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 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 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, and Zn and for pH, soil organic matter, and cation exchange capacity (CEC). 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 and 2b.

Root yield, sugar content per ton, and sugar content produced per acre varied among the six varieties across all four 2017 (Table 3a) and 2017 (Table 3b) locations. The four site average for each of the variables is given in Tables 3a and 3b. 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 all nutrient concentrations. Nutrient concentrations differed among locations except for calcium, magnesium, sulfur, and zinc which did not differ based on location. The location by time interaction was significant for nearly all nutrients except for nitrate-N, calcium, magnesium, and zinc. The time by variety and the three-way interaction of time x location x variety was mostly not significant. The exceptions for the location by variety interaction were total nitrogen, potassium, sulfur, boron, copper, and chloride where the two-way interaction was significant. The three-way time by location by variety interaction was significant for total nitrogen, potassium, sulfur, copper, and manganese. 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. Mobile nutrients (N, P, Ca, Mg) exhibited a general decrease in concentration for both leaf blade and petiole tissue over time except for potassium where the leaf blade tissue was relatively unchanged over time and the petiole potassium concentration decreased. The opposite effect was found for immobile nutrients (B, Cu, Mn, and Zn) where concentration increased over time. 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. 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.

Simple correlation between individual nutrient concentration in the leaf blade and petiole at each sampling time and sugarbeet root yield is summarized in Table 8. There were significant positive and negative correlations among many of the nutrients studied. The only nutrient which consistently showed little to no correlation with root yield was tissue phosphorus concentration. There was not instance where a single nutrient always showed a positive correlation with root yield. For example, total nitrogen content in the leaf blade and petiole was positively correlated with root yield at T1 but was not correlated by T3. The greatest correlation was between leaf blade total N at T1 and root yield ($r=0.79$) 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 T3 and leaf blade total phosphorus concentration at T1.

Table 9 summarizes the correlation between plant tissue and sucrose content and Table 10 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.

Correlations between individual nutrient concentrations and their respective soil test collected at the time of tissue sampling are summarized in Table 11. Significant positive correlations were found between soil test N (along with Nitrate-N), P, and K with leaf blade and petiole N, P, and K, respectively. 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 and K soil test values. For micronutrients, there were not significant correlations between leaf blade and petiole micronutrient 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 (1 week or greater) or short term (less than 1 week) 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.

Long term climatic effects explained over half of the variation leaf blade total N concentration and leaf blade and petiole total Cl concentration. There were more consistent effects for short term climatic factors. Soil test and other soil factors seldom explained a significant amount of variation in specific tissue nutrient concentrations followed by the time factor.

Conclusions: The data presented in the reports if for the first and second year of a three-year study assessing the variation in tissue nutrient concentration among sugar beet varieties. 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 mobile nutrients will decrease while the concentration of most immobile nutrients will increase 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. Data outlining a single sampling time is warranted to narrow down sufficiency levels for most nutrients. 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.

Literature Cited

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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	23	60	18
LL	8-May	21-Jun	12-Jul	2-Aug	Nicollet	A Hapludoll	33.7	28.7	35	33	33
M	29-Apr	21-Jun	12-Jul	2-Aug	Bearden-Quam	Ae Calciaquoll	28.0	22.2	15	45	40
R	6-May	21-Jun	11-Jul	1-Aug	Chetomba	T Endoaquoll	31.1	24.4	28	38	35
					2018						
CC	17-May	27-Jun	18-Jul	14-Aug	Bearden-Quam	Ae Calciaquoll	30.9	20.9	15	48	38
H	10-May	21-Jun	9-Jul	2-Aug	Crippin	A.P. Hapludoll	35.8	28.5	10	48	43
LL	7-May	21-Jun	9-Jul	2-Aug	Nicollet	A Hapludoll	31.3	23.7	28	38	35
M	18-May	27-Jun	16-Jul	14-Aug	Bearden-Quam	Ae Calciaquoll	35.2	28.2	8	50	43

‡A, aquic; Ae, aeric; A.P., aquic pachic; 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 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*≤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 3a. 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 $P \leq 0.10$.

