A Survey of Soybean Tissue Critical Nutrient Concentrations

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Introduction and Objectives

Research in soybean fertility is complex due to the number of essential nutrients and various pathways for uptake. Any study that observe a relationship under specific environmental conditions and soil types may not be reproducible in another field. Statewide surveys of soybean fields across many different soils and management styles can reveal a broader picture. 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. To observe critical values over various soils and management styles we sampled thirty fields across Delaware at the R1/R2 soybean stage and compared to yields. While direct recommendations cannot be given, statewide trends may point to better fertility projects.

Methods

Across Delaware, thirty full season soybean fields were selected with a range in productivity and soil types. This included sandy and organic soils in Sussex and finer textured soils in Kent and New Castle Counties. There were 15 fields from Sussex County, 10 fields from Kent County, and 5 fields from New Castle County. Tissue samples from the upper canopy were sampled across each field at R1/R2 in July 2019. Whole plant samples were also be taken at this time as well as a composite soil sample of the field. Yield, row spacing, and population was obtained from each grower. Tissue and soil samples were analyzed by the University of Delaware Soil Testing Lab.

Reading Statistical Analyses in the Correlation Tables
Data for soil tests, tissue tests and yields were analyzed using PROC CORR in SAS statistical software (Cary, NC). All correlations are found in Appendix A. There are two lines per correlation (e.g. Soil Zn compared to Soil Cu). The top line is the correlation coefficient, which indicates the direction and strength of the relationship. The closer the number is to zero, the lower the correlation. The second line indicates if the relationship is significant (p-value). For this study, any p-value less than 0.1 was considered significant, or that the relationship is greater than zero (not a flat line).

Results and Discussion

Soil Characteristics

Soil pH ranged from acidic (5.3) to mildly acidic (6.5) with an average of 5.9 (Table 1). Base saturation rose and fell with soil pH, with a very low of 40% and a high of 86%. Since this study included organic soils in Sussex County, there was a large range in both organic matter and cation exchange capacity (CEC). Organic matter ranged from 0.9 to 17.1%, while CEC ranged from 4.3 to 15.73 meq $100g^{-1}$. The higher CEC values coincide with soils that have higher organic matter. An average organic matter content of 2.96% would be expected for Delaware, as well as the CEC of 7.8 meq $100g^{-1}$. This range in soil characteristics influenced some nutrients, as discussed in the correlation analyses below, but was not always a dominant factor in fertility.

Table 1: Average, maximum, and minimum values for soil characteristics from the thirty Delaware fields.

	pH	Buffer pH	Organic Matter (%)	CEC (meq $100g^{-1}$)	Base Saturation (%)
Average	5.86	7.62	2.96	7.80	62.04
Maximum	6.50	7.84	17.10	15.73	86.04
Minimum	5.30	7.13	0.90	4.30	39.85

Soil Nutrient Contents

When averaged across all fields, nutrient levels in Delaware were within the optimum recommended ranges (Table 2). Some micronutrients, such as Mn and Zn, had greater average values than are recommended statewide. Based on individual fields, minimum values of all macronutrients (P, K, Ca, and Mg) were below the optimum range, with P, K, Ca, and Mg each having some fields with below optimum values (Table 2). All four macronutrients also had fields above optimum ranges, with P and Mg having the most at 16 and 14, respectively. Past poultry manure applications may explain the above optimum P levels while applications of dolomitic limestone may probably cause greater Mg levels in these fields. For DE soils, only Mn and Zn have official UD recommendations, as the other nutrients are not often lacking. No samples were found to be lacking either micronutrient, but 28 fields were above the Zn optimum range.

Tissue Data

Nutrient sufficiency ranges for soybean are known for the upper canopy leaves (Table 3). For the average concentration of leaf nutrients only Ca (0.74%) was lower than the suggested sufficiency range (0.8-1.4%), while all other average nutrient concentrations were above the lowest range value (Table 3). When broken down by fields, no leaf tissue samples were below the sufficiency range for the macronutrients P, K, or Mg. Instead, three fields had P levels above the range, while 26 fields were above the K sufficiency range. There were many samples lacking Ca, with 23 fields falling below the Ca sufficiency range, while two samples fell below the S sufficiency range. As indicated, more dolomitic lime may have been added to these soils, creating an imbalance between Ca and Mg soil levels (Table 2). However, all soybean leaf tissue samples were within the Mg range, and none were excessive. Still, these soils will need additional Ca added, without pushing tissue Mg below sufficiency.

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

	P	**K**	**Ca**	**Mg**	**Mn**	**Zn**	**Cu***	**Fe***	**B***	**S***	**Na**	**Al**
	ppm											
Average	148.45	129.30	680.11	127.58	24.78	5.31	3.02	126.70	0.35	16.23	14.97	896.65
Maximum	475.27	196.87	1505.63	255.07	89.75	16.43	9.85	211.03	1.25	23.73	22.73	1317.73
Minimum	18.47	60.81	260.43	37.15	3.48	1.20	0.58	73.06	0.12	10.88	11.08	497.10
Optimum Range	*50-100*	*91-182*	*500-1000*	*53-132*	*1.7*	*0.95-1.55*	-	-	-	-	*n/a*	*n/a*
Number Soils Below Optimum	4	5	4.00	1.00	0.00	0.00	-	-	-	-	*n/a*	*n/a*
Number Soils Above Optimum	16	1.00	4.00	14	-	28.00	-	-	-	-	*n/a*	*n/a*

**DE has not developed recommendations for some micronutrients that are not typically lacking in our soils.*

Table 3: Elemental analyses of leaf and whole tissue samples including two non-nutrients (Na and Al) and their optimum ranges in Delaware.

