Plant analysis as a management tool for corn and soybean fields

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INTRODUCTION

With increased use of plant tissue testing for nutrient management, there are questions on how fields should be sampled and on the validity of the test results. According to current University of Minnesota guidelines, there is no basis for equating nutrient content from a plant sample to a fertilizer recommendation for corn and soybean. In general, plant sampling is recommended to confirm a nutrient deficiency or assess a fertilizer management program after the fact. Plant analysis is normally used in a comparative system - samples are collected from areas in a field with nutrient deficiency and also from areas where plants are healthy. The values from the plant analyses are then compared to determine the nutrient causing the deficiency. Samples taken for plant analysis typically involve singular plant parts at specific growth stages, such as the ear leaf at silking in corn. Over time, researchers and agronomists have developed ranges of nutrient values in plant tissues that are either sufficient or deficient for optimizing yield. However, some nutrients are not mobile in the plant and since nutrient uptake can be affected by environmental factors, thus the concentration of these nutrients in a particular plant part can differ based on environmental factors and crop growth stage. In addition, some crop advisors have noticed that there can be significant variability in nutrient concentration among hybrids or varieties for a specific crop, potentially making tissue testing less reliable for certain hybrids or varieties. Thus, an assessment of variability in nutrient concentration in plant tissue should be completed to determine the range in optimum values for the standard recommended plant analysis of corn and soybean. This would help growers understand what a plant tissue test really means to them, and if it has any value for helping them make nutrient management decisions.

Another issue with plant tissue sampling is that plant samples are seldom taken from more than a handful of areas within a field. In addition, the recommended sampling is later in the season in early reproductive stages. At these times it can be difficult to take samples from a larger area within fields. While soil samples may be collected from many points within a field, there are no set guidelines for taking plant samples in a similar fashion. Most university researchers recommend sampling multiple areas of fields in order to compare areas of the fields that are exhibiting nutrient deficiency symptoms with areas that are not. If planned correctly, this type of sampling could better define nutrient deficiency in a field and improve predictability of yield response to a nutrient application. Integrating an intensive sampling approach into a plant tissue testing program may aid in evaluating potential yield difference in a field and also to evaluate the fertilizer management program within the field. However, with the lack of research on this subject, the amount of work and cost associated with the collection and analysis of plant tissue samples collected with an intensive sampling approach is difficult for most growers to justify.

This study proposes three separate trials focusing on: 1) a survey of the nutrient concentration in plant tissues for different hybrids across locations; 2) an evaluation of utilizing intensive plant sampling based on grids; and 3) an evaluation of current benchmark values for N, P, K, and S used to determine sufficiency of plant nutrients form corn and soybean. The objectives of this work are:

1. Determine standard values for nutrient concentration in the corn ear leaf at the R2 growth stage.

2. Compare tissue analysis values among corn hybrids within and across locations.

3. Evaluate an intensive plant sampling program for helping to predict nutrient deficiencies and the effect on farmers' fields for both corn and soybean.

4. Utilizing pre-existing field trials, collect plant tissue samples to determine sufficiency level values for N, P, K, and S, and then compare these with sufficiency levels that are currently being recommended to growers.

Abbreviations N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; S, sulfur; B, boron; Fe, iron; Cu, copper; Mn, manganese; Zn, Zinc.

Trial 1 – Survey of Corn Leaf Tissue Nutrient Concentration

This study examined the nutrient concentration of the ear leaf for 34 hybrids at the 6 southern locations of the University of Minnesota corn hybrid trials and 26 hybrids for the 3 northern locations. Since the relative maturities used varied, no hybrid could be sampled across all nine locations. Each hybrid was replicated 3 times at each location. A total of ten ear leaves were sampled, dried, ground, and sent out to a commercial lab for analysis. Data are reported based on the sufficiency level approach. The DRIS (Diagnosis and Recommendation Integrated System) analysis has not been run on these samples due to a lack of for DRIS norms. The concentration data from each location was analyzed to determine differences between locations and hybrid and to determine whether an interaction between location and hybrid was significant. To further look at the interaction of location and hybrid, the mean of each hybrid for a given nutrient was plotted with the mean of the location to determine the stability of concentration over locations. All sufficiency data was compared using the current University of Minnesota plant analysis publication.

Results: Corn Hybrid Sampling Study

Location information for the 9 sites is given in Appendix Table 1. Appendix Table 2 summarizes soil test data from the locations. At this time the soil test data has not been used to correlate to the responses at the individual locations. Genotype and environment main effects were significant for all measured variables. However, our main interest was to look further at whether there was a significant interaction between genotype and environment. The effect of a genotype by environment (GxE) interaction was seldom significant for the northern locations. This is due to the low number of sites and few samples collected compared to the southern sites were the GxE interaction was significant for all variables except for ear leaf potassium (K) and iron (Fe) concentration. The GxE interaction was what we were interested in looking at but will be discussed further later in this report.

Table 3a. Summary of statistical significance for genotype (hybrid) and environment (location) for the nine trials studied in 2012 broken down for northern and southern sites. The data are summarized for each plant tissue concentration determined and corn grain yield.

	Southern Trials (n=6)			Northern Trials (n=3)		
	Genotype†	Environment	GxE	Genotype†	Environment	GxE
Nitrogen	***	***	**	***	**	ns
Phosphorus	***	**	***	***	**	*
Potassium	***	***	ns	***	***	*
Calcium	***	*	*	***	**	ns
Magnesium	***	***	*	***	**	ns
Sulfur	***	**	*	***	***	ns
Boron	***	***	***	***	***	ns
Copper	***	***	***	***	**	*
Iron	***	***	ns	***	***	ns
Manganese	***	**	*	***	***	ns
Zinc	***	*	*	***	*	ns
Yield	***	***	*	***	**	ns

†Denotes significance at $P<0.05$ (*), 0.01 (**), and 0.001 (***). ns, effect is not significant.

The data analysis in Table 3a indicates that hybrids vary in their tissue concentration. A summary of hybrid averages across locations for the northern trials is given in Appendix Table 4 and the southern trials are given in Appendix Table 5. A means separation procedure was not used for the data since the divisions between hybrids were not clear. When examining the tables the differences generally follow that the highest values differ from the middle values and the middle from the lower. The main finding is that while hybrids do differ in concentration, there does not appear to be a single hybrid that is always higher in all nutrient concentrations and one that is the lowest. With the amount of variation seen, it would be difficult to establish whether sufficiency levels need to be established on a hybrid by hybrid basis. The ranking for each hybrid was considered. The relative ranking within a location for a hybrid remained similar regardless of the site where it was grown. This means that while a hybrid may vary in its' tissue concentration depending on where it is grown if it is has one of the highest concentrations among a set of hybrids at one location it will generally have one of the highest concentrations at all locations. There are some exceptions which will be discussed in the section on GxE interaction.

Table 3b. Summary of statistical significance for genotype (hybrid) and environment (location) for the eighteen trials studied between 2012 to 2013 broken down for northern and southern sites. The data are summarized for each plant tissue concentration determined and corn grain yield for a subset of hybrids used both years of the study.

	Southern Trials (n=12)			Northern Trials (n=6)		
	Genotype†	Environment	GxE	Genotype†	Environment	GxE
Nitrogen	***	***	0.20	*	***	0.60
Phosphorus	***	***	***	***	***	**
Potassium	***	***	**	***	***	0.73
Calcium	***	***	0.15	***	***	0.57
Magnesium	***	***	0.70	***	***	0.84
Sulfur	***	***	***	***	***	0.10
Boron	***	***	**	***	***	0.08
Copper	***	***	**	***	***	**
Iron	0.09	***	*	*	**	0.34
Manganese	***	***	0.18	***	***	0.08
Zinc	***	***	0.10	***	***	0.54
Yield	*	***	0.33	***	***	*

†Denotes significance at P<0.05 (*), 0.01 (**), and 0.001 (***). ns, effect is not significant.

In order to increase the total number of environments tested samples were collected during the 2013 growing season. Only 7-8 or the hybrids sampled in 2012 were carried over into the 2013 hybrid trials. Thus, while attempting to increase the number of enviornments we lost some power in testing differences among hybrids. Table 3b summarizes the statistical analysis of the subset of hybrids sampled across both years. Of those hybrids, all statistically differened ($P \leq 0.10$) in all nutrient concentrations for both the northern and southern trials. Environments also differed. There was a decrease in the amount of GxE interaction that was a direct result of testing fewer hybrids. However, the lack of GxE and overall significance of hybrid still indicate that hybrids do vary but the variation is more predictable when fewer hybrids are tested. Hybrid still must be factored in when deciding to take tissue samples. Since hybrids vary in their tissue concentration, the level of variation could be determined prior to release of the hybrid for commercial use. However, determining the potential difference may not be that meaningful unless tissue analysis will become a primary tool for use in determining nutrient applications. Since soil testing still is the recommended too for making nutrient management decisions, the fact that hybrids vary in their tissue concentration is less important. Knowledge of differences is important in order to best utilize tissue test results.

Table 6. Site mean tissue concentration averaged across hybrid for the 12 southern Minnesota locations sampled 2012 and 2013. Below the critical level (CL) represents the percentage of the total samples taken which had tissue concentrations that fell below the established critical level.

