Crop Response to Soil Acidity Factors in Ultisols and Oxisols in Puerto Rico. X. Pigeon Peas[1,2]

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ABSTRACT

The effect of various soil acidity factors on yield and leaf composition of pigeon peas [*Cajanus cajan* (L.) Huth] was determined in two Ultisols and one Oxisol. Pigeon peas barely responded in yield to soil acidity levels in the Oxisol, but responded strongly to variations in soil acidity in the two Ultisols. Yields increased from almost zero at the highest level of acidity (about pH 4 and 80% Al saturation) to more than 8 t/ha at about pH 6.0 with no exchangeable Al present. Yields increased with increasing soil pH, decreasing exchangeable Al content, and increasing exchangeable Al:Ca ratio. Yields were highest when pH was about 6.0, exchangeable Al was less than 20%, and exchangeable Al:Ca was less than 1.0. Soil acidity did not affect leaf composition, except that Ca content decreased with increasing acidity and correlated well with yields, ranging from about 0.5% with lowest yields to more than 1% with the highest yields. Number of nodules per plant was not affected by acidity factors, except at the highest level of acidity, at which no nodules were found.

INTRODUCTION

Pigeon peas are an important source of protein in the tropics, particularly in the Caribbean area and India. Considerable research has been conducted on pigeon peas in many tropical countries, including Puerto Rico (9), but we have found no reference to studies on the effect of soil acidity factors on pigeon pea yields.

The present studies were conducted to determine the relationship between the various soil acidity factors and the yield and foliar composition of intensively managed pigeon peas growing on two Ultisols and one Oxisol in the humid region of Puerto Rico.

MATERIALS AND METHODS

The experiments were carried out on 30 plots in a Corozal clay soil (clayey, mixed, isohyperthermic Aquic Tropudults), on 30 plots in a Corozal subsoil, and on 40 plots in a Coto sandy clay (clayey, kaolinitic isohyperthermic Tropeptic Haplorthox). All plots were 4 m^2 and were surrounded by ditches to prevent runoff from one plot onto another. The experimental design was a randomized series of plots with different

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[2] This paper covers work carried out cooperatively between the Agricultural Research Service, USDA, and the Agricultural Experiment Station, College of Agricultural Sciences, Mayagüez Campus, University of Puerto Rico.

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acidity levels and concentrations of Al resulting from different lime rates applied over previous years.

The upper 15 cm. of soil was tilled with a motor driven hand tiller. On August 15, 1980, the Puerto Rico 147 pigeon pea cultivar was planted at 15 cm between plants and 90 cm between rows. All plots received 560 kg/ha of 10-10-10 fertilizer at planting and 2 months later.

Supplementary overhead irrigation was applied when weekly rainfall was less than 15 mm. Weeds were controlled by hand weeding. Insects and diseases were controlled as recommended by the College of Agricultural Sciences, University of Puerto Rico (1).

Two months after the peas were planted and before the second fertilizer application, the soil in each plot was sampled by taking 10 borings at 0–15 cm depths. The samples were air dried, passed through a 20-mesh sieve, and analyzed for various soil constituents. Exchangeable bases were extracted with neutral *N* NH_4OAc. Ca and Mg were determined by the Versenate titration method (7). K was determined by flame photometry, and Mn was determined by colorimetry as $KMnO_4$. Exchangeable Al was extracted with 1*N* KCl and determined by McLean's double titration method (8). Percent Al saturation of the soil was calculated on the basis that exchangeable Ca+Mg+K+Al+H was the effective cation exchange capacity of the soil. Soil reaction was measured with a glass electrode pH meter, a 1.0:1.5 soil-to-water ratio.

Three months after the peas were planted, samples from mature-active leaves from the upper middle branches were taken from plants in the center row of each plot, washed in distilled water, dried at 70° C and analyzed for N by the Kjeldahl method; for P, by colorimetry; for K, by flame photometry; for Ca and Mg, by the Versenate method (7); and for Mn by colorimetry as $KMnO_4$.

Pods were hand picked when mature-green, in three pickings from December 12, 1980, to January 7, 1981. Yields were expressed in terms of weight of green pods, 47% of which are green peas.

During the peak of the crop three plants in the central row of each plot were dug up and the number of nodules on the roots was determined.

For tabulation and comparisons, plots were grouped in 15% Al saturation ranges, with 0 content as a separate range. Soil acidity factors were correlated with yield components through regression analyses.