	P %	**K %**	**Ca %**	**Mg %**	**S %**	**Mn ppm**	**Zn ppm**	**Cu ppm**	**Fe ppm**	**B ppm**	**Na ppm**	**Al ppm**
Average	0.52	2.49	0.74	0.38	0.28	62.13	58.70	9.36	125.79	44.60	24.32	86.26
Maximum	0.66	2.89	0.95	0.47	0.33	128.66	99.60	11.87	470.43	65.14	59.99	543.86
Minimum	0.42	2.04	0.58	0.33	0.24	35.90	38.80	6.65	69.91	26.99	7.76	13.62
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*
Number Plants Below the Range	0.00	0.00	23.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	*n/a*	*n/a*
Number Plants Above the Range	3.00	26.00	0.00	0.00	0.00	2.00	5.00	0.00	1.00	3.00	*n/a*	*n/a*
	Whole Plant Analyses											
Average	0.36	3.32	1.02	0.36	0.20	49.34	52.30	8.87	108.41	34.84	37.41	106.22
Maximum	0.42	4.14	1.44	0.52	0.25	114.23	108.40	11.62	341.15	49.28	82.66	365.27
Minimum	0.26	2.54	0.83	0.29	0.15	21.96	27.88	6.04	41.44	25.17	14.39	13.50

Of the micronutrients tested in these tissue samples, there were no samples below the sufficiency ranges, while B, Zn, and Fe each had at least one sample above the sufficiency range (Table 3). Zinc had both the most tissue (5) and soil (28) samples above their optimum ranges and recommended levels (Table 2, Table 3). While this only represents 30 fields across DE, it does suggest that Zn may not be lacking in most soils, or fertilizer additions are keeping the micronutrient at optimum levels.

Whole plant values are given in Table 4, although no sufficiency ranges are developed to compare values to. These values can be used to determine total nutrient uptake. Of the nutrients tested, both K and Ca had higher concentrations in the whole plant versus the upper canopy trifoliate leaves. For K, this is not usual as it often is found in the stem of soybeans in higher concentrations. All other nutrients were more dilute in concentration across the whole plant, but not often by a large percentage.

Yield

Yield ranged from 39-80 bu/acre, even though most nutrients were at optimum levels (Table 4). Yields will be the result of several factors, including pest pressures and irrigation. Plating population ranged from 85,000-185,000 seeds/acre and row spacings ranged from 7.5-30 inches. Due to the amount of data in correlation tables, they have been placed in Appendix A. Yield did not correlate to any soil properties or soil nutrient contents but did positively correlate to leaf sodium (Na) concentration (Appendix A). This correlation was not very strong (0.47), but it is a curious relationship. Sodium is not an essential nutrient but has been found to be beneficial to some crops. It is possible that sodium in plant tissue is a sign of fields that have been irrigated, and water was the limiting factor in yield in this sample of DE fields.

Table 4: Yield and Planting Data

	Row Spacing	Population	Yield
Average	NA	146822	58
Maximum	30	185000	80
Minimum	7.5	85000	39

Correlations of Soil and Plant Nutrient Contents

Soil Nutrients

Due to the size of the entire data set, all correlations can be found in Appendix A. The total number of significant correlations for soil, leaf, and whole plant nutrients can be found in Tables 5-6. Most of the soil characteristics across Delaware were significantly correlated to each other. Both pH and buffer pH were correlated to all of the soil characteristics, including each other. All the pH correlations were expected, since higher pH should correlate to higher base saturation ($r = 0.77$). Another interesting correlation is that of organic matter to CEC ($r = 0.88$), indicating the importance of organic matter to nutrient holding capacity in our coastal soils. As our soils are dominated by sandier, low CEC particle sizes, organic matter can make up much of the nutrient holding capacity in Delaware.

Soil Zn correlated to all five soil properties and 9/12 of the soil elements (Na and Al are not nutrients) measured (Table 5). Most of the correlations to soil properties make sense, with Zn being negatively correlated to pH, but positively correlated to organic matter and CEC (Appendix A). As a micronutrient with a positive charge, Zn is more likely to be tied up and not bioavailable at higher soil pH, which may also reduce extractable Zn. Of the soil elements, Zn had the strongest relationship with soil P (r = 0.87), but it is not clear why, unless they are both being added through poultry litter. Zinc also had a strong positive relationship with Cu (0.80). Another soil nutrient that correlated to 9/12 of the other elements measured was P, but the only strong relationship was with Cu (r = 0.89).

Soil Mg had stronger correlations with both pH and base saturation than Ca, which also supports that these soils may have received more dolomitic lime in the past. The only other nutrient with high correlations to soil properties was boron (B), which was correlated to both pH (r = 0.67) and base saturation (r = 0.71), but not organic matter. Boron is an anion in the soil solution and should leach easily from the soil. Therefore, it is often tied to soil organic matter contents as well as mineralization. Soil B does tend to bond to soil particles better at higher pH, so this could explain higher contents correlating to soil pH and soil bases.

Of the 12 soil elements measured, there were not as many correlations to the twelve leaf elements (Table 5). Soil K had the most with 5 correlations, but only Zn was particularly strong (-0.55). The same relationship was observed when soil elements were correlated to whole plant tissue tests, with more correlations to Cu and S, but still very few (Table 5).