	2012 Sites†						2013 Sites†						Below
	3	4	5	6	7	9	11	12	13	14	15	18	CL
	---------------%											-------------	--%--
N	2.62	2.73	2.87	3.02	3.07	2.71	3.11	2.88	2.96	2.81	3.03	3.15	19
P	0.32	0.24	0.37	0.31	0.27	0.25	0.36	0.24	0.22	0.33	0.28	0.35	6
K	2.11	1.18	1.49	1.31	1.53	1.53	1.99	1.41	1.47	1.73	1.52	1.77	71
Ca	0.56	0.62	0.58	0.60	0.53	0.57	0.61	0.55	0.52	0.62	0.58	0.49	1
Mg	0.27	0.68	0.68	0.55	0.46	0.36	0.43	0.56	0.61	0.40	0.68	0.29	1
S	0.17	0.18	0.18	0.17	0.16	0.15	0.25	0.17	0.18	0.19	0.17	0.25	0
	---------------ppm											-------------	
B	6.1	8.9	6.9	4.8	4.5	8.4	5.9	10.2	5.9	5.2	4.9	6.4	0
Cu	8.3	9.9	11.1	10.1	11.7	9.2	9.6	9.2	9.4	8.4	10.7	8.3	0
Fe	93	121	98	93	89	92	94	121	103	98	122	102	0
Mn	46	39	82	39	42	50	52	68	87	47	49	52	0
Zn	15.2	16.8	15.5	17.9	17.7	18.0	20.9	16.3	20.0	20.8	19.4	20.6	73
	---------------Bushels/acre											-------------	
Yield	238	217	271	187	226	209	185	155	205	106	210	238	

†Locations referenced by the site number are give in Appendix Table 1.

Site means for the southern locations are given in Table 6. Tissue nutrient concentration and yield significantly differed across all locations. Analysis was conducted separately for the southern and northern locations (Table 7) since the hybrids used varied. At this time the differences between locations has not been fully assessed by looking at differences in climatic conditions and soil test values given in Tables 1 and 2. Similar to varieties, the sites did not consistently vary to the low or high side in all nutrients. However, there were some dramatic differences in concentration. For instance, the samples showed that 72% of the samples collected in the southern sites were low in K and 73% tested low in Zn. What is interesting is a situation like the 2012 Rochester location which had the second lowest average K concentration but out-yielded the other sites by at least 50 bushels per acre. Further investigation on the critical levels for each of the nutrients needs to be examined to see if the norms currently used are accurate. A discussion of the K sufficiency levels will be given later in this report. Similar patterns were found at the northern locations where low yield or high yield did not result in low or high concentrations, respectively. Potassium and zinc concentration were still consistently low at the northern sites, but the percentage of samples were much less than the southern sites.

Table 7. Site mean tissue concentration averaged across hybrid for the 6 northern Minnesota locations sampled in 2012 and 2013. Below the critical level (CL) represents the percentage of the total samples taken which had tissue concentrations that fell below the established critical level.

	2012 Sites†			2013 Sites†			Below
	1	2	8	10	16	17	CL
	--%--						--%--
N	3.08	2.78	3.14	3.00	2.96	3.31	9
P	0.27	0.26	0.34	0.27	0.32	0.33	5
K	1.82	1.02	2.52	2.00	1.89	2.27	34
Ca	0.51	0.80	0.62	0.43	0.74	0.71	6
Mg	0.66	0.79	0.21	0.63	0.54	0.27	4
S	0.19	0.17	0.23	0.21	0.22	0.25	0
	---ppm---						
B	7.5	7.0	4.2	6.9	9.1	7.0	3
Cu	13.1	10.3	9.0	10.6	9.1	8.5	0
Fe	90	116	172	88	113	188	0
Mn	120	77	32	98	112	42	0
Zn	18.2	21.7	21.3	13.3	16.7	29.7	47
	---------------------------------Bushels/acre---------------------------------						
Yield	149	184	225	144	209	161	

†Locations referenced by the site number are give in Appendix Table 1.

Table 8. Spearman rank correlation coefficients in ear leaf nutrient concentration and grain yield for the 6 southern locations across 34 corn hybrids. Correlations between –0.08 and 0.08 are not considered significant at $P \leq 0.05$. (n=532)

	P	K	S	Ca	Mg	Zn	Fe	Mn	Cu	B	Yield
N	0.07	-0.13	0.29	0.04	0.14	0.39	-0.02	0.15	0.61	-0.30	0.03
P		0.42	0.32	0.02	-0.36	-0.05	-0.11	-0.16	-0.19	-0.27	0.36
K			0.04	-0.50	-0.88	-0.11	-0.25	0.08	-0.26	-0.03	-0.09
S				0.27	0.04	0.19	0.46	0.11	0.27	0.12	0.16
Ca					0.48	0.08	0.28	0.00	0.14	0.13	0.26
Mg						0.04	0.32	-0.13	0.32	-0.09	0.06
Zn							-0.01	0.33	0.37	0.15	-0.11
Fe								0.10	0.08	0.39	-0.05
Mn									0.32	0.09	-0.25
Cu										-0.09	-0.21
B											-0.27

Spearman rank correlations were used to determine if patters of increasing tissue concentration levels for individual nutrients followed patters of increasing corn grain yield. Data from the northern and southern sites (2012 data only) are given in Tables 8 and 9, respectively. The same data also can be used to look at relationships between tissue concentration levels. Positive values indicate an increase in variable A would result in an increase in variable B, while negative correlation would show that an increase in variable A would result in a decrease in variable B. Values closer to either 1 or -1 would indicate a strong positive or negative relationship, respectively. Values between -0.08 and 0.08 would not be considered significant at the southern locations, and the range for northern sites was -0.13 to 0.13. The difference between the northern and southern data is due to differences in the total number of samples being compared. While variables outside this range would be significant they would not necessarily result in any meaningful relationship.

Table 9. Spearman rank correlation coefficients in ear leaf nutrient concentration and grain yield for the 3 northern locations across 26 corn hybrids. Correlations between –0.13 and 0.13 are not considered significant at $P \leq 0.05$. (n=200)

	P	K	S	Ca	Mg	Zn	Fe	Mn	Cu	B	Yield
N	0.45	0.58	0.64	-0.27	-0.43	0.15	0.28	-0.21	0.12	-0.38	0.20
P		0.73	0.60	-0.15	-0.52	0.20	0.47	-0.43	-0.17	-0.47	0.31
K			0.71	-0.25	-0.76	0.17	0.55	-0.51	-0.24	-0.68	0.45
S				-0.06	-0.39	0.12	0.49	-0.24	0.13	-0.37	0.15
Ca					0.09	0.25	0.43	-0.22	-0.23	-0.01	0.22
Mg						-0.35	-0.67	0.73	0.54	0.78	-0.75
Zn							0.42	-0.36	-0.23	-0.09	0.45
Fe								-0.80	-0.52	-0.62	0.71
Mn									0.71	0.71	-0.76
Cu										0.55	-0.70
B											-0.66

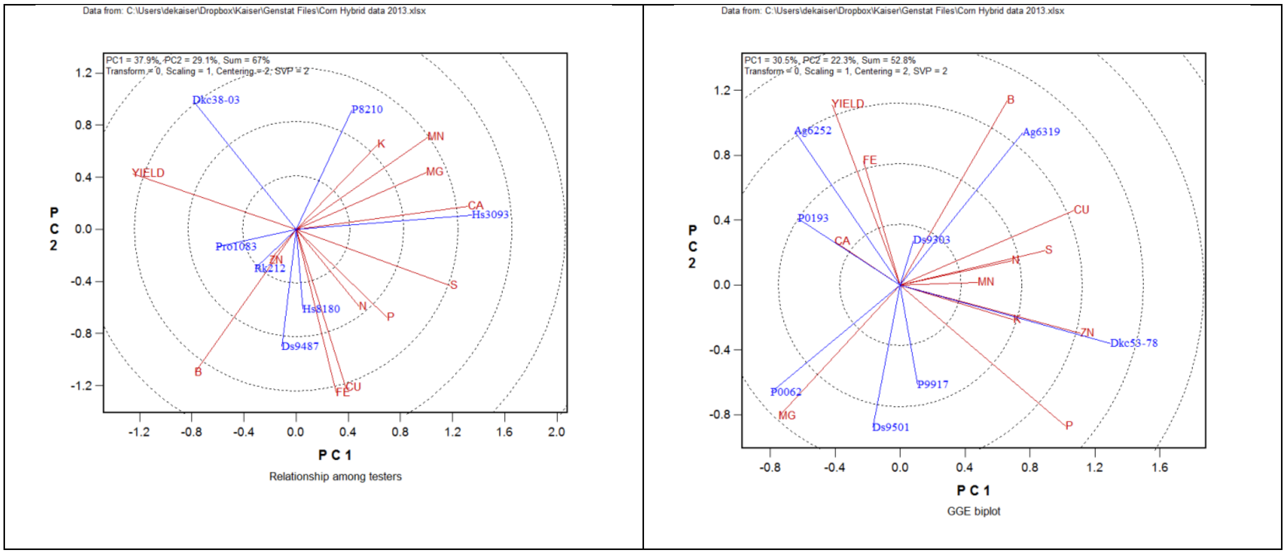
The strongest positive correlation to yield was seen for P and Ca at the southern locations and Fe and Zn at the northern sites. Significant negative correlations were seen with Mn and B in the south and Mg, Mn, Cu, and B in the north. For the southern locations, the relationship between P and Ca is likely not important as in both cases the levels in the tissue were seldom in the range that would be considered low (Table 6). For the northern locations roughly half the samples came back low in Zn but none were low in Fe (Table 7). The relationships between the nutrient concentrations in the plant tissue can clearly be seen in the northern sites, but were not as clear in the southern locations. This alone may be why yield was better correlated to tissue concentration for northern location. It also would be easier to see trends with the few locations and samples collected. Overall this data does raise some interesting questions. If we assume that individual hybrids have differing yield potentials due to genetics, are differences in nutrient concentration within plant tissue meaningful. Concentration in plant tissue is driven by two factors, nutrient uptake and plant mass. If two plants differ in mass but have the same uptake the plant with the higher mass would have a lower tissue concentration by default. Uptake therefore may be a better measurement to assess deficiencies but would not work that well since plant mass can be affected by many factors. Since we do show hybrids clearly differ in nutrient concentration, this raises doubts on some of the data used for making suggestions on sufficiency levels for plant nutrients. This is especially true if the data being used comes from few locations with very few hybrids being tested. A large number of locations over many years would be needed to ensure an accurate assessment of what a sufficiency level of a particular nutrient is.

