VARIATION IN PLANT TISSUE CONCENTRATION AMONG SUGARBEET VARIETIES

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Justification: Plant tissue analysis has increasingly been used for crops as a tool to fine tune nutrient management. Plant analysis was developed as a diagnostic tool and is generally not been used to determine nutrients to apply. For sulfur, analysis of sulfur in plant tissue is commonly determined using inductively coupled plasma emission spectroscopy (ICP) even though older data that is typically used to develop sufficiency ranges may have been determined by dry combustion. Recent work in Minnesota on corn and soybean has found differences in the assessment of sulfur concentration by ICP versus combustion. Comparison of methods of analysis for sulfur for additional crops such as sugarbeet would help to determine the accuracy of ICP and where additional research in correlation of plant tissue tests to crop yield should be conducted. If differences in the methods can be documented, it would indicate that sugarbeet growers should exercise extreme caution when interpreting plant tissue results for sulfur.

Plant tissue analysis has resulted in more recent questions on boron application than other micro-nutrients. Reports that list boron as being low typically suggest a foliar application of boron containing fertilizer sources. However, there is no documented evidence that tissue sufficiency ranges currently used are accurate and that when a low tissue boron concentration is reported that application will increase crop yield. Comparisons of yield response to tissue concentration are needed to provide evidence that a sufficiency range actually has meaning when deciding if fertilizer should be applied.

Recent surveys of corn, soybean, and hard red spring wheat plant tissue has shown significant variation in nutrient concentration when multiple hybrids/varieties are sampled in the same field at the same time. If taken at face value, tissue nutrient concentration should be reflective of soil nutrient status. Past research on corn, soybean, and wheat showed a significant portion of the variation in nutrient concentration was due to growth stage differences among hybrids/varieties at sampling. What needs to be addressed for sugarbeet if the degree of variation in tissue nutrient concentration in petioles and leaf blades for varieties grown at multiple locations and years and whether plant tissue analysis can be related to root or sugar yield. If there is significant variation in concentration that is reflective of genetics and not of yield potential, there should be a significant degree of caution when interpreting tissue results without further documentation of deficiencies with additional analysis such as soil tests.

Summary of Literature: Plant tissue analysis is being utilized more as a tool to determine whether nutrients should be applied in-season to maximize yield of crops. Plant analysis is only suggested for use for diagnosing problems that may occur in field (Kaiser et al., 2013). Fertilizer

decisions should be made using soil samples which have been correlated and calibrated to crop response. Never the less, samples are being taken in fields and are being used to sell products which are likely not needed. Databases for “sufficient” levels for nutrients have been developed for use in diagnosing problem areas within fields (Bryson et al., 2014). It is not known whether these sufficiency values were generated using crop response data that documents that yield will be reduced when tissue concentrations are below the stated sufficiency level. It is more likely that the sufficiency values used currently for nutrients such as sulfur or boron are developed based on tissue concentration averages for plots where either nutrient was added but no yield response was achieved. Since both boron and sulfur can be taken up by plants in excess quantities, utilizing averages values of fertilized plots can result in the development of sufficiency ranges that are higher than what would actually be required for maximum crop yield. Most of the research previously cited has shown the effects of boron or sulfur on petiole or leaf blade boron or sulfur concentration the works have not taken the next step in correlating it to crop yield.

Understanding potential sources of variation is important when interpreting plant tissue analysis results. One major source of variation can be differences in uptake patterns among hybrids or varieties. In Minnesota, unpublished survey data for corn and soybean and published data for hard red spring wheat (Kaiser et al., 2014b) found significant variation among hybrids/varieties for a majority of the nutrients analyzed. For the wheat trials, the majority of the variation in nutrient concentration across locations could be attributed to when the samples were collected and the stage of development of the plant at the time of sampling. For all crops the variation in yield could not be explained by one or more nutrients measured in the plant tissue. For sulfur, data collected from multiple crops has noted differences in the amount of sulfur reported in plant tissue based on how the samples are analyzed in the lab (Sterrett et al., 1987). These sources of variation indicate that varieties may have their own sufficiency range for nutrients and that ranges need to be developed based on specific laboratory methods used to determine the concentration of nutrients in plant tissue.

Objectives:

1. Compare nutrient concentration in petioles and leaf blades among varieties at three sampling times.
2. Determine if tissue nutrient concentration is predictive of root and sugar yield when sampling adequately fertilized fields.

Materials and Methods: Six sugarbeet varieties (listed below) were planted at four locations [three locations were sampled in 2019 (Table 1)] and tissue analysis samples was collected at three sampling times over the growing season. Varieties were planted in four replications at each site. Sampling times were early- to mid-June, early July, and late July to early August. The newest developed leaf was sampled. The petiole and leaf blade will be sampled at once then separated for individual analysis. All samples were dried, ground, and analyzed for nitrate N and

Cl via extraction with 5% acetic acid, total N by combustion, and P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn by ICP. A single composite soil sample consisting of six to eight cores was taken from the 0-6 and 6-24 inch depths from each site at each plant sampling date. Soil samples were analyzed using recommended procedures of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, and Cl and for pH (1:1 soil:water), soil organic matter (loss on ignition), and cation exchange capacity [CEC (ammonium saturation and displacement)]. Plant tissue nutrient concentration was correlated with yield and quality to determine what factors may be important for the prediction of root and sugar yield. All data was subject to an analysis of variance procedure assuming fixed effects of location, sampling time, and variety and random blocking effects.

Varieties used in the sampling trial:

1. Crystal RR018 – Check variety: Good disease tolerance, average yield but below average sugar.
2. Maribo 109 – Check variety: Good disease tolerance with average sugar content. Below average tons. Tends to have a smaller leaf canopy than other varieties.
3. Beta 92RR30 –Average tons and average sugar.
4. Beta 9475 –Good Cercospora leaf spot resistance, high yield, average sugar
5. Crystal M579 –High sugar content.
6. Crystal M509 – Good cercospora resistance, low sugar content and high yield.

Results: Sample timings were targeted to occur within three week intervals near the 50-80 day suggested for sugarbeet sampling. Actual sampling dates averaged 45, 65, and 88 days after planting which was ideal for the trial to study early, suggested, and late sampling timings. Soil types, chemical properties, and cation exchange capacity was relatively similar among soils at the eight locations. Results for chemical soil tests for samples collected from each location at the time samples were collected are summarized in Table 2a, 2b, and 2c.

Root yield, sugar content per ton, and sugar content produced per acre varied among the six varieties across all four 2017 (Table 3a), 2018 (Table 3b), and 2019 (Table 3c) locations. The four site average for each of the variables is given in Tables 3a, 3b, and 3c. However, analysis indicated a significant interaction between site and variety for each year providing evidence of variation in the ranking of varieties among the sites. Overall, root yield, sugar content, and sugar production followed anticipated patterns based on past varietal response data, but variety rankings did slightly vary by year. Some variation in varietal ranking may be due to differences in yield potential as a result of cercospora which had a greater incidence across locations in 2018 (not shown) Root yield and quality did vary allow for correlation between yield and quality and plant tissue concentration.

Results for the analysis of variance for leaf blade tissue concentration are summarized across locations and years in Table 4. The effect of time and variety was significant for most nutrient concentrations. Exceptions were when differences were not found among sampling times for

sulfur and boron and among varieties for total nitrogen, sulfur, and boron. Nutrient concentrations differed among locations except for phosphorus, potassium, magnesium, sulfur, and boron which did not differ based on location. The location by time interaction was significant for nearly all nutrients except for total nitrogen, phosphorus, sulfur, and boron. The time by variety and location by variety interactions along with the three-way time by location by variety interaction was significant at roughly half the locations. For the interest of time, the discussions will not be discussed extensively in this report. Similar results were found for petiole concentration (Table 5).

Differences in leaf blade nutrient concentration among varieties, when averaged across time and location, are summarized in Table 6. While significant, the relative differences in plant nutrient concentrations among the varieties were relatively small. The ranking among varieties (maximum to minimum concentrations) were not consistent indicating that varieties with greater nutrient concentration of a single nutrient were not greater for all nutrients. This indicates that plant nutrient uptake is not relatively greater for one variety versus another for all nutrients. Table 6 also lists the anticipated sufficiency range according to Bryson et al., 2014. The average for boron tissue concentration was the only instance where a concentration average was close to the low end of the sufficiency range. However, the boron concentration in the leaf blade tissue did not necessarily indicate that boron was limiting yield. Results for leaf blade nitrate nitrogen and chloride are listed in Table 6 but there is no given sufficiency ranges for these nutrients.

Effects on all nutrient concentrations were similar for petioles (Table 7) as with leaf blades. However, the concentration of nutrients tended to be less in the petiole than in the leaf blade tissue. The major exceptions were potassium and chloride where the concentration was greater in the petiole than in the leaf blade. There is no identified sufficiency range for petiole tissue to compare results with established ranges.

The effect of time on macro- and micronutrient concentrations is summarized in Figures 1 and 2, respectively. Most nutrients decreased in concentration in both the leaf blade and petiole samples over time starting at time one through time three. There were exceptions where some nutrients did not change over time or showed a temporary decrease from T1 to T2 but then increased from T2 to T3. Iron did exhibit a decrease over time, but this decrease was likely due to less soil contamination on leaves later in the growing season. As more leaves developed it was less likely that rain drops would reach the soil surface resulting in splashing of soil particles onto plant tissue. Due to contamination, tissue iron concentration should not be used as a predictor of yield and quality parameters. There was a large increase in copper from T2 to T3. The concentration of copper spiked in the leaf tissue at sampling time three as a result of copper being applied to treat cercospora. Tissue sulfur concentration generally increased in the leaf blade while it decreased in the petiole.

Table 8 summarizes the 25 to 75% confidence interval for each nutrient by sampling time for leaf blade tissue and petiole concentrations are summarized in Table 9. The 25-75% confidence

interval is typically used to identify where the “true mean” lies. Population statistics are sometimes used in lieu of sufficiency data to represent “normal” values for tissue concentration. In this case the confidence interval ranges were much smaller than the ranges used for sufficiency ranges, and in the case of the early sampling time 1, the 25% value was generally higher than the low end of the reported sufficiency ranges for leaf blade tissue. The main issue to note is the general decrease in the sufficiency range over time indicating that a singular set of recommendations from 50-80 days after planting may not be relevant as value may get lower over time increasing the likelihood of insufficient nutrient levels being reported to growers. Others may report sufficiency ranges as plus or minus two standard deviations from the mean. In any event, without supporting data on yield or quality changes due to differences in nutrient concentrations one cannot be certain whether a reported low value has meaning and needs to be corrected.

