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NUTRIENT CONCENTRATION AND YIELD VARIATION WITHIN SOUTHERN SOYBEAN GERMPLASM GROWN ON ACID NORFOLK SOIL

KEY WORDS: Soil acidity, *Glycine max.* L., plant analyses

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ABSTRACT

Seventy-one soybean genotypes were grown in the field on an acid Norfolk loamy sand to evaluate growth, seed yield, and nutrient concentrations in aerial plant fractions. The pH values in the Ap, A2, and B horizons were 4.6, 4.4, and 4.4, respectively. Cation exchange capacities (CEC) were 2.1, 0.9, and 2.8 me/100 g with an Al saturation of 34, 49, and 40%, respectively. Very few visual toxicity or deficiency symptoms were found among the genotypes. Analyses of aerial plant fractions collected when the genotypes were in bloom or early pod fill showed some significant differences, but in general P, K, Ca, and Mg concentrations were adequate, while Al, Fe, Mn, and Zn concentrations were very high. Average yields of genotypes in maturity groups IV, V, VI, VII, and VIII were 2.7, 2.7, 2.6, 2.4, and 2.2 t/ha, respectively. There were significant differences in seed yield among genotypes in maturity groups IV and VIII, but differences among genotypes in the other maturity groups were nonsignificant. Correlations between yield and nutrient concentration showed some significant relationships, but in general, this technique did not differentiate genotypes according to their tolerance to acid soil conditions.

INTRODUCTION

Acid soils are a factor which continue to plague soybean (*Glycine max* L.) production throughout the South. Despite active programs encouraging the use of soil testing and lime application, many growers are not maintaining soil pH at an optimum level for crop production. Recent data from Clemson Soil Testing Laboratory showed that 27% of the samples tested were below pH 5.5 [2], while Jones and Nelson[3] reported that 36% of the samples received by the Mississippi Soil Testing Laboratory had pH values less than 5.5.

Aluminum and Mn toxicities, Ca and Mo deficiencies, decreased nodulation, and a lack of plant response to endomycorrhizal infection are among the adverse effects of acid soils on soybean production[4,5,6,7]. Selecting and developing cultivars which are tolerant to acid soils is one approach to increasing yields where soil acidity cannot or has not been corrected through liming[8,9]. Arminger et al.[10] screened 48 soybean genotypes representing ten maturity groups and found significant variation in the tolerance of the germplasm to an acid Bladen (clayey, mixed, thermic Typic Albaquult) soil. Devine[11] stated that although entries in the National Uniform Soybean Test were periodically screened for Al tolerance in solution culture, testing these advanced breeding materials in soil media would be advisable.

Foy and Long[12] observed Al toxicity in sensitive barley and snapbean cultivars when they grew them on the A2 horizon of a Norfolk soil similar to the one upon which this research was conducted. Therefore, 71 soybean genotypes were evaluated in a field experiment which had the following objectives: (a) to grow, observe, and estimate the seed yield of these genotypes when grown on an acid Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult); (b) to measure nutrient concentrations in the aerial plant fractions; and (c) to determine if correlations between nutrient concentration and seed yield could differentiate the genotypes according to their tolerance to acid soil conditions.

METHODS AND MATERIALS

The experiment was established on a Norfolk loamy sand which had pH values of 4.6, 4.4, and 4.4; CEC values of 2.1, 0.9, and 2.8 me/100 g; and an Al saturation of 34, 49, and 40% in the Ap, A2, and B horizons, respectively. Horizon depth, texture, and chemical properties are presented in Table 1. The A2 horizon was fractured by subsoiling to a depth of 50 cm to minimize potential physical limitations to root development. Preplant fertilizer providing 56 kg/ha P_2O_5 and K_2O and Treflan[1] (Trifluralin) herbicide were broadcast and incorporated by disking. Sixty genotypes from the 1979 Uniform Soybean Test[13] representing maturity groups IV-VIII, and eleven traditional southern soybean genotypes were grown using a randomized complete block design which was replicated four times. The quantity of seed available was limited, so single row plots 4 m long were planted using a cone planter instead of the standard 4-row, 6 m plots. Two border rows of the cultivar Ransom were planted around the experiment so that light effects would be uniform. Genotypes were blocked according to maturity group. Vacuum gauge tensiometers were placed in the row at 30- and 60-cm depths and used to monitor the soil water status. Four (4) cm of water was applied through twin-wall trickle irrigation tube during the vegetative growth stages. The amount and distribution of rainfall eliminated the need for supplemental irrigation during the reproductive growth stages. Visual observations were recorded every two weeks from emergence to maturity to determine if any visual toxicity or deficiency symptoms occurred.

