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 for Clara City, Lake Lillian, Murdock, and Renville, respectively, were 48, 44, 53, and 46 days after planting (DAP) for sample date 1; 69, 65, 74, and 66 DAP for sample date 2; and 89, 96, 96, and 87 DAP for sample date 3 (Table 1). Soil types, chemical properties, and cation exchange capacity was similar among soils at the four locations. Results for chemical soil tests for samples collected from each location at the time samples were collected are summarized in Table 2.

Root yield, sugar content per ton, and sugar content produced per acre varied among the six varieties across all four locations (Table 3). The four site average for each of the variables is given in Table 3. However, analysis indicated a significant interaction between site and variety 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. 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 in Table 4. The effect of time and variety was significant for all nutrient concentrations Nutrient concentrations differed among locations for all nutrients except for calcium. The location by time interaction was significant for nearly all nutrients while the time by variety and the three-way interaction of time x location x variety was consistently non-significant. 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 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, but the boron concentration in the leaf blade tissue did not necessarily indicate that boron was limiting yield.

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 exception was potassium 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 increased and the petiole potassium concentration decreased. The opposite effect was found for immobile nutrients (S, 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.

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 negatively correlated by T3. The greatest correlation was between leaf blade Fe and root yield ($r=0.69$). However, differences in Fe concentration early in the growing season can be impacted by the number and size of leaves on the plant which affects contamination of plant tissue by Fe splashed onto the leaves by raindrops hitting the soil.

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 any 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, 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, the only significant positive correlation was between leaf blade Cu and Zn and their soil test values and leaf blade boron and the boron soil test at 6-24 inches. 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. 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. Further work is planned for the sugarbeet data but the 2017 data at four sites was not enough to conduct a correlation between outside factors and concentration. Further research is planned using the same varieties in subsequent years which will be needed to fully determine what factors can explain variations in tissue nutrient concentrations among sites and varieties.

Conclusions: The data presented in the reports if for the first year of a three-year study assessing the variation in tissue nutrient concentration among sugar beet varieties. The first year 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 mobile nutrients will decrease while the concentration of 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; LL, Lake Lillian; M, Murdock; R, Renville).

	Date of				Soil			CEC	
Location	Planting	Sample 1	Sample 2	Sample 3	Series	Texture†	Classification‡	0-6”	6-24”
								meq/100g	
CC	25-May	12-Jul	2-Aug	22-Aug	Colvin-Quam	SiCL	T Calciaquoll	31.6	25.5
LL	8-May	21-Jun	12-Jul	2-Aug	Nicollet	SiCL	A Hapludoll	33.7	28.7
M	29-Apr	21-Jun	12-Jul	2-Aug	Bearden-Quam	SiCL	Ae Calciaquoll	28.0	22.2
R	6-May	21-Jun	11-Jul	1-Aug	Chetomba	SiCL	T Endoaquoll	31.1	24.4

† SiCL, silty clay loam.

‡A, aquic; Ae, aeric; T, typic

Table 2. Summary of 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
		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
		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
	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
		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
	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
		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
	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
		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
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
		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
	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
		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
	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
		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
	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
		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
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
		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
	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
		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
	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
		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
	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
		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

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

Location	Variety						*P*>F
	Crystal RR018	Maribo 109	Beta 92RR30	Beta 9475	Crystal M579	Crystal M509	
	---------------------------------------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 4. Summary of analysis of variance for leaf blade nutrient concentration averaged across four locations in 2017 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-	------------------	------------------	
Nitrogen	***	***	***	***	*	**	0.17
Phosphorus	***	***	***	***	0.45	**	0.46
Potassium	***	***	***	***	***	0.16	0.17
Calcium	***	0.21	**	***	***	*	0.11
Magnesium	***	***	***	***	0.39	0.07	0.54
Sulfur	***	***	***	***	**	0.31	0.60
Boron	***	***	***	***	0.06	*	0.31
Copper	***	***	***	*	***	0.06	*
Iron	***	***	***	***	***	0.37	0.06
Manganese	***	0.08	***	***	***	0.62	0.96
Zinc	***	***	***	***	***	*	***