Simple correlation between individual nutrient concentration in the leaf blade and petiole at each sampling time and sugarbeet root yield is summarized in Table 10. There were significant positive and negative correlations among most of the nutrients studied. There was no instance where a single nutrient always showed a positive correlation with root yield. For example, total nitrogen content in the leaf blade and petiole were positively correlated with root yield at T1 but was not correlated by T3. The greatest correlation was between leaf petiole total N at T1 and root yield (r=0.73) which was similar to the correlation between root yield and petiole total N concentration. The next strongest correlation was a negative relationship between leaf and petiole calcium concentration and root yield at T2 and leaf blade total nitrogen concentration at T1.

Table 11 summarizes the correlation between plant tissue and sucrose content and Table 12 summarizes correlation with sugar production per acre. Similar to root yield, there were no instances where sugar content or yield showed a consistent correlation with multiple nutrient. It would be expected that if a nutrient is limiting or if yield or quality is a function of nutrient concentration then there should be consistent correlation over time between these factors and the concentration of nutrient in the plant tissue. Nutrient concentration in plant tissue does not necessarily account for variations in plant growth and differences in nutrient remobilization among varieties. The data overall indicates that some caution should be exercised when interpreting plant tissue results as a correlation between yield and quality and a concentration of a specific nutrient at a single point during the growing season does not prove that uptake of any nutrient is driving final yield or sugar production.

What has been interesting is the change in correlation values as more data has been added to the study. Previous correlations are not given in this report but are listed in older reports. Over time there have been changes in what nutrients are more, and which are less correlated to the root yield and quality parameters. The change over time indicates that some caution should be exercised when using correlation data. Also, correlation does not prove that one factor drives the other factor rather is shows there is a relationship. In order to be certain that a tissue

concentration impacts yield or quality separate research needs to be conducted using cause and effect to determine how application of nutrients change tissue nutrient concentrations and whether yield or quality factors are impacted.

Correlations between individual nutrient concentrations and their respective soil test collected at the time of tissue sampling are summarized in Table 13. Significant positive correlations were found between the respective soil test and leaf and petiole tissue for nitrogen, nitrate-nitrogen, phosphorus, and potassium. Leaf blade and petiole calcium was correlated to the 6-24” soil test Ca content but not the 0-6” Ca soil test. There was no correlation between leaf tissue and soil test magnesium and sulfur. The strongest correlations were for the 0 to 6-inch depth but significant positive correlations were also found between tissue N and K and the 6-24 inches N soil test values. For micronutrients, there were no significant correlations between leaf blade and petiole micronutrient concentrations for many nutrients. Exceptions were leaf blade boron, petiole copper, and leaf blade zinc concentrations. Since the sites were maintained at high fertility levels it is not surprising that there was little correlation between soil test values and tissue nutrient concentration for micronutrients. Environmental factors such as temperature and precipitation and crop development at sampling have been shown to influence variation in nutrient concentration among research sites for other crops.

Average nutrient concentrations by location were regressed with multiple soil and environmental factors to determine if variation in tissue concentrations could be explained by variations in factors which cannot be controlled. Multiple environmental factors were studied including average minimum and maximum temperature, total precipitation, and growing degree day. All the previous factors were summarized based on the time from planting to sampling, 1 day, 3 days, 1 week, 2 weeks, and 3 weeks prior to sampling. Significant factors were grouped into long term (greater than 2 weeks) or short term (2 weeks or less) factors for summary in Figures 3 and 4. All soil factors in Tables 2a and 2b were utilized and were grouped into soil test or other soil (soil) factors after the analysis. Time factor considers the time (days) between planting and sampling. The remaining variation which could not be explained by the model was marked as unknown. Two micronutrients, iron and copper, were not regressed with soil factors as contamination of iron and copper through soil adhering to the plant tissue or foliar application of the nutrient due to greater than expected concentrations of either nutrient not as a result of plant uptake.

A total of 11 nutrients were examined for both the leaf blade and petiole samples for a total of 22 comparisons. Of the 22 comparisons, Long term climate factors explained the majority of variability in plant tissue concentration for 3 comparisons while short term factors provided the best explanation in one instance. Soil chemical and physical properties other than soil test values explained most variation in five instances. Time factors such as days after planting and growing degree day accumulation also represented the majority of variation in five instances. The soil test for a particular nutrient explained the largest portion of variation in nutrient concentrations in five instances. Three of the five instances were related to nitrogen (blade and petiole nitrate-N

and petiole total N). Unknown factors explained the majority of variation in three of 22 instances. The fact that soil test for individual nutrients were not the most important factor in explaining most variation in tissue nutrient concentration indicate most variability in tissue concentration is dictated by factors out of human control. In most instances the variation in tissue concentration is likely related to stress factors not related to a specific nutrient availability thus correcting for tissue concentrations which are identified as low likely will not fully correct a nutrient deficiency. Taking multiple samples from different areas of fields to compare poorer with good plant growth would provide better data giving a comparison of nutrient concentrations in order to identify if a problem occurs rather than just a random sample collected in a field to search for nutrient deficiencies. It is likely that a nutrient deficiency will be found with a random sample within a field when using book values for nutrient concentrations but it is doubtful deficiencies identified in this way can be corrected.

Figure 7 summarizes the relationship between blade total N concentration and root yield, and blade total Ca concentration and recoverable sugar. Best fit models show a general relationship between the factors. However, in the case both graphs, clustering of values within sites result in the positive relationships and it is questioned how accurate a model developed to predict yield or quality can do so. Figure 8 shows the negative relationship between petiole Ca and root yield which demonstrates that positive relationships do not always exist between nutrient concentration and yield factors. Both graphs use actual yield and recoverable sugar values and prediction models typically use values relative to a maximum value in order to reduce the impact of random factors not accounted for in the model from influencing the relationship between yield or quality factors and tissue concentrations. For example, crop yield is an interaction between the varieties genetic potential and optimal growth factors at an individual site. Soil nutrient availability is one factor impacting yield but not the sole factor thus adjusting yield data. For this report yield data was not adjusted on a relative basis as it is unclear how to make adjustments when differences in yield are based on genetic factors only. With nutrient availability trials the maximum yield produced by increasing rates of nutrient applied are used to compare the yield produced by treatments to generate a relative yield as it relates to maximum yield potential by site for a specific cultivar.

The equations a through f below represent results from multiple regression analysis to determine if multiple factors combined can help predict root yield and recoverable sugar per ton. Equations a, b, and c identify significant prediction for root yield using plant tissue factors for sample times 1, 2, and 3, respectively. Equations e, f, and g identify prediction factors for recoverable sugar per ton for times 1, 2, and 3, respectively.

(a) root yield = -31.8 + 5.04(Blade N) + 1.28 (Blade B) – 0.000136 (Pet Cl)

(b) root yield = 57.0 – 27.7(Blade Mg) – 17.9 (Pet Ca) – 0.88 (Pet Cu)

(c) root yield = -20.7 + 0.82(Blade Zn) – 11.4 (Pet K) + 2.65 (Pet B)

(d) rec. sugar per ton = 80.6 -0.005(Blade NO3) + 20.9 (Blade P) -126.6 (Blade S) + 2.37 (Blade Zn) + 0.008 (Blade Cl) + 756.86 (Pet S)

(e) rec. sugar per ton = 446.6 – 213.9 (Blade Mg) – 332.7 (Blade S) + 1.09(Pet Mn)

(f) rec. sugar per ton = 351.7 – 183.3(Blade P) – 63.5(Blade Mg) – 0.17 (Blade Cu) + 1.41 (Blade Zn) – 80.4 (Pet Ca)

Table 14 summarized partial r^2 values for each nutrient in the above equations showing how much of the total variation is explained by individual leaf blade or petiole nutrient concentration deemed significant in the model. Time 1 prediction models could be used to predict 99% of the variability in yield and in recoverable sugar per ton with a combination of multiple factors. Combined r^2 values were poorer at time 2 compared to time 1 and for root yield at time 3 compared to time 1, but not for recoverable sugar at time 3 which had a total r^2 similar to Time 1. This indicates that prediction is generally better for Time 1 than the later sampling dates. What should be noted though is that all factors in the model do not necessarily have a positive impact on root yield or recoverable sugar. For example in equation a, root yield increased with increasing blade N and B concentration and decreasing petiole Cl content. One item to note is that there is some correlation between the different blade and petiole nutrient concentration as uptake of a single nutrient can impact the uptake of other nutrients. Also, prediction models are always better at backwards predicting values and seldom are good at forward predicting what may happen in future years. For example, many models exist to predict iron deficiency chlorosis in soybean but many fail to predict the severity and where IDC will occur when used in studies where the models did not generate data. Care should always be exercised when using multiple regression models as the data may be specific to the sites where the studies were conducted or cultivars used for the studies.

Conclusions: The data showed that there were clear differences in yield and quality among the sugarbeet varieties used in the study. Tissue (leaf blade and petiole) nutrient concentration will vary among sugarbeet varieties sampled in the same field at the same time. The concentration of most nutrients will decrease when sampling the same leaf relative to the top part of the canopy over time. The decrease or increase will occur for each nutrient similar for the leaf blade and petiole sample. Due to this variation, a large range in the recommended sampling time for leaf blade samples (50-80 days after planting) should not be used. The data indicates that earlier sampling around 40-50 days after planting may be more predictive of yield response compared to later samples. However, there was not strong evidence that root yield or recoverable sugar could be fully predicted by plant tissue concentration and that concentration of nutrients in leaf blade and petiole tissues could be explained by factors other than the soil test of a nutrient indicating much of the variation in plant tissue concentration is controlled by uncontrollable factors. The data indicates that significant caution should be exercised when collecting a single sample from a well fertilized field as there is no evidence that the concentration of a nutrient in the leaf or petiole has a direct impact on yield or quality.

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Table 1. Location, planting and sampling information, dominant soil series, and cation exchange capacity (CEC) for each location (CC, Clara City; H, Hector; LL, Lake Lillian; M, Murdock; R, Renville).