Whole plant samples were collected and partitioned into leaves, petioles, and stems when genotypes were in bloom or early pod fill. The plant samples were rinsed in distilled water, dried at 70C, ground to pass a 0.5 mm screen, and digested with a 1:1 mixture of nitric and perchloric acids. The P concentration was measured colormetrically on a Technicon Autoanalyzer using Industrial Method 334-74 WC/B[14]. Potassium was measured by flame emission spectrophotometry while Ca, Mg, Al, Fe, Mn, and Zn concentrations were measured by atomic absorption spectrophotometry. Seed yield was measured by hand harvesting 3 m of row, drying the plants, and threshing. Data were analyzed using least significant difference (LSD) and Duncan's Multiple Range Test at P (.05) as outlined by Steel and Torrie[15].

RESULTS AND DISCUSSION

I. Growth and Seed Yields:

Soil chemical analyses (Table 1) showed that the entire profile was very acid. Phosphorus, K, and Mg concentrations in the Ap horizon were in the medium range, but the Ca concentration was very low. Zinc, Mn, and Fe concentrations were adequate for soybean production. Aluminum saturation exceeded 30% in all horizons. Kamprath[16] found a reduction in soybean growth when the Al saturation of a Norfolk soil having a CEC of 1.11 me/100 g exceeded 20% (0.22 me Al/100 g). These soil analyses and previous nearby research[12] indicated that Al toxicity might occur in this experiment.

A crinkling or cupping of the youngest leaves was observed within plots of Biloxi, CNS, GaSoy-17, Hill, Jupiter, and Roanoke cultivars. The symptoms appeared when the plants were in the late vegetative growth stages just as soil water tensions at 30 cm began to exceed 25 cb. These visual symptoms indicated that the acid soil conditions may have impaired root activity in these genotypes and thereby placed them under water stress before the other genotypes. Irrigation was applied just after these visual

TABLE 1

Chemical properties of a Norfolk loamy sand where soybean germplasm was evaluated for tolerance to acid conditions.

Horizon	Depth cm	Texture	Water pH	Buffer† pH	Mehlich 1 Extractant‡ P	K	Ca	Mg	Zn	Mn	Fe	Al§	CEC
					ppm							me/100g	
Ap	0–20	ls	4.6	7.6	21	74	78	33	1.7	31	40	0.72	2.1
A_2	20–40	ls	4.4	7.8	5	20	15	8	0.5	4	18	0.44	0.9
B	40	scl	4.2	7.6	2	51	156	79	0.4	2	14	1.11	2.8

† Adams-Evans buffer
‡ (0.05 N HCl + 0.025 N H_2SO_4)
§ 1 N KCl Exchangeable

observations were made. The application of 2 cm of water at that time may have prevented the other genotypes from showing any visual stress symptoms. Armiger[10] described similar symptoms as Al toxicity or possibly Al-induced Ca deficiency. Chemical analyses of the leaf, petiole, and stem tissue showed little difference in the Ca and Al concentrations of these genotypes compared to others which showed no visual symptoms. Armiger[10] also found Biloxi to be the most tolerant to an acid Bladen soil. Analysis of the leaf tissue in this investigation showed that Biloxi had the highest Ca concentration (2.03%) and one of the lower Al concentrations (264 ppm) even though it exhibited the cupping symptom. Random observations of several root systems from many of the genotypes showed that nodulation did occur in a "normal" manner, although neither nodule number nor nodule efficiency were measured.