Leaf Nutrients

The total number of correlations leaf tissue samples had for soil, leaf, and whole plant characteristics is found in Table 6. Of the measured elements in the trifoliate leaves, Zn and Cu correlated to the most soil properties at 3/5 each (Table 6). Leaf Zn also correlated to 7/12 soil elements, the strongest being to Cu (r = 0.66) and P (r = 0.62). Two leaf elements, S and Na, both had zero correlations to soil elements. Overall, elements measured in the leaves had very few correlations with any measured in the soil. This is to be expected, as each leaf element should correlate better with itself in the soil (e.g. Soil Cu vs Tissue Cu), rather than other nutrients. However, only K, Mn, Zn, and B had any kind of correlation between their leaf and soil concentrations. Of those, Zn was the highest (r = 0.60), while all others were below 0.50. While concentrations of soil nutrients did not correlate very well with their leaf tissue counter parts, this may just indicate good fertility management. In other words, we need soils with less than optimum nutrient levels to coincide with lower plant tissue concentrations. In these fields, this was not the case, as most fields were at optimum concentrations in soil and tissue samples (Table 2, Table 3), besides Ca.

There were also very few correlations between elements within the leaves (Table 6), the highest being S with four correlations, only three of which were nutrients (Mg, Cu, and B). The highest correlation within the leaves was between Al and Fe (0.87), which are both cations available at more acidic pH. Neither correlated with their soil counterpart, so this may indicate more of a similar uptake mechanism, rather than soil concentration.

Leaf element concentrations also did not correlate well with whole plant nutrients (Table 6), where several had zero total correlations (P, K, Fe, and Na). The nutrient with the most correlations was S, which correlated to plant Mg, S, Cu, and B. The correlation of leaf S to plant S was the highest ($r = 0.60$), while all others were below 0.45. Many other leaf nutrients correlated to their plant counterpart, including Ca (0.31), Mg (0.76), Mn (0.80), Zn (0.87), Cu (0.74), and B (0.71). Besides Mg, all of these are considered immobile within the plant, and their high correlations indicate they all rise at similar rates in the leaves and whole plant, although their concentrations are a little different. This also means that P, K, and Fe were the only nutrients to not correlate between leaf and whole plant samples, as well as the non-nutrient Na and Al elements. Whether this indicates random distribution of the nutrients through plant parts and fields, or that as they rise in one part of the plant, they remain level in the other, is not known.

Whole Plant Nutrients

Although there was a range in soil properties, with CEC between 4.3 and 15.7 meq/100g and organic matter between 0.9-17.1%, there were very few relationships with whole plant nutrient concentrations (Table 7). For soil properties, Mg, Zn, and B had the most correlations at 3 out of 5 each, while Ca, Fe, Na, and Al all had zero. Much like soybean leaves, whole plant Zn had negative correlations to soil pH and base saturation, indicating that higher pH may make less Zn available in these soils. As noted above, there was no correlation between Zn and yield, so higher pH was not a limiting factor for this study. However, wherever Zn deficiencies are noted in Delaware soils, pH should be managed in a lower range.

Similar to soybean leaves, whole plant Zn had the most correlations (10 out of 12 possible) of any nutrient to soil elements. Some of the stronger correlations were with soil P ($r = 0.80$), soil Zn ($r = 0.81$), and soil Cu ($r = 0.81$). Soils may have in-situ levels of Zn and Cu from the parent material, but P is more likely to come from organic sources in an agricultural soil. However, soil P did not correlate to whole plant P, and soil Cu did not correlate to whole plant Cu. Instead, the relationship of whole plant Zn to soil P and Cu might be uptake mechanisms. Phosphorus can suppress Zn uptake and is noted in the UD recommendations for soybean fertility. However, twenty-eight of thirty fields were above the UD recommended Zn levels, which may explain why P did not have a negative effect in these soils. Plant Cu did not correlate to soil Zn, so the same relationship does not exist in that direction.

Whole plant B concentrations had 6/12 correlations to soil elements, but the strongest was to soil B ($r = 0.70$). Typically soil B, as an anion, leaches easily from the soil and Mehlich-3 extractions don’t always correlate well. As noted above, leaf B also correlated to soil B, although at a lower level (0.40). For this study, extractions of soil B were good predictors of plant uptake, which may be due to the range in organic matter contents observed, or the timing of sampling. Rather than sample in the fall or spring, soil samples were taken at the time of tissue sampling, which may give a better idea of soil B status.

Table 5: Number of correlations each soil element has when compared to soil or plant tissue nutrients.

Property (# Possible)	Soil P	Soil K	Soil Ca	Soil Mg	Soil S	Soil Mn	Soil Zn	Soil Cu	Soil Fe	Soil B	Soil Na	Soil Al
Soil Properties (5)	3	2	4	2	2	3	5	3	0	3	3	5
Soil Elements (12)	9	5	4	5	5	5	9	7	5	6	4	4
Leaf Nutrients (12)	1	5	4	3	0	4	1	2	0	2	1	1
Plant Nutrients (12)	3	2	3	4	3	5	3	4	2	4	3	2

Table 6: Number of correlations each leaf tissue element has when compared to soil or plant tissue nutrients.

Property (# Possible)	Leaf P	Leaf K	Leaf Ca	Leaf Mg	Leaf S	Leaf Mn	Leaf Zn	Leaf Cu	Leaf Fe	Leaf B	Leaf Na	Leaf Al
Soil Properties (5)	2	0	1	1	2	1	3	3	0	2	1	1
Soil Elements (12)	3	1	3	2	0	3	7	1	1	1	0	1
Leaf Nutrients (12)	1	1	2	2	4	2	1	2	2	1	2	2
Plant Nutrients (12)	0	0	2	2	4	2	2	4	0	1	0	1

Table 7: Number of correlations each whole plant element has when compared to soil or plant tissue nutrients.