	Date of				Soil		CEC		Particle Size		
Location	Planting	Sample 1	Sample 2	Sample 3	Series	Classification‡	0-6”	6-24”	Sand	Silt	Clay
							meq/100g			%	
					2017						
CC	25-May	12-Jul	2-Aug	22-Aug	Colvin-Quam	T Calciaquoll	31.6	25.5	18	53	30
LL	8-May	21-Jun	12-Jul	2-Aug	Nicollet	A Hapludoll	33.7	28.7	25	40	35
M	29-Apr	21-Jun	12-Jul	2-Aug	Bearden-Quam	Ae Calciaquoll	28.0	22.2	14	48	38
R	6-May	21-Jun	11-Jul	1-Aug	Chetomba	T Endoaquoll	31.1	24.4	22	43	36
					2018						
CC	17-May	27-Jun	18-Jul	14-Aug	Bearden-Quam	Ae Calciaquoll	30.9	20.9	16	48	37
H	10-May	21-Jun	9-Jul	2-Aug	Crippin	A.P. Hapludoll	35.8	28.5	10	49	41
LL	7-May	21-Jun	9-Jul	2-Aug	Nicollet	A Hapludoll	31.3	23.7	30	37	33
M	18-May	27-Jun	16-Jul	14-Aug	Bearden-Quam	Ae Calciaquoll	35.2	28.2	11	48	41
					2019						
H	7-May	17-Jun	11-Jul	31-Jul	Crippin	A.P. Hapludoll	40.5	34.9	18	42	40
LL	6-May	17-Jun	11-Jul	31-Jul	Okaboji-Canisteo	C.V. Endoaquoll	36.0	30.9	13	50	37
M	31-May	15-Jul	31-Jul	19-Aug	Byrne-Buse	C. Hapludoll	27.7	23.9	21	50	29

‡A, aquic; Ae, aeric; A.P., aquic pachic; C, calcic; C.V., cuuulic vertic; T, typic.

Table 2a. Summary of 2017 soil test results for samples collected with plant tissue samples at Clara City (CC), Lake Lillian (LL), Murdock (M), and Renville (R).

					Ammonium Acetate				DTPA								
Time	Location	Depth	NO_3-N	P	Ca	K	Mg	SO_4-S	Cu	Fe	Mn	Zn	B	Cl	O.M.	pH	CCE
		in	ppm												-%-		-%-
1	CC	0-6	17.5	12	5852	242	832	12	1.0	7.8	18.1	2.7	1.2	11.2	7.0	7.9	27
		6-24	11.5	3	5058	153	1076	10	1.4	10.0	7.2	0.6	0.8	11.6	4.0	8.1	28
	LL	0-6	31.0	36	4833	182	562	15	1.0	43.8	29.5	0.9	0.6	8.6	6.2	7.0	0
		6-24	17.2	8	4679	153	548	11	1.2	43.5	17.3	0.6	0.6	8.6	4.7	7.0	2
	M	0-6	9.3	8	5960	189	696	12	1.0	7.1	18.6	1.9	1.6	7.8	5.3	8.0	32
		6-24	14.0	2	6330	163	869	133	1.2	6.4	8.0	0.8	1.0	6.7	3.1	7.8	31
	R	0-6	6.9	8	5152	348	583	12	1.4	17.2	29.9	1.6	0.9	9.6	5.1	7.5	2
		6-24	6.9	3	5581	217	608	8	1.4	9.2	11.3	0.5	0.6	7.7	3.1	7.9	11
2	CC	0-6	12.6	12	5938	249	817	11	1.0	7.3	14.7	2.7	1.3	6.9	6.6	8.0	28
		6-24	3.4	3	5139	134	1016	10	1.5	8.2	7.4	0.8	0.7	7.8	4.3	8.2	34
	LL	0-6	16.4	35	4772	156	523	14	1.0	36.0	26.4	0.8	0.5	6.7	6.0	7.3	3
		6-24	4.4	4	4480	138	543	10	1.3	40.7	16.3	0.4	0.5	6.9	4.2	7.1	0
	M	0-6	3.5	9	5877	163	657	11	1.1	7.6	15.3	1.9	1.5	8.0	5.2	8.1	33
		6-24	3.0	3	6824	155	717	160	1.2	6.2	7.6	0.8	1.1	6.8	3.5	7.8	32
	R	0-6	3.4	9	5126	316	537	11	1.3	12.1	24.0	1.4	0.8	9.0	5.2	7.7	1
		6-24	1.6	2	5280	147	693	6	1.4	8.2	8.2	0.3	0.6	9.8	2.9	8.0	10
3	CC	0-6	4.5	16	5957	214	801	11	1.0	8.0	14.0	2.8	0.9	8.6	6.6	8.0	29
		6-24	7.1	2	4835	138	1004	9	1.6	7.6	4.5	0.8	0.6	5.7	3.1	8.2	38
	LL	0-6	4.3	34	4718	142	545	14	1.1	39.6	23.3	1.0	0.6	7.6	6.2	7.3	0
		6-24	1.6	8	3552	135	550	12	1.2	46.0	20.7	0.4	0.7	7.4	4.7	6.8	0
	M	0-6	3.5	7	5943	169	667	11	1.3	6.2	13.4	2.0	1.2	7.1	5.2	8.1	34
		6-24	2.9	3	6236	156	723	61	1.3	5.8	6.5	1.0	1.1	7.5	3.5	7.9	30
	R	0-6	3.4	8	5034	312	558	11	1.4	15.0	22.6	1.4	0.8	8.6	5.2	7.6	1
		6-24	1.7	3	5539	188	688	8	1.4	10.0	10.0	0.4	0.6	8.4	3.2	7.8	6

CCE, calcium carbonate equivalency.

Table 2b. Summary of 2018 soil test results for samples collected with plant tissue samples at Clara City (CC), Hector (H), Lake Lillian (LL), and Murdock (M).

					Ammonium Acetate				DTPA								
Time	Location	Depth	NO_3-N	P	Ca	K	Mg	SO_4-S	Cu	Fe	Mn	Zn	B	Cl	O.M.	pH	CCE
		in	ppm												-%-		-%-
1	CC	0-6	4.9	10	8309	158	467	149	0.7	4.3	18.2	1.8	1.5	9.6	6.7	7.6	37
		6-24	4.3	2	9711	78	660	184	1.1	5.6	6.5	0.6	0.7	9.8	3.3	7.6	38
	H	0-6	14.0	9	6440	208	492	5	1.2	5.9	22.8	0.9	1.3	15.8	6.2	7.7	3
		6-24	9.9	2	5469	99	558	3	1.9	5.9	5.5	0.5	0.6	15.9	3.0	7.9	12
	LL	0-6	10.7	18	5262	200	556	6	0.9	10.8	26.6	1.2	0.8	18.4	5.0	7.7	3
		6-24	11.1	3	4783	106	654	7	1.2	7.3	8.5	0.5	0.5	16.6	2.7	7.7	9
	M	0-6	9.2	21	6191	178	807	10	1.1	6.0	17.4	1.6	1.4	14.1	5.7	7.8	8
		6-24	10.1	3	5343	123	1030	7	1.4	5.6	6.2	0.8	1.0	8.4	3.3	8.0	12
2	CC	0-6	4.3	10	7583	164	394	171	0.6	4.4	14.6	1.6	1.8	56.7	7.3	7.6	38
		6-24	5.5	3	13289	68	441	215	0.6	3.3	3.9	0.3	1.0	12.4	4.5	7.7	37
	H	0-6	3.5	8	6190	242	467	4	1.2	5.9	18.5	0.9	1.2	14.0	6.2	7.7	3
		6-24	2.2	2	5495	121	531	3	1.7	5.4	4.4	0.4	0.6	10.6	3.0	7.9	14
	LL	0-6	2.8	15	5189	156	521	6	0.8	10.0	21.9	1.0	0.8	13.0	5.0	7.8	2
		6-24	6.0	2	5194	114	699	4	1.1	7.6	8.4	0.4	0.6	12.6	3.0	7.7	10
	M	0-6	3.2	10	5993	179	780	5	1.0	5.5	11.7	1.5	1.5	12.8	5.6	7.8	8
		6-24	3.2	3	5022	102	944	5	1.3	5.3	3.7	0.7	0.9	34.2	3.0	8.0	15
3	CC	0-6	2.8	9	7018	162	488	79	0.6	4.1	7.3	1.7	1.5	41.7	7.2	7.6	36
		6-24	1.7	2	10821	66	616	121	0.9	3.1	2.6	0.3	0.9	10.7	3.9	7.7	39
	H	0-6	2.1	6	6284	183	478	4	1.2	5.6	12.8	0.8	1.0	16.8	6.3	7.8	4
		6-24	1.0	1	5773	88	565	3	1.7	5.2	3.9	0.3	0.8	19.8	3.4	7.9	10
	LL	0-6	1.9	14	4942	159	543	5	0.9	10.9	19.1	1.1	0.7	7.5	5.1	7.7	3
		6-24	1.1	1	4837	98	682	4	1.0	7.5	6.9	0.3	0.6	11.1	2.9	7.8	8
	M	0-6	2.3	11	5997	150	771	5	1.0	5.3	6.9	1.5	1.2	8.4	5.8	7.9	7
		6-24	1.8	3	5143	118	937	6	1.3	4.7	2.9	0.7	1.0	16.3	3.3	8.1	15

CCE, calcium carbonate equivalency.

Table 2c. Summary of 2019 soil test results for samples collected with plant tissue samples at Hector (H), Lake Lillian (LL), and Murdock (M).