Location	Variety						
	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 4. Summary of analysis of variance for leaf blade 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	***	***	***	***	*	**	*
Nitrate-N	*	0.08	0.12	0.14	0.21	0.48	0.57
Phosphorus	***	***	***	***	0.43	*	0.09
Potassium	***	***	***	***	***	*	**
Calcium	0.07	0.22	0.19	0.19	0.32	0.63	0.55
Magnesium	0.07	0.22	0.18	0.18	0.47	0.54	0.55
Sulfur	***	0.17	***	***	**	***	**
Boron	***	***	***	***	***	***	0.11
Copper	***	0.24	***	***	***	*	**
Iron	***	***	***	***	**	0.26	0.33
Manganese	***	***	***	***	***	0.15	**
Zinc	0.45	0.23	0.37	0.44	0.51	0.70	0.69
Chloride	***	***	***	***	0.06	0.08	0.21

†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	***	***	***	***	***	**	***
Nitrate-N	***	***	***	***	***	0.06	*
Phosphorus	**	***	***	***	*	0.38	**
Potassium	***	***	***	***	***	**	**
Calcium	***	0.11	***	***	***	***	0.10
Magnesium	*	0.10	0.09	0.12	0.13	0.38	0.36
Sulfur	***	***	***	***	0.45	0.06	**
Boron	***	***	***	***	**	0.30	0.40
Copper	***	***	***	***	0.11	0.38	***
Iron	***	***	***	0.18	***	***	***
Manganese	***	**	***	***	***	**	0.10
Zinc	***	0.20	*	0.49	0.78	0.27	0.68
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 eight locations from 2017-2018 and three sampling times at each location. Within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

Nutrient	Variety						Suffic.†
	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509	
	---% ---						
Total-N	5.09a	4.72b	4.69bc	4.66bc	4.63c	4.71b	4.3-5.0
Phosphorus	0.49a	0.50a	0.42d	0.44c	0.41d	0.47b	0.45-1.1
Potassium	3.80a	3.63b	3.45c	3.48c	3.57b	3.48c	2.0-6.0
Calcium	0.69	0.77	0.76	0.67	0.68	0.72	0.5-1.5
Magnesium	0.48	0.54	0.58	0.51	0.52	0.53	0.25-1
Sulfur	0.37a	0.35d	0.34e	0.36c	0.35d	0.37b	0.21-0.5
	---ppm---						
Nitrate-N	778	433	649	667	509	561	
Boron	31b	32a	32a	29c	31b	29c	31-200
Copper	39b	46a	39b	37b	45a	36b	11-40
Iron	439ab	342c	435ab	398b	450a	457a	60-140
Manganese	67cd	72b	80a	66d	83a	70bc	26-360
Zinc	43	37	41	40	43	43	10-80
Chloride	2992bcd	3512a	3039bc	3120b	2937cd	2934d	

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

Table 7. Varietal differences in petiole nutrient concentration across eight locations from 2017-2018 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	2.29cd	2.35b	2.41a	2.23de	2.21e	2.35bc
Phosphorus	0.32c	0.40a	0.32c	0.32c	0.30d	0.34b
Potassium	4.25b	4.32b	4.01d	4.16c	4.00d	4.56a
Calcium	0.44d	0.57a	0.51b	0.47c	0.49b	0.59a
Magnesium	0.25	0.27	0.28	0.24	0.24	0.24
Sulfur	0.11b	0.13a	0.11b	0.12b	0.11b	0.12b
	---------------------	---------------------	-----ppm	-----------------	---------------------	---------------------
Nitrate-N	4311c		5315a	4281c	3997c	4777b
Boron	0.23c	0.26a	0.24b	0.24b	0.23c	0.26a
Copper	8.3a	8.5a	7.5b	8.6a	7.4b	8.4a
Iron	295	285	266	257	292	276
Manganese	28c	29b	28c	26d	34a	30b
Zinc	18	19	15	16	16	18
Chloride	4980b		5880a	5742a	5665a	6103a

Table 8. Simple correlation (r) between sugarbeet root yield and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled 45, 65, and 88 days after planting. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	NO3	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Cl
Time 1 Blade	0.79	0.37	0.61	0.05	-0.21	0.26	-0.17	0.33	0.31	0.47	0.03	0.65	-0.30
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	0.35	0.08	0.38	-0.32	-0.64	-0.42	-0.03	-0.21	0.58	0.05	-0.41	0.11	-0.15
Time 2 Petiole	0.01	0.19	0.33	-0.53	-0.67	-0.10	0.05	0.01	-0.07	0.12	-0.26	-0.10	-0.31
Time 3 Blade	0.07	-0.13	-0.22	0.13	-0.27	-0.17	-0.16	0.11	-0.27	-0.30	0.12	0.11	-0.09
Time 3 Petiole	-0.26	-0.07	0.03	-0.32	-0.32	-0.18	-0.16	0.14	-0.06	-0.37	-0.05	-0.19	-0.20