RESULTS AND DISCUSSION

COROZAL CLAY

Table 1 shows that pigeon peas were relatively tolerant to soil acidity, producing 93% of maximum yield, even at pH 4.7 with 32% Al saturation and an Al:Ca ratio of 0.6. Yields dropped to about half of maximum when

TABLE 1.—*Effect of soil acidity factors on yield, nodulation and foliar composition of pigeon pea variety 147 grown on two Ultisols and one Oxisol. All values are averages of at least 3 plots for Corozal soils and 5 for Coto soil*

Soil acidity factors				Yield data		Nodules per plant	Leaf composition					
pH	Average Al Sat.	Average Ca Sat.	Al/Ca	Green pods	Green peas		N	P	K	Ca	Mg	Mn
	%	%		*kg/ha*	*kg/ha*		%	%	%	%	%	*p/m*
Corozal clay soil (Aquic Tropudults)												
6.00	0	76	.00	8,473	3,982	45	3.54	.22	1.76	1.01	.23	59
4.90	15	68	.24	7,856	3,535	35	3.43	.18	1.74	.94	.16	85
4.70	32	52	.60	7,887	3,628	38	3.45	.18	1.72	.90	.19	85
4.45	45	43	1.07	4,558	2,142	41	3.22	.18	1.77	.88	.19	73
4.10	76	12	7.55	1,412	678	0	3.49	.20	2.12	.55	.15	127
Corozal clay subsoil (Aquic Tropudults)												
6.00	0	76	.00	7,312	3,290	20	3.56	.20	1.72	1.05	.26	40
5.00	10	72	.14	6,908	3,247	26	3.58	.18	1.45	.94	.24	33
4.60	36	50	.72	5,682	2,670	16	3.20	.14	1.57	.85	.19	57
4.40	51	36	1.40	3,706	1,779	8	3.40	.22	1.78	.98	.18	60
4.10	79	8	11.17	634	292	0	3.53	.26	1.92	.52	.13	80
Coto sandy clay (Tropeptic Haplorthox)												
5.30	0	67	.00	5,410	2,396	—	3.89	.24	1.16	.55	.24	162
4.80	6	52	.11	5,143	2,360	—	3.83	.24	1.17	.55	.22	223
4.60	16	50	.32	5,326	2,047	—	3.77	.22	1.16	.51	.30	260
4.50	22	43	.51	5,195	2,348	—	3.96	.24	1.23	.48	.29	225
4.35	35	35	1.00	4,156	2,064	—	3.77	.24	1.22	.52	.24	240
4.20	48	27	1.77	4,140	2,064	—	4.07	.24	1.27	.57	.24	273

soil pH was 4.45 and Al saturation of the soil increased to 45%, and decreased to only 17% of maximum when soil pH was 4.1 and Al saturation was 76%.

Soil acidity had no effect on the number of nodules per plant, except that none was found at the highest level of soil acidity.

The N, P, and K contents of the pigeon pea leaves were not affected by variations in soil acidity (table 1). Manganese content, however, was much higher at the highest acidity level than at the other levels, but the content was not high enough to be toxic and, thus to be considered a contributing factor to the low yields. Calcium content decreased consistently as Ca saturation decreased and soil acidity and Al saturation increased. At the highest level of soil acidity, Ca content was only about half of that at pH 6.0 with no exchangeable Al in the soil. Except for that of the plants grown on Coto sandy clay, Mg content of the leaves was lowest at the highest level of acidity, and in all soils Mg content generally tended to increase with decreasing acidity.

The chemical composition of the pods (table 2) was not affected by variations in the acidity of Corozal clay soil. The green seeds contained an average of 22% crude protein (N × 6.25), 0.30% P and 0.25% Ca.

Regression analyses of the data (table 3) indicated that pod yields and the Ca content of the leaves were closely correlated with the soil acidity factors studied. The soil acidity factors explained at least 80% of the variations in yield.

Figure 1 indicates that pod yields were significantly correlated with the Ca content of the leaves. The relationship explained 70% of the variations, and a 1% Ca content was associated with maximum yield.

COROZAL CLAY SUBSOIL

Pigeon pea yields in the subsoil were somewhat lower than in the normal soil at comparable acidity levels (table 1). Maximum pod yield (7,312 kg/ha) was only 86% of that produced on the Corozal clay soil at the same pH level. At the highest soil acidity level, only 634 kg/ha of pods was produced, or 45% of the yield produced on the normal soil at the same acidity level.