					Ammonium Acetate				DTPA								
Time	Location	Depth	NO_3-N	P	Ca	K	Mg	SO_4-S	Cu	Fe	Mn	Zn	B	Cl	O.M.	pH	CCE
		in	ppm												-%-		-%-
1	H	0-6	10.2	28	6201	289	629	9	1.6	20.0	27.8	1.8	0.8	12.9	7.7	7.7	0
		6-24	7.4	5	5926	210	770	8	1.9	22.1	13.4	0.9	0.6	13.4	5.4	7.3	1
	LL	0-6	4.5	36	6467	307	642	6	1.6	19.9	25.4	1.7	0.6	12.6	7.4	7.4	4
		6-24	7.4	4	5067	217	830	5	2.0	20.8	8.8	0.5	0.6	11.2	4.4	7.1	8
	M	0-6	3.4	27	6018	271	611	7	2.0	21.2	21.2	1.9	0.8	10.1	7.6	7.6	7
		6-24	7.4	8	5652	219	817	5	2.0	25.3	11.6	1.3	0.7	10.7	5.4	7.3	4
2	H	0-6	22.5	14	7521	240	881	10	1.4	13.4	15.9	1.2	1.0	12.6	7.2	7.2	0
		6-24	7.5	3	6454	196	1178	10	1.8	11.0	5.2	0.5	0.6	11.5	3.7	7.6	0
	LL	0-6	4.3	18	7589	251	803	9	1.3	14.3	15.5	1.4	1.0	11.4	7.3	7.3	6
		6-24	7.7	3	6447	225	1121	5	1.7	12.4	4.4	0.4	0.6	11.9	3.5	7.7	9
	M	0-6	3.1	12	7294	205	824	5	1.3	12.3	11.9	1.8	1.2	13.5	7.4	7.4	8
		6-24	7.6	2	6338	220	1130	5	1.8	13.4	3.6	1.1	0.6	13.0	3.5	7.7	10
3	H	0-6	18.6	8	6122	226	639	7	1.2	11.4	14.5	2.1	0.8	10.1	5.0	5.0	0
		6-24	7.7	2	5019	212	833	6	1.4	11.6	6.0	0.8	0.5	10.0	2.8	7.7	0
	LL	0-6	8.1	7	5949	212	630	4	1.3	12.7	13.3	2.3	0.8	11.5	4.8	4.8	5
		6-24	7.8	2	5497	193	848	4	1.6	11.3	5.6	1.1	0.4	10.9	2.7	7.8	9
	M	0-6	2.0	7	6205	209	650	6	2.3	12.4	13.6	4.5	0.9	9.0	5.0	5.0	8
		6-24	7.7	2	5390	201	806	6	1.4	11.7	4.8	0.8	0.5	8.1	2.6	7.8	6

CCE, calcium carbonate equivalency.

Table 3a. Summary of analysis of variance for the main effect of sugarbeet variety by and across 2017 locations. Numbers within rows which are followed by the same letter are not significantly different at $P \leq 0.10$.

	Variety						
Location	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509	*P*>F
	----------Root Yield (tons/acre) ----------						
Clara City	26.8a	23.0ab	19.2b	26.6a	26.2a	25.1a	0.06
Lake Lillian	33.6b	29.0c	28.0c	33.9b	35.0b	38.2a	<0.001
Murdock	37.4b	36.7b	33.2c	37.6b	35.5bc	41.7a	<0.001
Renville	32.6b	29.1c	30.0c	34.3ab	35.0a	36.3a	<0.001
Average	32.5b	29.3c	27.8d	33.1b	32.9b	35.4a	<0.001
	----------Recoverable Sugar (lbs/ton) ----------						
Clara City	266bc	278ab	272b	272bc	289a	260c	0.01
Lake Lillian	269a	268a	257b	263ab	270a	249c	<0.001
Murdock	294ab	289bc	297ab	288bc	305a	280c	0.04
Renville	285cd	295b	302a	293b	289bc	280d	<0.01
Average	280b	283b	281b	279b	288a	267c	<0.001
	----------Recoverable Sugar (lbs/acre) ----------						
Clara City	7130ab	6413bc	5278c	7254ab	7561a	6555ab	0.05
Lake Lillian	9056a	7789b	7185b	8912a	9421a	9526a	<0.001
Murdock	11011b	10614b	9837c	10820b	10832b	11673	<0.01
Renville	9282bc	8590c	9067c	10014ab	10125a	10173a	<0.01
Average	9110a	8300b	7873c	9265a	9489a	9490a	<0.001

Table 3b. Summary of analysis of variance for the main effect of sugarbeet variety by and across 2018 locations. Numbers within rows which are followed by the same letter are not significantly different at $P \leq 0.10$.

	Variety						
Location	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509	*P*>F
	----------Root Yield (tons/acre) ----------						
Clara City	15.9b	13.6c	18.6a	16.9ab	17.4ab	18.6a	0.01
Hector	27.7c	29.8b	30.1b	31.1b	30.4b	35.8a	<0.001
Lake Lillian	--	--	--	--	--	--	--
Murdock	28.1c	28.0c	27.9c	32.0b	30.8b	35.0a	<0.001
Average	23.9c	23.8c	25.5b	26.7b	26.2b	29.8a	<0.001
	----------Recoverable Sugar (lbs/ton) ----------						
Clara City	231	235	242	219	239	229	0.12
Hector	247	251	250	251	260	249	0.62
Lake Lillian	257	263	262	260	267	252	0.14
Murdock	265	278	273	263	282	271	0.11
Average	250b	257a	257a	248b	262a	250b	<0.001
	----------Recoverable Sugar (lbs/acre) ----------						
Clara City	3679bc	3181c	4525a	3721bc	4153ab	4273ab	0.02
Hector	6859c	7478b	7537b	7796b	7915b	8908a	<0.001
Lake Lillian	--	--	--	--	--	--	--
Murdock	7440d	7771cd	7616d	8412bc	8683b	9495a	<0.001
Average	5992c	6143c	6559b	6643b	6917b	7558a	<0.001

Table 3c. Summary of analysis of variance for the main effect of sugarbeet variety by and across 2019 locations. Numbers within rows which are followed by the same letter are not significantly different at $P \leq 0.10$.

	Variety						
Location	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509	*P*>F
	----------Root Yield (tons/acre) ----------						
Hector	24.1ab	18.4b	26.0a	28.9a	26.2a	29.4a	0.05
Lake Lillian	33.8bc	32.1c	33.4bc	35.7b	33.3c	42.0a	<0.001
Murdock	23.6c	22.9c	20.9d	25.2b	26.0b	28.9a	<0.001
Average	27.2c	24.5d	26.8c	29.9b	28.5bc	33.4a	<0.001
	----------Recoverable Sugar (lbs/ton) ----------						
Hector	258	236	259	255	266	243	0.22
Lake Lillian	278b	279b	285a	282ab	283ab	267c	<0.001
Murdock	263c	288a	296a	286ab	290a	270bc	0.03
Average	265bc	268bc	280a	274ab	280a	260c	<0.01
	----------Recoverable Sugar (lbs/acre) ----------						
Hector	6555	4397	6768	7391	6982	7120	0.14
Lake Lillian	9401c	8974c	9490bc	10067b	9421bc	11199a	<0.001
Murdock	6182d	6595cd	6186d	7187bc	7528ab	7799a	<0.001
Average	7346cd	6722d	7481c	8215ab	7977bc	8706a	<0.001

Table 4. Summary of analysis of variance for leaf blade nutrient concentration averaged across eight locations from 2017-2019 and three sampling times at each location.

Nutrient	Time (T)	Location (L)	T x L	Variety (V)	T x V	L x V	T x L x V
	----------*P*>F----------						
Total-N	*	0.10	0.16	0.14	0.60	0.56	0.59
Nitrate-N	***	***	***	***	***	***	***
Phosphorus	0.08	0.15	0.19	0.09	0.51	0.58	0.64
Potassium	***	0.18	***	***	***	0.06	0.01
Calcium	***	***	***	***	***	0.11	***
Magnesium	***	0.21	***	***	***	***	**
Sulfur	0.14	0.17	0.14	0.12	0.35	0.49	0.54
Boron	0.15	0.18	0.25	0.13	0.33	0.42	0.58
Copper	***	***	***	***	***	**	***
Iron	***	***	***	***	**	0.05	**
Manganese	**	***	***	***	***	*	***
Zinc	**	***	***	***	*	0.44	0.51
Chloride	***	***	***	***	*	*	0.18

†Asterisks represent significance at $P<0.05$,*; 0.01, **; and 0.001, ***.

Table 5. Summary of analysis of variance for petiole nutrient concentration averaged across eight locations from 2017-2018 and three sampling times at each location.

Nutrient	Time (T)	Location (L)	T x L	Variety (V)	T x V	L x V	T x L x V
	----------*P*>F----------						
Total-N	***	***	***	***	***	0.24	0.15
Nitrate-N	***	***	***	***	***	0.06	*
Phosphorus	0.38	0.17	0.28	0.07	0.45	0.57	0.58
Potassium	*	0.17	0.13	0.15	0.31	0.57	0.61
Calcium	***	***	***	***	***	**	0.17
Magnesium	***	***	***	***	***	***	***
Sulfur	0.10	0.10	0.35	0.23	0.50	0.64	0.56
Boron	***	0.11	***	***	**	0.20	0.38
Copper	0.11	0.14	0.25	0.34	0.46	0.53	0.48
Iron	*	0.21	0.11	0.38	0.32	0.48	0.53
Manganese	*	0.34	0.13	0.12	0.37	0.51	0.57
Zinc	0.13	0.27	0.42	0.57	0.78	0.65	0.69
Chloride	*	***	***	***	0.1	0.27	0.41

†Asterisks represent significance at $P<0.05$,*; 0.01, **; and 0.001, ***.

Table 6. Varietal differences in leaf blade nutrient concentration across eleven locations from 2017-2019 and three sampling times at each location. Within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

	Variety						
Nutrient	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509	Suffic.†
	----------%----------						
Total-N	5.25a	4.87b	4.84b	4.88b	4.79b	4.87b	4.3-5.0
Phosphorus	0.53a	0.55a	0.46c	0.48bc	0.45c	0.51ab	0.45-1.1
Potassium	3.95a	3.74b	3.63d	3.62d	3.71bc	3.65cd	2.0-6.0
Calcium	0.68b	0.74a	0.73a	0.65c	0.67bc	0.69b	0.5-1.5
Magnesium	0.48d	0.52b	0.56a	0.50c	0.50c	0.52b	0.25-1
Sulfur	0.38	0.36	0.35	0.37	0.36	0.38	0.21-0.5
	----------ppm----------						
Nitrate-N	752a	400e	609bc	634b	478d	580c	
Boron	30	31	32	29	30	29	31-200
Copper	35c	40a	36bc	33c	39ab	33c	11-40
Iron	494a	389c	502a	439b	516a	516a	60-140
Manganese	65cd	68b	76a	63d	79a	67bc	26-360
Zinc	46ab	39c	44ab	44b	44ab	47a	10-80
Chloride	3059b	3516a	3076b	3117b	2996bc	2895c	

†Suffic, sufficiency range identified by Bryson et al., 2014.