Table 9. Simple correlation (r) between sugarbeet sugar content (pounds per ton) and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled 45, 65, and 88 days after planting. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	NO3	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Cl
Time 1 Blade	0.52	-0.09	0.36	-0.11	-0.56	-0.18	-0.46	0.33	0.33	0.05	-0.38	0.49	-0.04
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	0.10	-0.25	0.17	-0.05	-0.38	-0.34	-0.24	-0.14	0.51	0.16	-0.14	0.17	0.22
Time 2 Petiole	0.10	-0.11	0.29	-0.18	-0.50	0.06	0.20	0.18	0.09	0.10	0.06	-0.05	-0.02
Time 3 Blade	0.03	-0.20	-0.33	0.31	0.14	0.08	0.11	0.06	-0.36	0.02	0.45	0.42	0.29
Time 3 Petiole	-0.24	-0.01	-0.24	-0.08	-0.09	-0.02	-0.22	-0.12	-0.28	-0.22	0.21	-0.07	0.23

Table 10. Simple correlation (r) between sugarbeet sugar production (pounds per acre) and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled 45, 65, and 88 days after planting. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	NO3	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Cl
Time 1 Blade	0.78	0.24	0.61	0.03	-0.33	0.15	-0.29	0.41	0.34	0.42	-0.08	0.68	-0.25
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	0.29	-0.04	0.34	-0.26	-0.64	-0.48	-0.07	-0.21	0.63	0.06	-0.40	0.14	-0.05
Time 2 Petiole	-0.01	0.09	0.33	-0.49	-0.68	-0.10	0.10	0.05	-0.02	-0.10	-0.21	-0.10	-0.25
Time 3 Blade	0.05	-0.19	-0.29	0.21	-0.17	-0.13	0.16	0.12	-0.32	-0.26	0.24	0.21	0.01
Time 3 Petiole	-0.31	-0.09	-0.06	-0.28	-0.28	-0.18	-0.21	0.09	-0.14	-0.36	0.02	-0.18	-0.10

Table 11. 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	0.40	0.57
	Petiole	0.56	0.78
Nitrate-N	Leaf Blade	0.58	0.72
	Petiole	0.57	0.83
Phosphorus	Leaf Blade	0.45	0.32
	Petiole	0.34	0.25
Potassium	Leaf Blade	0.58	0.30
	Petiole	0.44	0.12
Calcium	Leaf Blade	0.27	0.16
	Petiole	0.45	0.27
Magnesium	Leaf Blade	-0.08	0.24
	Petiole	-0.03	-0.08
Sulfur	Leaf Blade	0.01	-0.13
	Petiole	0.21	0.25
Boron	Leaf Blade	0.18	0.41
	Petiole	-0.05	-0.15
Copper	Leaf Blade	0.22	0.17
	Petiole	0.27	0.18
Iron	Leaf Blade	0.10	0.08
	Petiole	0.04	0.02
Manganese	Leaf Blade	0.21	0.13
	Petiole	0.38	0.03
Zinc	Leaf Blade	0.28	0.35
	Petiole	0.03	0.12
Chloride	Leaf Blade	0.06	-0.23
	Petiole	0.25	-0.15