Pigeon peas produced 94% of maximum yields when Al saturation of the soil was 10%, and dropped to 50% at 51% Al saturation and to only 9% of maximum at the highest acidity level.

The number of nodules per plant decreased as Al saturation of the soil increased beyond 10%, with only eight nodules per plant at 51% Al saturation, and none at 79% Al saturation.

The N, P, and K contents of the leaves were not affected by variations in soil acidity (table 1). The Ca and Mg contents decreased as pH

TABLE 2.—*Effect of soil acidity factors on chemical composition of pigeon pea pods. All values are average of at least 3 plots*[1]

Soil acidity factors				Chemical composition of pigeon pea pods									
				Hulls					Seed				
pH	Average Al Sat.	Average Ca Sat.	Al/Ca	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	%	%		%	%	%	%	%	%	%	%	%	%
Corozal clay soil													
6.00	0	76	.00	1.18	.14	1.49	.33	.09	3.42	.32	1.80	.28	.05
4.90	20	68	.24	1.06	.11	1.42	.34	.10	3.40	.30	1.75	.26	.05
4.70	32	52	.60	1.11	.10	1.30	.35	.10	3.39	.32	1.71	.26	.05
4.45	45	43	1.07	.94	.12	1.46	.37	.16	3.42	.30	1.87	.25	.08
4.10	76	12	7.55	1.17	.12	1.43	.38	.09	3.73	.24	1.99	.22	.04
Corozal subsoil													
6.00	0	76	.00	1.15	.13	1.43	.30	.13	3.43	.34	1.69	.26	.05
5.00	10	72	.14	1.12	.10	1.38	.33	.14	3.32	.34	1.75	.26	.06
4.60	36	50	.72	1.12	.10	1.42	.35	.11	3.39	.32	1.72	.28	.07
4.40	51	36	1.40	1.14	.12	1.43	.33	.12	3.38	.34	1.71	.26	.07
4.10	79	8	11.17	1.05	.12	1.38	.38	.10	3.45	.30	1.71	.25	.07

[1] No data were collected for Coto sandy clay soil.

TABLE 3.—*Relationships between pigeon pea yields, calcium content of the leaves and soil acidity factors*

	Soil acidity factor vs. yield of pods (kg/ha)		Calcium content of leaves	
	Corozal clay			
pH	r = .90**	F = 56.33**	r = .79**	F = 22.7**
	Y = −66873.1 + 25700.1X − 2156.5X²		Y = 3.69 + 1.59X − .13X²	
Percent Al saturation	r = −.94**	F = 107.7**	r = .78**	F = 44.4**
	Y = 8499.9 − 24.64X − .91X²		Y = 1.03 − .0058X	
Percent Ca saturation	r = .94**	F = 100.6**	r = .78**	F = 44.8**
	Y = 654.45 + 183.3X − .84X²		Y = .50 + .007X	
Exch. Al/exch Ca	r = .93**	F = 86.38**	r = .76**	F = 38.3**
	Y = 8282.3 − 1944.5X + 118.3X²		Y = .97 − .05X	
	Corozal clay subsoil			
pH	r = .90**	F = 56.22**	r = .81**	F = 24.9**
	Y = 66514.3 + 25307.7X − 2140.4X²		Y = 3.38 + 1.46X − .12X²	
Percent Al saturation	r = .95**	F = 127.82**	r = .80**	F = 48.65**
	Y = 7207.7 − 29.68X − .65X²		Y = .98 − .005X	
Percent Ca saturation	r = .95**	F = 134.7**	r = .81	F = 53.76**
	Y = 397.1 + 145.17X − .61X²		Y = .52 + .006X	
Exch. Al/exch Ca	r = .94**	F = 104.9**	r = .81**	F = 55.18**
	Y = 6936.0 − 1376.2X + 67.2X²		Y = .93 − .04X	
	Coto sandy clay			
pH	r = .38*	F = 3.4*	Non significant	
	Y = 54.05.5 + 3419.55X − 260.6X²			
Percent Al saturation	r = .44**	F = 4.8*	Non significant	
	Y = 5371.2 − 39.08XX + .28X²			
Percent Ca saturation	Non significant		Non significant	
Exch. Al/exch Ca	r = .43*	F = 4.33	Non significant	
	Y = 5305.6 − 1419.6X + 434.0X²			

decreased and Al saturation of the soil increased, from 1.05 and 0.26%, respectively, at the lowest level of acidity, to 0.52 and 0.13% at the highest level of acidity. Although Mn content increased steadily with increasing acidity, the highest content observed was not considered toxic.