Table 7. Varietal differences in petiole nutrient concentration across eleven locations from 2017-2019 and three sampling times at each location. Within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

	Variety					
Nutrient	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509
	----------%----------					
Total-N	2.54bc	2.60ab	2.65a	2.52cd	2.46d	2.61ab
Phosphorus	0.35bc	0.43a	0.35bc	0.35bc	0.33c	0.37b
Potassium	4.56	4.58	4.28	4.40	4.29	4.76
Calcium	0.44c	0.56a	0.49b	0.45c	0.49b	0.57a
Magnesium	0.26b	0.28a	0.28a	0.24d	0.24c	0.24c
Sulfur	0.14	0.15	0.13	0.14	0.14	0.14
	----------ppm----------					
Nitrate-N	4311c		5315a	4281c	3997c	4777b
Boron	23c	25s	24b	24b	23c	26a
Copper	9.6	9.5	8.6	9.9	9.0	9.5
Iron	307	300	267	257	289	285
Manganese	28b	29b	28b	26b	34a	30b
Zinc	20	21	18	18	19	20
Chloride	4980b		5880a	5742a	5665a	6103a

Table 8. Summary of leaf blade tissue concentration across locations and sugarbeet varieties from 2017-2019 and three sampling times at each location. Within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

	Sampling 1			Sampling 2			Sampling 3		
Nutrient	25%	50%	75%	25%	50%	75%	25%	50%	75%
	----------%----------								
Total-N	4.9	5.5	5.8	4.5	4.9	5.4	4.0	4.5	5.1
Phosphorus	0.44	0.54	0.64	0.42	0.51	0.62	0.34	0.42	0.51
Potassium	3.4	4.1	4.7	2.9	3.2	3.7	3.3	3.6	4.0
Calcium	0.66	1.09	1.34	0.41	0.52	0.75	0.32	0.42	0.57
Magnesium	0.49	0.77	0.98	0.32	0.39	0.52	0.27	0.31	0.43
Sulfur	0.33	0.36	0.40	0.31	0.35	0.39	0.33	0.37	0.41
	----------ppm----------								
Boron	26	28	31	27	30	34	28	31	34
Copper	9.1	11.1	14.9	11.7	14.4	18.5	21.6	48.7	118.0
Iron	274	505	763	230	423	874	113	151	221
Manganese	59	77	87	49	59	79	37	51	92
Zinc	37	44	48	36	45	51	35	41	49

Table 9. Summary of petiole tissue concentration across locations and sugarbeet varieties from 2017-2019 and three sampling times at each location. Within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

	Sampling 1			Sampling 2			Sampling 3		
Nutrient	25%	50%	75%	25%	50%	75%	25%	50%	75%
	----------%----------								
Total-N	3.0	3.7	4.0	1.9	2.4	3.1	1.2	1.6	2.4
Phosphorus	0.30	0.36	0.44	0.31	0.36	0.42	0.28	0.35	0.41
Potassium	4.8	5.5	6.4	3.4	3.9	4.6	3.2	3.7	4.2
Calcium	0.43	0.74	0.95	0.26	0.34	0.47	0.24	0.31	0.43
Magnesium	0.26	0.37	0.47	0.16	0.19	0.25	0.14	0.17	0.22
Sulfur	0.13	0.15	0.18	0.10	0.13	0.16	0.09	0.11	0.16
	----------ppm----------								
Boron	22	24	29	21	23	25	20	22	23
Copper	6.5	7.7	9.0	6.1	8.6	10.7	8.1	9.9	13.0
Iron	288	439	672	93	160	359	26	38	75
Manganese	29	37	44	20	26	33	17	21	26
Zinc	18	22	27	14	18	23	10	13	18

Table 10. Simple correlation (r) between sugarbeet root yield and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled 44, 65, and 87 days after planting. Correlation r values when between -0.11 and 0.11 are not considered significant at $P \leq 0.10$.

	N	NO_3	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Cl
Time 1 Blade	0.59	0.33	0.27	-0.08	-0.05	0.28	-0.22	0.21	0.07	0.39	-0.12	0.11	-0.27
Time 1 Petiole	0.73	0.39	0.34	0.38	-0.37	0.30	0.10	0.48	0.43	0.19	0.13	0.53	-0.29
Time 2 Blade	0.28	0.12	0.33	-0.33	-0.48	-0.32	0.03	-0.17	-0.01	0.16	-0.13	0.11	-0.18
Time 2 Petiole	-0.05	0.18	0.28	-0.54	-0.61	-0.11	-0.02	0.04	-0.17	-0.02	-0.17	-0.10	-0.26
Time 3 Blade	0.10	0.07	-0.10	0.04	-0.26	-0.14	0.22	0.11	-0.21	-0.28	0.08	0.13	-0.11
Time 3 Petiole	-0.15	-0.02	0.01	-0.33	-0.32	-0.18	-0.08	0.11	-0.11	-0.23	-0.18	-0.17	-0.17

Table 11. Simple correlation (r) between sugarbeet sugar content (pounds per ton) and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled 44, 65, and 87 days after planting. Correlation r values when between -0.11 and 0.11are not considered significant at $P \leq 0.10$.

	N	NO_3	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Cl
Time 1 Blade	0.47	-0.10	0.24	-0.13	-0.49	-0.21	-0.22	0.35	0.34	-0.03	-0.32	0.37	-0.15
Time 1 Petiole	0.40	0.13	0.31	-0.01	-0.61	-0.07	0.04	0.38	0.45	-0.17	-0.30	0.34	-0.20
Time 2 Blade	0.08	-0.26	0.09	-0.02	-0.29	-0.32	-0.13	-0.15	0.35	0.23	-0.02	0.18	0.15
Time 2 Petiole	0.09	-0.13	0.18	-0.16	-0.46	0.04	0.16	0.10	0.12	0.16	0.09	-0.04	-0.07
Time 3 Blade	0.05	-0.14	-0.21	0.20	0.05	0.01	0.05	0.04	-0.36	0.06	0.33	0.37	0.19
Time 3 Petiole	-0.07	-0.03	-0.21	-0.12	-0.10	0.04	-0.02	-0.09	-0.19	0.09	0.22	0.02	0.15

Table 12. Simple correlation (r) between sugarbeet sugar production (pounds per acre) and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled 44, 65, and 87 days after planting. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	NO_3	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Cl
Time 1 Blade	0.60	0.22	0.30	-0.08	-0.16	0.18	-0.26	0.29	0.13	0.34	-0.19	0.18	-0.24
Time 1 Petiole	0.69	0.31	0.34	0.30	-0.47	0.22	0.08	0.51	0.46	0.10	0.01	0.53	-0.30
Time 2 Blade	0.24	0.01	0.29	-0.28	-0.49	-0.39	-0.01	-0.18	0.06	0.18	-0.13	0.14	-0.10
Time 2 Petiole	-0.05	0.08	0.27	-0.50	-0.63	-0.11	0.02	0.06	-0.12	0.01	-0.13	-0.10	-0.22
Time 3 Blade	0.09	0.01	-0.14	0.11	-0.19	-0.11	0.21	0.12	-0.28	-0.23	0.16	0.22	-0.02
Time 3 Petiole	-0.16	-0.04	-0.06	-0.31	-0.28	-0.16	-0.08	0.07	-0.16	-0.20	-0.10	-0.14	-0.09

Table 13. Correlation between leaf blade and petiole nutrient concentration across locations and sample time with the soil test concentration for the same nutrient for soil samples collected at 0-6 and 6-24 inch soil depths.

Nutrient	Plant Part	0-6” Soil Test	6-24” Soil Test
Nitrogen	Leaf Blade	0.49	0.61
	Petiole	0.54	0.75
Nitrate-N	Leaf Blade	0.56	0.67
	Petiole	0.54	0.68
Phosphorus	Leaf Blade	0.43	0.38
	Petiole	0.34	0.35
Potassium	Leaf Blade	0.59	0.35
	Petiole	0.57	0.35
Calcium	Leaf Blade	0.29	0.30
	Petiole	0.43	0.43
Magnesium	Leaf Blade	-0.17	-0.24
	Petiole	-0.02	-0.10
Sulfur	Leaf Blade	0.13	0.03
	Petiole	-0.11	-0.10
Boron	Leaf Blade	0.37	0.49
	Petiole	-0.03	0.03
Copper	Leaf Blade	-0.12	-0.12
	Petiole	0.51	0.36
Iron	Leaf Blade	0.08	0.06
	Petiole	0.07	0.05
Manganese	Leaf Blade	0.29	0.30
	Petiole	0.38	0.21
Zinc	Leaf Blade	0.35	0.65
	Petiole	0.18	0.47
Chloride	Leaf Blade	-0.01	-0.22
	Petiole	0.24	-0.07

Correlations between -0.30 and 0.30 are not significant at $P \leq 0.10$

Table 14. Correlation between leaf blade and petiole nutrient concentration across locations and sample time with the soil test concentration for the same nutrient for soil samples collected at 0-6 and 6-24 inch soil depths.

