CHLORIDE AND SULFUR NEEDS IN SUGAR BEET PRODUCTION

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In 2012, sugar beet canopies in parts of the Red River Valley (RRV) quickly turned yellow in the middle of the growing season. In most cases, the affected fields were well fertilized with nitrogen (N) and weather conditions the previous winter and spring would not raise suspicion of N loss through denitrification or leaching. Several of the fields near Warren, Minnesota expressed such symptoms. Soil and plant analysis of the affected and unaffected areas within a field suggested a deficiency of chloride (Cl) and to a lesser extent, sulfur (S). Strips within the affected fields were fertilized with sources of Cl and SO_4-S by Scott Edgar, crop consultant with North Star Ag Services who first identified the symptoms, showed a distinct canopy greening.

Fields showing the symptoms tended to be finer textured soils with organic matter in the 5% + range. In these soils, the soil test for S has very little predictive values in terms of predicting the crop response to the application of sulfate sulfur (SO_4-S) fertilizer. Chloride soil tests are seldom done on these soils. It is apparent that an evaluation of Cl and S fertilization of sugar beet is needed, especially in the northern half of the RRV. It is also apparent that a geographic area has been identified where there is a possibility of a crop response to the application of these nutrients.

Both Cl^- and SO_4-S are highly water soluble and can easily move within the soil water and underground water table. 2012 was a dry year compared to the previous 17 years though the area where symptoms have occurred had sufficient rainfall in 2012. Many anecdotal testimonies have indicated the water table has dropped substantially compared to what it might have been a couple of years ago. If this is the case, then perhaps the Cl^- and SO_4-S moved deeper into the soil profile. In addition, there may also have been dry zones within the soil profile. Both of these factors may have affected sugar beet root access to either Cl^- or SO_4-S. A second factor is the exceptionally high yields of all crops in the cropping system in recent years. These soils usually test sufficient for potassium (K) so KCl fertilizer is seldom applied. KCl, where it is used, is an excellent source of Cl^- . Have production levels reached a point where the natural ability of the soil to supply Cl^- or SO_4-S is insufficient to meet crop needs? Has the dryer weather conditions experienced in 2012 compared to previous years exacerbated the insufficiencies? Both Cl^- and SO_4^- are anions and as such compete with nitrate nitrogen (NO_3^-), which is also an anion, for uptake by the plants. James et al. (1970) found that Cl concentration in recently matured sugar beet petioles increased as soil Cl content increased. However, they also found that as N fertilizer rate increased the NO_3 concentration in the recently matured sugar beet petioles increased and Cl concentration decreased. The addition of KCl fertilizer with the higher rates of N fertilizer increased petiole Cl and decreased petiole NO_3 concentrations. This was a clear illustration of the antagonistic effects of NO_3 and Cl uptake. Many of the fields where Cl deficiencies occurred in the RRV in 2012 had been heavily fertilized with nitrogen. Moraghan (1987) also found sugar beet canopy Cl concentration decreased with increasing N fertilizer but, the total Cl uptake increased as a result of greater biomass production associated with increasing N rates. The vast majority of the Cl accumulation, greater than 80%, is in the sugar beet canopy and not the roots indicating that the Cl is not removed from the field at harvest, but is returned to the soil when the beets are detopped at harvest (Moraghan and Ananth, 1985).

Two major questions arise about the Cl deficiency symptoms observed in 2011 and to a much greater extent in 2012. As growers increase N fertilizer rates to meet the presumed need for additional N to sustain crop yields, are they inadvertently causing the Cl deficiencies? Are the symptoms showing up on soils that are naturally low in residual Cl? Can the Cl deficiencies be corrected with the addition of Cl fertilizer given the high rates of N fertilization? Sulfur deficiencies are also suspected on some of the sugar beet fields in the geographic area where Cl deficiencies are suspected. Predicting the need to apply S fertilizer is difficult on these soils because of finer soil texture and relatively high organic matter. Early research suggested these soils mineralized sufficient organic S to meet crop needs (Moraghan, 1969; Steward and Whitfield, 1965). In addition, many soils in the RRV contain gypsum, which also supplies SO_4-S to a crop (Moraghan, 1969). Twenty years later Lamb (1989) found no sugar beet response to S fertilizer even though the soil test SO_4-S levels were very low. One concern with Lamb's study was that he used elemental S, which requires time to convert to SO_4-S before it can be absorbed by the plant. Would the results have been different had a more readily available S source been used?