The seed yields produced by these genotypes when grown on an acid Norfolk loamy sand are presented in Table 2. Among genotypes in the Uniform Southern Soybean Test[13], there were significant differences only in maturity groups IV and VIII. Among the cultivars which showed the visual symptoms, Biloxi and Jupiter did not mature because of frost; Hill produced the least seed of any group V genotype; and among group VII genotypes CNS and GaSoy-17 produced low seed yields, but Roanoke produced one of the highest seed yields. Undoubtedly, the limited amount of seed which restricted plot size to single row units did not adequately measure the yield potential of these genotypes when grown on an acid soil, but despite this limitation the two conclusions regarding seed yield which can be made are: (a) in general, differences in productivity among soybean genotypes at this site were minor and (b) that average seed yields at this site for group VI, VII, and VIII soybeans were only 69, 64, and 57%, respectively, as high as the average yields produced by these genotypes in the Uniform Test conducted 5 km away on a well-limed Faceville loamy sand (clayey, kaolinitic, thermic Typic Paleudult)[13].

TABLE 2

Seed yields of soybean genotypes when grown on an acid Norfolk loamy sand.

Genotype	Group	Yield t/ha	Genotype	Group	Yield t/ha
Hutton	8	2.46	Bragg	7	2.74
Cobb	8	1.63	GaSoy-17	7	2.13
Coker 338	8	1.95	Braxton	7	2.25
Coker 488	8	1.89	Wright	7	2.02
F72-6460	8	2.34	F73-7082	7	2.68
F74-1493	8	2.79	N74-1572	7	1.96
Co75-689	8	2.37	F76-8846	7	2.90
F76-8757	8	2.50	GaT73-24	7	2.24
F76-8827	8	2.10	N74-1341	7	2.46
Ga76-316	8	2.57	N76-1415	7	2.72
GAT74-10	8	1.55	N76-1505	7	2.88
N76-1507	8	2.60	Ts77-5	7	2.30
LSD(.05)		0.54			NS
Tracy	6	2.60	Essex	5	3.07
Centennial	6	2.29	Forrest	5	2.42
D74-7741	6	2.23	Bedford	5	2.69
N73-693	6	2.70	R74-511	5	3.06
N73-1102	6	2.56	D75-12035	5	2.56
D75-7527	6	2.70	D76-9375	5	3.14
N75-2213	6	2.65	Nathan	5	2.39
R74-1625	6	2.70	N76-098	5	2.84
D74-7711	6	2.65	N76-683	5	2.42
D76-9665	6	2.40	R76-45	5	3.09
N76-325	6	3.00	S76-2120	5	2.77
R75-868	6	2.31	V75-345	5	2.29
LSD(.05)		NS			NS
Columbus	4	2.66	Hill	5	1.61
Crawford	4	3.10	S-100	5	1.59
Douglas	4	2.56	Lee	6	2.45
S76-2392	4	2.18	Ransom	6	2.41
C1573	4	2.30	CNS	7	1.22
S76-2109	4	2.78	Jackson	7	3.25
S76-2203	4	2.92	Palmetto	7	2.27
S76-2229	4	1.86	Roanoke	7	2.89
V74-315	4	2.70	Biloxi	8	0.60†
V76-398	4	2.90	Hardee	8	2.32
V76-465	4	3.11	Jupiter	9	0.38†
V76-482	4	2.92			
LSD(.05)		0.69			-‡

† These cultivars did not mature before frost.
‡ Statistical analyses were not run because of variation in maturity group.

II. Nutrient Concentrations:

The nutrient concentrations within the leaves of the 71 genotypes are presented in Tables 3, 4, and 5. Overall, these analyses showed that P, K, Ca, and Mg concentrations were sufficient and that the Al, Fe, Mn, and Zn concentrations were high or excessive[17]. Among genotypes there were significant differences in nutrient concentrations within the leaf fraction except for Al and Mn in group VII (Table 3), Mn in group VI, Fe, Mn, and Zn in group V (Table 4), and Al, Fe, and Mn in group IV (Table 5). The high concentrations of micronutrients in all genotypes probably reflect their high availability in the acid soil.