	Root Yield		Recoverable Sugar (ton)	
DAP	Tissue	Partial R^2	Tissue	Partial R^2
44	Blade N	0.88	Blade Zn	0.58
	Blade B	0.11	Blade S	0.24
	Pet Cl	0.003	Blade P	0.11
		0.99	Blade NO3	0.04
			Pet S	0.02
			Blade Cl	0.01
				0.99
65	Pet Ca	0.55	Blade Mg	0.33
	Pet Cu	0.17	Blade S	0.27
	Blade Mg	0.10	Pet Mn	0.26
		0.82		0.86
87	Pet K	0.30	Blade P	0.61
	Blade Zn	0.23	Blade Mg	0.06
	Pet B	0.31	Blade Cu	0.09
		0.84	Blade Zn	0.11
			Pet Ca	0.11
				0.98

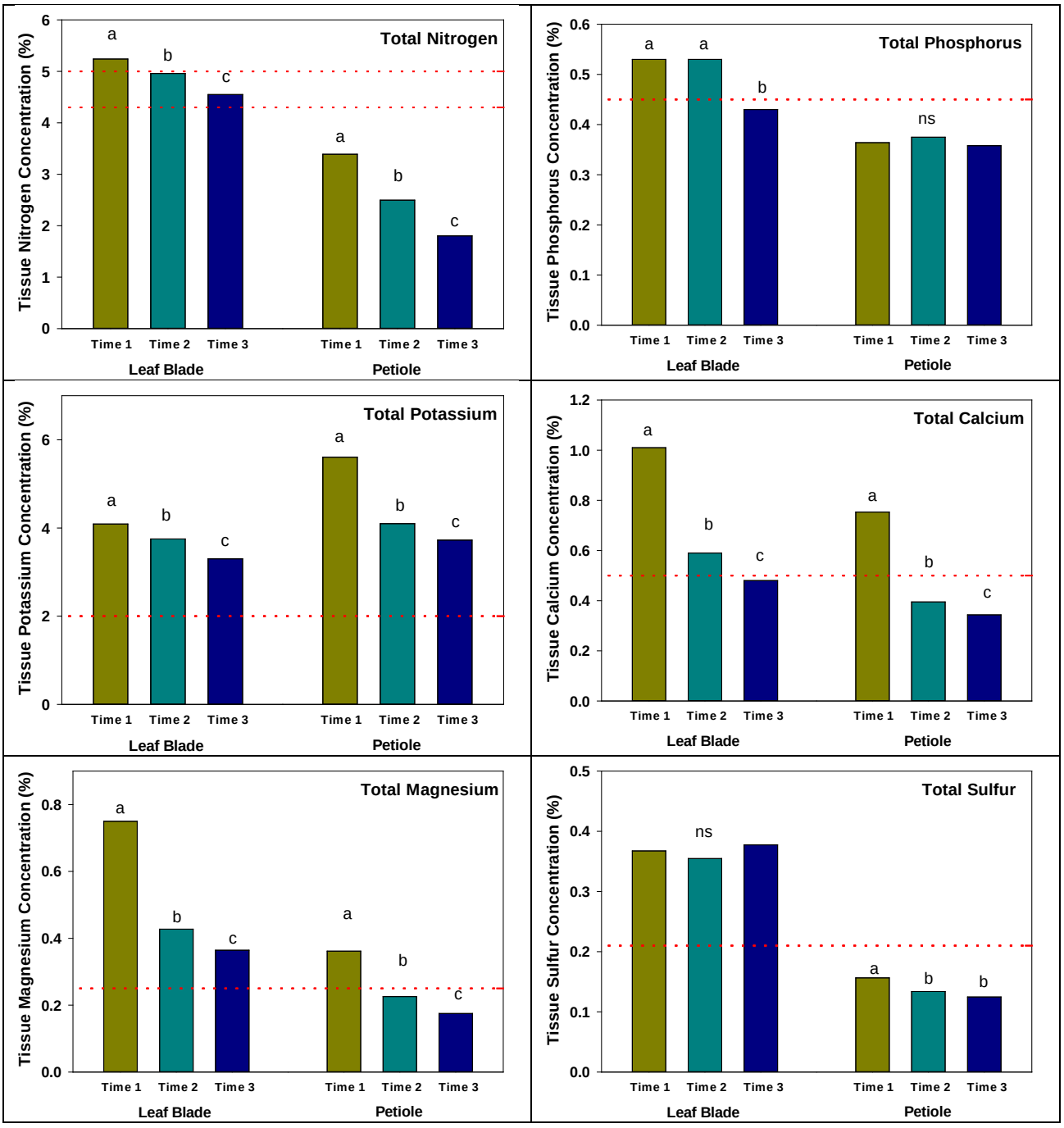

Figure 1. Summary of the impact of time on sugarbeet total macronutrient concentrations for leaf blade and petiole samples collected from six sugarbeet varieties. Letters denote significance among sampling times for leaf blade or petiole samples at $P \leq 0.10$. Horizontal dashed lines represent the upper and lower end of the sufficiency range for leaf blade samples according to Bryson et al., 2014. A single dashed line represents the low end of the sufficiency range.

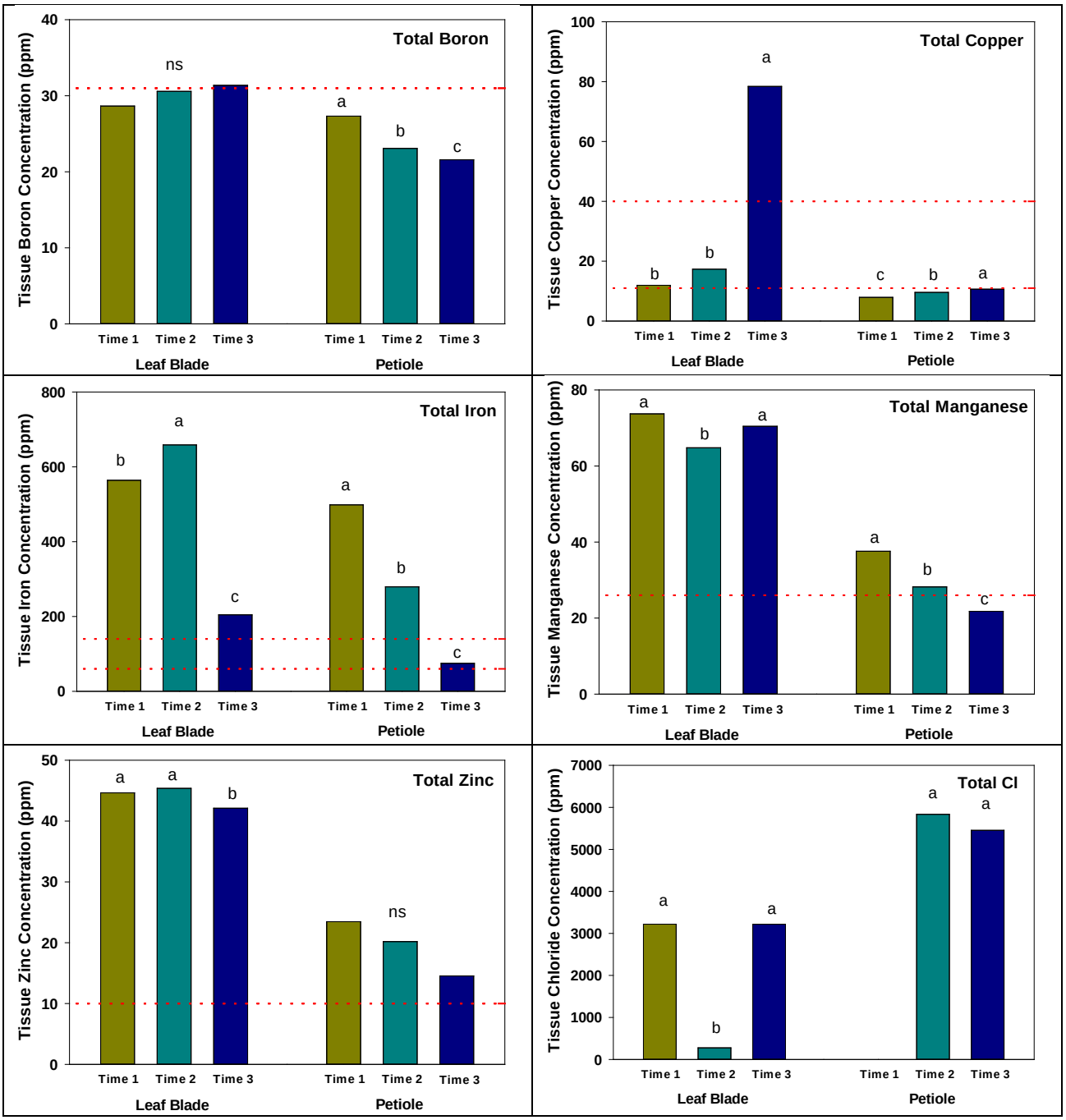

Figure 2. Summary of the impact of time on sugarbeet total micronutrient concentrations for leaf blade and petiole samples collected from six sugarbeet varieties. Letters denote significance among sampling times for leaf blade or petiole samples at $P \leq 0.10$. Horizontal dashed lines represent the upper and lower end of the sufficiency range for leaf blade samples according to Bryson et al., 2014. A single dashed line represents the low end of the sufficiency range.