†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 four locations in 2017 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-	------------------	------------------	
Nitrogen	***	***	***	***	*	0.17	0.07
Phosphorus	***	**	***	***	0.34	0.06	0.07
Potassium	***	***	***	***	**	0.06	*
Calcium	***	0.23	***	***	**	**	*
Magnesium	***	***	***	***	***	***	***
Sulfur	***	***	***	***	0.23	0.18	0.40
Boron	***	***	***	***	***	0.61	0.79
Copper	***	**	***	***	0.13	0.24	0.24
Iron	***	***	***	***	*	0.96	0.98
Manganese	***	0.37	***	***	0.22	0.93	0.92
Zinc	***	0.78	***	***	*	0.65	0.81

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

Table 6. Varietal differences in leaf blade nutrient concentration across four locations in 2017 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.†
			---%---				
Nitrogen	5.45a	5.02b	4.99bc	4.98bc	4.90c	5.03b	4.3-5.0
Phosphorus	0.53a	0.54a	0.45d	0.47c	0.44d	0.51b	0.45-1.1
Potassium	3.81a	3.61bc	3.47d	3.50cd	3.65b	3.41d	2.0-6.0
Calcium	0.59b	0.69a	0.67a	0.59b	0.59b	0.61b	0.5-1.5
Magnesium	0.45c	0.54a	0.56a	0.50b	0.50b	0.51b	0.25-1
Sulfur	0.39a	0.36b	0.34c	0.37b	0.36b	0.38a	0.21-0.5
			---ppm---				
Boron	29b	32a	31a	28c	29b	27c	31-200
Copper	26ab	24abc	24bc	23bc	27a	21c	11-40
Iron	443b	366c	436b	437b	517a	541a	60-140
Manganese	72c	85b	87b	72c	94a	77c	26-360
Zinc	47a	41d	45b	44bc	42cd	48a	10-80

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

Table 7. Varietal differences in petiole nutrient concentration across four locations in 2017 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
			%			
Nitrogen	2.50b	2.64a	2.62a	2.42b	2.42b	2.66a
Phosphorus	0.34c	0.42a	0.35c	0.33d	0.33d	0.37b
Potassium	4.28b	4.28b	4.07c	4.20bc	4.12c	4.53a
Calcium	0.34e	0.47b	0.41c	0.37d	0.41c	0.52a
Magnesium	0.26c	0.31a	0.31a	0.26c	0.27b	0.27b
Sulfur	0.12c	0.14a	0.12c	0.12c	0.12c	0.13b
			ppm			
Boron	25d	29a	27b	26bc	25.5cd	29a
Copper	9.0a	8.5b	7.7c	8.9a	7.7c	8.6ab
Iron	218c	302a	245bc	225c	262b	270b
Manganese	27d	32b	29c	26d	36a	32b
Zinc	16c	21a	16c	17c	18b	20a

Table 8. Simple correlation (r) between sugarbeet root yield and leaf blade and petiole nutrient concentration for the newest fully developed leaf sampled the third week in June, first week in July, and fourth week in July. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Time 1 Blade	0.58	0.16	0.20	0.52	0.29	0.05	0.27	-0.43	0.69	0.47	0.31
Time 1 Petiole	0.59	-0.28	0.38	0.51	0.32	0.26	0.42	-0.14	0.57	0.48	0.47
Time 2 Blade	0.11	0.03	-0.18	-0.50	-0.65	0.56	0.28	0.40	-0.42	-0.48	0.07
Time 2 Petiole	-0.46	-0.07	-0.55	-0.39	-0.64	0.01	-0.29	0.08	-0.61	-0.54	-0.35
Time 3 Blade	-0.27	-0.40	0.19	-0.11	-0.36	0.22	0.47	0.10	-0.41	-0.04	-0.50
Time 3 Petiole	-0.51	0.05	-0.38	0.03	-0.57	-0.18	0.42	-0.05	0.04	-0.12	-0.30