Correlations between -0.40 and 0.40 are not significant at $P \leq 0.10$

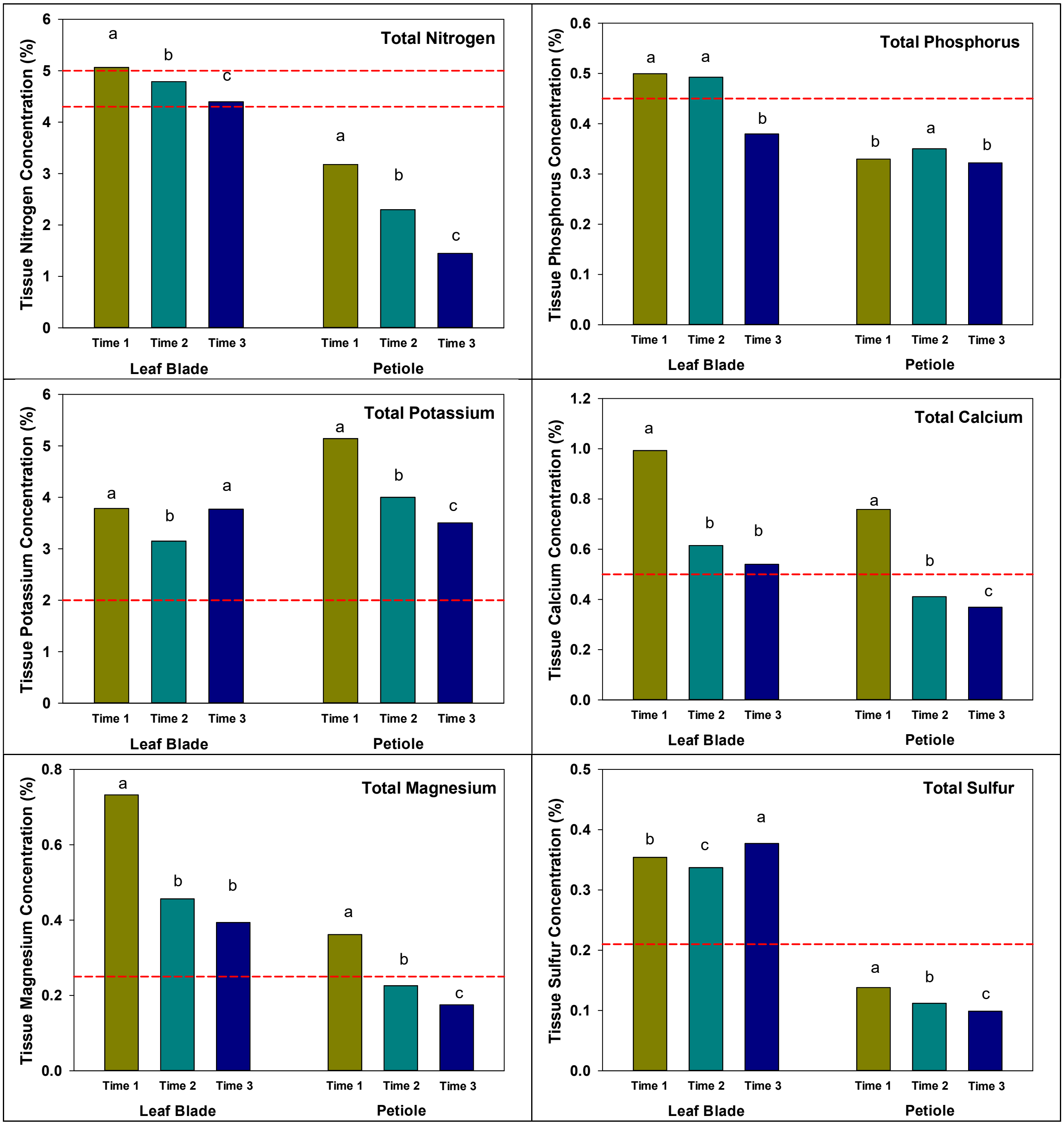

Figure 1. Summary of the impact of time on sugarbeet total macronutrient concentrations for leaf blade and petiole samples collected from six sugarbeet varieties. Letters denote significance among sampling times for leaf blade or petiole samples at $P \leq 0.10$. Horizontal dashed lines represent the 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.