Property (# Possible)	Plant P	Plant K	Plant Ca	Plant Mg	Plant S	Plant Mn	Plant Zn	Plant Cu	Plant Fe	Plant B	Plant Na	Plant Al
Soil Properties (5)	1	1	0	3	1	1	3	2	0	3	0	0
Soil Elements (12)	1	5	4	2	1	2	10	2	3	6	1	1
Leaf Nutrients (12)	1	2	2	4	2	1	2	2	0	2	0	0
Plant Nutrients (12)	2	4	4	5	5	3	3	3	2	2	0	1

Whole plant nutrients that correlated to themselves in the soil include K (r = 0.52), Mn (r = 0.51), Zn (r = 0.81), B (r = 0.70). Sodium, which is not an essential element but will be taken up by plants, also correlated to Na soil levels (r = 0.37). Compared to leaf nutrients, whole plants are lacking correlations between Ca, Mg, and Cu with their soil counterparts. This may indicate that these nutrients are preferentially absorbed into leaves with greater soil concentrations.

Conclusions

Soil and soybean tissue samples were taken a range of Delaware soil types and management types. When nutrient contents of soils, soybean leaves, and whole plant samples were compared, there was no correlation to yield. This can be explained by the optimum levels of most soil nutrients within all the fields sampled, which resulted in sufficient levels of nutrients in most tissue samples. The only consistently deficient nutrient was Ca, which either means the sufficiency range is incorrect, or something is preventing Ca uptake into the plant. One possibility is soil Mg, which was above recommended levels in 14 soils, probably due to the use of dolomitic limestone. Compared to Ca, soil Mg had stronger correlations to soil pH and base saturation, which may be another indicator that Mg was applied in excess over Ca and may have reduced Ca uptake into the plant. Summation of total correlations for soil elements revealed they correlate to each other more than tissue nutrients. This probably indicates the range in organic matter content or fertility management, with soils with greater fertility being higher in other nutrients.

There were very few correlations between soil nutrient and tissue concentrations. This is probably due to the optimal soil concentrations and subsequent sufficient tissue levels. If there had been more of a gradient across fields in fertility, this may have created more relationships between soil and tissue levels. This would suggest that the thirty fields in this study are well managed in terms of their fertility. One nutrient that was consistently correlated to soil and tissue nutrients was both leaf and whole plant Zn concentrations. Zinc was above optimal levels in 28 out of 30 field and correlated to 7 out of 12 soil elements when in the leaves, and 10 out of 12 when extracted from the whole plant. For both leaf and tissue Zn, there were strong, positive correlations with soil Zn, Cu, and P levels. It is not certain what this relationship may be. Additionally, Zn had a negative correlation with soil pH, which is expected as more Zn will preferentially sorb to the soil with higher pH, and not be plant available. Overall, Zn does not correlate to yield, and is not lacking in tissue analyses. For fields that do lack Zn, maintaining lower pH will be necessary.

Boron in plant tissues also had good correlation with extracted soil B, which is not always expected. It is possible that samples taken mid-season are a better representation of available soil B, vs fall or spring, when B has either leached or is yet to mineralize from soil organic matter, respectively.

Fertility management across Delaware soybean fields remains fairly robust, and it appears the recommendations being given and applied by Delaware soybean producers are not limiting yields. Further works should be done in examining Ca sufficiency levels and the relationship between Zn, Cu, and P in Delaware soils.

Appendix A: Correlations of Soil and Tissue Elements

(Shaded is Significant at p = 0.10)

	BpH	OM	CEC	Bsat	Yield
pH	0.765	-0.482	-0.436	0.775	0.110
	<.0001	0.007	0.016	<.0001	0.609
BpH	1.000	-0.718	-0.785	0.707	0.202
		<.0001	<.0001	<.0001	0.344
OM		1.000	0.878	-0.168	-0.298
			<.0001	0.376	0.158
CEC			1.000	-0.139	-0.269
				0.465	0.204
Bsat				1.000	0.081
					0.706

	SoilP	SoilK	SoilCa	SoilMg	SoilMn	SoilZn	SoilCu	SoilFe	SoilB	SoilS	SoilNa	SoilAl
pH	-0.441	0.360	-0.071	0.490	0.487	-0.505	-0.427	-0.158	0.672	-0.211	-0.390	-0.357
	0.015	0.051	0.709	0.006	0.006	0.004	0.019	0.405	<.0001	0.262	0.033	0.053
BpH	-0.509	0.131	-0.382	0.290	0.352	-0.625	-0.354	0.094	0.474	-0.325	-0.222	-0.756
	0.004	0.490	0.037	0.120	0.057	0.000	0.055	0.622	0.008	0.080	0.238	<.0001
OM	0.234	-0.141	0.771	0.146	-0.201	0.531	0.016	-0.039	-0.155	0.153	0.399	0.434
	0.213	0.458	<.0001	0.441	0.288	0.003	0.933	0.840	0.413	0.420	0.029	0.017
CEC	0.276	0.115	0.862	0.285	-0.197	0.541	0.102	0.019	-0.023	0.328	0.465	0.621
	0.139	0.546	<.0001	0.127	0.298	0.002	0.591	0.919	0.902	0.077	0.010	0.000
Bsat	-0.457	0.391	0.341	0.753	0.328	-0.352	-0.422	0.169	0.715	-0.096	0.137	-0.450
	0.011	0.033	0.065	<.0001	0.077	0.056	0.020	0.371	<.0001	0.613	0.472	0.013