The chemical composition of the pods (table 2) was essentially the same as the composition of those produced in the normal soil and was not affected by soil acidity.

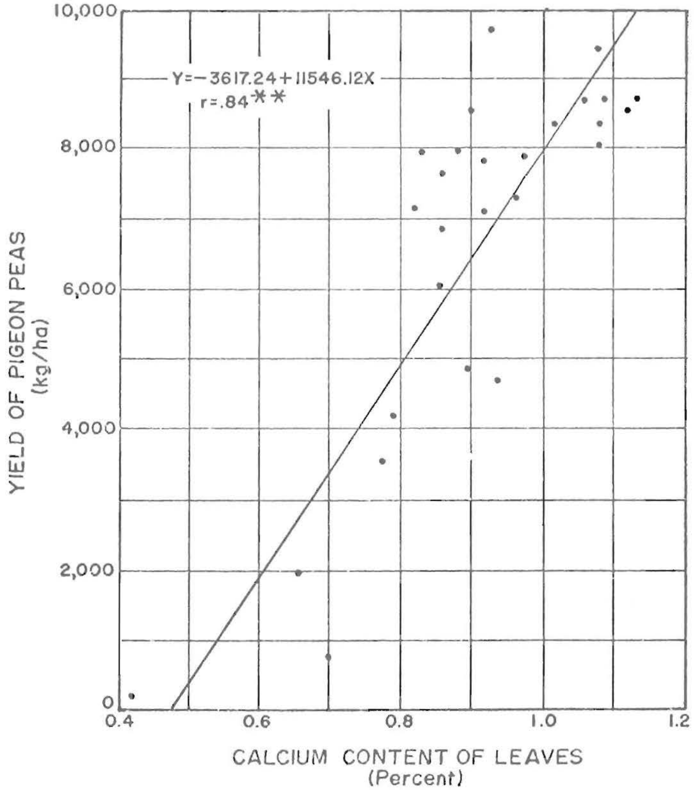

FIG. 1.—Relationship between the calcium content of the leaves and the yield of pigeon peas grown in a Corozal clay soil.

Regression analyses of the data (table 3) indicated that, as in the normal soil, yields and Ca content of the leaves were correlated, as were yields and the soil acidity factors studied. The best correlations were between yields and percentages of Al and Ca saturation of the soil, explaining 90% of the variations observed. The Ca content of the leaves was significantly correlated with all soil acidity factors studied, explaining about 65% of the variations in yield.

Figure 2 indicates that Ca content of the leaves is a good index for predicting the response of pigeon peas to liming. A Ca content higher than 1% was associated with optimum yield in the Corozal clay subsoil. The Mg content of the leaves was not correlated with yields.

COTO SANDY CLAY

Table 1 shows, that soil acidity ranging from pH 4.2 to 5.3, corresponding to Al saturations of 48 and 0%, respectively, had little effect on yields

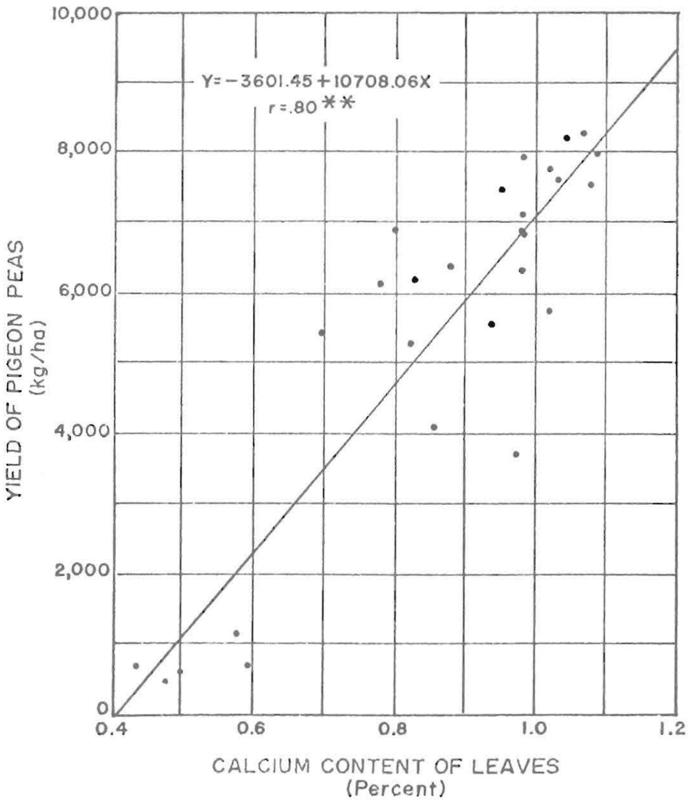

FIG. 2.—Relationship between the calcium content of the leaves and the yield of pigeon peas grown in a Corozal clay subsoil.

of pigeon peas in Coto sandy soil. However, the lowest yield (4,140 kg/ha) was produced at the highest level of acidity, and the highest yield (5,410 kg/ha) was produced at the lowest level of acidity.

