A Survey of Delaware Soybean Variety Tissue Nutrient Concentrations

Jarrod O. Miller and Amy L. Shober

University of Delaware Extension

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Introduction and Objectives

University variety trials provide an opportunity to study nutrient uptake across a range of maturity dates and soil types. This includes both full season and double crop soybeans, where nutrient uptake may be influenced by availability and timing due to natural cycling. Statewide analyses of soybean fields across our regional soils can reveal a broader focus for future research. This includes evaluating the current state of critical nutrient concentrations. Critical nutrient levels have been developed for many crops, including soybeans. These values indicate whether a nutrient was lacking in crops, even though adequate fertilizer may have been applied. Some of these values were developed with older hybrids and may need updating, and variety trials are a good environment to observe these levels.

Methods

Full season variety trials were planted in May and double crop trials were planted in July 2020 by the Carvel Farm management crew. Full season trials in Georgetown were not sampled due to potential residual herbicide damage. Trials in Dagsboro and Middletown were selected instead. Double crop trials had limited plantings due to covid19 restrictions, restricting us to sampling the Georgetown trials only. Full season and double crop soybean leaf and tissue samples were collected at R1/R2 (July/August) from all trials. Maturity groups sampled ranged from 3.4 to 4.8.

Tissue and soil samples were analyzed by the University of Delaware Soil Testing Lab in the winter of 2021. Data was first analyzed by maturity group, but no significant differences were found. Soil and tissue nutrient levels were then analyzed as a completely randomized design by planting location, which were the dominant factors in nutrient uptake. Mean separation was analyzed by least significant difference (α =0.1). Numbers in the tables followed by different letters are considered significantly different from each other.

Results and Discussion

Yields and Soil Characteristics

Average yields across the maturity groups sampled (3.4 to 4.8) were highest in Middletown (59.1

bu/acre), followed by Dagsboro (51.4 bu/acre), and lowest in Georgetown (35.2 bu/acre). The Georgetown trials were irrigated double crop beans and may have suffered from herbicide carryover in some locations. Soil pH was lowest in Dagsboro, which is more common for soils higher in organic matter, which was also highest in Dagsboro (6.5%). While Middletown only contained 1.7% organic matter, it is almost double what is found in sandy Georgetown soils (1.0% OM). The cation exchange capacity (CEC) also followed organic matter trends, being highest in Dagsboro (11.9 meq $100g^{-1}$) and lowest in Georgetown (4.7 meq $100g^{-1}$). These soil characteristics explain some of the yield differences, as higher CEC and organic matter contents can benefit nutrient cycling. The Middletown site may also have benefited from better rainfall and moisture conditions in 2020.

Table 1: Soybean Yields (bu/acre) and soil properties for each of the trial locations (α=0.1).

	Yields (bu/acre)	pH	Organic Matter (%)	CEC (meq $100g^{-1}$)
Dagsboro	51.4 b	5.37 b	6.5 a	11.9 a
Georgetown	35.2 c	6.1 a	1.0 c	4.7 c
Middletown	59.1 a	6.0 a	1.7 b	6.6 b
p-value	0.0001	0.0001	0.0001	0.0001

Soil Nutrient Contents

When averaged by site, there was variation in soil nutrient levels (Table 2). When considering optimum ranges, P was low in Middletown (20.2 ppm), K was excessive in Dagsboro (198.2 ppm), Ca was medium FIV in Georgetown (476.8 ppm), and Mg was excessive in Georgetown (178.7 ppm). Both S and Mn were excessive at all sites. Otherwise nutrients were at optimum levels.

Compared by site, all macro and micronutrients varied by site, as well as Na and Al levels. Dagsboro had the highest P, K, Ca, S, Zn, Cu, Na, and Al concentrations (Table 2), while Middletown had the highest Mn and B concentrations. Georgetown had the highest Mg and Fe levels. Macronutrients (P, K, Ca, Mg) are likely higher in soils due to fertilizer and lime applications, although the low pH in Dagsboro doesn't support recent Ca additions from lime.