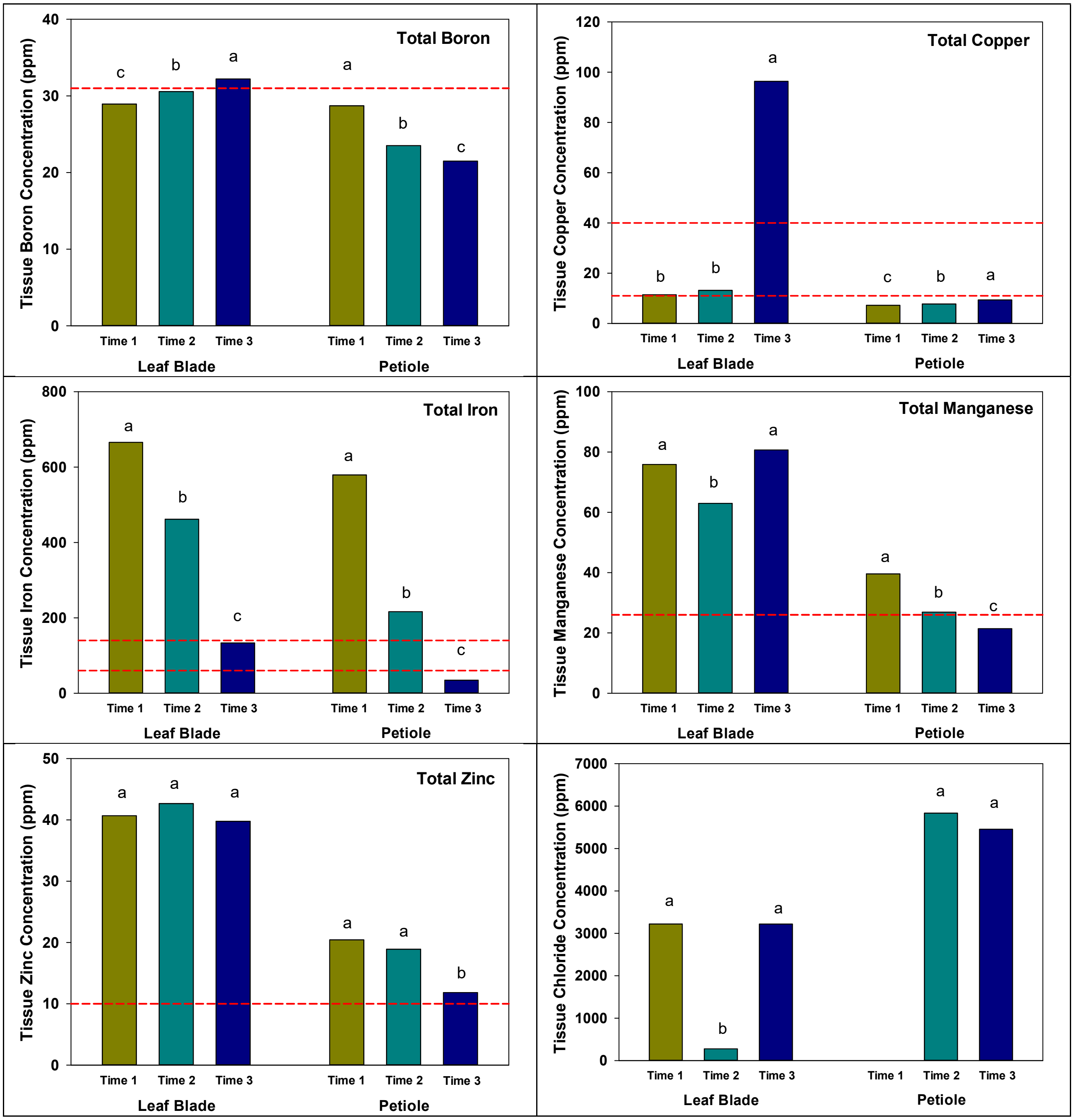

Figure 2. Summary of the impact of time on sugarbeet total micronutrient concentrations for leaf blade and petiole samples collected from six sugarbeet varieties. Letters denote significance among sampling times for leaf blade or petiole samples at $P \leq 0.10$. Horizontal dashed lines represent the 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.