Sulfur deficiencies in sugar beet are usually a yellowing of the leaf canopy. Sulfur deficiency in sugar beet results in a decrease of CO_2 uptake and assimilation (Terry, 1976). As sulfur decreases below a critical level, chlorophyll content decreases which in turn decreases photosynthesis. Quoted sulfur content considered sufficient is 250 ppm in the most recently mature sugar beet leaf blade (Terry, 1976; Moraghan, 1969; Humbert and Ulrich, 1967). Humbert and Ulrich (1967) reported visual S deficiencies appeared when the sugar beet leaf blade S concentration was between 50 and 200 ppm. Moraghan (1969) found that leaf blade S tended to increase as the growing season progressed while the petiole NO_3-N decreased. This may suggest the mineralization of soil S as the growing season progresses. The importance of S as a nutrient in sugar beet production is not in dispute. But, considering the difficulty in predicting the need for S fertilizer using a soil test in most RRV soils, simple S experiments to see if the crop is responding is probably the only real practical approach. Why would we expect a different response than what Lamb (1989) or Moraghan (1969) found? Again, is it possible that production levels today compared to then have increased to the point the soils natural ability to supply S is insufficient?

MATERIALS AND METHODS

Working with Ryan Johnson, American Crystal Agriculturalist, 23 fields were selected in the fall of 2012 that were to planted to sugar beet in 2013. Within each field, a point was selected where three 4 ft soil cores were taken and composited by depth. The location within the field was identified with GPS coordinates. The soil cores were divided into 0-1, 1-2 and 2-4 ft depth increments and analyzed for Cl by both the NWROC soils analytical laboratory and Agvise Laboratory. During late July of 2013, leaf petioles from the most recently fully expanded leaf were collected from about 12 plants from the same geographic location the soil cores were taken. These petioles were analyzed for Cl and nitrate-N in the NWROC soils analytical laboratory. In the second week of September, 12 ft of row were harvested from the same geographic location as the soil cores and petioles were collected. Sugar beets were hand dug and separated into root and tops. Tops were weighted, chopped, and a subsample was taken back to the NWROC laboratory for drying and later analysis of Cl and N. The roots were taken back to NWROC laboratories and processed. The processing consisted of washing the roots and selecting 10 representative roots to be sent to American Crystal Quality Lab for sugar and quality measurements. The rest of the roots were split into halve. One halve from each root was sampled by pushing the entire cut face against an industrial sized cheese grater. The grated root was dried and later analyzed for Cl and N.

Of the 23 original fields selected, 5 did not have sugar beets grown on them in 2013 and were discarded. Two fields were selected to host a replicated field trial that tested various rates of Cl and S.

These sites were selected to host the replicated trials because they offered a reasonably uniform land area sufficient to host the trial. One field was located just south of Stephen, Minnesota and is referred to as the East Site. The second field was located about 10 north and 2 miles east of Oslo, Minnesota and is referred to as the West Site. The East site was on a Fargo sic soil (Fine, smectitic, frigid, typic epiaquert) and the West Site was on a Colvin-Fargo complex (Colvin: fine-silty, mixed, superactive, frigid, typic Calciaquoll).

At each of the two fields, trials with a 3 by 3 factorial treatment design were established in a randomized complete block experimental design with four blocks or replications. The factorial treatments were three rates of Cl (0, 40, and 80 lbs. Ac^{-1}) and three rates of S (0,25, and 50 lbs. Ac^{-1}) for a total of nine treatments. Cl was supplied as potassium chloride (KCl) and S was supplied as dipotassium sulfate (K_2SO_4) and were broadcast and incorporated prior to planting sugar beet in the spring of 2013. Sixty pounds of P_2O_5 as 0-46-0 and about 150 lbs. N at the West Site and 120 lbs. N at the East site as urea were also broadcast and incorporated prior to planting. Sugar beet, Crystal 885 RR, was planted on May 6 at a seeding rate of 240 seed per 100 ft of row. Each plot was 6 rows wide (22 inch rows) and 30 ft long. Three gallons of 10-34-0 was applied in the seed furrow at planting. Herbicides and fungicides were applied as needed to control weeds, Rhizoctonia root rot, and Cercospora leaf spot.