The nutrients S and B leach easily and higher concentrations are associated in soils with higher organic matter. While S is highest in Dagsboro, possibly due to organic matter mineralization, but B was higher in Middletown. The higher B in Middletown may be due to higher clay content which has some anion exchange capacity. The metals Al, Zn and Cu were also higher in Dagsboro, where organic matter will be both a nutrient source and chelating agent for metals.

Table 2: Elemental analyses of soil samples including two non-nutrients (Na and Al) and their optimum ranges in Delaware (α=0.1)..

	P	K	Ca	Mg	S	Mn	Zn	Cu*	Fe*	B*	Na*	Al*
	ppm											
Optimum Range	*50-100*	*91-182*	*500-1000*	*53-132*	*1.7*	*0.95-1.55*	-	-	-	-	*n/a*	*n/a*
Dagsboro	287.6 a	198.2 a	954.1 a	143.2 b	19.1 a	6.6 c	7.4 a	3.4 a	91.8 b	0.28 b	10.9 a	1223.5a
Georgetown	156.7 b	105.2 c	476.8 c	178.7 a	10.4 b	11.5 b	3.0 b	1.8 b	114.5 a	0.33 ab	9.4 b	762.5 b
Middletown	20.2 c	125.2 b	607.9 b	53.5 c	10.2 b	58.4 a	0.9 c	0.7 c	81.9 c	0.38 a	7.9 c	792.1 b
p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.025	0.0004	0.0001

**DE has not developed recommendations for some micronutrients that are not typically lacking in our soils while Na and Al are not essential nutrients.*

Table 3: Elemental analyses of leaf and whole tissue samples and their optimum ranges in Delaware (α=0.1)..

	P %	K %	Ca %	Mg %	S %	Mn ppm	Zn ppm	Cu ppm	Fe ppm	B ppm	Na* ppm	Al* ppm
Sufficiency Range	*0.3-0.6*	*1.5-2.25*	*0.8-1.4*	*0.25-0.70*	*0.25-0.6*	*17-100*	*21-80*	*4-30*	*25-300*	*20-60*	*n/a*	*n/a*
Dagsboro	0.41 b	2.43 b	0.73	0.39 b	0.30 a	53.28	72.4 a	9.99 a	99.37 b	34.37 b	21.19	32.64 b
Georgetown	0.49 a	2.55 a	0.78	0.37 c	0.26 b	51.7	42.2 b	8.41 b	114.38b	36.28 b	25.24	134.5 a
Middletown	0.49 a	2.21 c	0.71	0.45 a	0.30 a	52.3	39.6 b	10.22 a	182.85a	44.30 a	19.96	141.63a
	0.0001	0.0001	0.1723	0.0001	0.0001	0.7858	0.0001	0.0001	0.0123	0.0001	0.1093	0.054
	Whole Plant Analyses											
Dagsboro	0.33 a	3.2 a	0.95	0.36 b	0.20	43.66 b	64.4 a	8.57 b	104.52c	34.13	24.22 b	169.2 b
Georgetown	0.34 a	2.7 b	1.1	0.34 b	0.20	43.53 b	34.8 b	8.69 b	342.36b	31.12	28.84 b	868.55a
Middletown	0.27 b	2.3 c	1.07	0.51 a	0.21	55.59 a	31.2 b	10.18 a	564.03	33.19	41.99 a	839.38a

** Na and Al are not essential nutrients, but may still be absorbed by the plant.*

Tissue Data

Nutrient sufficiency ranges for soybean are known for the upper canopy leaves (Table 3). Phosphorus, Mg, S, Mn, Zn, Cu, Fe, and B were all within sufficiency ranges, but did not exceed them. Sulfur was just within sufficiency at Georgetown, while higher M3 levels did not increase leaf tissue S in Dagsboro. The only nutrient below the sufficiency range was Ca (Table 3). This occurred at all locations. The soil test Ca in Dagsboro was just below excessive, but did not result in higher Ca levels, but it may have been suppressed by high K in those soils.

While P was three times higher than optimum in Dagsboro, average leaf tissue values were the lowest. Dagsboro also had the highest soil K, but second highest leaf tissue K. Middletown had the lowest soil Fe concentrations, but highest leaf tissue Fe. Dagsboro soils had the highest soil Al, but leaf tissue samples were very reduced compared to Georgetown and Middletown.