	SoilP	SoilK	SoilCa	SoilMg	SoilMn	SoilZn	SoilCu	SoilFe	SoilB	SoilS	SoilNa	SoilAl	Yield
SoilP	1	-0.317	0.042	-0.377	-0.417	0.871	0.886	0.457	-0.344	0.550	0.191	0.413	0.216
		0.088	0.827	0.040	0.022	<.0001	<.0001	0.011	0.063	0.002	0.312	0.023	0.310
SoilK		1.000	0.186	0.418	0.222	-0.329	-0.337	-0.173	0.476	0.229	-0.216	0.330	0.041
			0.324	0.022	0.238	0.076	0.068	0.360	0.008	0.224	0.251	0.075	0.848
SoilCa			1.000	0.567	-0.020	0.370	-0.090	0.138	0.324	0.220	0.553	0.279	-0.238
				0.001	0.918	0.044	0.635	0.469	0.081	0.243	0.002	0.136	0.263
SoilMg				1.000	0.187	-0.251	-0.421	0.066	0.578	-0.019	0.256	-0.108	-0.200
					0.322	0.180	0.020	0.730	0.001	0.920	0.171	0.569	0.349
SoilMn					1.000	-0.352	-0.410	-0.299	0.467	-0.298	-0.392	-0.255	-0.238
						0.057	0.024	0.109	0.009	0.109	0.032	0.174	0.263
SoilZn						1.000	0.801	0.471	-0.269	0.504	0.427	0.368	0.145
							<.0001	0.009	0.151	0.005	0.019	0.045	0.500
SoilCu							1.000	0.568	-0.309	0.474	0.256	0.215	0.294
								0.001	0.097	0.008	0.173	0.253	0.164
SoilFe								1.000	0.072	0.363	0.468	-0.222	0.222
									0.705	0.049	0.009	0.237	0.296
SoilB									1.000	0.194	-0.085	-0.131	0.003
										0.305	0.654	0.491	0.990
SoilS										1.000	0.288	0.505	0.263
											0.123	0.004	0.214
SoilNa											1.000	-0.107	-0.019
												0.573	0.930
SoilAl												1.000	0.012
													0.954

	LeafP	LeafK	LeafCa	LeafMg	LeafS	LeafMn	LeafZn	LeafCu	LeafFe	LeafB	LeafNa	LeafAl
pH	0.124	-0.002	-0.119	-0.058	0.290	-0.054	-0.586	0.287	-0.065	0.236	-0.018	-0.016
	0.513	0.990	0.533	0.760	0.120	0.775	0.001	0.125	0.731	0.209	0.923	0.934
BpH	0.107	-0.126	-0.070	0.204	0.401	0.133	-0.432	0.548	0.042	0.310	-0.027	0.156
	0.573	0.509	0.715	0.281	0.028	0.485	0.017	0.002	0.824	0.095	0.887	0.409
OM	0.307	0.069	-0.103	-0.218	-0.232	-0.138	0.173	-0.616	-0.126	-0.161	-0.242	-0.177
	0.099	0.716	0.588	0.248	0.217	0.468	0.362	0.000	0.507	0.395	0.197	0.351
SoilP	-0.146	0.028	0.281	0.047	-0.115	-0.177	0.624	0.062	-0.115	-0.220	-0.017	-0.210
	0.442	0.882	0.132	0.807	0.545	0.350	0.000	0.744	0.546	0.243	0.929	0.265
SoilK	-0.002	0.379	-0.356	-0.391	0.102	-0.319	-0.556	0.017	0.128	0.250	0.199	0.156
	0.993	0.039	0.054	0.033	0.590	0.085	0.001	0.929	0.501	0.183	0.292	0.409
SoilCa	0.420	0.051	-0.248	-0.491	-0.052	-0.379	-0.172	-0.468	-0.157	0.146	-0.302	-0.245
	0.021	0.787	0.187	0.006	0.784	0.039	0.363	0.009	0.408	0.440	0.105	0.193
SoilMg	0.429	-0.002	-0.601	-0.152	0.226	-0.195	-0.612	-0.124	-0.163	0.264	-0.197	-0.154
	0.018	0.993	0.000	0.423	0.229	0.302	0.000	0.516	0.390	0.159	0.296	0.415
SoilMn	0.156	-0.083	-0.238	-0.192	-0.271	0.465	-0.431	-0.261	0.376	0.015	-0.195	0.420
	0.410	0.661	0.206	0.310	0.148	0.010	0.017	0.163	0.041	0.938	0.302	0.021
SoilZn	0.071	0.003	0.214	-0.196	-0.187	-0.224	0.601	-0.209	-0.130	-0.220	-0.121	-0.246
	0.710	0.988	0.256	0.299	0.324	0.233	0.000	0.268	0.494	0.243	0.526	0.190
SoilCu	-0.197	-0.084	0.313	0.070	-0.018	-0.141	0.655	0.212	-0.097	-0.173	-0.034	-0.178
	0.296	0.658	0.092	0.713	0.924	0.458	<.0001	0.262	0.612	0.361	0.857	0.346
SoilFe	0.005	-0.201	0.046	-0.004	0.135	-0.133	0.281	0.239	-0.145	0.240	-0.131	-0.192
	0.978	0.286	0.811	0.984	0.477	0.484	0.133	0.204	0.445	0.201	0.491	0.310
SoilB	0.206	0.065	-0.295	-0.283	0.268	-0.139	-0.424	0.062	-0.025	0.401	-0.138	-0.028
	0.276	0.734	0.114	0.130	0.152	0.465	0.020	0.743	0.895	0.028	0.468	0.882
SoilS	0.004	0.179	-0.133	-0.207	0.178	-0.303	0.161	0.163	-0.078	-0.038	0.105	-0.261
	0.982	0.345	0.483	0.272	0.347	0.104	0.396	0.389	0.681	0.841	0.583	0.164
SoilNa	0.435	-0.141	-0.115	-0.165	0.175	-0.305	0.152	0.001	-0.153	0.119	-0.260	-0.266
	0.016	0.457	0.545	0.384	0.354	0.101	0.422	0.996	0.421	0.533	0.165	0.155
SoilAl	-0.279	0.237	0.034	-0.300	-0.151	-0.273	0.105	-0.300	0.032	-0.092	0.320	-0.080
	0.136	0.206	0.858	0.107	0.425	0.145	0.582	0.107	0.865	0.627	0.084	0.674
CEC	0.217	0.116	-0.196	-0.424	-0.244	-0.323	0.069	-0.613	-0.128	-0.069	-0.167	-0.243
	0.248	0.542	0.300	0.020	0.194	0.081	0.715	0.000	0.502	0.718	0.377	0.195
Bsat	0.428	-0.075	-0.307	-0.166	0.384	-0.150	-0.624	0.218	-0.038	0.417	-0.204	-0.006
	0.018	0.693	0.099	0.382	0.036	0.428	0.000	0.247	0.843	0.022	0.279	0.973