The soil was much higher in both exchangeable and easily reducible Mn than were the Ultisols, but had a lower Al content at any given pH. The lack of response to acidity in this soil may have been related to reduced Al activity in the soil solution as a result of the high Mn concentration

Soil acidity factors had no effect on the chemical composition of pigeon pea leaves. The Ca content of the leaves was considerably lower in this Oxisol than in the Ultisols, but the Mn content was much higher than in the Ultisols. Abruña et al. (4) found that the ratio Ca:Mn in the leaves of snap beans, when expressed in terms of chemical equivalents, was

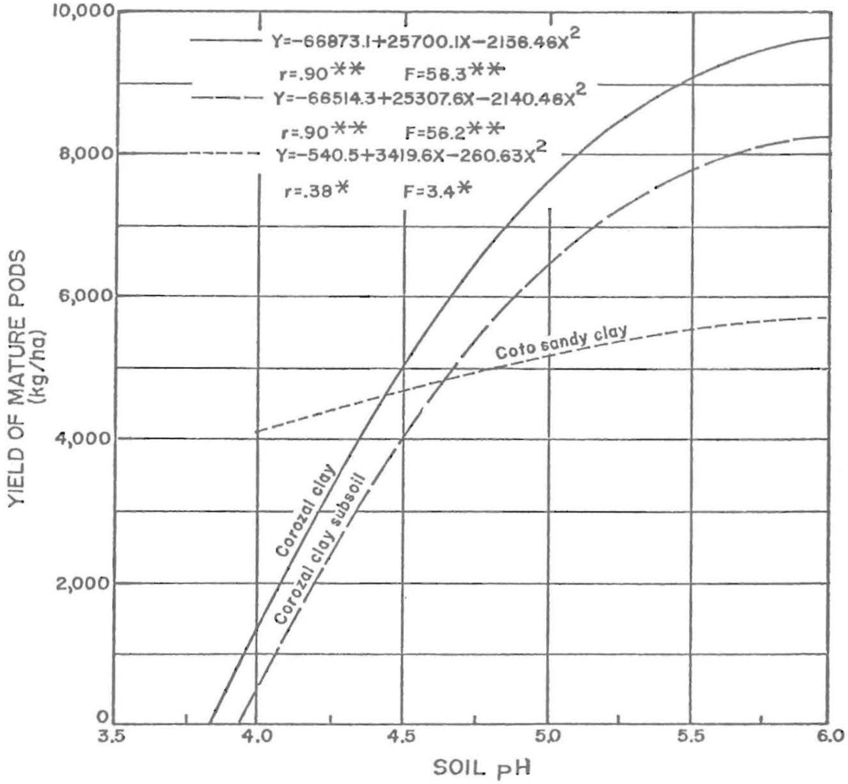

FIG. 3.—Relationship between pH of two Ultisols and one Oxisol and yields of pigeon peas.

closely related to yield. Such a relationship did not exist with pigeon peas.

ALL SOILS

The data presented in this paper indicate that Al saturation of the exchange complex is the main cause of depressed yields on acid Ultisols. Yields levelled off at about pH 6.0 when all of the active Al^{3+} was precipited as $Al(OH)_3$ (fig. 3) and yield was essentially zero at 80% Al saturation of the soil (fig. 2). Expressed in terms of relative yield the response curves for the Corozal soil and subsoil shown in figure 3 are almost identical. Both soils produced 95% of maximum yield at pH 5.5, 79% at pH 5.0 and 50% at pH 4.5. On the Coto soil, on the other hand, yields reached 70% of maximum even at pH 4.0. On Corozal soil and subsoil (fig. 4) yields were 90% of maximum at 20% Al saturation, and