The response of genotype (hybrid) by the environment (location) it was grown was examined by taking the mean for a given nutrient for a location versus the particular hybrid within the location. This data was plotted and examined using linear regression. The slope of the line produced was used to look at the GxE effect of a given hybrid. When the initial analysis of variance indicated that GxE was significant we were interested in two questions. First, was the GxE effect for a hybrid significant? If not it would indicate that the ear leaf concentration was relatively stable across environments. Second, if the GxE effect was significant did the hybrid response similarly to other hybrids to a given increase in concentration (slope of the line=1)? If the analysis indicated the slope of the line differed from 1 then the data was summarized whether the slope was greater or less than 1. If the slope was greater than 1 it would indicate that the concentration tended to increase relatively more compared to other hybrids when the site average was high. When the slope was less than 1, the hybrid would response less when the site average. If we consider the ear leaf concentration to be a true indicator of nutrient sufficiency it would indicate that a given hybrid may be able to take more or less advantage of increased nutrient availability within a given location. As was stated previously, some of the differences could be due to dilution/accumulation effects from differing plant mass. For this discussion we will consider this effect to be insignificant. This analysis only looks at how the hybrids respond and not whether the mean tissue concentration differs.

The northern data is summarized in Table 10. However, there did not appear to be a significant GxE effect for most nutrients and yield. There was some effect on ear leaf P and Cu. Potassium also was significant but the stability analysis did not find any differences between hybrids in their response to the environment they were grown. For P, 4 hybrids were relatively stable across the locations and 2 tended to respond better environments. For Cu, 3 hybrids were stable and one responded better. Due to having fewer locations, we really could not determine a significant GxE effect in the north. Additional years and locations would be beneficial.

Data was clearer as to GxE interactions in southern Minnesota (Table 11). Only two nutrients, K and Fe, appeared to be relatively stable across locations. Levels of K were generally low and probably limiting due to the dry weather conditions. The most variation was seen in ear leaf B and Cu concentration. This indicates a significant amount of variation in how the hybrids responded to their environment. Even though the analysis indicated this variation it did not mean that these nutrients were deficient. In terms of yield, there were only two of the hybrids that appeared to be able to take better advantage of higher yielding environments. For the rest, the relative ranking appeared to be the same. Considrering the differences in nutrient concentration seen this would indicated that any differences were inherent to the genetics and have no bearing on the final yield of the variety. There were also not hybrids that had stable nutrient concentrations across the locations. It should be noted that some of the differences seen could be due to differences in the relative maturity of the hybrid since concentrations of some nutrients can decline over time and if samples were taken later in the season. However, this effect should not have much bearing on the stability data since differences in RM and nutrient concentration should be accounted for within the effects of the location. This will be further examined over the next year.

According to the current guidelines, none of the Cu values were considered low and only 0.2% of the samples came back low in B. Recently, more reports of tissue concentrations low in B have been surfacing. The low values could either be due the critical level being set too high or uptake being limited early in the season but the plant recovering late in the season and being able to take up enough nutrients for normal growth. With immobile nutrients such as B and Cu, uptake may differ significantly from nutrients such as N and K which can be taken up in large quantities early in the season. Therefore a deficiency, as long as it does not affect growth and uptake of other nutrients, may not be that important if it is only temporarily seen during the growing season. In addition, early season concentrations and be affected by rapid plant growth which can result in low concentrations of nutrients due to a dilution of the total amount taken up by the plant. Sampling later in the season is preferential as it gives a better picture of the sufficiency since more of the total amount of a nutrient taken up would have occurred by tasselling or later. However, sampling later in the season does not allow for any corrective measures, if any can be made? The major question is how are our current suggested critical levels performing? This will be discussed later in this report.



Biplots summarizing the relationship between hybrids and the measured variables for hybrids sampled over two years of the study. Variables that form angles close to 0 and 180^o are considered positively and negatively correlated, respectively. Variable forming angles near 90^o are not correlated.

An additional analysis was conducted on the data to examine GxE by studying data bi-plots. Bi-plots have been used by plant breeders to study variety performance. The data from the hybrid subset that was sampled 2012-2013 was subject to a biplot analysis. A simiple analysis of variation was also conducted at the results are given in Tables 4b and 5b. The use of bi-plots can provide to be difficult. The bi-plot shows relationships between entries and testors through the use of lines that run through the center (0,0). Lines that form angles near 0 or 180^o would represent a perfect positive or negative relationship, respectively, between a entry and testor. For instance, Dekalb '52-78' (Left hand figure) was close to the same position as Zn indicating that this hybrid had a higher than average level of Zn in the ear leaf tissue. Agrigold 'AG6252' appeared to be above average in grain yield, but below average in tissue P concentration. Hybrids and variables close to the center would be those considered average with little variation. The farther from the center indicates an entry or tester to be much more exceptional. While this data does not paint a clear picture of what is happening it is currently being further studied to determine how to use this to better test GxE interactions in soil fertility studies.

Trial 2 – Intensive plant sampling early in the season in grower fields

Four field sites were selected, two fields planted to corn and two to soybean. Fields used were previously grid sampled on 2.5 acre grids at three of the locations. At the fourth location, 2.5 acre grids were established for sampling. Using hand held GIS units; the grids were sampled at the V5 growth stage taking 10 plant samples from within a 20 foot radius of the cell center. The samples were dried, ground, and sent to a commercial lab for analysis. The fields were be harvested with a combine equipped with GIS receiver, the yield recorded, and averaged for each sampled field zone. Data was cleaned to remove high and low yield points. Values within 20' of the edge of each grid cell will be discarded to make sure yield points used were those that would be uniquely identified to that grid cell. Yield data was correlated to nutrient concentration using Spearman's rank correlation. The rank correlation differs from normal correlation in that it ranks data from high to low and uses the ranks for correlation. This type of correlation works better for non-normally distributed data and when the relationship between the data is non-linear. The main reason to use this correlation is to determine if high yielding areas of the fields correlate to high tissue concentration or nutrient uptake. Elevation and soil data was examined but not used for the analysis. In addition, soil test data were not available for all of the locations. When available, fertilizer would have been applied therefore the bearing on the data would be questionable if the appropriate rate were applied to take care of any deficiency.

Results: Farmer Field Sampling

Table 12. Summary of soils which constituted greater than 5% of the area within the field studied in 2012.

Location	Crop	Major Soil Series							
Stewart	Corn	Glencoe	54%	Okaboji	8%	Nicollet	8%	Clarion	7%
	Soybean	Glencoe	51%	Nicollet	21%	Crippin	10%		
Northfield	Corn	Racine	35%	Waukegan	26%	Kenyon	9%	Littleton	8%
	Soybean	Racine	44%	Littleton	26%	Timula	8%	Port Byron	6%

Soil series information for the field studied is given in Table 12. The fields were selected that had a high degree of variability and allowed for the collection of at least 60 samples from 2.5 acre grids. The samples were collected at V5 since this time would represent the time where we still could sample using an ATV. Overall, soils did not vary between fields at each of the given locations. In general, one major soil type dominated each field, with one larger secondary series and many smaller series. The elevation data is not given in this report but differences in elevation were greater at the Northfield locations than at Stewart. However, there were still some significant differences in elevation within the Stewart location.

Summary statistics for the corn locations are given in Table 13. Yields averages and variation was similar at both locations averaging over 200 bu/ac across both the field locations. Plant tissue nutrient concentration varied by location. At Northfield, plant samples collected from 66% of the grids indicated N was low; P was low in 31%, B in 22%, Cu in 20%, and Mg in 18%.

All other nutrients were only deficient in less than 10% of the grid cells while S, Fe, and Mn were indicated to be sufficient across the location. At Stewart, 81% of the samples were indicated as being low in N, 41% in K, and the rest of the samples were generally sufficient in all other nutrients. Since both locations experience high amounts of rainfall early in the season the low N would be expected. The number of micro-nutrients coming back low would not be expected since little to no response to micro-nutrients, other than Zn, has been shown in Minnesota. The amount of samples low in K at Stewart also is not surprising with the dry weather conditions that occurred following the heavy May rainfall. From the soil test levels present in the field there were no areas that were low in K in this field that would explain these low tissue K concentrations.

Spearman correlation coefficients for the corn locations are given in Table 14 for Northfield, and Table 15 for Stewart. At Northfield, the only significant correlations in plant nutrient concentration with yield were found for both Ca and Cu. Even though correlated there was no evidence that either was low for a large percentage of the field. Plant Ca was only low for 9% of the field areas and Cu was for 20%. A greater correlation was seen between plant weight at V5 and yield indicated that the factors affecting yield also appeared to be affecting plant growth. Plant nutrient uptake was also compared but all nutrients were correlated to yield due to the high degree of correlation between early plant growth and nutrient uptake. Thus, the effects of uptake were discounted and the data not included. The nutrient that showed the greatest deficiency at Northfield was N, but there was no correlation to final yield. Further investigation of the data shows that both Ca and Cu concentration were correlated to each other and copper was also correlated to V5 plant weight. Therefore, when looking at data from a field it can be difficult to detect a cause for a particular nutrient deficiency unless there is evidence proving that the supply capacity of an element may be low.

At Stewart, corn yield was positively correlated to plant K concentration and negatively correlated to Mg and Mn. Corn grain yield was better correlated to V5 plant weight similar to the effect seen at Northfield. With the high degree of samples testing low in K according to the sufficiency level of this nutrient, there is a likelihood that K may have been deficient in this field. The negative response to Mg and Mn with yield also follows a similar to response between Mg, Mn, and K. Plant N concentration again was considered low across most of the site but there was no effect on yield. This may indicate a temporary unavailability of this nutrient which increased in availability over time. To our knowledge no high rates of supplemental N were applied to either field. However, at the V5 sampling only about 5% of the total amount of nutrients have been taken up so the uptake following this time may be more important in helping to determine the final grain yield and potentially make corrective fertilizer applications based on tissue analysis data. Tissue Cu concentration was not related to yield at Stewart, which was expected. The effect of Cu on yield needs to be looked at further. Concurrent studies are being run looking at Cu response to corn, but the data has not clearly demonstrated a response to this nutrient after 2 years of study.