In mid-July and again in mid-August, twelve petiole and leaf blades were collected from rows 3 and 4 of each plot. Every attempt was made to collect petiole and leaf blades from the most recently fully expanded leaf in the selected plant. Petiole and leaf blades were separated and placed in a cooler for transport back to the NWROC laboratory. Both were frozen then later heat dried and ground to a fine powder. The leaf blade was analyzed for sulfur and the petiole was analyzed for chloride.

In the second week of September, six ft from each of rows 3 and 4 of each plot were hand dug and processed as described above. In the third week of September, the remaining beets in rows 3 and 4 were mechanically harvested. Beets were weighed and 10 randomly selected beets were sent to the American Crystal Quality Laboratory for sugar and quality analysis.

Statistical analysis was performed on all measured variables using Proc Mixed in SAS 9.2 and a model that reflected the 3 by 3 factorial RCB design. Contrasts were used to analyze effects of Cl and S rates on the measured variables.

RESULTS

The two field sites that hosted the replicated trials were situated about 10 miles apart. The East site was about half a mile west of U.S. Hwy 75 and 2 miles south of Stephen, Minnesota. The West site was about 2 miles south of Marshall County Hwy 4 and 2 miles east of Minnesota Hwy 220. They could be considered to represent the eastern side and western sides of the sampling range that occurred in the fall 2012. Sulfur soil tests were not determined at either site as the soil organic matter is sufficiently high that the test is not predictive enough to be useful. The chloride soil test was done at both locations and there was a substantial difference between the two sites. Chloride soil tests were conducted in both the NWROC soils analytical laboratory and Agvise Laboratories. Both labs agreed quite closely on the West site. The two labs did vary in the East site results, but both labs indicated the East site had substantial Cl in the surface 2 ft of the soil profile and even more in the 2 to 4 ft soil depths. The West site had substantially lower amounts of soil Cl than the East site, but the West site was not necessarily sufficiently low to be listed as Cl deficient. The difference between the two sites was several fold regardless of whether NWROC or Agvise lab analyses was used.

Throughout the growing season visual observations of the two sites suggested the East site's sugar beets might look better than the West site's. At the West site, at no time during the growing season could differences among the treatments be visually distinguished. But at the East site, the highest rate of Cl fertilizer was visually discernable in seven of the nine high Cl rate plots. The high Cl rate plots appeared to have sugar beet canopies that were taller and perhaps more full than lower Cl rate plots. These were visual observations that were subtle enough that it was difficult to see these differences in photographs.

<u>Chloride Concentration and Content:</u>

Petiole Cl concentration was very responsive to Chloride fertilizer rates at both sites (Table 1 and 2). As Cl fertilizer rate increased, petiole Cl increased (Fig 1). There was also a substantial difference in petiole Cl concentration between the two sites. The East site petiole Cl concentrations were considerably greater than those at the West site. This was probably due to the East site having substantially greater soil Cl than the West site. Ulrich et al. (1993) reported that petioles from leaves showing Cl deficiency symptoms can have Cl concentrations lower than 400 ppm. None of the petioles sampled in this trial at either site had petiole Cl concentrations lower than 5000 ppm. Ulrich et al, (1993) also reported that normal looking sugar beet plants could have petiole Cl levels as high as 85,000 ppm. Petioles from the East site approached the 40,000 ppm Cl levels when 80 lbs. Cl Ac^{-1} was applied in the fertilizer.