Petiole and stem tissue from each of the genotypes were also analyzed, but for brevity these data are not presented. Among genotypes within the various maturity groups, there were significant differences in P, K, Ca, Mg, and Zn concentrations in these plant fractions, but the concentrations of Al, Fe, and Mn were generally not significantly different.

Athough genotypic differences in nutrient concentration were found in all plant fractions, the ranking among genotypes was not always the same. A comparison of these analyses with nutrient concentrations reported in the literature[17] for the various plant fractions showed that these results were different and perhaps more comprehensive. Therefore, because genotypic differences were small, data from 12 genotypes in maturity groups IV, V, VI, VII, and VIII from the 1979 Uniform Soybean Test[13] were averaged for further discussion (Table 6).

Table 6 shows that among maturity groups the average nutrient concentration in each plant fraction was similar. Phosphorus and Mg concentrations were similar to those reported in the literature[17], but Ca concentrations were generally lower and micronutrient concentrations were much higher. The low Ca and high micronutrient concentrations undoubtedly reflected the acid soil conditions upon which these genotypes were grown. The K concentration in the stem fraction was generally higher than reported[17],

TABLE 3

Nutrient Concentrations in Soybean Leaves from Cultivars Representing Maturity Groups VII and VIII in the Uniform Southern Soybean Test When Grown on an Acid Norfolk Loamy Sand.

Genotype	Maturity Group	P	K	Ca	Mg	Al	Fe	Mn	Zn
		%				ppm			
Hutton	8	.35ab†	1.93cde	1.18a	.56ab	360a	253ab	196a	95a
Cobb	8	.35ab	1.96cde	1.10ab	.49cd	244ab	244ab	140b	80abc
Coker 338	8	.33b	2.04bcde	1.19a	.59a	374a	250ab	139b	63d
Coker 388	8	.32b	2.02bcde	1.23a	.59a	375a	284ab	174ab	84ab
F72-6460	8	.34ab	1.78e	1.09abc	.58ab	261ab	212b	145b	67cd
F74-1493	8	.35ab	1.85de	1.05abcd	.57ab	336ab	226ab	144b	86ab
Co75-689	8	.38a	2.34a	0.86e	.56ab	380a	281ab	179ab	90ab
F76-8757	8	.35ab	2.15abc	0.89de	.48d	360ab	303ab	165ab	76bcd
F76-8827	8	.34ab	1.95cde	1.12ab	.58ab	229ab	361a	158ab	74bcd
Ga76-316	8	.37ab	2.25ab	0.99bcde	.62a	199b	202b	165ab	93a
GAT74-10	8	.37ab	2.16abc	0.92cde	.51b	289ab	255ab	170ab	68cd
N76-1507	8	.33b	2.06bcd	1.06abcd	.55abc	379a	299ab	160ab	81abc
Bragg	7	.35ab	1.97b	0.98ab	.55abc	331a	278ab	130a	77abcd
GaSoy-17	7	.34bc	2.12ab	1.06ab	.48bc	257a	248ab	142a	68d
Braxton	7	.32bc	1.80d	1.20a	.60a	341a	250ab	179a	80abcd
Wright	7	.33bc	1.92c	0.98ab	.48bc	319a	260ab	162a	80abcd
F73-7082	7	.35ab	2.14ab	1.10ab	.54abc	419a	255ab	174a	83ab
N74-1572	7	.32bc	2.18a	1.01ab	.52abc	294a	192b	118a	72b
F76-8846	7	.39a	2.06abc	0.99ab	.47c	367a	270ab	122a	81abc
Gat73-24	7	.32bc	1.98abcd	1.07ab	.51bc	432a	227ab	132a	69c
N74-1341	7	.34bc	1.97b	1.08ab	.56ab	303a	224ab	105a	70c
N76-1415	7	.34bc	2.15ab	1.06ab	.52abc	426a	285a	150a	89a
N76-1505	7	.33bc	2.16ab	1.04ab	.55abc	337a	258ab	157a	89a
Ts77-5	7	.31c	1.98abcd	0.94b	.52abc	324a	232ab	124a	81abc

† Means followed by the same letter are not significantly different at P(.05) using Duncan's Multiple Range Test.