Compared to leaf tissue samples, whole plant nutrient levels followed soil test values closer, with Dagsboro having both the highest soil test and whole plant P and K levels (Table 3). A more confusing observation is that Middletown had the lowest Mg, Cu, and Fe in the soil, but the highest in the whole plant tissue.

Correlations of Yield and Macronutrients

For macronutrients, yield increased with soil K, Ca, and Mg, with Mg having the strongest correlation to yield. Magnesium also had strong, positive relationships with yield in whole plant and leaf tissue samples. Potassium, while having a positive effect based on soil test levels, had a negative relationship with yield when present in the leaf tissue. This may indicate some kind of stress or environmental response that increased K in the leaf tissue. Other negative nutrient effects included whole plant P and leaf tissue Ca. Sulfur was only related to yield in leaf tissue samples, showing a positive relationship.

Table 4: Yield correlations to macronutrients in the soil and tissue.*

SoilP	SoilK	SoilCa	SoilMg	SoilS
-0.32251	0.39267	0.3443	0.84186	0.21786
0.1243	0.0577	0.0995	<.0001	0.3065
PlantP	**PlantK**	**PlantCa**	**PlantMg**	**PlantS**
-0.42321	-0.11812	-0.11959	0.62344	0.10167
0.0393	0.5825	0.5778	0.0011	0.6364
LeafP	**LeafK**	**LeafCa**	**LeafMg**	**LeafS**
-0.04377	-0.51769	-0.37199	0.75991	0.65767
0.8391	0.0096	0.0735	<.0001	0.0005

**Significant correlations highlighted in gray*

Correlations of Yield and Micronutrients

Soil Fe had a strong negative correlation with yield, but that may have been due to environmental factors lowering yield in Georgetown, where soil Fe was also the highest (Table 5). Similarly, the positive correlation with Mn doesn't mean soil Mn increased yield, but that Middletown Mn levels and yields were higher in 2020. However, whole plant Mn levels were also related to higher yields (Table 5), which may give credence to improved Mn management. The only other whole plant nutrient related to yield was Cu, which also increased in the plant as yield increased.

Mn in the leaf tissue was not related to yield, although whole plant levels were. There may be reason to observe whole plant Mn levels future studies to determine if uptake across the whole plant is more important than focusing on leaf tissue. Boron was the opposite, where only leaf tissue samples had a positive relationship with yield.

Higher sodium in the soil was not related to yield, although higher levels in both the whole plant and leaf tissue were related to lower yield. In the 2019 study of 30 fields across DE, some fields with higher Na in the tissue did have higher yield. Aluminum also had no strong observable effects on yield.

Table 5: Yield correlations to micronutrients in the soil and tissue.*

SoilMn	**SoilZn**	**SoilCu**	**SoilFe**	**SoilB**	**SoilNa**	**SoilAl**
0.5756	-0.10015	-0.17257	-0.83109	0.23757	-0.25434	0.25808
0.0032	0.6415	0.42	<.0001	0.2637	0.2304	0.2234
PlantMn	**PlantZn**	**PlantCu**	**PlantFe**	**PlantB**	**PlantNa**	**PlantAl**
0.47328	0.06445	0.42726	0.0056	0.16577	-0.50235	-0.36844
0.0302	0.7648	0.0373	0.9808	0.4389	0.0124	0.1003
LeafMn	**Leafzn**	**LeafCu**	**LeafFe**	**LeafB**	**LeafNa**	**LeafAl**
0.07652	0.20639	0.783	0.23173	0.35027	-0.48979	0.19226
0.7223	0.3332	<.0001	0.2759	0.0933	0.0151	0.3681

**Significant correlations highlighted in gray. Na and Al are not essential nutrients.*

Correlations of Selected Leaf Tissue Nutrients

From the tissue samples observed above, Mg, S and Cu had the strongest postive relationship to yield, while leaf K concentrations had the strongest negative relationship to yield (Tables 4 and 5). When compared to other nutrient tissue concentrations, leaf Mg had strong positive correlations with total plant Mg concentrations (Table 6), as well as leaf S and Plant Mn. Not every element correlated between their whole plant and leaf tissue samples. Like yield, leaf Mg had a negative correlation to Na in both whole plant and leaf tissue samples.