During the second week of September, hand dug sugar beet samples were analyzed for total Cl accumulated in the sugar beet plant. As with petiole Cl concentrations, Cl content in the roots and tops was significantly responsive to Cl fertilizer rates at both sites (Table 1 and 2). As the Cl fertilizer rate increased so did the Cl content in both roots and tops (Fig 2). The vast majority of the Cl in the plant is in the tops. There was actually very little difference in root Cl content between the two sites, but there was a large difference in Cl content of the tops (Fig 2). As with petiole Cl, high Cl content at the East site was probably caused by greater soil Cl levels.

Sulfur Concentrations:

Leaf blade sulfur concentrations were responsive to the sulfur fertilizer rates applied at both sites (Table 1 and 2). As sulfur fertilizer rates increased, leaf blade sulfur also increased with some degree of variation (Fig 3). At the East site, leaf blade S increased from 0 to 25 lbs. S Ac^{-1}. There was very little increase with additional to the 50 lbs. S Ac^{-1} rate. At the West site, leaf blade S increased throughout the S fertilizer range, but only in the August sampling. There was little difference among S rate treatments in the July sampling. Ulrich et al. (1993) reported that total sulfate- S concentration in leaf blades below 750 ppm is considered deficient. None of the leaf blades sampled at either site or in either July or August was below 1000 ppm S

It appears the accumulation of Cl, and to a lesser extent S, in the green biomass of sugar beet plants is dependent on the availability of the nutrient whether supplied via fertilizer or naturally in the soil. None of the petiole or leaf blade Cl and S concentrations would suggest the sugar beet crop was deficient at either site though there was a great difference between the two sites in soil Cl. Total biomass production, whether in the roots or the tops, was not affected by Cl or S applications. In addition, there was little difference in tops and root biomass between the two sites. It is not certain what caused the visual appearance of Cl response at the East site. It is possible the increased Cl concentration in the tops may have altered the moisture content of the tops and caused the high Cl treatment to have a more upright and erect leaf structure that would give the appearance of a taller canopy.

Final Harvest:

There was no effect of either Cl or S treatments on the harvested root yield, sucrose yield or any of the sugar beet root quality parameters at the East site (Table 3). At the West site, there was not root yield response to Cl and S treatments, but there appears to be a slight response of sucrose yield to increasing Cl fertilizer rates (Table 4). This response was barely significant at the 0.05 rate. Neither the sugar concentration nor the LTM concentration was significantly affected by Cl rates.

Survey Results:

There was a wide range of Cl soil test values across the sampling area that covered a zone from north of Argyle to Stephen, Minnesota starting on the east side of U.S. Hwy 75 and running west 2 to5 miles either side of Marshall Hwy 4 to Minnesota Hwy 220. Soil test Cl ranged from several thousand pounds per acre to just a few pounds per acre in the surface two feet of the soil profile. A similar trend occurred when the two to four ft soil depth was added. Most of the very high soil test Cl was on the east side of the sampling zone and was less to the west (Fig 4).

Of the original 23 sites sampled in fall 2012, only 17 were sampled during the growing season of 2013. Two of the sites not sampled hosted the replicated trials described above. Five of the sites were not planted to sugar beets in 2013.

Petioles sampled from the 17 field sites in mid-July had Cl concentrations ranging from 5000+ ppm to over 30,000 ppm. Like the replicated trials, as the soil test Cl increased so did petiole Cl concentration upto a certain soil test Cl range, which was nearly 1000 lbs. Cl Ac^{-1}. Below that soil test level, there was a large range in petiole Cl concentration. Where soil tests were greater than 1000 lbs. Cl there was little variation in petiole Cl. There was no evidence that any of the sampled sites were deficient in Cl even though there was a great range in soil test Cl. Whole plants sampled in the second week of September indicated there was little root yield or sucrose yield that could be attributed to the variation in soil test Cl.

The survey portion of this trial did not reveal any clear correlation between soil test Cl and sugar beet production. However, 17 sampling points is too few sampling points to establish such a correlation. But, there was not sufficient evidence to suggest we should pursue this further at this point. We are also not sure whether some of the growers may have fertilized with Cl prior to planting sugar beets, but after we soil sampled. That information is being sought at the moment.