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 the third week in June, first week in July, and fourth week in July. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Time 1 Blade	-0.02	-0.27	0.41	-0.10	-0.38	-0.54	0.52	0.08	0.07	-0.05	0.33
Time 1 Petiole	-0.07	-0.44	0.30	-0.20	-0.32	-0.25	-0.18	0.15	-0.05	-0.10	0.04
Time 2 Blade	-0.47	-0.58	0.26	0.01	-0.40	-0.21	0.62	0.33	-0.43	-0.15	0.01
Time 2 Petiole	-0.62	-0.45	-0.03	-0.13	-0.62	-0.27	-0.16	0.07	-0.40	-0.26	-0.12
Time 3 Blade	-0.64	-0.59	0.57	0.46	-0.21	-0.47	0.51	0.38	-0.01	0.32	0.02
Time 3 Petiole	-0.59	-0.38	0.23	0.32	-0.59	-0.23	0.30	0.19	0.45	0.30	0.01

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 the third week in June, first week in July, and fourth week in July. Correlation r values when between -0.15 and 0.15 are not considered significant at $P \leq 0.10$.

	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Time 1 Blade	0.52	0.06	0.29	0.43	0.14	-0.12	0.40	-0.35	0.64	0.41	0.38
Time 1 Petiole	0.51	-0.39	0.42	0.39	0.19	0.15	0.32	-0.09	0.49	0.40	0.43
Time 2 Blade	-0.04	-0.15	-0.10	-0.45	-0.71	0.43	0.43	0.46	-0.50	-0.47	0.08
Time 2 Petiole	-0.59	-0.20	-0.50	-0.38	-0.77	-0.07	0.30	0.11	-0.66	-0.56	-0.34
Time 3 Blade	-0.43	-0.53	0.33	0.03	-0.39	0.05	0.58	0.20	-0.37	0.05	0.43
Time 3 Petiole	-0.63	-0.07	-0.28	0.12	-0.69	-0.23	0.47	0.01	0.17	-0.02	-0.26

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	0.56	0.64
	Petiole	0.69	0.69
Phosphorus	Leaf Blade	0.52	0.26
	Petiole	0.65	0.52
Potassium	Leaf Blade	0.72	0.69
	Petiole	0.63	0.49
Calcium	Leaf Blade	-0.12	0.13
	Petiole	-0.06	0.13
Magnesium	Leaf Blade	-0.27	-0.36
	Petiole	-0.08	-0.20
Sulfur	Leaf Blade	0.40	-0.21
	Petiole	0.45	0.31
Boron	Leaf Blade	0.30	0.59
	Petiole	-0.01	-0.13
Copper	Leaf Blade	0.54	0.23
	Petiole	0.17	0.40
Iron	Leaf Blade	0.10	0.09
	Petiole	0.20	0.16
Manganese	Leaf Blade	-0.01	0.13
	Petiole	0.20	0.13
Zinc	Leaf Blade	0.67	0.44
	Petiole	0.03	0.17