	PlantP	PlantK	PlantCa	PlantMg	PlantS	PlantMn	PlantZn	PlantCu	PlantFe	PlantB	PlantNa	PlantAl
pH	0.1774	0.3397	-0.1685	0.1617	0.2000	0.0833	-0.6510	0.0571	0.1495	0.4029	-0.1755	0.1183
	0.3485	0.0663	0.3734	0.3932	0.2892	0.6617	<.0001	0.7646	0.4303	0.0273	0.3537	0.5334
BpH	0.2854	0.1671	-0.3010	0.4081	0.3309	0.2516	-0.5474	0.3033	0.0108	0.4389	-0.1416	0.1174
	0.1264	0.3774	0.1060	0.0252	0.0741	0.1798	0.0017	0.1032	0.9547	0.0153	0.4556	0.5366
OM	-0.3198	0.1252	-0.0375	-0.4043	-0.2767	-0.1594	0.2919	-0.4430	-0.1882	-0.1874	0.0405	-0.2651
	0.0849	0.5099	0.8442	0.0267	0.1389	0.4001	0.1175	0.0142	0.3194	0.3215	0.8318	0.1568
SoilP	0.1574	-0.1565	0.3198	0.1132	-0.2283	-0.2235	0.7950	0.1351	0.1261	-0.3788	-0.0456	-0.0455
	0.4061	0.4088	0.0850	0.5516	0.2250	0.2351	<.0001	0.4766	0.5068	0.0390	0.8111	0.8114
SoilK	-0.0644	0.5234	-0.0707	-0.2113	0.1174	-0.2840	-0.5167	-0.0297	0.1576	0.2927	0.0744	0.2682
	0.7352	0.0030	0.7104	0.2623	0.5365	0.1283	0.0035	0.8764	0.4056	0.1165	0.6959	0.1518
SoilCa	-0.2218	0.3717	0.0526	-0.4792	-0.1127	-0.2773	-0.0074	-0.3928	-0.0796	0.1535	0.1726	-0.2270
	0.2389	0.0431	0.7827	0.0074	0.5532	0.1379	0.9689	0.0318	0.6758	0.4179	0.3617	0.2278
SoilMg	0.0591	0.4198	-0.1533	0.0278	0.3545	-0.0365	-0.4716	-0.0481	-0.0227	0.4345	0.2527	-0.0169
	0.7564	0.0209	0.4185	0.8840	0.0546	0.8482	0.0085	0.8007	0.9051	0.0164	0.1780	0.9296
SoilMn	-0.0727	0.0713	-0.1103	-0.1255	-0.0392	0.5053	-0.4545	-0.3971	0.3080	0.3561	-0.1849	0.2395
	0.7026	0.7081	0.5618	0.5089	0.8373	0.0044	0.0116	0.0298	0.0977	0.0534	0.3280	0.2025
SoilZn	-0.0086	-0.1798	0.3524	-0.1169	-0.2551	-0.2193	0.8138	-0.1343	0.0646	-0.3296	0.0114	-0.2262
	0.9639	0.3417	0.0561	0.5386	0.1736	0.2443	<.0001	0.4792	0.7345	0.0753	0.9525	0.2294
SoilCu	0.2333	-0.3858	0.4115	0.2345	-0.1052	-0.1215	0.8134	0.2238	0.0729	-0.3263	-0.0694	-0.0963
	0.2148	0.0352	0.0239	0.2122	0.5801	0.5224	<.0001	0.2346	0.7018	0.0784	0.7155	0.6126
SoilFe	0.3576	0.0763	0.0965	0.2540	0.0972	-0.1060	0.4235	0.1670	-0.0089	0.2033	0.1667	-0.1793
	0.0524	0.6886	0.6122	0.1756	0.6092	0.5771	0.0197	0.3778	0.9630	0.2812	0.3786	0.3432
SoilB	-0.0503	0.3773	-0.0518	-0.0485	0.2562	-0.0027	-0.4545	-0.1024	0.3316	0.6992	-0.0653	0.2726
	0.7918	0.0399	0.7856	0.7991	0.1717	0.9887	0.0116	0.5903	0.0735	<.0001	0.7317	0.1450
SoilS	-0.0744	0.0095	0.4455	0.1219	0.2743	-0.2077	0.3796	0.2125	0.3220	0.1007	0.0937	0.1482
	0.6962	0.9601	0.0136	0.5212	0.1424	0.2707	0.0385	0.2597	0.0827	0.5965	0.6222	0.4346
SoilNa	-0.0536	-0.1096	0.1733	-0.0812	0.2070	-0.1647	0.3324	0.0755	-0.1860	0.0132	0.3770	-0.3229
	0.7784	0.5643	0.3598	0.6695	0.2723	0.3846	0.0727	0.6915	0.3251	0.9446	0.0400	0.0818
SoilAl	-0.2507	0.1429	0.3002	-0.3645	-0.1082	-0.4182	0.2091	-0.1356	0.1007	-0.1758	0.0962	0.0989
	0.1816	0.4513	0.1070	0.0476	0.5691	0.0215	0.2675	0.4750	0.5965	0.3528	0.6132	0.6030
CEC	-0.2909	0.1720	0.1911	-0.5119	-0.2088	-0.3208	0.2528	-0.4072	-0.0479	-0.1190	0.2205	-0.1862
	0.1189	0.3636	0.3119	0.0038	0.2681	0.0839	0.1778	0.0255	0.8017	0.5311	0.2417	0.3246
Bsat	0.1234	0.4950	-0.2719	0.0979	0.2886	0.0075	-0.5971	0.0080	-0.0157	0.5366	-0.0114	-0.0590
	0.5161	0.0054	0.1461	0.6070	0.1220	0.9686	0.0005	0.9667	0.9345	0.0022	0.9522	0.7569