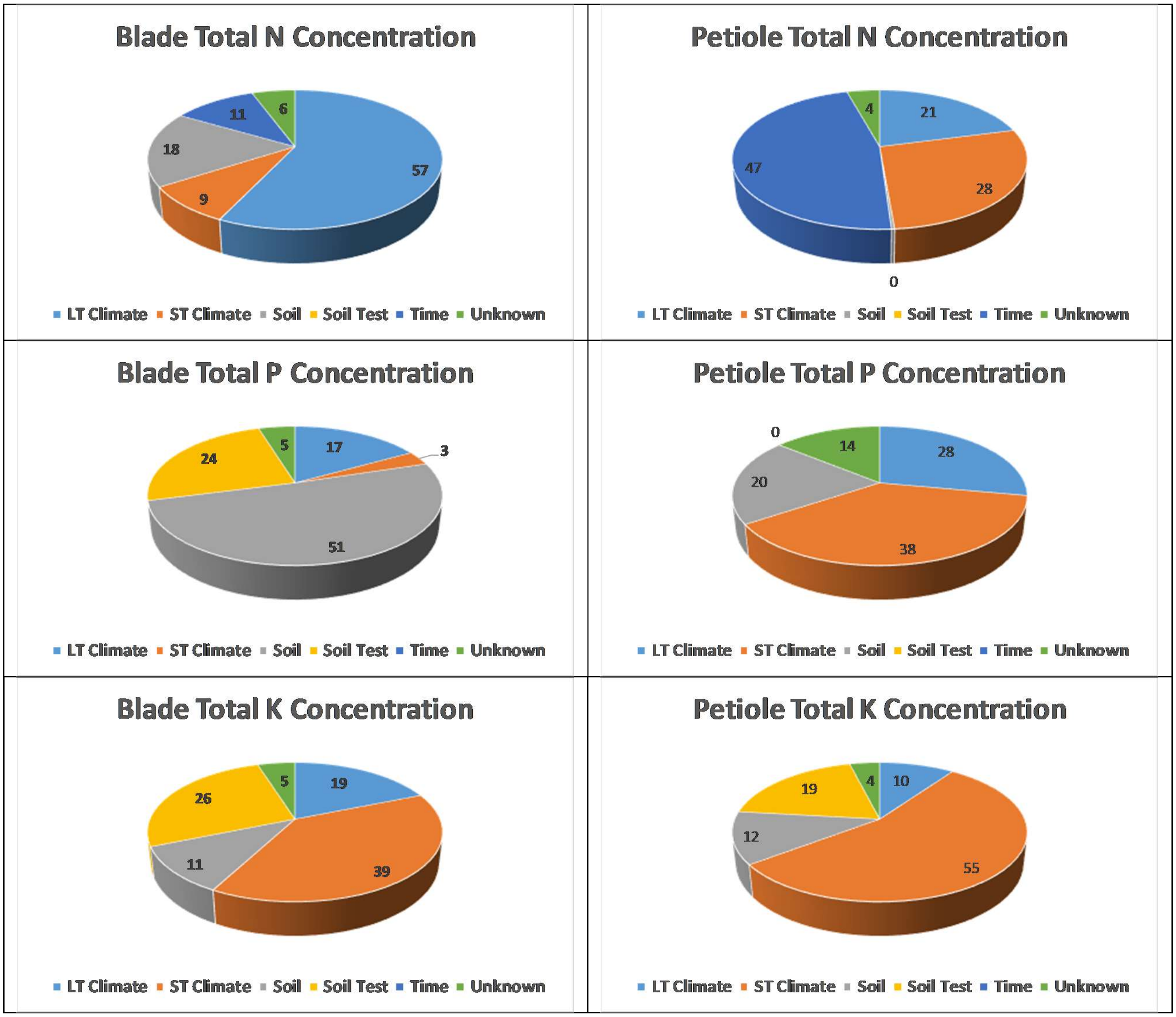

Figure 3. Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet primary macro-nutrient concentration. Long term (LT) climate factors represent temperature averages or precipitations total of 1 week or greater while short term (ST) represent totals less than a week. Unknown factors represent the portion of the R^2 not predicted by the model.