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Table 1. Statistical analysis East Site hand sampled variables in the second week of September and petiole and leaf blade samples collected in July and August.

	------------ Measured Variables§ -----------										
Source§§	TopDM	RtDM	NetSuc	Sugar	LTM	JulPetCl	AugPetCl	JulLfS	AugLfS	RtCl	TopCl
	------------ Significance Level§§§ -----------										
Cl rate	ns	ns	ns	ns	ns	***	**	ns	ns	*	***
Lin	ns	ns	ns	ns	ns	***	**	ns	ns	**	***
Quad	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sulfur rate	ns	ns	ns	ns	ns	ns	ns	***	***	ns	ns
Lin	ns	ns	ns	ns	ns	ns	ns	***	***	ns	ns
Quad	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cl*S	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

§ TopDM, RtDM represent tops and root dry matter when hand sampled, NetSuc, Sugar, LTM represent concentrations of sugar quality parameters from American Crystal Quality Lab; JulPetCl and AugPetCl represent petiole Cl concentration at the July and August sampling; JulLfS and AugLfS represent leaf blade S at the July and August sampling, RtCl and TopCl represent Cl content in both roots and tops when hand sampled.

§§ Lin and Quad represent linear and quadratic regression analysis over Chloride rates and Sulfur rates

§§§ ***, **, *, and ns represent significance at 0.001, 0.01, and 0.05 levels and non-significant, respectively.

Table 2. Statistical analysis West Site hand sampled variables in the second week of September and petiole and leaf blade samples collected in July and August.

	------------ Measured Variables§ -----------										
Source§§	TopDM	RtDM	NetSuc	Sugar	LTM	JulPetCl	AugPetCl	JulLfS	AugLfS	RtCl	TopCl
	------------ Significance Level§§§ -----------										
Cl rate	ns	ns	*	*	*	***	***	ns	ns	***	***
Lin	ns	ns	**	**	**	***	***	ns	ns	***	***
Quad	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sulfur rate	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Lin	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quad	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
Cl*S	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

§ TopDM, RtDM represent tops and root dry matter when hand sampled, NetSuc, Sugar, LTM represent concentrations of sugar quality parameters from American Crystal Quality Lab; JulPetCl and AugPetCl represent petiole Cl concentration at the July and August sampling; JulLfS and AugLfS represent leaf blade S at the July and August sampling, RtCl and TopCl represent Cl content in both roots and tops when hand sampled.

§§ Lin and Quad represent linear and quadratic regression analysis over Chloride rates and Sulfur rates

§§§ ***, **, *, and ns represent significance at 0.001, 0.01, and 0.05 levels and non-significant, respectively.

Table 3. Statistical analysis of harvest variables at the East Site.

	------------ Measured Variables[§] -----------				
Source[§§]	RtYld	SucYld	Sugar	LTM	NetSuc
	------------ Significance Level[§§§] -----------				
Cl rates	ns	ns	ns	ns	ns
Lin	ns	ns	ns	ns	ns
Quad	ns	ns	ns	ns	ns
Sulfur rates	ns	ns	ns	ns	ns
Lin	ns	ns	ns	ns	ns
Quad	ns	ns	ns	ns	ns
Cl*S	ns	ns	ns	ns	ns

§ Rtyld, SucYld, Sugar, LTM, and NetSuc represent root yield, sucrose yield, sugar concentration, sugar loss to molasses concentration, and net sucrose concentration, respectively.

§§ Lin and Quad represent linear and quadratic regression analysis over Chloride rates and Sulfur rates

§§§ ***, **, *, and ns represent significance at 0.001, 0.01, and 0.05 levels and non-significant, respectively.

Table 4. Statistical analysis of harvest variables at the West Site.

	------------ Measured Variables[§] -----------				
Source[§§]	RtYld	SucYld	Sugar	LTM	NetSuc
	------------ Significance Level[§§§] -----------				
Cl rates	ns	ns	ns	ns	ns
Lin	ns	*	ns	ns	ns
Quad	ns	ns	ns	ns	ns
Sulfur rates	ns	ns	ns	ns	ns
Lin	ns	ns	ns	ns	ns
Quad	ns	ns	ns	ns	ns
Cl*S	ns	ns	ns	ns	ns

§ Rtyld, SucYld, Sugar, LTM, and NetSuc represent root yield, sucrose yield, sugar concentration, sugar loss to molasses concentration, and net sucrose concentration, respectively.