Summary statistics for the soybean locations are given in Table 16. Critical levels for whole plant tissue concentrations were no included since no source of data can be found. Most recommended sampling at this time frame for soybean only includes the upper most fully developed leaf (without petiole). We have no way of determining sufficiency levels for the given grid cells at either of the locations. Yields were generally high at both locations averaging 54.5 bu/ac at Northfield and 66.5 bu/ac at Stewart. Maximum yield achieved was 70.2 bu/ac at Northfield and 79.8 bu/ac at Stewart.

Spearman correlation coefficient data for the Northfield soybean location is given in Table 17. Plant P concentration was positively correlated to yield while plant mass was negatively correlated to yield. No other nutrients could be identified as significantly related to yield and the effect of P was barely significant. At Stewart (Table 18), plant Ca and Mn concentration were both positively correlated to yield which V5 plant mass, and plant N concentration were negatively correlated to yield. At both sites the greatest correlations were with V5 plant mass and yield indicating a poor predictive power of nutrient concentration determining final plant yield. While this data only represents conditions at two field locations, it does indicate that V5 whole plant nutrient concentration should not be used in order to determine nutrient sufficiency.

Trial 3 – Evaluation of current benchmark values for N, P, K, and S concentration in recommended mid-season plant samplings.

Pre-existing trials were used. These trials included P and K trials from which plant samples will be taken at the recommended mid-season sampling times. The recommendation is the ear leaf at R2 for corn and the upper most fully developed trifoliate leaf at R2 for soybean. Using this data and previously collected data, we can then evaluate crop response as it is related to nutrient concentration. Sites selected have shown a response to nutrients and also have multiple nutrient application rates. The critical level defined by the data will be the point at which the relative yield is 90% of maximum. The sufficiency range is defined as the concentration at 90% and 100% of maximum relative yield.

Summary: Critical Levels Study

Only the samples collected at R2 were considered with this work. Samples have been collected from the V5 growth stage in many of the studies sampled. However, the tissue concentrations cannot be related back to final yield unless there was a clear response to a given nutrient within a particular site, as with P and K.

Table 19. Sufficiency ranges as determined by the data collected between 2008-2013 and ranges used in the current U of M plant analysis publication (FO-3176-B) that were sourced from the Plant Analysis Handbook II.

			U or M Data		Plant Analysis Handbook	
Crop	Stage	Nutrient†	Low	High	Low	High
			----------------------------%----------------------------			
Corn	R2	N	1.9	2.5	2.7	3.5
	V5	P*	0.29	0.37	0.3	0.5
	R2	P	0.26	0.38	0.2	0.4
	V5	K*	1.7	3.1	2.5	4
	R2	K*	0.9	1.4	1.7	2.5
	V5	S‡*	0.21	0.31	0.15	0.50
	R2	S‡	0.11	0.15	0.10	0.30
Soybean	V5	P*	0.19	0.23	na	na
	R2	P*	0.30	0.45	0.26	0.5
	V5	K*	0.8	3.1	na	na
	R2	K*	1.0	1.3	1.7	2.5
	R2	S‡	0.25	0.31	0.21	0.40

† *, indicates where nutrient concentration poorly predicts yield response (R^2<0.10).
‡ Analysis was conducted by ICP following wet digestion.

Data in Table 19 summarizes the critical nutrient concentration from the corn ear leaf and soybean trifoliate data summarized in Figures 1 and 2. This data represents all of the P and K data collected and most of the N and S. Some studies in previous years have not been included therefore values may change as data are added. Corn ear leaf Zn was also studied but there was no clear yield response such that a critical level could not be determined. For corn, the sufficiency range determine with this data fits with the current numbers used. The only differences was for the Low end of the sufficiency range with was lower than than what is in the current publication. For P and S, the values determined from the data are mostly within the range used. However, the range between the Low and High end of the sufficiency range is less than what is used in the current publication. It also should be noted that the S value was determined with and ICP. The currently used standards were developed before ICP's were available and there is some evidence that the values obtained with and ICP may vary with those obtained with a combustion analyzer. This is not the case for all samples but is important since differing sufficiency ranges may need to be used depending on how the sample was analyzed. The surprising part of the data was for ear leaf K in which the sufficiency range determine from this data was lower than used by the older recommendations. It is likely that the sufficiency range for K should be looked at more closely since there also is data from Iowa that indicates that the range used is too high for current hybrids. An additional year of sampling is planned for this study to determine if some of the low values could be due to dry weather conditions. At this time we cannot determine if this is the case. However, a lower critical level would be supported by the hybrid data in which K did not appear to be limiting but the concentration in the ear leaf tissue was low for a majority of the samples.

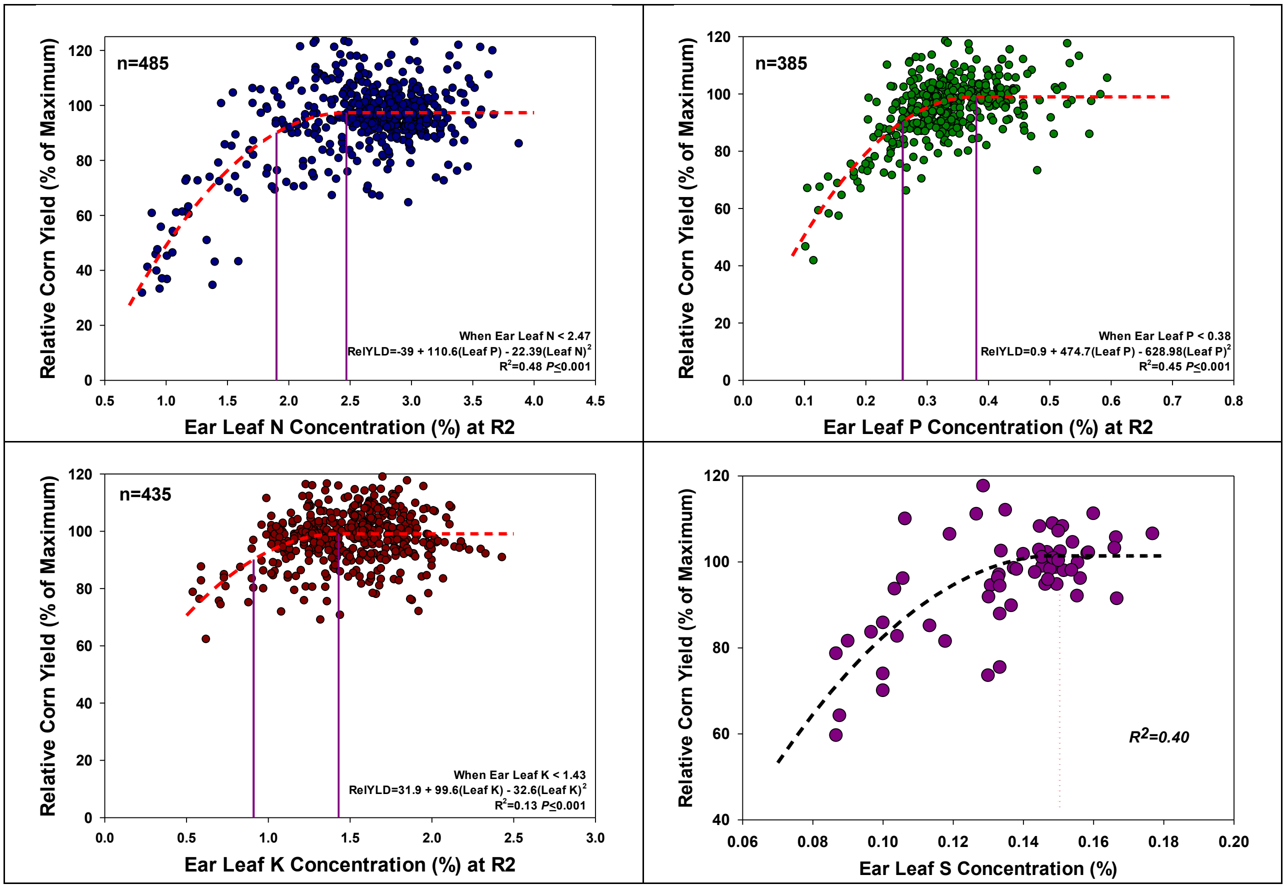


Figure 1. Summary data for R2 corn ear leaf N, P, K, and S concentration summarized from sample collected from 2008 to 2012 (N and S data). P and K data only from 2012. The vertical line represents the concentration where the relative yield is 100%.

Soybean data followed that of corn in which P and S ranges were within the currently suggested range but the difference between the low and high end of the range was less with the field data compared to the book values. Trifoliate K concentration again was found to be lower than the current book values. However, a slightly lower concentration would be expected since the petiole was included in the samples collected from this study. The difference with and without the petiole would at best be expected to be around 0.1%. It appears that more samples need to be collected to look at K. In addition, our database for soybean has fewer points that for corn. More information would be beneficial to fine tune sufficiency ranges. An addition point of importance is that the current book values may have been developed without the consideration of yield data. For the most part the book values appear to be averages of large populations of data. If this is the case there is no data to support that yields are lower when a value is said to be Low. With the data collected in this study a reduction in expected yield can be determined to give some assurance the concentration data actually has a significant meaning for crop management. Another item of interest is the population split for the soybean data. It is unknown if this was due to varietal differences or differences due to when the samples were taken.