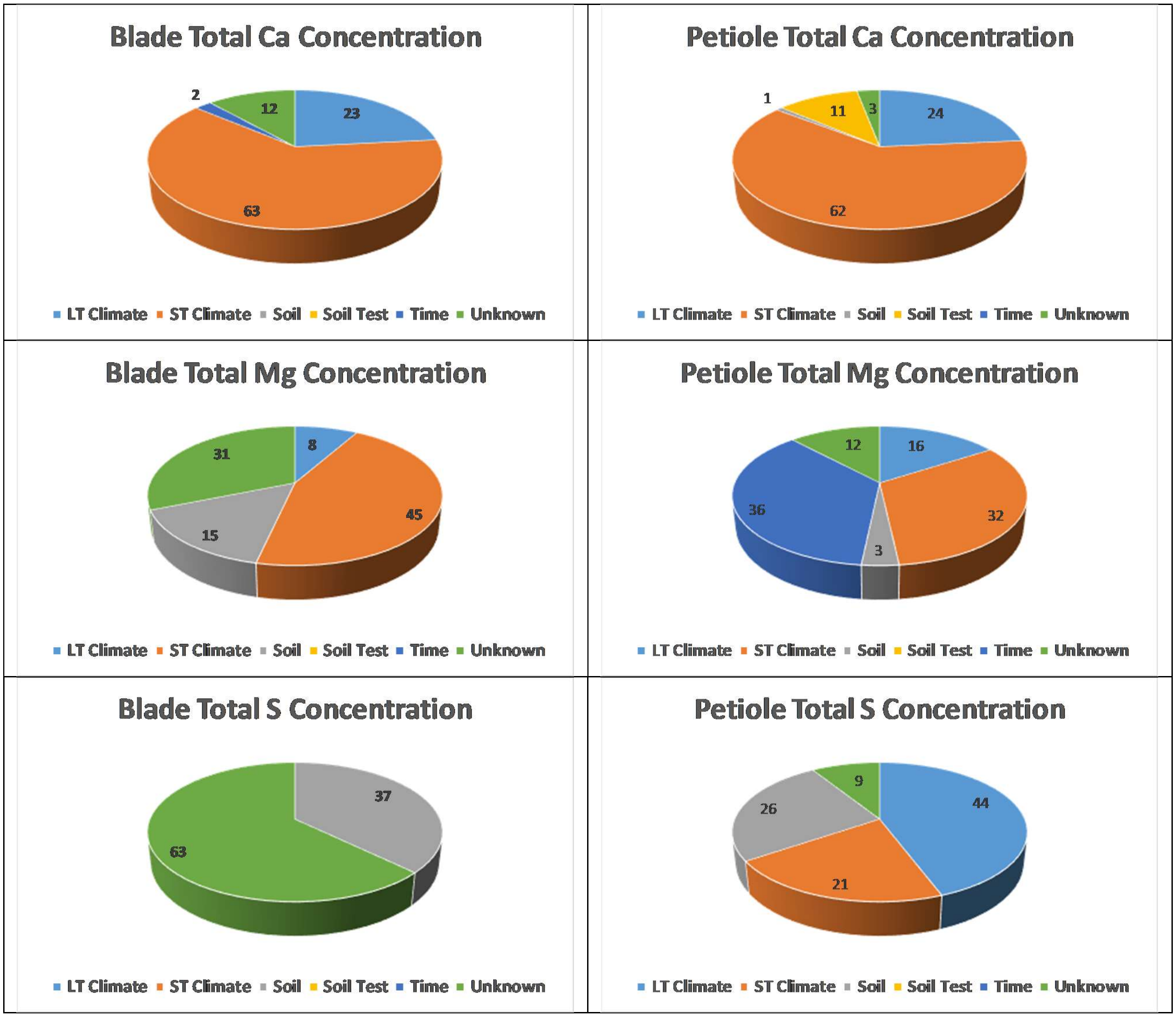

Figure 4 Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet secondary macro-nutrient concentration. Long term (LT) climate factors represent temperature averages or precipitations total of 1 week or greater while short term (ST) represent totals less than a week. Unknown factors represent the portion of the R^2 not predicted by the model.