TABLE 4

Nutrient Concentrations in Soybean Leaves from Cultivars Representing Maturity Groups V and VI in the Uniform Southern Soybean Test When Grown on an Acid Norfolk Loamy Sand.

Genotype	Maturity Group	P	K	Ca	Mg	Al	Fe	Mn	Zn
		---	%	---	---	---	ppm	---	---
Tracy	6	.33ab†	2.35a	0.90cde	.48d	390ab	248bc	143a	77ab
Centennial	6	.30b	2.04bc	0.84de	.50cd	323ab	249bc	142a	68ab
D74-7741	6	.35a	1.87e	0.84de	.52cd	326ab	252abc	131a	76ab
N73-693	6	.31b	1.82e	1.09abcd	.55bcd	284ab	256abc	152a	72ab
N73-1102	6	.33ab	1.88e	1.17ab	.58abc	322ab	263abc	106a	74ab
D75-7527	6	.32ab	1.85e	1.12abc	.54cd	253ab	220bc	124a	69ab
N75-2213	6	.31b	1.89d	1.12abc	.66a	499a	359ab	108a	71ab
R74-1625	6	.32ab	1.90d	1.12abc	.58abc	411ab	393a	148a	82a
D74-7711	6	.31b	1.92c	0.80e	.49d	202b	182c	112a	64b
D76-9665	6	.33ab	1.81e	1.00bcde	.55bcd	380ab	242bc	130a	77ab
N76-325	6	.31b	2.08b	1.28a	.64ab	430ab	214c	102a	69ab
R75-868	6	.33ab	2.01bcd	0.88cde	.54cd	259ab	203c	127a	80a
Essex	5	.38a	1.98a	1.16b	.57b	310bcd	242a	173a	78a
Forrest	5	.31b	1.90ab	1.08b	.57b	338bcd	259a	169a	62a
Bedford	5	.35ab	1.94a	1.19b	.52b	448ab	239a	138a	62a
R74-511	5	.34ab	1.84ab	0.96b	.60b	197d	189a	100a	70a
D75-12035	5	.32b	1.78ab	1.13b	.61b	511a	313a	148a	71a
D76-9375	5	.33ab	1.94a	1.11b	.56b	242d	200a	122a	61a
Nathan	5	.35ab	1.90ab	1.32b	.50b	322bcd	254a	124a	68a
N76-098	5	.32b	1.82ab	1.01b	.50b	262cd	220a	116a	71a
N76-683	5	.32b	1.84ab	1.29b	.78a	266cd	184a	164a	76a
R76-45	5	.30b	1.72b	1.01b	.52b	412abc	253a	117a	54a
S76-2120	5	.34ab	1.96a	1.00b	.51b	227d	202a	107a	64a
V75-345	5	.34ab	1.71b	1.68a	.82a	276cd	220a	198a	71a

† Means followed by the same letter are not significantly different at P(.05) using Duncan's Multiple Range Test.

TABLE 5

Nutrient Concentrations in Soybean Leaves from Cultivars Representing Maturity Groups from Traditional Cultivars and Those Representing Maturity Group IV in the Uniform Southern Soybean Test When Grown on an Acid Norfolk Loamy Sand.