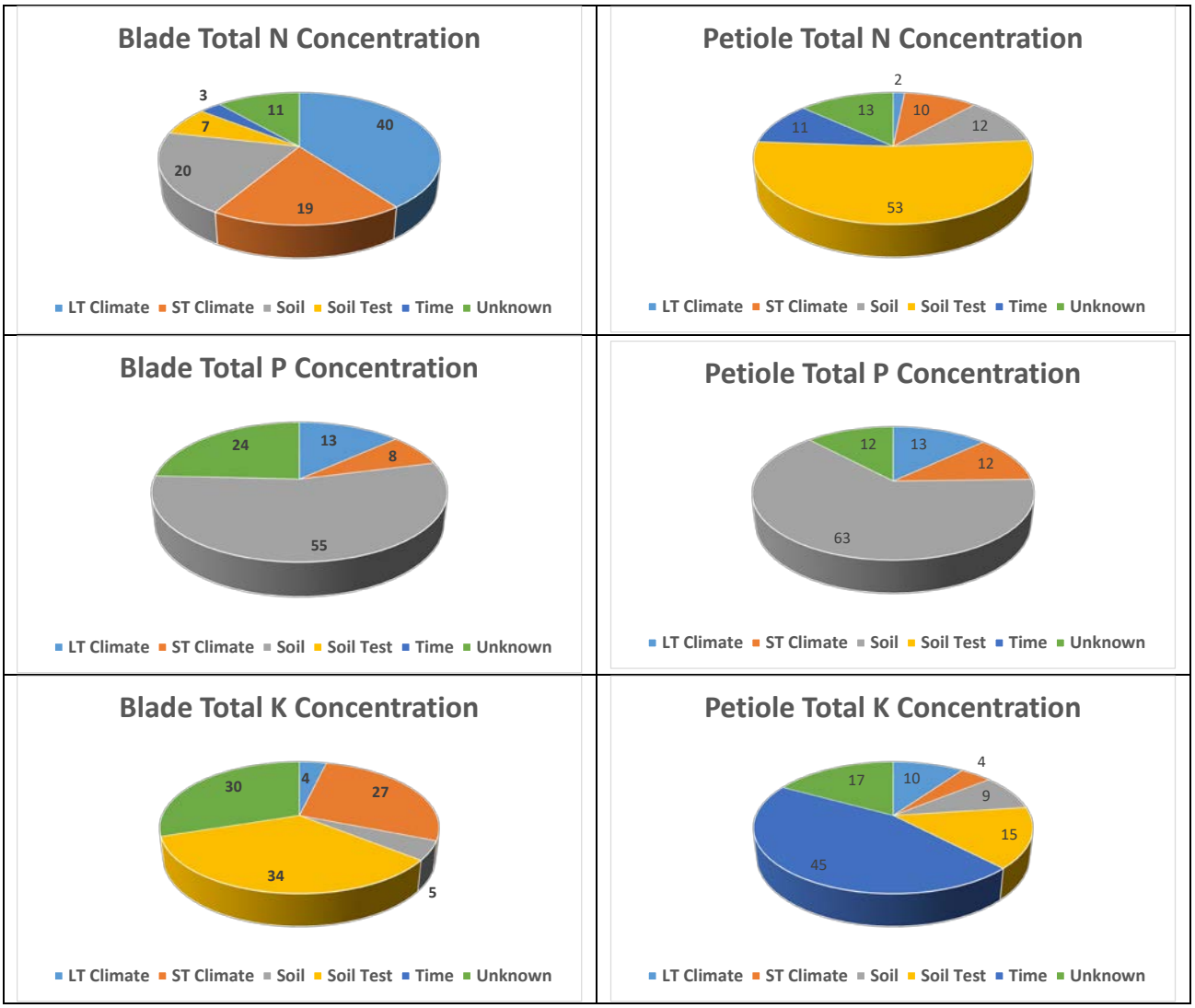

Figure 3. Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet primary macro-nutrient concentration. Long term (LT) climate factors represent temperature averages or precipitations total of greater than 2 week or greater while short term (ST) represent totals 2 weeks or less. Unknown factors represent the portion of the R^2 not predicted by the model.

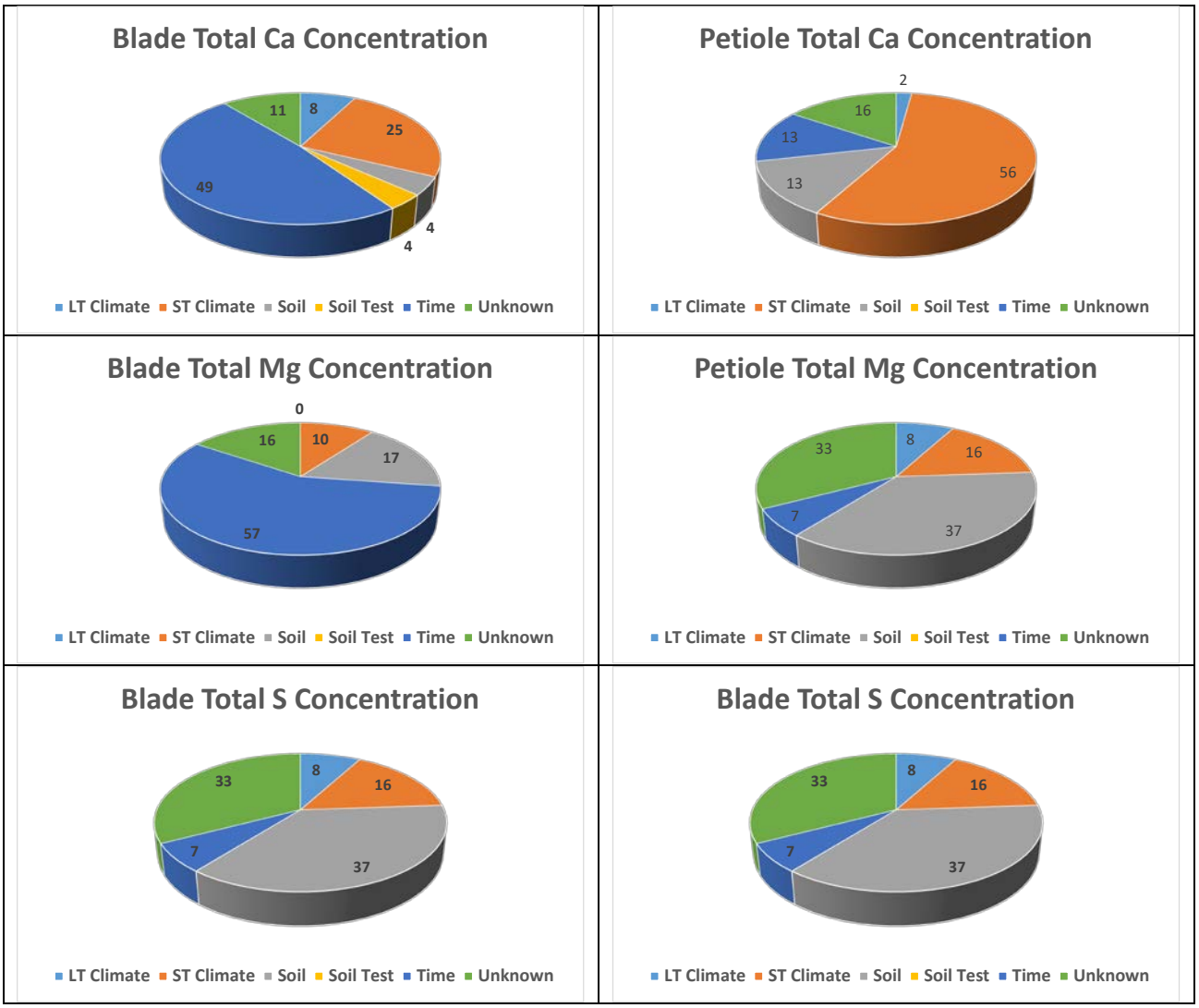

Figure 4 Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet secondary macro-nutrient concentration. Long term (LT) climate factors represent temperature averages or precipitations total of greater than 2 week or greater while short term (ST) represent totals 2 weeks or less. Unknown factors represent the portion of the R^2 not predicted by the model.

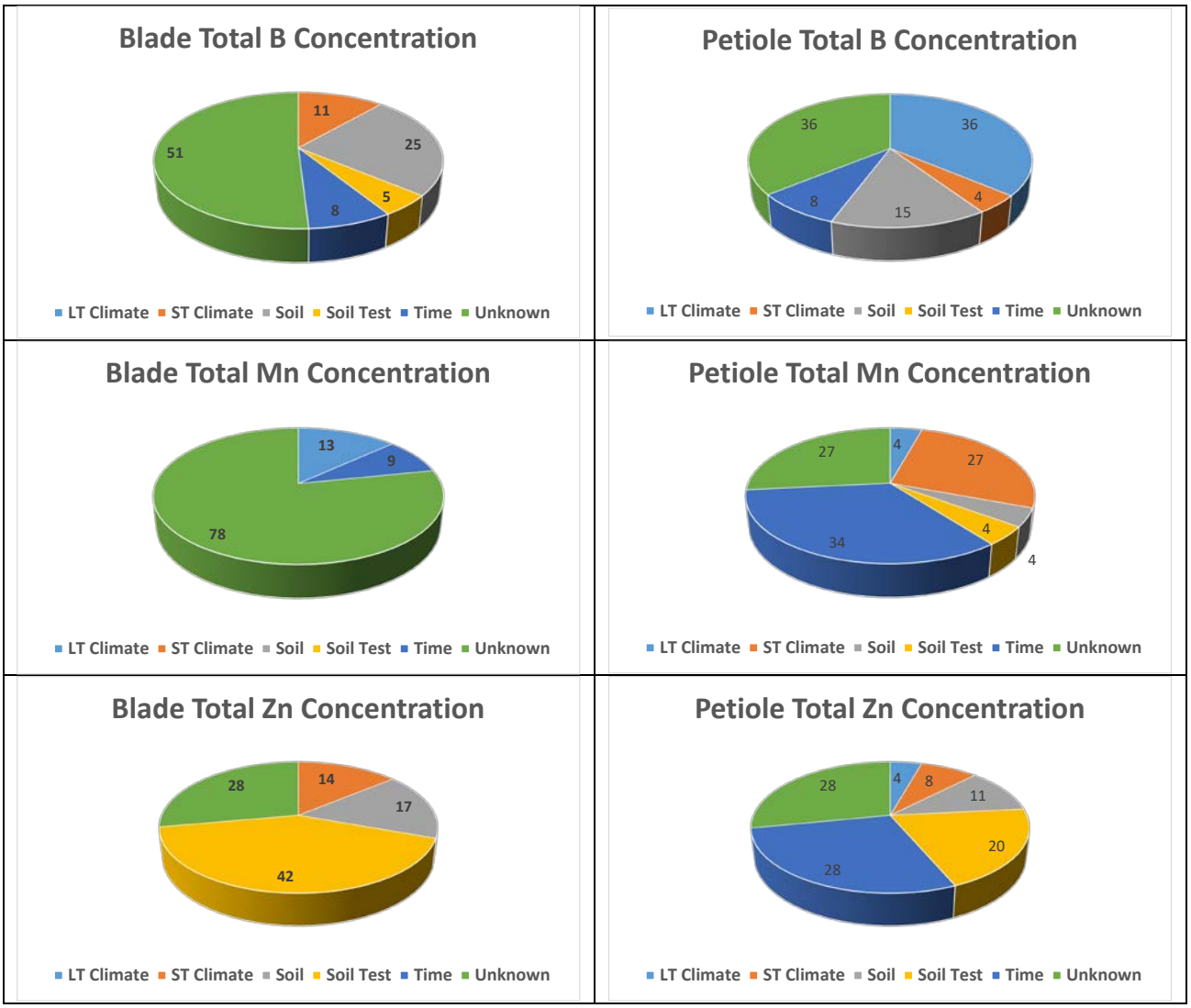

Figure 5. Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet micro-nutrient concentration. Long term (LT) climate factors represent temperature averages or precipitations total of greater than 2 week or greater while short term (ST) represent totals 2 weeks or less. Unknown factors represent the portion of the R^2 not predicted by the model.