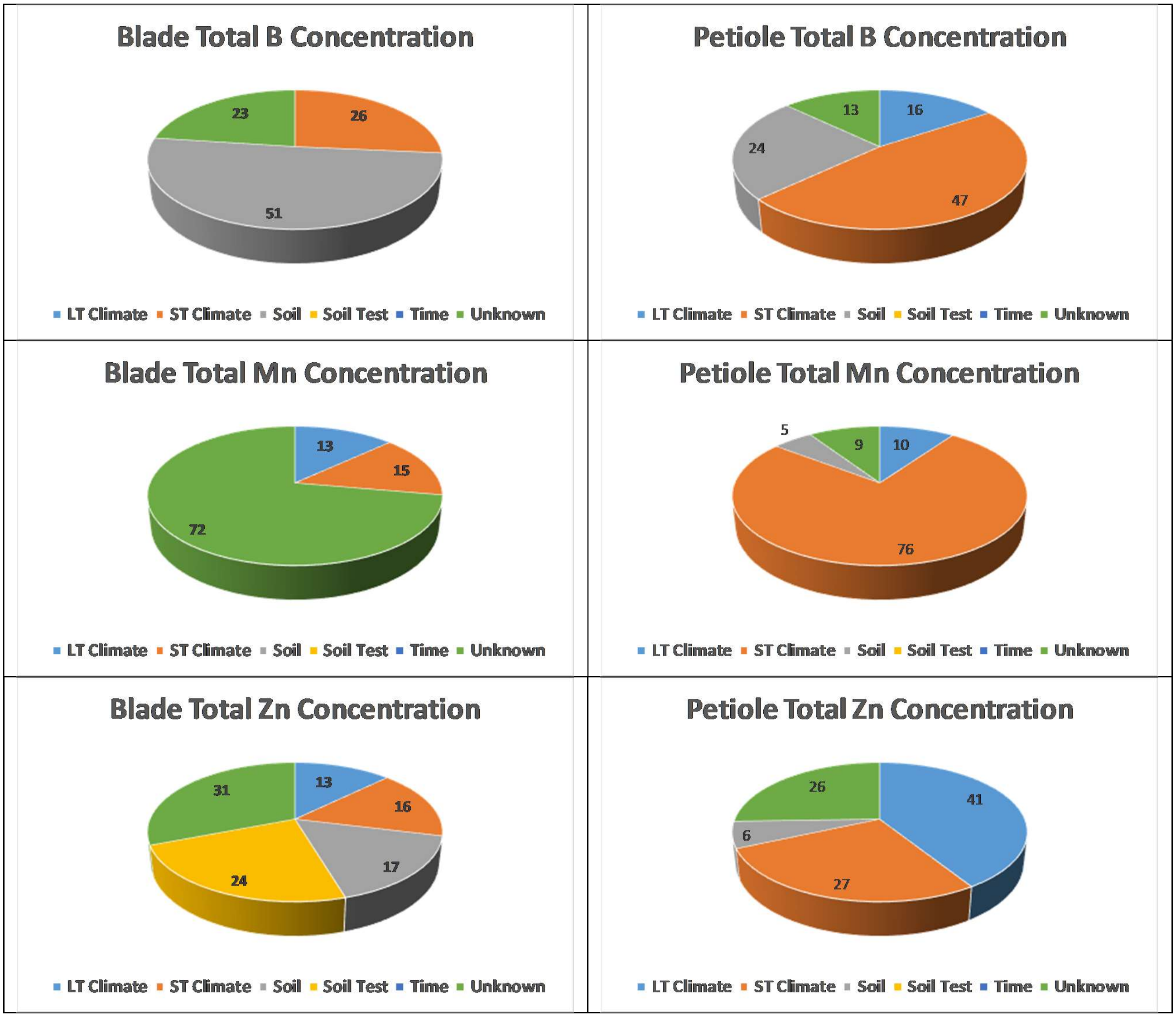

Figure 5. Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet micro-nutrient concentration. Long term (LT) climate factors represent temperature averages or precipitations total of 1 week or greater while short term (ST) represent totals less than a week. Unknown factors represent the portion of the R^2 not predicted by the model.

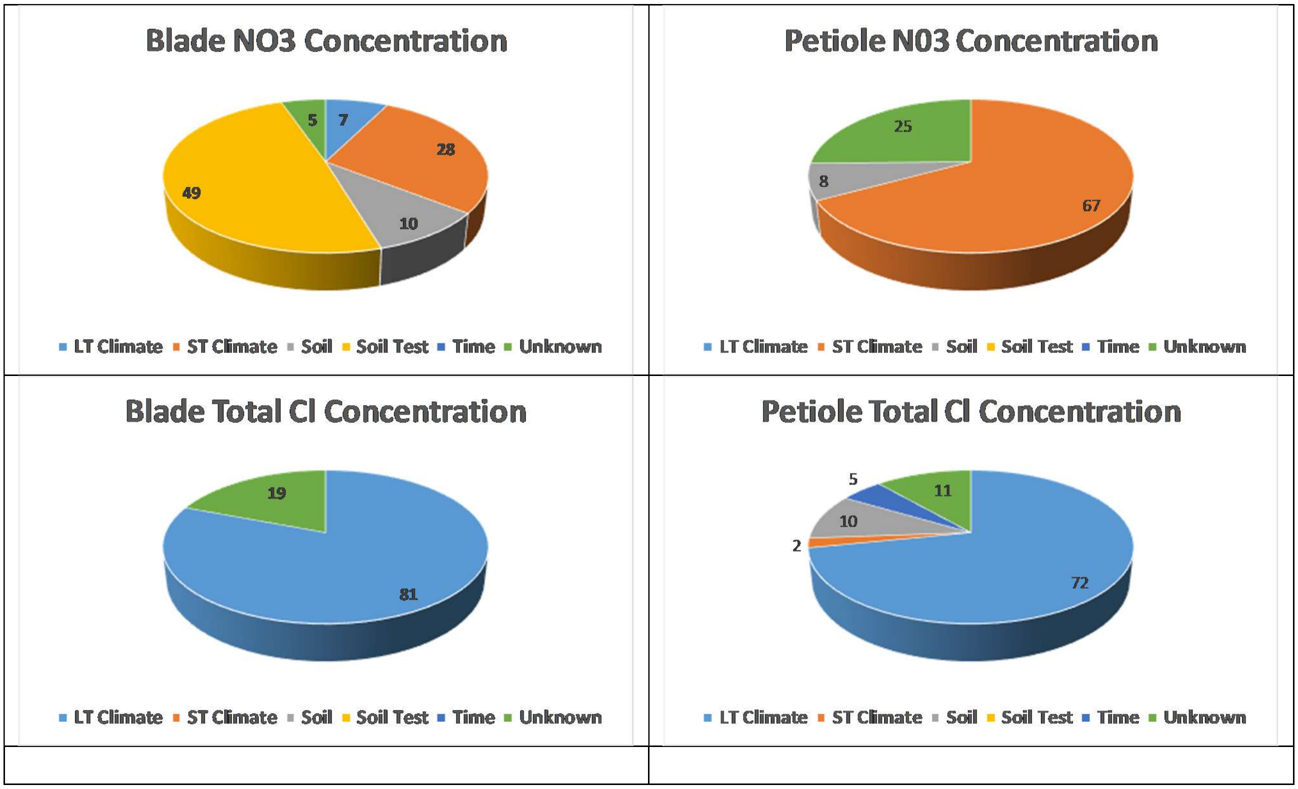

Figure 6. Summary of multiple regression output summarizing climate and soil relationships prediction of sugarbeet nitrate nitrogen and chloride concentration. Long term (LT) climate factors represent temperature averages or precipitations total of 1 week or greater while short term (ST) represent totals less than a week. Unknown factors represent the portion of the R^2 not predicted by the model.