Correlations between -0.50 and 0.50 are not significant at $P \leq 0.10$

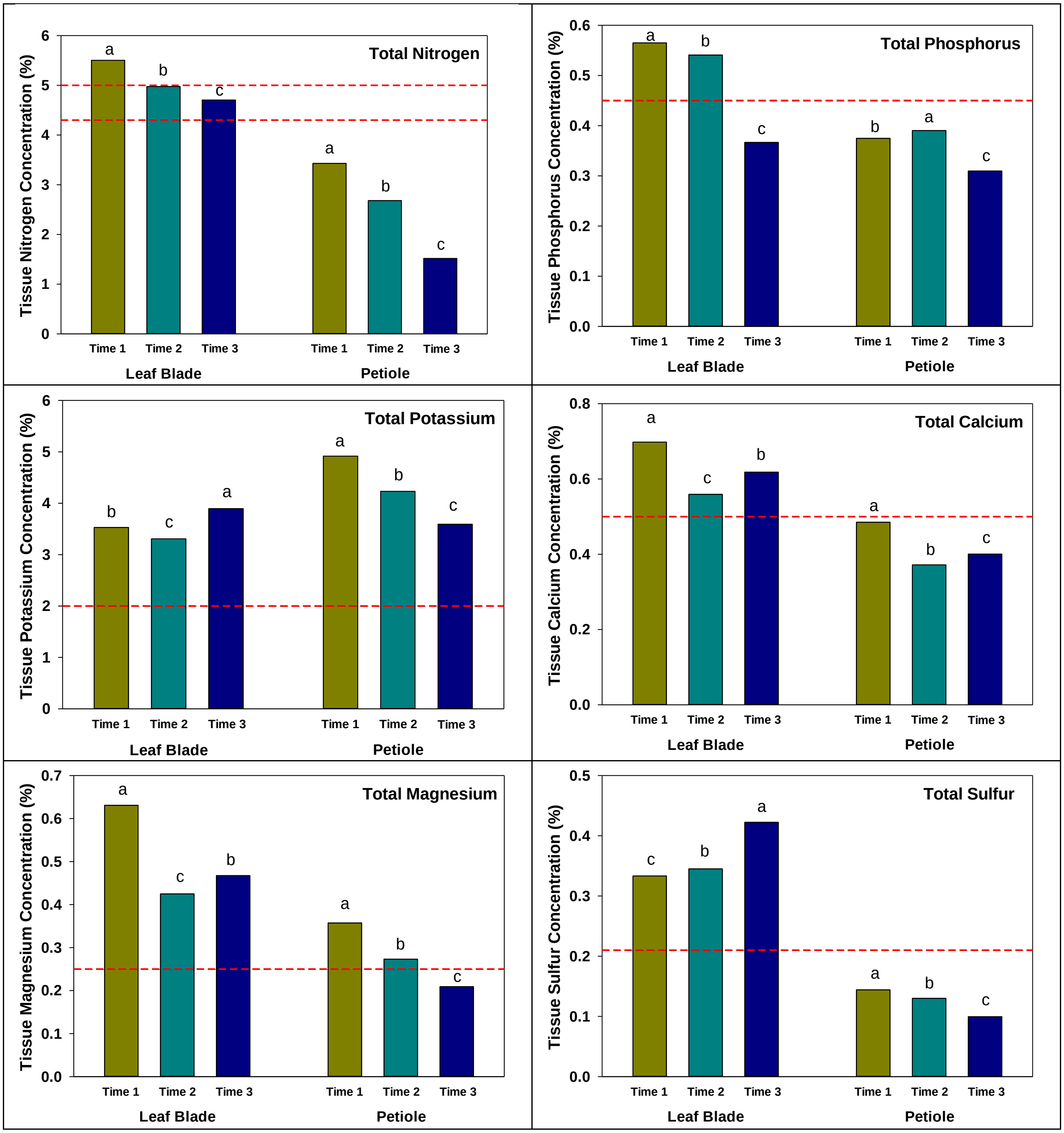

Figure 1. Summary of the impact of time on sugarbeet total macronutrient concentrations for leaf blade and petiole samples collected from six sugarbeet varieties. Letters denote significance among sampling times for leaf blade or petiole samples at $P \leq 0.10$. Horizontal dashed lines represent the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