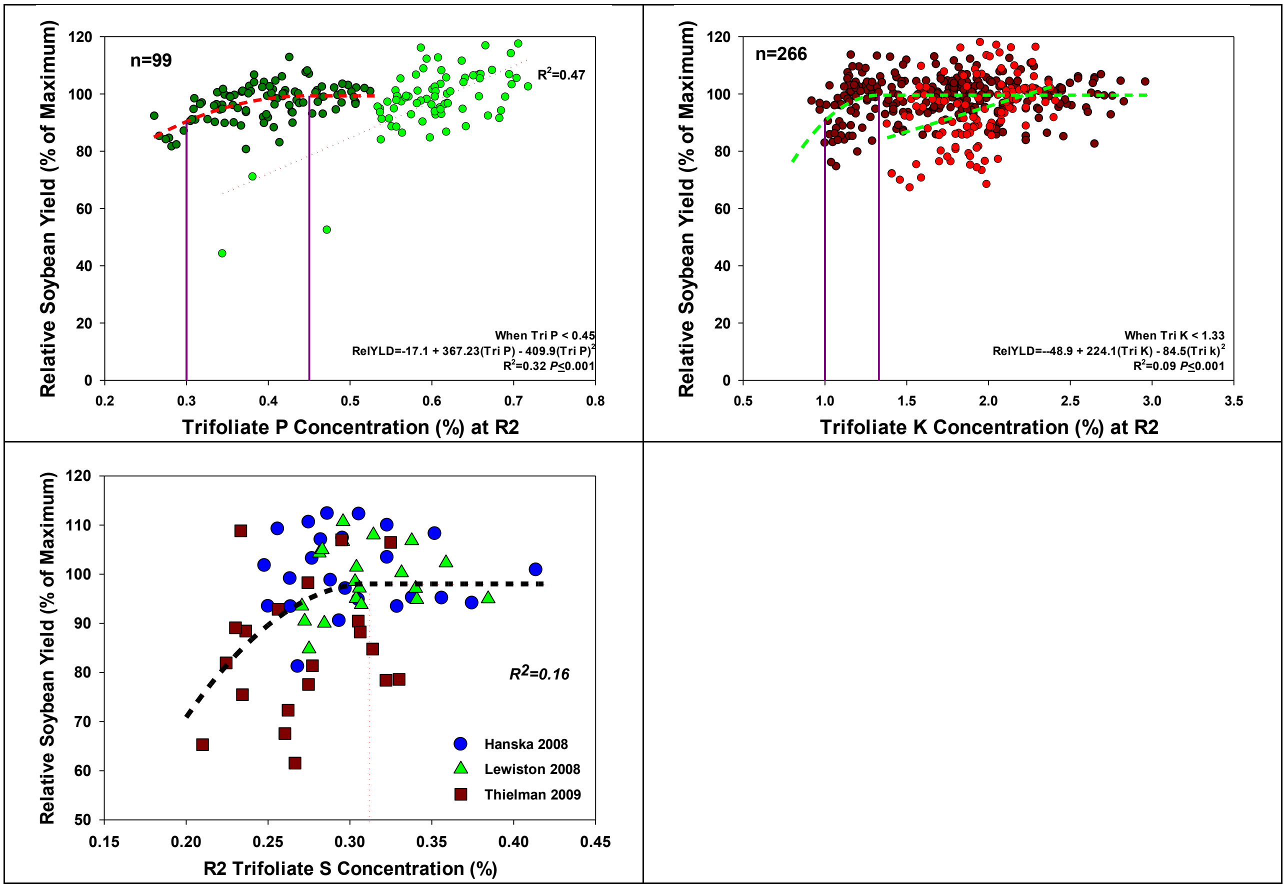


Figure 2. Summary data for R2 soybean trifoliate (with petiole) P, K, and S concentration summarized from sample collected from 2008 to 2012 (S data). P and K data only from 2012. The vertical line represents the concentration where the relative yield is 100%.

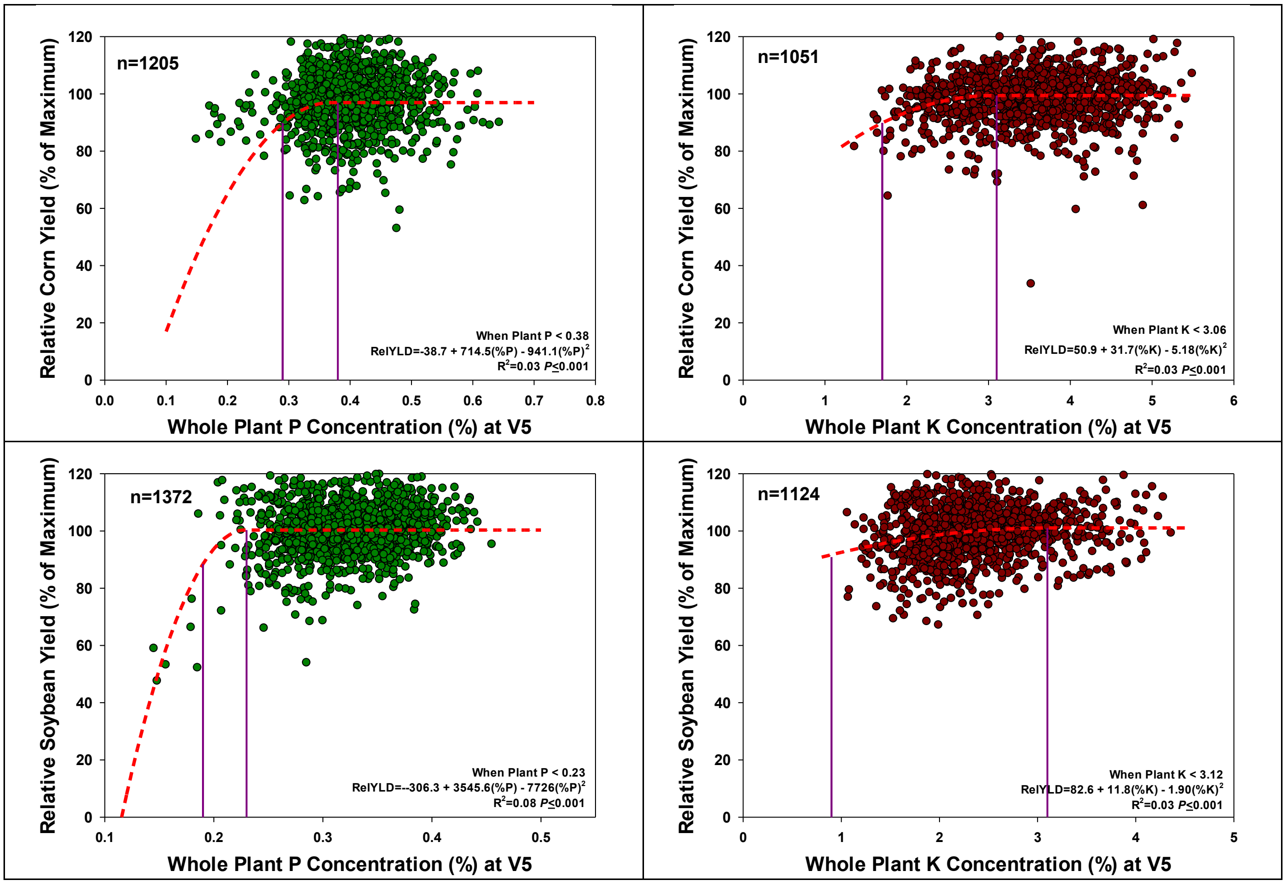


Figure 3. Summary of relative corn (top figures) and soybean (bottom figures) yield response based on whole plant concentration of P or K for samples taken at the V5 growth stage.

Early whole plant P and K concentration data for corn or soybean are summarized in Figure 3. Examination of the data shows a poor correlation between V5 concentration of either P or K for either corn or soybean. Critical levels can be established but the data should be viewed as unreliable for making management decisions. Sampling early in the growing season presents risks as the majority of a nutrient is not yet taken up. In addition, limitations in growth due to cool conditions or growth promotion from starter could change the concentration of a nutrient in the plant.

Conclusions

The data shows that hybrids do significantly vary in their ear leaf nutrient concentration and the differences are not reflected in final yield. For the southern Minnesota locations, only potassium and iron concentrations were found to be stable across locations. All other nutrient concentrations varied by location and hybrids tended to differ in their response by location. Overall the data indicates that single sufficiency values for nutrients may not be adequate as each may have their own sufficiency level for a given nutrient.

Early season plant samples were taken from two corn and two soybean fields. The soybean data showed no meaningful relationship between V5 whole plant tissue concentration and final yield. Data was better for corn showing a relationship between potassium concentration and yield at one location and calcium and copper at another location which was seldom shown to be deficient by comparing concentrations to currently used sufficiency ranges. Plant mass appeared to be a better indicator for final yields in both corn and soybean fields. However, plant mass was negatively correlated to final plant soybean yield. Overall, the tissue analysis showed some stress in the field but there was no indication on the cause of the stress or whether it coud be alleviated by fertilizer applications.

Currently used sufficiency ranges were studied for N, P, K, and S for corn and soybean. The data in this study supported the current ranges for P and S. Nitrogen values for corn followed the current levels suggested but the low end of the range was lower for the current data as what is suggested for many publications. The sufficiency range for potassium was found to be lower than the current published values. However, it is not clear whether this is a result of the dry weather conditions. More work is planned in 2013 to collect additional samples to develop a database that can relate tissue concentration to final plant yield.

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Table 1. Location, planting and sampling information, and the dominant soil series for each environment (Env.).