	LeafP	LeafK	LeafCa	LeafMg	LeafS	LeafMn	LeafZn	LeafCu	LeafFe	LeafB	LeafNa	LeafAl	Yield
LeafP	1.0000	0.1116	-0.3023	0.0397	0.1903	-0.0382	-0.0540	0.0196	-0.0181	0.0239	-0.4367	-0.1198	-0.2140
		0.5570	0.1045	0.8349	0.3139	0.8412	0.7769	0.9181	0.9244	0.9001	0.0158	0.5282	0.3153
LeafK		1.0000	0.1192	-0.1127	-0.1615	-0.3666	-0.1095	-0.0730	-0.2405	-0.2838	0.3050	-0.1548	0.1342
			0.5305	0.5533	0.3938	0.0463	0.5645	0.7016	0.2005	0.1285	0.1012	0.4140	0.5320
LeafCa			1.0000	0.0962	0.1985	-0.0835	0.4493	0.1871	-0.1748	0.2020	0.4279	-0.1791	0.2328
				0.6131	0.2931	0.6609	0.0128	0.3222	0.3555	0.2843	0.0183	0.3437	0.2737
LeafMg				1.0000	0.3400	0.2842	0.2017	0.4026	-0.1986	-0.0725	-0.1394	-0.0659	-0.2082
					0.0660	0.1280	0.2851	0.0274	0.2929	0.7033	0.4626	0.7294	0.3289
LeafS					1.0000	-0.1975	-0.0045	0.6409	-0.2666	0.5212	0.1078	-0.3258	0.1076
						0.2955	0.9811	0.0001	0.1544	0.0031	0.5706	0.0790	0.6167
LeafMn						1.0000	0.0769	-0.2265	0.3204	-0.1277	-0.1663	0.3307	-0.0463
							0.6862	0.2288	0.0843	0.5013	0.3797	0.0742	0.8298
LeafZn							1.0000	0.0362	-0.0712	-0.0527	-0.0225	-0.1874	0.0037
								0.8493	0.7084	0.7819	0.9060	0.3213	0.9862
LeafCu								1.0000	-0.0489	0.1509	0.0199	-0.0694	0.1791
									0.7976	0.4261	0.9170	0.7157	0.4024
LeafFe									1.0000	0.0024	0.1175	0.8729	0.0143
										0.9901	0.5362	<.0001	0.9471
LeafB										1.0000	0.2160	0.0034	0.0282
											0.2517	0.9857	0.8958
LeafNa											1.0000	0.0498	0.4675
												0.7939	0.0213
LeafAl												1.0000	-0.0427
													0.8430