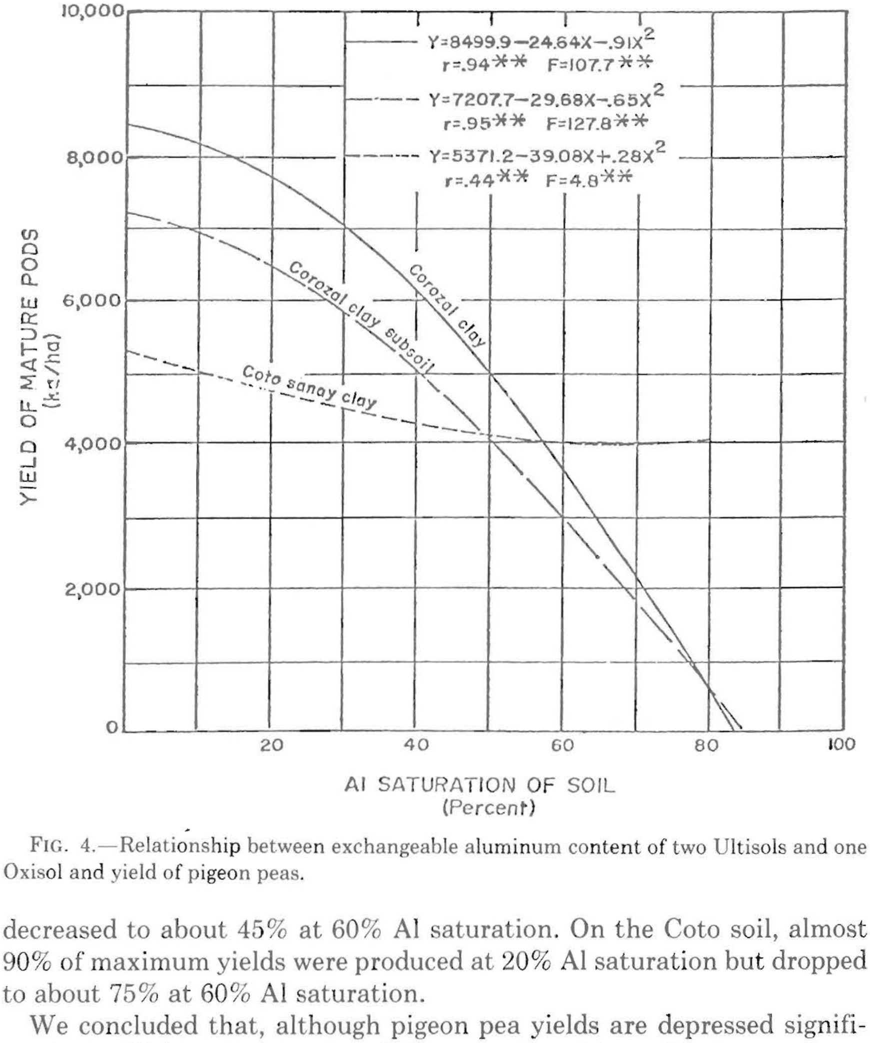

FIG. 4.—Relationship between exchangeable aluminum content of two Ultisols and one Oxisol and yield of pigeon peas.

decreased to about 45% at 60% Al saturation. On the Coto soil, almost 90% of maximum yields were produced at 20% Al saturation but dropped to about 75% at 60% Al saturation.

We concluded that, although pigeon pea yields are depressed significantly as pH drops below 5.5 and Al saturation of the soil increases above 40%, they are more tolerant to soil acidity than are soybeans (5), corn

(3) and snap beans (2), but are more sensitive to soil acidity than cassava (6).

RESUMEN

Se estudió el efecto de los factores de acidez de dos Ultisol y un Oxisol sobre el rendimiento y la composición quimica del gandul.

En los dos Ultisol los gandules respondieron señalademente al encalado y el rendimiento se correlacionó significativamente con los distintos factores de acidez resultantes de incrementos en el encalado.

El rendimiento aumentó de casi nada al nivel más alto de acidez, pH 4.0 y 80% del complejo coloidal del suelo saturado con aluminio, a 8 Tm/ha con pH de 6.0 y una saturación del complejo coloidal con aluminio de 20% o menos y cuando la razón de aluminio cambiable a Ca cambiable fue inferior a 1.0.

El contenido en calcio en las hojas correlacionó bien con los rendimientos de alrededor de 0.5% con los más bajos a más de 1.0% con los más altos.

El gandurl respondió sólo levemente a las aplicaciones de cal en el Oxisol a pesar de variaciones notables en pH y saturación de aluminio. Esto puede atribuirse a una menor actividad del ion aluminio debido a la preponderancia del ion manganeso en la solución del suelo.

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