			Date		Soil		
Env.	Year	Location	Planting	Sampling	Series	Texture†	Classification‡
1	2012	Crookston	9-May	17-Jul	Wheatville	FSL	A. Calciaquoll
2		Fergus Falls	10-May	24-Jul	Forman	CL	C. Argiudoll
3		Hutchinson	30-Apr	19-Jul	Harps	CL	T. Calciaquoll
4		Lamberton	14-May	23-Jul	Normania	L	A. Hapludoll
5		Morris	10-May	23-Jul	McIntosh	SiL	A. Calciudoll
6		Rochester	15-May	23-Jul	Port Byron	SiL	T. Hapludoll
7		Rosemount	1-May	16-Jul	Waukegan	SiL	T. Hapludoll
8		Staples	9-May	27-Jul	Verndale	SL	T. Argiudoll
9		Waseca	26-Apr	18-Jul	Nicollet	CL	A. Hapludoll
10	2013	Crookston	15-May	26-Jul	Wheatville	FSL	A. Calciaquoll
11		Hutchinson	17-May	6-Aug	Clarion	L	T. Hapludoll
12		Lamberton	3-Jun	29-Jul	Ves	L	C. Hapludoll
13		Morris	15-May	1-Aug	Doland	SiL	C. Hapludoll
14		Rochester	3-Jun	19-Aug	Mt. Carroll	SiL	M. Hapludalf
15		Rosemount	4-Jun	5-Aug	Waukegan	SiL	T. Hapludoll
16		Rothsay	14-May	6-Aug	Aazdahl	CL	A. Hapludoll
17		Staples	16-May	6-Aug	Verndale	SL	T. Argiudoll
18		Waseca	13-May	2-Aug	Webster	SiCL	T. Endoaguoll

†C, clay; CL, clay loam; FSL, fine sandy loam; L, loam; SiCL, silty clay loam; SiL, silt loam; SL, sandy loam.
‡A, aquic; C, calcic; M, Mollic; T, Tpic

Table 2. Summary of extractable macronutrients and soil organic matter for studies conducted in 2011 and 2012

				Ammonium Acetate				DTPA						
Year	Location	NO_3-N	P	K	Ca	Mg	SO_4-S	Zn	Fe	Cu	Mn	B	O.M.	pH
		ppm											-%-	
2012	Crookston	67	10	143	4410	800	32	0.4	7	0.8	14	0.9	3.7	7.8
	Fergus Falls	45	18	129	2490	409	7	1.5	61	1.1	67	0.5	4.4	6.1
	Hutchinson	11	46	247	4086	418	10	3.7	28	1.5	27	0.8	5.4	7.3
	Lamberton	29	13	151	2894	636	8	0.9	85	1.8	43	1.2	4.2	6.0
	Morris	12	12	119	4095	583	5	1.5	25	1.2	17	0.7	4.3	7.8
	Rochester	9	22	138	2360	327	5	1.0	47	0.7	22	0.4	4.3	6.8
	Rosemount	31	10	156	1912	438	6	1.3	61	1.0	45	0.5	4.1	5.9
	Staples	14	36	100	1017	111	4	6.8	31	0.9	16	0.3	1.9	6.6
	Waseca	6	9	177	3136	495	5	0.8	114	1.3	32	1.1	4.9	6.0
2013	Crookston	6	14	157	4387	845	6	0.5	6	0.7	11	1.2	3.9	7.7
	Hutchinson	11	17	147	4020	410	17	3.4	35	2.2	25	1.3	5.2	7.1
	Lamberton	6	14	167	2059	436	8	0.8	100	1.7	59	0.8	4.1	5.6
	Morris	5	6	124	5004	514	6	1.3	10	1.1	18	0.9	4.6	7.7
	Rochester	14	15	148	2656	325	8	1.7	53	1.3	28	0.6	5.0	6.8
	Rosemount	14	7	121	1936	456	8	1.3	46	1.4	35	0.5	4.1	6.2
	Rothsay	10	38	193	2582	486	9	2.4	67	1.6	59	1.2	5.6	6.1
	Staples	10	23	86	1163	138	5	5.3	34	0.9	22	0.4	2.0	6.3
	Waseca	6	12	206	4230	640	8	1.9	58	1.6	15	1.2	6.1	6.5

Table 4. Mean ear leaf tissue concentration and grain yield data for the 3 northern locations for each of the hybrids sampled.

		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
		---------------------------%-------------------------						---------------------ppm--------------------					Bu/ac
Dahlman Seed	R41-44VT2P	--	--	--	--	--	--	--	--	--	--	--	--
	R45-20VT2P	2.99	0.25	1.61	0.61	0.50	0.16	5.1	9.3	93.8	79.0	19.0	213.5
Dairyland Seed	DS6780	3.06	0.29	2.11	0.75	0.59	0.23	6.2	11.8	127.6	80.7	17.9	167.4
	DS9487SSX	2.99	0.35	1.73	0.63	0.52	0.20	6.7	11.2	131.3	79.8	20.6	178.4
Dekalb	DKC33-77	3.02	0.29	1.63	0.54	0.70	0.19	7.0	10.0	108.9	60.8	17.7	175.1
	DKC38-03	2.86	0.24	1.83	0.62	0.54	0.19	5.9	9.9	115.0	74.9	18.4	222.3
Dyna-Gro Seed	D31VP31	3.06	0.25	1.56	0.65	0.63	0.19	6.7	10.9	110.8	85.3	20.4	196.1
G2 Genetics	5H-890™	2.88	0.24	1.68	0.61	0.68	0.17	7.0	9.2	114.0	89.0	23.7	212.9
Hyland Seeds	3093	3.10	0.30	2.16	0.75	0.58	0.22	6.0	11.3	128.0	87.7	17.7	152.4
	8180	2.99	0.31	1.52	0.65	0.57	0.20	6.4	11.4	145.0	76.9	21.9	176.8
	8234	3.03	0.39	2.03	0.52	0.54	0.19	6.3	10.8	107.2	82.0	21.8	178.6
	HL 3085	3.08	0.33	2.01	0.64	0.68	0.23	6.9	10.4	121.3	81.4	18.6	149.9
Kussmaul Seeds	GL-885 Quad	3.06	0.28	1.80	0.58	0.53	0.19	5.8	10.0	126.8	65.2	19.9	181.6
	GL-890 Quad	3.02	0.26	1.59	0.70	0.68	0.21	7.9	10.4	126.4	86.4	18.7	193.0
Legacy Seeds	L-2910 VT3Pro	3.00	0.24	1.73	0.61	0.45	0.19	6.8	10.6	120.6	97.1	20.7	214.0
	L-3011 VT3Pro	3.08	0.25	1.62	0.65	0.60	0.20	6.8	10.9	117.8	92.7	22.6	217.8
NuTech	3A-8801™	3.23	0.29	2.01	0.64	0.51	0.19	5.8	11.4	117.8	74.8	19.9	179.0
Peterson Farms Seed	PFS 74K89	2.83	0.24	1.48	0.63	0.55	0.18	6.9	9.7	117.1	84.9	20.1	193.6
	PFS 92G84	2.97	0.25	1.59	0.63	0.53	0.19	6.3	11.1	140.7	66.6	21.0	191.0
Pioneer	38H09	2.81	0.29	1.58	0.70	0.64	0.18	5.1	9.6	121.4	72.1	19.2	194.5
	P8210HR	3.03	0.30	1.82	0.66	0.65	0.19	5.7	9.6	116.7	84.9	24.1	184.3
Proseed	1083 GTCBLL	3.00	0.25	1.77	0.62	0.47	0.19	6.6	11.1	124.2	67.1	20.6	195.6
Renk	RK212GT	3.03	0.26	1.70	0.59	0.55	0.18	6.6	11.1	121.4	61.6	19.6	192.1
Seeds 2000	2852 GTCBLL	3.00	0.24	1.63	0.68	0.60	0.20	7.2	10.9	147.8	68.6	21.4	193.5
	8801 VT2P	3.09	0.26	1.76	0.53	0.58	0.19	5.9	10.9	116.8	78.4	20.1	188.4
Wensman	W 7089VT3	3.13	0.29	1.74	0.56	0.64	0.19	6.0	11.0	113.3	83.8	22.2	200.3

Table 5. Mean ear leaf tissue concentration and grain yield data for the 6 southern locations for each of the hybrids sampled.

		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
		---------------------------%-------------------------						----------------------ppm--------------------					Bu/ac
AgriGold	A6252VT3Pro	2.69	0.24	1.39	0.62	0.46	0.16	8.1	10.1	102.1	58.6	15.9	232
	A6276VT3	2.97	0.25	1.61	0.62	0.46	0.18	10.4	14.3	101.8	59.6	21.8	232
	A6319VT3Pro	2.92	0.28	1.69	0.48	0.36	0.18	9.9	10.6	101.8	52.8	17.6	208
Dairyland	DS6903	2.86	0.25	1.50	0.60	0.58	0.17	8.1	10.9	103.9	57.8	16.2	229
Seeds	DS9303SSX	2.87	0.28	1.40	0.65	0.53	0.19	7.6	10.6	101.5	48.7	16.7	224
	DS9402SSX	2.83	0.28	1.48	0.55	0.46	0.17	6.2	11.3	85.7	46.7	16.0	206
	DS9501SSX	2.83	0.30	1.36	0.59	0.51	0.16	6.2	10.2	94.5	59.9	16.9	221
Dekalb	DKC48-12	2.86	0.31	1.59	0.63	0.47	0.17	7.4	9.7	96.3	54.4	18.7	221
	DKC50-77	2.86	0.26	1.59	0.56	0.41	0.17	7.5	10.8	113.7	69.4	15.7	209
	DKC52-04	3.10	0.27	1.36	0.64	0.47	0.18	7.8	10.5	104.7	44.2	18.8	236
	DKC53-78	2.96	0.34	1.71	0.56	0.43	0.18	7.8	11.2	99.7	54.2	17.9	227
Epley Bros.	E9808VIP	2.76	0.26	1.52	0.64	0.51	0.19	8.7	9.1	96.2	36.1	16.6	222
G2	5H-202™	2.71	0.23	1.60	0.52	0.47	0.16	7.1	10.2	100.8	38.1	14.9	261
Genetics	5H-399™	2.79	0.26	1.32	0.61	0.56	0.16	6.7	9.4	96.4	45.2	17.3	223
	5H-502™	2.99	0.28	1.55	0.61	0.42	0.18	9.2	9.5	105.3	39.3	19.8	225
	5X-0004™	2.80	0.33	1.38	0.65	0.53	0.16	6.6	9.3	100.3	38.7	14.6	217
	5X-903™	2.78	0.29	1.47	0.57	0.62	0.16	6.7	9.2	96.4	44.7	19.2	218
	5Z-198™	2.86	0.27	1.48	0.63	0.56	0.16	7.7	10.5	102.9	52.1	18.2	211
	5Z-802™	2.70	0.26	1.37	0.74	0.61	0.16	6.4	9.9	97.1	45.6	15.9	223
NuTech	5N-001™	2.84	0.27	1.48	0.59	0.46	0.17	8.9	8.6	95.4	34.9	18.4	223
Pioneer	P0062XR	2.64	0.28	1.59	0.52	0.54	0.15	5.6	9.1	94.3	43.9	15.6	233
	P0193HR	2.92	0.26	1.46	0.60	0.49	0.16	6.8	9.6	98.2	40.7	16.1	244
	P9917AM1	2.80	0.29	1.58	0.52	0.49	0.16	5.7	9.7	97.2	50.7	18.0	217
Renk	RK576VT3P	2.92	0.25	1.55	0.61	0.44	0.17	7.4	11.1	104.5	63.8	17.2	204
	RK580SSTX	3.01	0.32	1.61	0.57	0.41	0.18	11.1	11.8	97.7	60.0	19.7	207
	RK629VT3P	2.84	0.25	1.66	0.51	0.44	0.17	7.7	10.1	112.9	60.3	16.4	235

Table 5. Mean ear leaf tissue concentration and grain yield data for the 6 southern locations for each of the hybrids sampled (continued).