Genotype	Maturity Group	P	K	Ca	Mg	Al	Fe	Mn	Zn
		%				ppm			
Columbus	4	.34ab†	1.99abc	1.22bc	.70ab	326a	250a	167a	89a
Crawford	4	.36a	2.02ab	0.98cd	.53cde	304a	238a	166a	81ab
Douglas	4	.32ab	1.96abc	1.03cd	.56cde	523a	324a	152a	72bc
S76-2392	4	.28c	1.95abc	0.82d	.45e	260a	197a	144a	70bc
C1573	4	.34ab	2.08a	1.10bc	.55cde	305a	198a	131a	67bc
S76-2109	4	.35ab	1.98abc	1.24bc	.60bcd	218a	179a	101a	60c
S76-2203	4	.33ab	1.86b	1.33b	.56cde	354a	226a	146a	79ab
S76-2229	4	.32b	2.12a	1.21bc	.70ab	350a	234a	120a	69bc
V74-315	4	.35ab	1.81c	1.14bc	.51de	315a	238a	123a	67bc
V76-398	4	.35ab	1.86b	1.62a	.73a	278a	228a	143a	70bc
V76-465	4	.34ab	1.87b	1.19bc	.64abc	281a	214a	144a	71bc
V76-482	4	.35ab	1.86b	0.99cd	.54cde	315a	238a	134a	70bc
Hill	5	.32‡	1.98	0.92	.42	421	179	132	61
S-100	5	.39	2.16	1.83	.47	299	275	104	77
Lee	6	.32	1.96	1.10	.56	243	217	84	57
Ransom	6	.38	1.89	0.97	.59	487	342	88	57
CNS	7	.35	2.21	1.31	.47	384	210	167	74
Jackson	7	.38	2.00	1.08	.60	235	198	161	84
Palmetto	7	.37	1.88	0.99	.53	440	289	131	72
Roanoke	7	.36	2.18	0.99	.54	230	279	133	83
Biloxi	8	.33	2.21	2.03	.50	264	196	147	68
Hardee	8	.38	2.12	0.97	.42	250	196	134	75
Jupiter	9	.32	2.27	1.21	.64	271	189	96	56

†Means followed by the same letter are not sigificantly different at P(.05) using Duncan's Multiple Range Test.

‡Mean values, statistics were not run because of the variation in maturity groups.

TABLE 6

Average nutrient concentrations at bloom within leaf, petiole, and stem tissue of 60 soybean genotypes grown in the field on an acid Norfolk loamy sand.

Plant Fraction	Maturity Group	P	K	Ca	Mg	Al	Fe	Mn	Zn
		%				ppm			
Leaves	8	.35	2.03	1.06	.56	316	264	161	80
Petioles	8	.23	3.95	.84	.37	143	106	58	28
Stems	8	.21	2.36	.49	.26	97	91	28	15
Leaves	7	.34	1.95	1.03	.53	346	248	141	78
Petioles	7	.24	3.83	.84	.36	122	92	53	28
Stems	7	.21	2.33	.47	.26	81	67	27	16
Leaves	6	.32	1.86	1.01	.55	340	257	127	73
Petioles	6	.24	3.68	.81	.37	158	109	55	28
Stems	6	.23	2.18	.48	.30	109	94	30	16
Leaves	5	.33	1.95	1.16	.59	318	231	140	67
Petioles	5	.23	3.88	.83	.39	134	102	54	26
Stems	5	.21	2.47	.45	.30	94	78	26	14
Leaves	4	.33	2.04	1.16	5.9	320	230	139	72
Petioles	4	.26	3.96	.89	.38	161	95	52	28
Stems	4	.26	2.37	.45	.34	100	71	26	17

although this was probably in direct response to the low levels of Ca. The high K in the petiole suggests that this plant fraction would be most sensitive for monitoring K in the soybean plant.

The nutrient concentration data shows that although there were genotypic differences within leaf, petiole, and stem fractions, the differences were neither great nor consistent among plant fractions. The average nutrient concentrations within the maturity groups grown were very similar. Potassium appeared to compensate for low Ca concentrations in the stem fraction.

III. Correlation Analyses:

Correlation analyses were used to determine if there were any significant relationships between seed yield and nutrient concentration within the three plant fractions. Genotypic variation in both seed yield and nutrient concentration was mimimal, so average values for 12 genotypes in each of the maturity groups were used. There were no significant correlations for genotypes in maturity group VIII. Among group VII genotypes, petiole P, and leaf P, Fe, and Zn concentrations were significantly correlated with seed yield at P(.05). The "r values" for these correlations were .59, .70, .65, and .61, respectively.