Many of these relationships are also found between leaf S and Cu, which both positively correlate to Mg in the leaf and whole plant tissue (Table 6). They also both have negative relationships with plant tissue Na concentrations, but only S had a negative correlation to leaf tissue Na.

Additionally, leaf S had a positive relationship with whole plant B and leaf Cu had a negative relationship with leaf Ca levels. These may be artifacts of the study or related to uptake mechanisms between the nutrients.

Potassium, whose soil concentrations were positively related to yield, but leaf tissue concentrations had negative correlation, had reverse relationships with Mg, S and Cu. For these study sites, either excessive uptake of K lower yield or uptake of other nutrients. However, as noted above, Mg concentrations were lowest in Middletown soils, but highest in the tissue samples. Whether uptake or environment relationships are responsible, this observational study can’t provide an answer. Instead, these relationships point to the difficult in determining the sufficient soil and tissue levels to maintain yield, when all of the factors affecting uptake are poorly understood.

Table 6: Correlations of leaf Mg, K, S, and Cu to selected soil, plant, and leaf tissue nutrients. [$]

	PlantMg	**LeafS**	**PlantMn**	**PlantNa**	**LeafNa**
Leaf Mg	0.86	0.67	0.60	-0.41	-0.40
	***	**	**	*	*
	SoilMg	**PlantMg**	**LeafMg**	**LeafS**	**LeafCu**
Leaf K	-0.67	-0.59	-0.76	-0.65	-0.54
	**	**	***	**	**
	SoilMg	**PlantMg**	**PlantB**	**PlantNa**	**LeafNa**
Leaf S	0.82	0.54	0.51	-0.66	-0.55
	***	**	*	**	**
	PlantMg	**LeafMg**	**LeafCa**	**LeafS**	**PlantNa**
Leaf Cu	0.45	0.61	-0.52	0.64	-0.53
	*	**	**	**	**

*$ - *(α=0.05), ** (α=0.01),***(α=0.0001)*

Conclusions

Strong relationships between maturity group and nutrient uptake were not observed in this study, but potential herbicide damage, drought, and other environmental conditions may have contaminated the study. Instead the strongest relationships in Delaware for soybean yield remain to be soil type and access to adequate moisture. Soil nutrient concentrations varied by site, which is not unusual considering variation in management and natural soil variability.

However, there were some interesting relationships for nutrient uptake and sufficiency ranges. The only nutrient that did not meet the sufficiency range was leaf concentrations of Ca. When compared to yield, higher Ca levels had a weak, but significantly negative relationship with yield. Whether this means Ca sufficiency levels are high, or nutrient imbalances needed corrected is not known. A more confusing observation is that Middletown had the lowest Mg, Cu, and Fe in the soil, but the highest in the whole plant tissue. Middletown also had the lowest P concentration, but a higher leaf P, but lowest whole plant P concentration.

Some of the strongest correlations to yield included Mg, S, and Cu, which all increased in the plant with higher yield. These three nutrients were also correlated to each other by plant tissue concentrations. Higher potassium in leaf samples was actually related to lower yield though, which may indicate some kind of stress or competitive uptake with Mg or Ca.

Sodium tissue levels were similar to the 2019 statewide survey, which was also the only plant nutrient which correlated to yield. In 2019 we assumed this to be a corollary to irrigation, with higher plant levels related to irrigation water salt concentrations. In the 2020 variety trial study, Na had a negative correlation to yield as well as Mg, S, and Cu. As a monovalent cation, it would also be expected that Na would have a negative relationship with K uptake, but this was not the case. With tissue levels similar to 2019, it can be assumed that Na uptake was either in competition with other nutrients, or the result of some kind of environmental stressor. As this study was not controlling for any nutrient or variable, that cannot be known.

This study leads us to conclude that Mg uptake, and its relationship to soil and nutrient characteristics, needs further study for soybeans in Delaware. Whether it is important for increasing yields or is a corollary to other abiotic controls on soybean growth warrants further investigation.