		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
		----------------------------%--------------------------						----------------------ppm--------------------					Bu/ac
TitanPro	1018	2.71	0.27	1.48	0.60	0.52	0.16	6.6	8.7	101.9	46.8	18.0	229
	1M02-SS	2.94	0.28	1.49	0.69	0.44	0.17	9.6	12.7	101.4	58.3	18.7	230
	1M99-3P	2.78	0.25	1.50	0.67	0.45	0.18	10.3	11.4	110.4	68.5	17.3	221
	81A02GL	3.11	0.29	1.48	0.65	0.44	0.19	8.0	11.5	103.3	55.1	18.4	220
	89A02GL	2.94	0.28	1.55	0.59	0.43	0.18	8.5	9.3	104.6	37.0	17.4	220
	X2M00-SS	2.84	0.25	1.47	0.62	0.50	0.17	9.7	10.0	100.1	61.2	18.3	224
Wensman	W7270VT3PRO	2.91	0.28	1.43	0.66	0.52	0.17	7.6	10.7	101.2	61.6	20.3	199
	W7290VT3PRO	2.82	0.25	1.44	0.64	0.47	0.17	8.2	10.3	103.6	55.4	16.9	230
	W7320VT3PRO	3.00	0.28	1.65	0.48	0.40	0.18	9.5	10.7	100.8	50.6	17.3	220
	W9288VT3PRO	2.85	0.25	1.42	0.64	0.44	0.17	9.5	9.6	92.6	53.2	17.7	239

Table 4b. Mean ear leaf tissue concentration and grain yield data for the subset of hybrids sample at the 6 northern locations during the 2012-2013 growing seasons.

		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
		----------------------------%--------------------------						----------------------ppm--------------------					Bu/ac
Dairyland Seed	DS9487SSX	3.04b	0.34a	1.84c	0.60d	0.51bcd	0.21b	7.7a	10.4ab	138a	79bc	21.8a	182b
Dekalb	DKC38-03	2.92c	0.28cd	2.02b	0.59d	0.48cd	0.20c	6.6c	9.2c	116c	78bc	18.8cd	211a
Hyland Seeds	3093	3.07ab	0.31b	2.23a	0.73a	0.55b	0.24a	6.3c	10.6a	133ab	88a	17.3d	148d
	8180	3.03b	0.31b	1.65d	0.66bc	0.52bc	0.24b	7.2b	10.8a	138a	80b	21.2ab	170c
Pioneer	P8210HR	3.06ab	0.30bc	1.90bc	0.67b	0.61a	0.21b	6.3c	9.2c	116c	93a	22.6a	173bc
Proseed	1083 GTCB	3.05ab	0.27d	1.92bc	0.61cd	0.45d	0.21b	7.4ab	9.9b	130ab	72cd	19.3c	183b
Renk	RK212GT	3.14a	0.28cd	1.88c	0.61cd	0.51bc	0.21b	7.1b	10.7a	124bc	70d	19.9cd	182b

Table 5b. Mean ear leaf tissue concentration and grain yield data for a subset of hybrids sampled at 12 southern locations during 2012-2013.

		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
		----------------------------%--------------------------						----------------------ppm--------------------					bu/ac
Dairyland	DS9303SSX	2.93bc	0.28c	1.48d	0.66a	0.53a	0.21a	7.3a	10.1a	105a	55b	18.2b	199bc
	DS9501SSX	2.88c	0.30b	1.46d	0.57bc	0.51ab	0.17d	6.1c	9.7b	99c	61a	17.5bc	193c
Dekalb	DKC53-78	2.99b	0.33a	1.74a	0.55c	0.43c	0.20b	7.4a	10.3a	100bc	59a	19.6a	201b
Pioneer	P0062XR	2.72d	0.29c	1.69a	0.53d	0.51ab	0.17d	5.6d	8.9c	103bc	50c	17.3c	201b
	P0193HR	3.06a	0.27d	1.54c	0.59b	0.50b	0.18c	6.7b	9.4b	103bc	46d	17.5bc	211a
	P9917AM1	2.89c	0.30b	1.60b	0.52d	0.50b	0.18c	6.0c	9.5b	103bc	54b	19.5a	200bc

Table 10. Stability data for nutrient concentration and yield for the northern locations.

Company	Hybrid	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
Dahlman Seed	R41-44VT2P												
	R45-20VT2P	ns	ns	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Dairyland Seed	DS6780	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	DS9487SSX	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Dekalb	DKC33-77	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	DKC38-03	ns	=	=	ns	ns	ns	ns	ns	ns	ns	ns	ns
Dyna-Gro Seed	D31VP31	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
G2 Genetics	5H-890™	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Hyland Seeds	3093	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	8180	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	8234	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	HL 3085	ns	↑	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Kussmaul Seeds	GL-885 Quad	ns	ns	=	ns	ns	ns	ns	ns	ns	ns	ns	ns
	GL-890 Quad	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Legacy Seeds	L-2910 VT3Pro	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	L-3011 VT3Pro	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
NuTech	3A-8801™	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Peterson Farms Seed	PFS 74K89	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	PFS 92G84	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Pioneer	38H09	ns	ns	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	P8210HR	ns	↑	=	ns	ns	ns	ns	ns	ns	ns	ns	ns
Proseed	1083 GTCBLL	ns	ns	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Renk	RK212GT	ns	=	=	ns	ns	ns	ns	↑	ns	ns	ns	ns
Seeds 2000	2852 GTCBLL	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
	8801 VT2P	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns
Wensman	W 7089VT3	ns	=	=	ns	ns	ns	ns	=	ns	ns	ns	ns

† ns, GxE effect was not significant; =, Hybrid responded equally as well/poor as the mean of all hybrids for a given location; ↓, hybrid responded less than others when concentration was higher; ↑, hybrid responded more than others at sites with higher nutrient concentrations.

Table 11. Stability data for nutrient concentration and yield for the southern locations.

Company	Hybrid	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Yield
AgriGold	A6252VT3Pro	=	=	ns	=	=	=	=	=	ns	=	=	=
	A6276VT3	=	=	ns	=	=	=	↑	↑	ns	=	↑	=
	A6319VT3Pro	=	=	ns	=	↓	=	↑	=	ns	=	=	=
Dairyland	DS6903	=	=	ns	ns	=	=	=	=	ns	=	ns	=
Seed	DS9303SSX	=	=	ns	=	=	↑	=	=	ns	=	=	=
	DS9402SSX	ns	↑	ns	ns	=	ns	↓	↑	ns	=	ns	=
	DS9501SSX	=	=	ns	ns	=	ns	=	=	ns	=	↑	=
Dekalb	DKC48-12	=	↑	ns	ns	=	=	=	=	ns	=	=	=
	DKC50-77	=	=	ns	=	=	ns	=	=	ns	=	ns	=
	DKC52-04	=	=	ns	=	=	=	=	=	ns	=	=	=
	DKC53-78	=	↑	ns	=	=	=	=	=	ns	↑	=	=
Epley	E9808VIP	=	=	ns	↑	=	↑	=	=	ns	=	=	=
G2	5H-202™	=	=	ns	=	=	ns	↓	=	ns	=	=	=
	5H-399™	=	=	ns	=	=	=	↓	=	ns	↓	ns	=
	5H-502™	=	=	ns	=	↓	=	=	=	ns	=	=	=
	5X-0004™	=	↑	ns	ns	=	=	↓	=	ns	↓	ns	=
	5X-903™	=	=	ns	ns	↑	ns	↓	=	ns	=	ns	=
	5Z-198™	=	=	ns	ns	=	ns	=	↑	ns	=	=	=
	5Z-802™	=	=	ns	ns	=	ns	↓	↑	ns	=	=	=
NuTech	5N-001™	=	=	ns	=	=	=	=	=	ns	=	ns	=
Pioneer	P0062XR	=	↑	ns	ns	=	=	↓	=	ns	=	=	=
	P0193HR	=	=	ns	=	=	=	=	=	ns	=	ns	=
	P9917AM1	=	=	ns	=	=	=	↓	↓	ns	↑	ns	=
Renk	RK576VT3P	=	=	ns	=	=	=	↓	=	ns	↑	=	=
	RK580SSTX	=	=	ns	=	=	=	↑	↑	ns	=	=	=
	RK629VT3P	=	=	ns	=	=	=	=	=	ns	=	=	↑
TitanPro	1018	=	=	ns	=	=	=	↓	↓	ns	=	ns	=
	1M02-SS	=	=	ns	=	=	=	↑	↑	ns	=	=	↑
	1M99-3P	=	↓	ns	=	=	=	↑	=	ns	↑	ns	=
	81A02GL	=	=	ns	=	=	=	=	=	ns	=	ns	=
	89A02GL	↓	=	ns	=	=	=	=	=	ns	↓	=	=
	X2M00-SS	=	=	ns	=	↑	=	↑	↓	ns	=	ns	=
Wensman	W7270VT3PRO	↑	=	ns	=	=	=	=	=	ns	=	↑	=
	W7290VT3PRO	=	=	ns	=	=	=	=	↓	ns	=	=	=
	W7320VT3PRO	=	=	ns	=	=	=	=	=	ns	=	ns	=
	W9288VT3PRO	=	↓	ns	=	↓	=	↑	=	ns	=	=	=

† ns, GxE effect was not significant; =, Hybrid responded equally as well/poor as the mean of all hybrids for a given location; ↓, hybrid responded less than others when concentration was higher; ↑, hybrid responded more than others at sites with higher nutrient concentrations.