Maturity group VI genotypes showed a signficant correlation between yield and leaf Ca (.74**) and between yield and petiole Ca (.59*). Yield and leaf Ca were also significantly correlated among group V genotypes (-.68**), but this time, the relationship was negative. Seed yield of group IV genotypes was significantly correlated to leaf P and K as well as stem K, Ca, Al, and Fe concentrations (.69**, -.64*, .59*, .59*, .60*, and .59*, respectively). Although some statistically significant relationships were identified, correlation analyses between seed yield and nutrient concentrations in the various plant fractions did not evaluate the tolerance of the germplasm to acid soil conditions.

Correlation analyses were also used to compare nutrient concentrations within and between plant fractions. Table 7 shows that except for leaf x stem correlations for Ca and Mg, nutrient concentrations in all three plant fractions correlated signifi-

TABLE 7

Correlation coefficients among nutrient concentrations in leaf, petiole, and stem tissue of 71 soybean genotypes grown in the field on an acid Norfolk loamy sand.

Correlation Pair	Nutrient							
	P	K	Ca	Mg	Al	Fe	Mn	Zn
Leaf x petiole	.38†	.34	.28	.22	.38	.48	.68	.47
Leaf x stem	.27	.16	NS	NS	.30	.31	.58	.29
Petiole x stem	.74	.61	.46	.38	.38	.51	.81	.41

† Significant at P(.01) unless indicated

TABLE 8

Correlation coefficients among nutrients in petiole and stem tissue of 71 soybean genotypes grown on an acid Norfolk loamy sand.

Petiole	P	K	Ca	Mg	Al	Fe	Mn	Zn
P	1.00†							
K	.36	1.00						
Ca	NS	NS	1.00					
Mg	NS	NS	.68	1.00				
Al	.14*	NS	.22	.18	1.00			
Fe	.20	NS	.24	.24	.58	1.00		
Mn	.16	.35	.19	.16	.24	.34	1.00	
Zn	.45	.36	.31	.29	.23	.36	.69	1.00
Stem								
P	1.00							
K	.46	1.00						
Ca	NS	.15*	1.00					
Mg	.32	.16	.45	1.00				
Al	.19	NS	.18	NS	1.00			
Fe	.18	.15*	.15	NS	.67	1.00		
Mn	.24	.22	.16	NS	.44	.39	1.00	
Zn	.48	.36	.17	.32	.35	.43	.57	1.00

†Significant at P(.01) unless noted with a single *

cantly at P(.01). Within the leaf fraction correlation coefficients for P and K (.31), Ca and Mg (.41), Al and Fe (.71), Mn and Zn (.60), and K and Mg (-.16) were significant at P(.01).

Correlation coefficients among nutrients in the petiole and stem fractions are presented in Table 8. The greater number of significant correlations in these plant fractions was probably due to smaller variations in nutrient concentrations. However, the nutrient pairs which had the highest correlations in the petiole and stem tissue were the same as in the leaf tissue, namely the Ca-Mg, Al-Fe, and Mn-Zn. The P-K and P-Zn correlations which were also quite high, indicate a strong interaction among these elements under these soil conditions.

Conclusions which can be made from this experiment are that (a) among the genotypes grown the differences in productivity as measured by seed yield were mimimal despite the very acid soil conditions; (b) genotypic variation in nutrient concentrations within leaf, petiole, and stem tissue was minimal; and (c) correlation analyses between seed yield and nutrient concentration did not differentiate tolerance to acid soil conditions. Finally, to accurately evaluate soybean germplasm to acid soil conditions, multiple row plots are needed and should be compared on-site to a well-limed, equally fertilized check plots. To screen genotypes in the field for tolerance to Al, removing the topsoil and screening on the A2 horizon[12] appears to be a more suitable technique because the amelioratory effects of organic matter and Ca are minimized.

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