§§ Lin and Quad represent linear and quadratic regression analysis over Chloride rates and Sulfur rates

§§§ ***, **, *, and ns represent significance at 0.001, 0.01, and 0.05 levels and non-significant, respectively.

Table 5. Harvest yields and quality parameters at two experiment sites (East or West) in response to Chloride fertilizer rates averaged over all Sulfur fertilizer rates and in response to Sulfur fertilizer rates averaged over all Chloride fertilizer rates.

Treatment	Root Yld		Sucrose Yld		Net Sucrose		LTM	
	Tons Ac^{-1}		lbs. Ac^{-1}		%		%	
Cl rate	East	West	East	West	East	West	East	West
0	32.0	31.7	9100	8345	14.2	13.2	1.64	1.69
40	31.5	31.9	9245	8614	14.7	13.5	1.60	1.68
80	31.5	31.9	9201	8793	14.6	13.8	1.61	1.63
S rate								
0	31.7	31.5	9184	8505	14.5	13.5	1.58	1.66
25	31.7	32.0	9069	8524	14.3	13.3	1.65	1.71
50	31.5	32.1	9293	8723	14.7	13.6	1.62	1.63

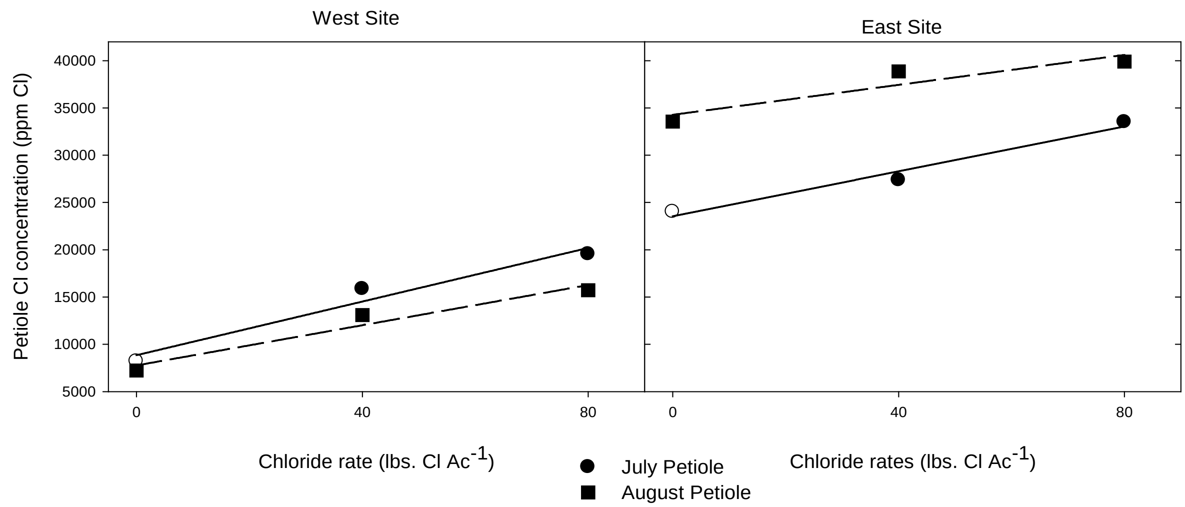

Figure 1. Petiole Chloride concentration response to increasing Chloride fertilizer rates at two sampling dates and two experimental sites.