	PlantP	PlantK	PlantCa	PlantMg	PlantS	PlantMn	PlantZn	PlantCu	PlantFe	PlantB	PlantNa	PlantAl	Yield
PlantP	1.0000	-0.0424	0.1297	0.4102	0.1946	0.0612	0.1572	0.5962	0.0822	-0.0390	-0.1780	-0.0667	-0.1475
		0.8241	0.4946	0.0244	0.3028	0.7482	0.4069	0.0005	0.6657	0.8381	0.3466	0.7263	0.4916
PlantK		1.0000	-0.3992	-0.3240	-0.2247	-0.4840	-0.4696	-0.0861	0.0193	0.2109	0.1030	0.1105	0.0900
			0.0289	0.0807	0.2326	0.0067	0.0088	0.6509	0.9193	0.2632	0.5879	0.5611	0.6759
PlantCa			1.0000	0.0201	0.3820	0.0880	0.4148	0.2071	0.4100	0.0221	0.2767	0.1421	0.1860
				0.9160	0.0372	0.6438	0.0226	0.2721	0.0245	0.9076	0.1388	0.4538	0.3841
PlantMg				1.0000	0.4075	0.4109	0.0800	0.4900	0.0595	0.0031	-0.1754	0.1863	0.0411
					0.0254	0.0241	0.6743	0.0060	0.7550	0.9870	0.3540	0.3242	0.8489
PlantS					1.0000	0.3171	-0.0629	0.4998	0.1672	0.4861	0.2379	0.1545	0.1125
						0.0877	0.7414	0.0049	0.3772	0.0065	0.2055	0.4149	0.6009
PlantMn						1.0000	0.0315	-0.0528	0.0939	0.2001	-0.2820	0.0676	-0.1768
							0.8687	0.7817	0.6217	0.2892	0.1312	0.7225	0.4084
PlantZn							1.0000	0.1585	0.0071	-0.3372	-0.0416	-0.2232	0.1063
								0.4028	0.9705	0.0684	0.8271	0.2357	0.6209
PlantCu								1.0000	-0.0234	-0.1118	-0.0771	0.0712	0.1438
									0.9022	0.5563	0.6855	0.7087	0.5025
PlantFe									1.0000	0.1658	0.1521	0.6268	0.1459
										0.3814	0.4224	0.0002	0.4963
PlantB										1.0000	0.2452	0.1342	0.0977
											0.1916	0.4796	0.6497
PlantNa											1.0000	0.0271	0.3228
												0.8868	0.1240
PlantAl												1.0000	-0.2056
													0.3352

	PlantP	PlantK	PlantCa	PlantMg	PlantS	PlantMn	PlantZn	PlantCu	PlantFe	PlantB	PlantNa	PlantAl
LeafP	0.0854	0.0576	-0.1722	0.0228	0.1480	0.0605	-0.0223	-0.0505	0.0274	0.1358	0.0518	-0.2370
	0.6536	0.7623	0.3630	0.9048	0.4351	0.7506	0.9070	0.7911	0.8858	0.4743	0.7858	0.2073
LeafK	0.1208	0.1983	0.2006	-0.1270	-0.0054	-0.2768	0.0271	0.1515	0.2300	-0.0955	0.2795	0.2450
	0.5248	0.2936	0.2879	0.5036	0.9774	0.1386	0.8871	0.4241	0.2214	0.6156	0.1347	0.1920
LeafCa	0.0664	-0.2332	0.3126	-0.1192	-0.1070	-0.0697	0.3527	0.0440	-0.0795	-0.0704	-0.0388	-0.0751
	0.7274	0.2149	0.0926	0.5304	0.5737	0.7146	0.0559	0.8174	0.6763	0.7115	0.8389	0.6933
LeafMg	0.2539	-0.3519	-0.2312	0.7600	0.1133	0.2850	0.0978	0.2929	-0.1498	-0.1719	-0.2004	0.1542
	0.1757	0.0565	0.2190	<.0001	0.5512	0.1269	0.6071	0.1163	0.4296	0.3636	0.2883	0.4161
LeafS	0.0887	-0.0441	0.0331	0.3562	0.6020	-0.0148	-0.0722	0.4299	-0.1039	0.3585	-0.0825	0.0392
	0.6413	0.8169	0.8622	0.0534	0.0004	0.9383	0.7046	0.0177	0.5848	0.0518	0.6647	0.8372
LeafMn	0.0125	-0.2595	-0.0486	0.3102	0.1259	0.8079	0.0259	-0.1261	0.1757	0.1497	-0.2006	0.0726
	0.9478	0.1661	0.7986	0.0952	0.5075	<.0001	0.8919	0.5066	0.3530	0.4298	0.2877	0.7030
LeafZn	0.0755	-0.4422	0.1500	0.0044	-0.2224	-0.0194	0.8741	0.0935	-0.0709	-0.2684	-0.1947	-0.2310
	0.6917	0.0144	0.4289	0.9816	0.2376	0.9191	<.0001	0.6231	0.7097	0.1515	0.3026	0.2194
LeafCu	0.4516	-0.0862	-0.0630	0.5308	0.3353	-0.0894	-0.0446	0.7488	-0.1269	0.0122	-0.2674	0.0322
	0.0123	0.6506	0.7410	0.0025	0.0701	0.6385	0.8150	<.0001	0.5040	0.9491	0.1532	0.8661
LeafFe	-0.1131	0.0890	-0.1710	-0.1720	-0.1063	0.1056	-0.1603	-0.1050	0.1717	-0.0769	-0.2276	0.0507
	0.5518	0.6401	0.3664	0.3633	0.5762	0.5788	0.3975	0.5809	0.3642	0.6863	0.2265	0.7902
LeafB	-0.1522	0.2856	-0.1299	-0.1462	0.2107	-0.1644	-0.2648	-0.1369	-0.0794	0.7118	0.1942	0.0744
	0.4222	0.1260	0.4938	0.4408	0.2639	0.3854	0.1573	0.4708	0.6768	<.0001	0.3039	0.6961
LeafNa	-0.1747	-0.0212	0.3054	-0.1467	0.2465	-0.1946	-0.0151	0.0700	-0.0213	0.1508	0.3836	0.0076
	0.3558	0.9113	0.1008	0.4391	0.1892	0.3027	0.9371	0.7132	0.9111	0.4264	0.0364	0.9684
LeafAl	-0.1712	0.1804	-0.3468	-0.0908	-0.2035	0.1224	-0.2896	-0.1666	0.0774	-0.1089	-0.2404	0.2878
	0.3658	0.3401	0.0604	0.6334	0.2808	0.5193	0.1207	0.3789	0.6845	0.5666	0.2007	0.1230