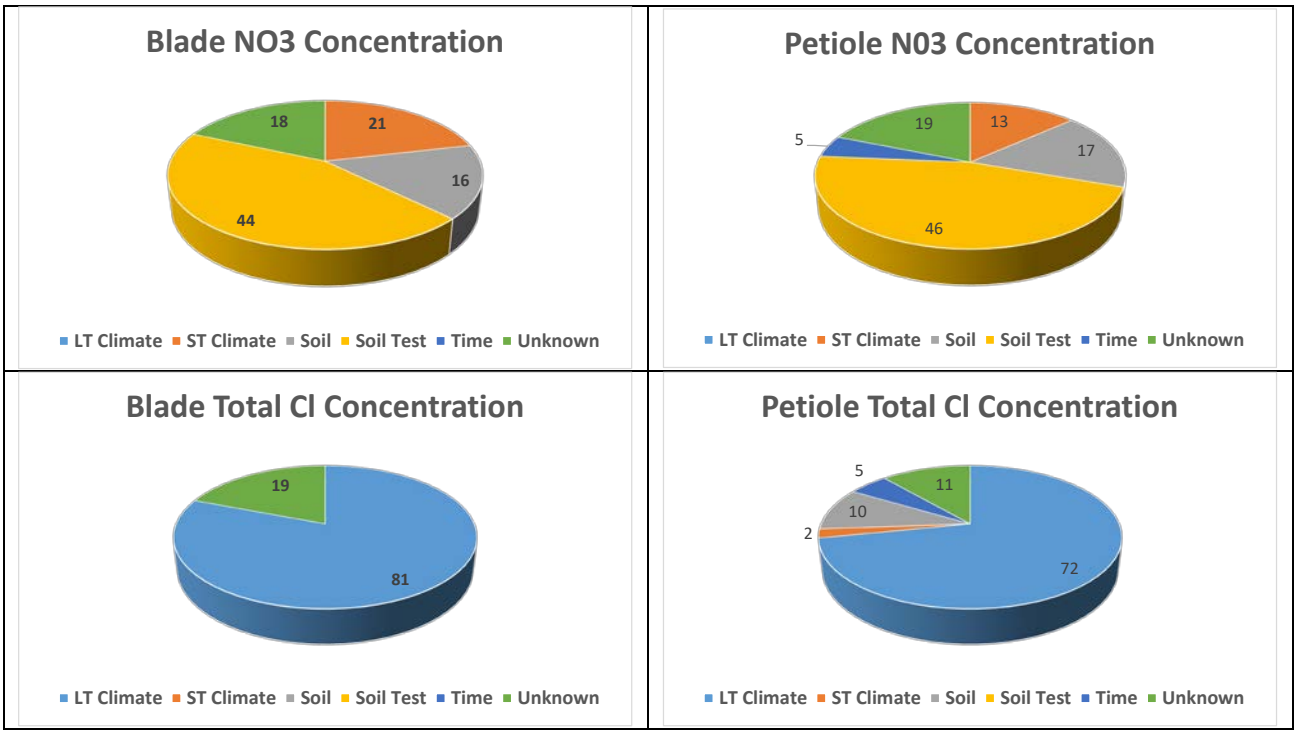

Figure 6. Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet nitrate nitrogen and chloride concentration. Long term (LT) climate factors represent temperature averages or precipitations total of greater than 2 week or greater while short term (ST) represent totals 2 weeks or less. Unknown factors represent the portion of the R^2 not predicted by the model.

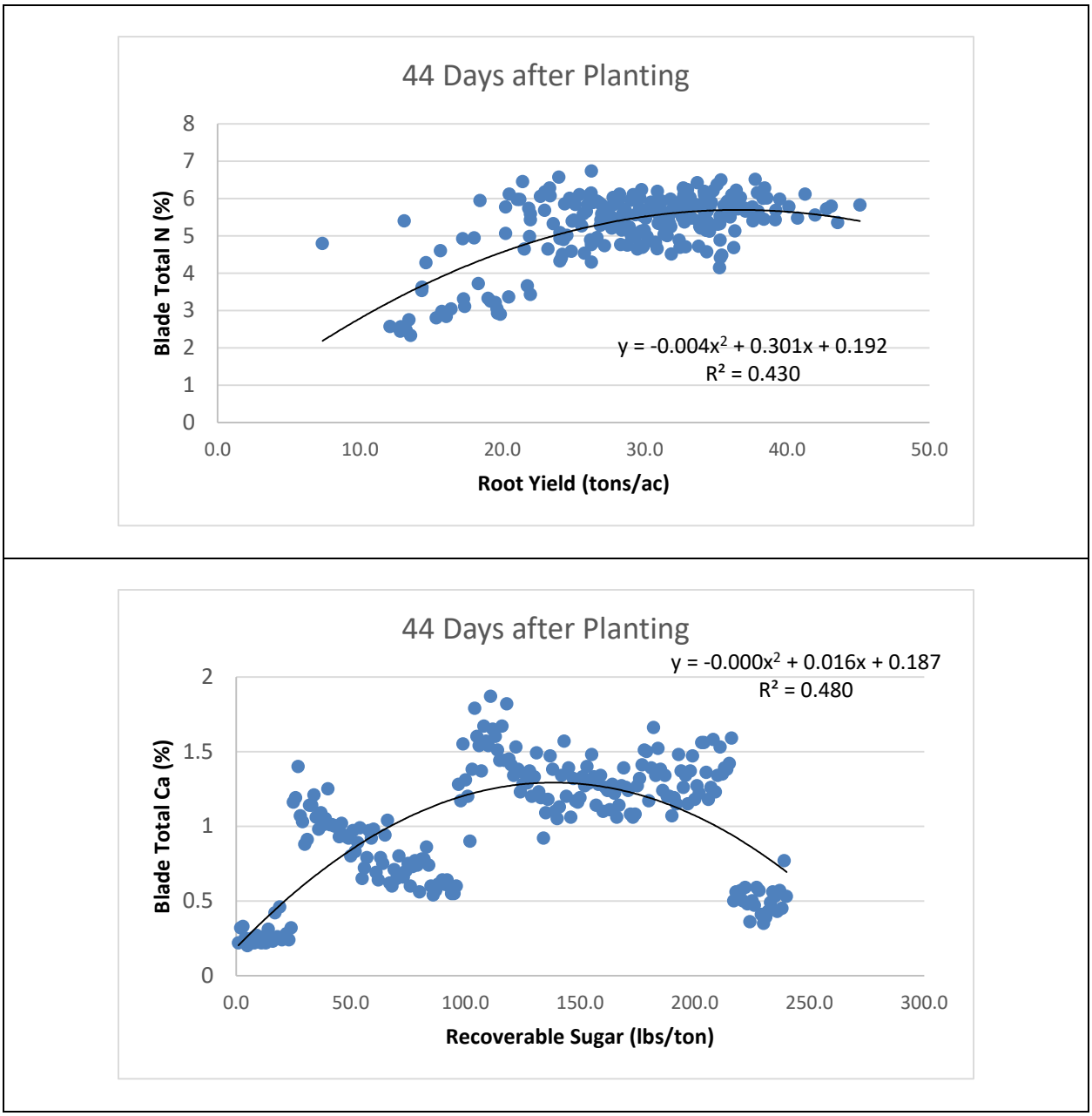

Figure 7. Relationship between blade total N concentration and root yield and blade total Ca concentration on recoverable sugar for tissue samples collected 44 days after planting.

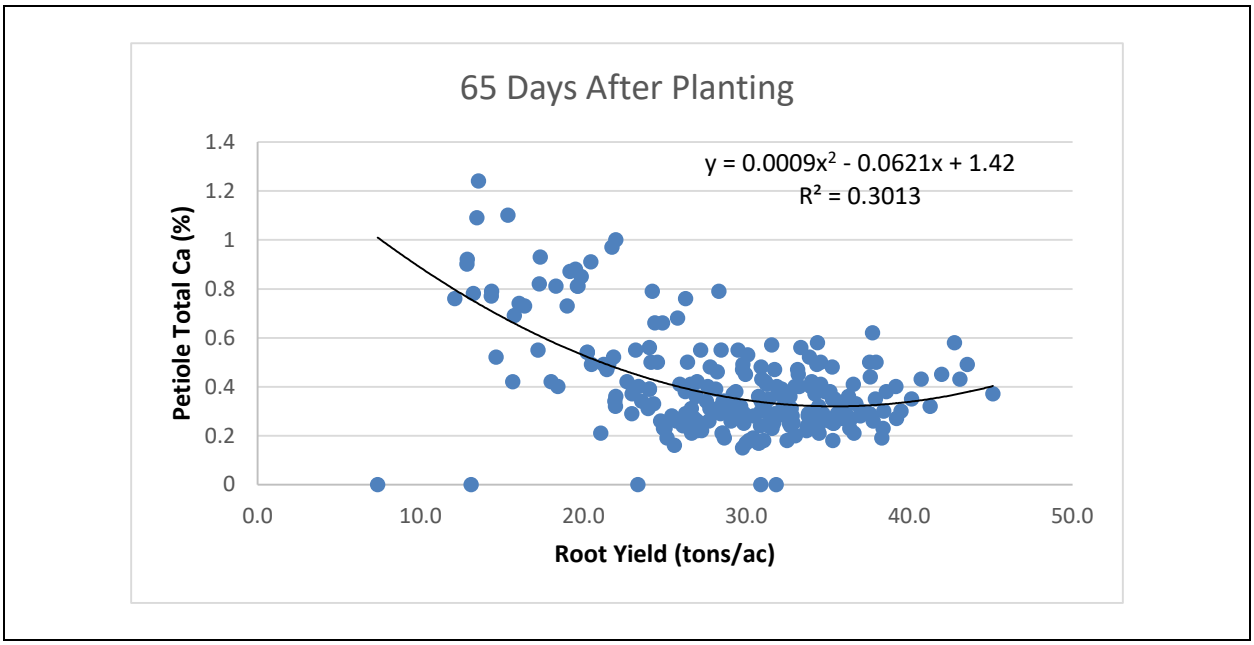

Figure 8. Relationship between petiole total Ca concentration and sugarbeet root yield for petiole samples collected 65 days after planting.