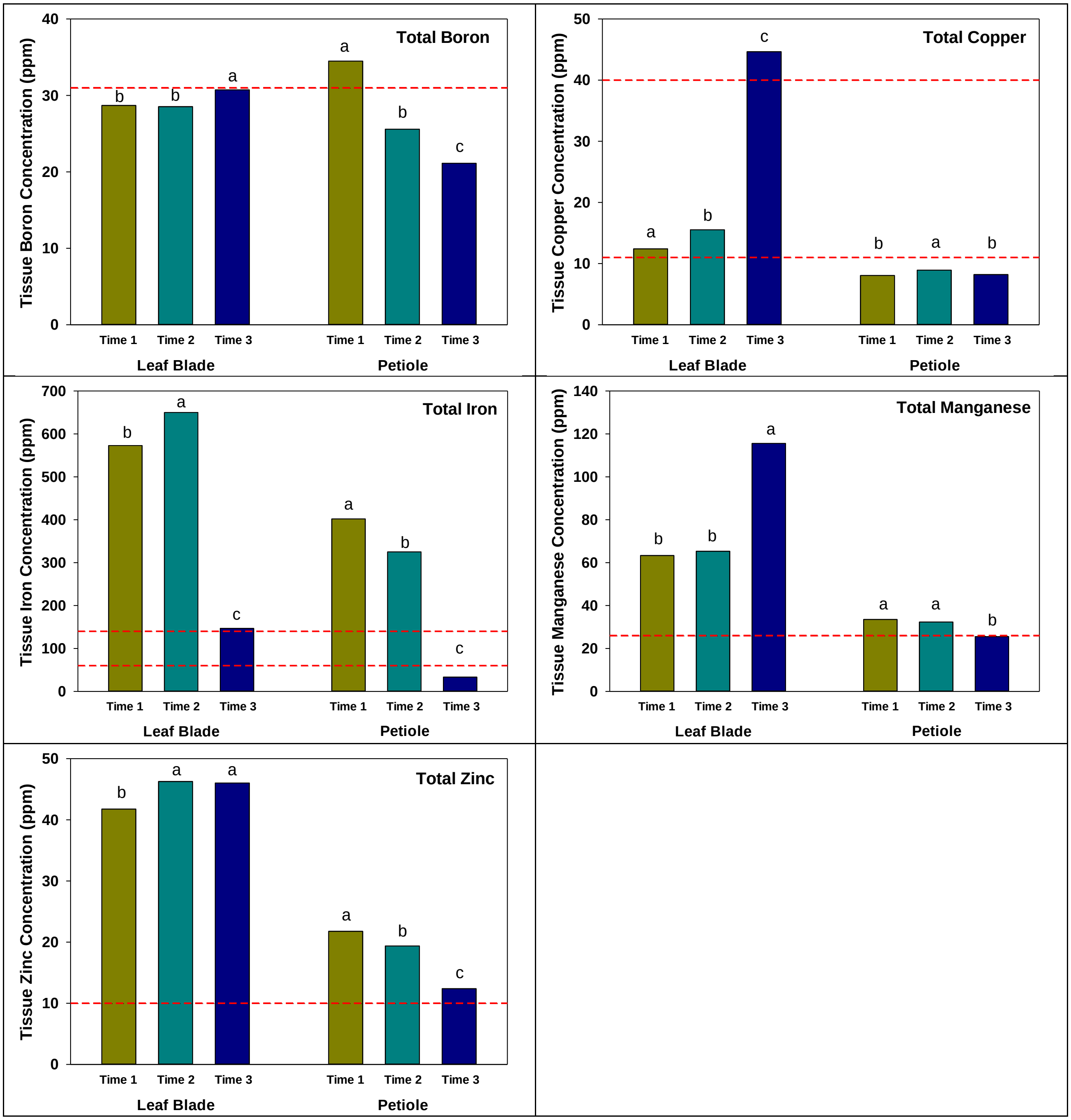

Figure 2. Summary of the impact of time on sugarbeet total micronutrient concentrations for leaf blade and petiole samples collected from six sugarbeet varieties. Letters denote significance among sampling times for leaf blade or petiole samples at $P \leq 0.10$. Horizontal dashed lines represent the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