Table 13. Summary statistics for the two corn locations plant sampled on 2.5 acre grids in 2012.

Location	Variable		Mean	Std Dev	Median	Minimum	Maximum	CL†	% < CL
Northfield	Yield	bu/ac	215.5	9.1	215.2	195.9	235.5		na
n=65	Plant Mass	g/plant	8.4	1.5	8.2	5.5	12.6		na
	N	%	3.34	0.37	3.35	2.48	4.21	3.5	66
	P	%	0.34	0.06	0.33	0.23	0.49	0.3	31
	K	%	3.88	0.69	3.88	2.34	5.34	2.5	2
	Ca	%	0.36	0.06	0.35	0.24	0.55	0.3	9
	Mg	%	0.19	0.05	0.17	0.13	0.37	0.15	18
	S	%	0.22	0.03	0.22	0.16	0.27	0.15	0
	B	ppm	5.4	0.8	5.3	3.7	9.6	5	22
	Cu	ppm	6.1	1.3	6.1	3.1	12.0	5	20
	Fe	ppm	452	337	404	153	2690	50	0
	Mn	ppm	69	19	68	39	115	20	0
	Zn	ppm	28	6	27	17	45	20	8
Stewart	Yield	bu/ac	223.5	9.1	223.9	200.5	240.2		na
n=63	Plant Mass	g/plant	3.5	1.1	3.4	1.6	6.4		na
	N	%	3.23	0.38	3.26	2.05	4.18	3.5	81
	P	%	0.41	0.06	0.41	0.25	0.55	0.3	3
	K	%	2.68	0.74	2.61	1.41	4.99	2.5	41
	Ca	%	0.63	0.08	0.62	0.39	0.88	0.3	0
	Mg	%	0.36	0.07	0.37	0.15	0.51	0.15	0
	S	%	0.20	0.04	0.19	0.15	0.38	0.15	2
	B	ppm	8.7	1.7	8.6	6.2	15.5	5	0
	Cu	ppm	7.3	1.0	7.6	5.0	9.4	5	0
	Fe	ppm	279	128	256	140	1090	50	0
	Mn	ppm	72	13	71	44	101	20	0
	Zn	ppm	30	6	30	20	45	20	2

†CL, defined critical level for a given nutrient; %<CL, percent of grid cells testing less than the critical level.

Table 14. Spearman rank correlation coefficients for the Northfield corn location. Values between -0.24 and 0.24 are not significant at $P \leq 0.05$ (n=65).

	PlWGT	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Yield	0.54	-0.11	-0.01	-0.09	0.29	0.20	-0.05	-0.06	0.29	0.06	-0.23	0.01
PlWGT		-0.11	-0.15	-0.15	0.29	0.18	-0.09	0.02	0.34	0.25	-0.11	0.12
N			0.46	0.65	0.19	0.20	0.79	0.42	0.27	-0.37	0.56	0.49
P				0.71	0.07	0.12	0.67	0.52	0.09	-0.15	0.27	0.48
K					-0.19	-0.15	0.77	0.48	0.05	-0.27	0.49	0.69
Ca						0.90	0.16	0.19	0.62	0.19	-0.13	-0.11
Mg							0.18	0.14	0.70	0.10	-0.15	-0.20
S								0.60	0.30	-0.34	0.52	0.59
B									0.19	-0.16	0.30	0.54
Cu										0.18	-0.13	0.10
Fe											-0.12	-0.18
Mn												0.33

†PlWGT, V5 plant mass.

Table 15. Spearman rank correlation coefficients for the Stewart corn location. Values between -0.25 and 0.25 are not significant at $P \leq 0.05$ (n=63).

	PlWGT	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Yield	0.52	-0.20	-0.05	0.40	0.03	-0.39	-0.13	-0.06	-0.17	0.19	-0.30	0.00
PlWGT		-0.16	-0.12	0.27	0.09	-0.15	0.01	0.12	-0.06	0.10	-0.15	0.13
N			0.06	-0.32	0.03	0.44	0.34	-0.05	0.25	-0.20	0.28	-0.04
P				0.08	-0.07	0.13	0.01	0.22	-0.01	0.16	-0.02	-0.12
K					-0.32	-0.79	-0.05	-0.20	-0.48	0.33	-0.46	-0.01
Ca						0.36	0.50	0.35	0.46	-0.01	0.42	0.11
Mg							0.12	0.19	0.47	-0.28	0.48	-0.04
S								-0.01	0.44	-0.21	0.33	0.24
B									-0.07	0.08	0.00	-0.22
Cu										-0.35	0.67	0.29
Fe											-0.07	-0.11
Mn												0.10

†PlWGT, V5 plant mass.

Table 16. Summary statistics for the two soybean locations plant sampled on 2.5 acre grids in 2012.

Location	Variable		Mean	Std Dev	Median	Minimum	Maximum
Northfield	Yield	bu/ac	54.5	7.0	55.4	33.2	70.2
n=66	Plant Mass	g/plant	5.2	1.5	5.0	2.0	9.4
	N	%	3.91	0.33	3.90	3.23	4.86
	P	%	0.31	0.04	0.32	0.23	0.42
	K	%	1.92	0.40	1.87	1.21	3.02
	Ca	%	1.53	0.12	1.52	1.28	1.85
	Mg	%	0.63	0.10	0.63	0.42	0.85
	S	%	0.24	0.01	0.24	0.20	0.28
	B	ppm	29.6	2.7	29.6	23.5	35.7
	Cu	ppm	10.4	1.7	10.4	4.5	13.6
	Fe	ppm	191	38	183	140	307
	Mn	ppm	53	10	52	36	76
Stewart	Zn	ppm	36	5	36	21	49
n=76	Yield	bu/ac	66.5	5.5	65.8	49.9	79.8
	Plant Mass	g/plant	3.8	1.2	3.9	0.5	6.5
	N	%	3.49	0.28	3.45	2.82	4.20
	P	%	0.30	0.03	0.30	0.24	0.38
	K	%	1.93	0.32	1.94	1.30	3.26
	Ca	%	1.77	0.26	1.76	1.33	2.59
	Mg	%	0.54	0.06	0.55	0.33	0.70
	S	%	0.20	0.04	0.19	0.15	0.45
	B	ppm	32.6	3.4	32.3	24.2	42.8
	Cu	ppm	8.4	1.3	8.4	5.3	14.0
	Fe	ppm	302	106	284	141	758
	Mn	ppm	89	32	83	39	193
	Zn	ppm	28	4	28	20	38

Table 17. Spearman rank correlation coefficients for the Northfield soybean location. Values between -0.24 and 0.24 are not significant at $P \leq 0.05$ (n=66).

	PlWGT	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Yield	-0.40	-0.09	0.25	0.11	-0.09	-0.01	0.11	-0.05	-0.23	-0.14	-0.01	-0.04
PlWGT		0.18	0.07	0.10	0.03	-0.07	0.04	0.00	0.07	-0.10	-0.16	0.26
N			0.27	0.07	0.18	0.08	0.48	0.05	0.04	-0.13	0.11	0.16
P				0.41	-0.31	-0.09	0.30	-0.35	-0.06	-0.17	-0.05	0.24
K					-0.39	-0.72	0.09	-0.41	-0.29	-0.03	-0.11	0.15
Ca						0.25	0.38	0.68	-0.14	0.01	-0.08	0.13
Mg							-0.04	0.07	0.48	0.04	0.17	-0.14
S								0.35	-0.05	0.08	-0.05	0.34
B									-0.12	0.03	-0.09	0.26
Cu										0.28	0.21	0.23
Fe											0.05	-0.07
Mn												-0.11

†PlWGT, V5 plant mass.

Table 18. Spearman rank correlation coefficients for the Stewart soybean location. Values between -0.23 and 0.23 are not significant at $P \leq 0.05$ (n=76).

	PlWGT	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Yield	-0.31	-0.28	-0.10	-0.12	0.30	0.15	-0.06	-0.24	0.01	0.07	0.28	-0.15
PlWGT		0.10	0.11	-0.01	-0.09	-0.06	0.10	0.22	-0.06	0.02	-0.22	0.05
N			0.17	0.01	-0.07	-0.02	0.52	0.43	-0.22	-0.16	-0.01	0.18
P				0.29	-0.20	-0.20	0.33	0.15	-0.26	0.22	-0.18	0.12
K					-0.37	-0.72	0.14	-0.23	-0.05	-0.08	-0.19	0.35
Ca						0.39	0.25	0.01	0.54	0.17	0.76	-0.06
Mg							-0.06	0.23	0.06	0.02	0.18	-0.29
S								0.41	0.16	0.05	0.39	0.47
B									-0.35	0.22	-0.07	0.02
Cu										0.13	0.57	0.33
Fe											0.15	0.00
Mn												0.09

†PlWGT, V5 plant mass.

Table 20. Critical plant tissue levels used for this study taken from Jones Jr. et al., Plant Analysis Handbook.

	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	---------------------------%--------------------------						---------------------ppm--------------------				
Corn V5	3.5	0.30	2.50	0.30	0.15	0.15	5	5	50	20	20
Corn R2	2.70	0.20	1.70	0.40	0.20	0.10	4	3	50	20	20
Soybean R2	4.01	0.26	1.71	0.36	0.26	0.21	21	10	51	21	20