N fertilizer. The negative response of sucrose percent to increased N availability was quite sensitive.

Of direct concern here is the effect of the Cl-NO_3 interaction on crop performance. In this respect, there was no detectable effect on root growth. There was, however, some effect on sucrose. It was pointed out previously (5) that positive sucrose responses to KCl fertilization have been noted quite frequently in this area. The increases ranged up to about 0.8%, generally averaging around 0.4%. Similar kinds of responses were observed in the 1967-68 experiments. These are summarized in Table 3. The criteria for judging the KCl effect was a difference of 0.2% sucrose between treatments 3 and 5 at each site. (The relative experimental error for sucrose percent is typically lower than for other plant nutrition and growth parameters. Differences of 0.2% sucrose are usually significant at the 1% level.) On this basis 54% of all experiments had a significant increase in sucrose, with 38% showing no effect. Eight percent showed a signficantly lower level of sucrose.

Table 3.—Changes in sucrose percent associated with additions of KCl fertilizer: A frequency distribution.

Type of response	No. of sites	Percent in category
Null	10	38
0.2% or greater increase	14	54
0.2% decrease	2	8
	—	—
Total	26	100

The nature of the sucrose response to KCl fertilizer was not readily predicted by soil test or by tissue analyses. Nevertheless, when there was a positive sucrose response to KCl fertilization, the most logical explanation is that the sugarbeet is responding to reduced NO_3 uptake. In other words, the change in sucrose is an indirect response to the Cl-containing fertilizer. Many of the other factors that affect sucrose accumulation can be related to N. For example, sugarbeets under furrow irrigation typically show a reduction in sucrose after a rainstorm which was preceded by a prolonged period of no precipitation. In this instance, NO_3-N has been washed from its position of isolation in the dry surface soil into the active root zone. On the other hand, the crop responds with increased content of sucrose to excessive irrigation as a result of N leaching. Thus, several unrelated variables could cancel the apparent effect of KCl on sucrose accumulation.

The foregoing interpretation of the plant Cl-sucrose relationships assumes that there are no direct connections between K uptake and sucrose accumulation beyond the point where K content is non-limiting to normal metabolism. In the examples given, the experimental design does not allow for a clear-cut separation of the effects of K and Cl. But increases in percent sucrose between treatments 3 and 4 (N_{200} versus N_{200} K_{200}) occurred when K in the petiole ranged from .55 and 2.14 meg/g. These numbers are well above the tissue-K levels associated with K deficiency (5).

Summary and Conclusions

Experiments involving N and K fertilizers were conducted in commercial sugarbeet fields in 1967 and 1968. These experiments were not designed initially with Cl nutrition in mind but analyses of soils, irrigation waters, and plant materials were made in an attempt to exp.ain some apparently anomalous results.

The investigations on Cl indicate that Cl is readily absorbed by sugarbeets. Uptake of Cl is essentially a exponential function of the amount of water-soluble Cl in the soil. Cl in the plant was also related to the load of Cl in irrigation water. The data indicate that certain areas of central Washington have very low Cl concentrations in both soil and water. This raises a question on the possibility of Cl-deficient sugarbeets in the area.

Results from fertilization with NH_4NO_3 and KCl confirm the well-documented antagonism in plant uptake of NO_3 and Cl. The way in which the antagonism expresses itself can be related to the background concentrations of NO_3 and Cl in the soil. The evidence points up the necessity of analyzing soils and plants for both Cl and NO_3 in order to properly evaluate soil N availability and the N nutritional status of the plant.

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