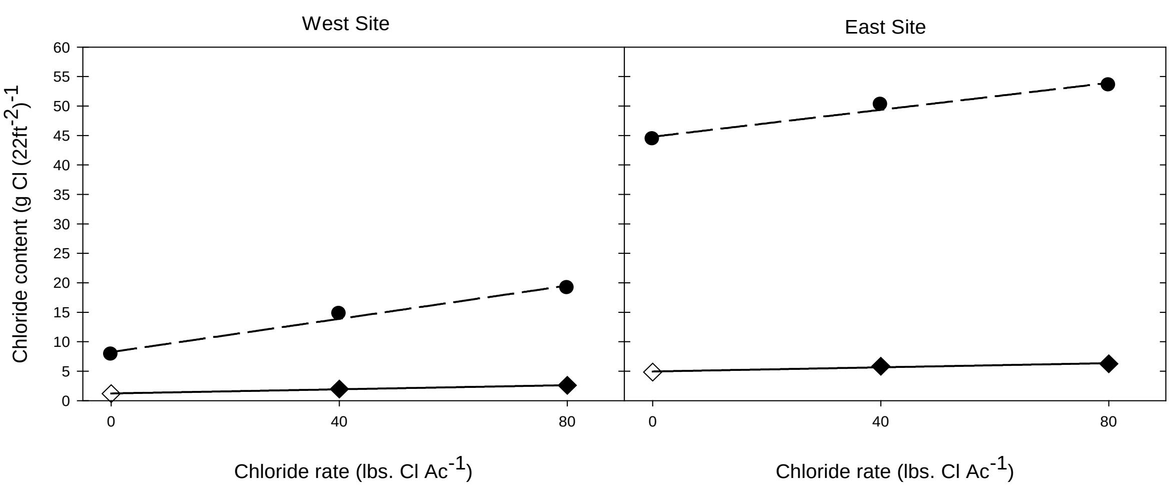

Figure 2. Total Chloride accumulation in sugar beet roots and tops in response to increasing Chloride fertilizer rates at two experimental sites.

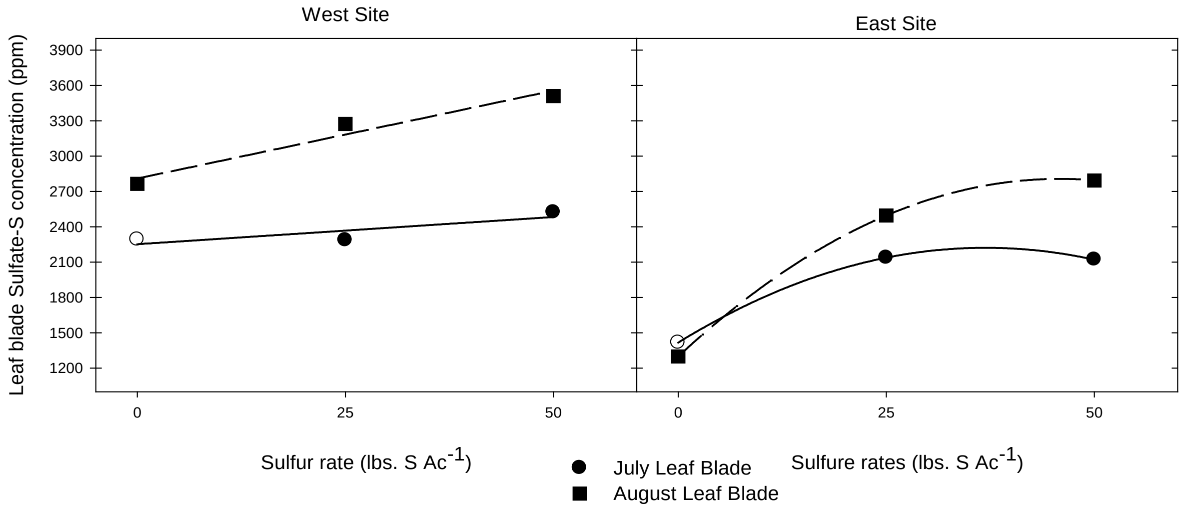

Figure 3. Leaf blade Sulfur concentration response to increasing Sulfur fertilizer rates at two sampling dates and two experimental sites.

Figure 4. Soil test Cl in the 0-2 ft soil depth at 23 sites. Values are lbs. Cl Ac^{-1}. The two communities shown along U.S. Hwy 75 (dark line along the right side) are Argyle and Stephen, Minnesota. North is to the top of the page.