RESPONSE OF GREEN BEANS TO ACIDITY FACTORS IN SIX TROPICAL SOILS

And

RESPONSE OF CORN TO ACIDITY FACTORS IN EIGHT TROPICAL SOILS

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Response of Green Beans to Acidity Factors in Six Tropical Soils[1,2]

Fernando Abruña, Raúl Pérez-Escolar, José Vicente-Chandler, Jacinto Figarella, and Servando Silva[3]

INTRODUCTION

Factors associated with soil acidity such as toxic concentrations of aluminum and manganese, deficiencies of calcium and magnesium, and fixation of phosphorus, are major causes for low crop yields on many soils of the Humid Tropics. The natural high acidity of the Ultisols and Oxisols of these regions is increased further by heavy fertilization with residually acid materials.

Little information is available as to the specific factors of acid soil infertility that influence yield and composition of tropical crops grown under intensive management. In Puerto Rico, Abruña et al. (3) found that yields of heavily fertilized Napier grass growing on an acid Ultisol were doubled by liming. Abruña and Vicente-Chandler (1) found that yields of heavily fertilized sugarcane growing on a typical Ultisol increased from 1 to 47 tons per acre yearly with increasing exchangeable base and decreasing exchangeable aluminum content of the soil. Abruña, et al. (2) reported that intensively managed coffee responded strongly to liming on acid soils high in manganese and did well at very high acidity and exchangeable aluminum levels in soils low in manganese. Abruña, et al. (4) found that tobacco responded strongly to liming on three Ultisols and an Oxisol and that response was closely related to the aluminum and manganese content of the soils. Abruña et al. (5) found that corn responded very strongly to liming on eight Ultisols and Oxisols typical of the Humid Tropics and that response was closely related to exchangeable aluminum and base contents of the soils.

The present study determined the effects of soil acidity on yields and

[1] Manuscript submitted to the Editorial Board July 18, 1973.

[2] This report covers work carried out cooperatively between the Agricultural Research Service, USDA, and the Agricultural Experiment Station, Mayagüez Campus, University of Puerto Rico, Río Piedras, P.R., partially funded by the U.S. Agency for International Development under research contract csd-2490 entitled: Soil Fertility Requirements to Attain Efficient Production of Food Crops on the Extensive, Deep, Well-Drained but Relatively Infertile Soils of the Humid Tropics.

[3] Soil Scientist, ARS, USDA, Soil Scientist, Puerto Rico Agricultural Experiment Station and Soil Scientist, Chemist and Agricultural Technician, ARS, USDA, respectively.

foliar composition of green beans grown in the field on five Ultisols and an Oxisol typical of the Humid Tropics.

MATERIALS AND METHODS

Characteristics of the experimental soils are shown in table 1.

Experiment sites were divided into from 30 to 60 plots of 12 feet × 12 feet each, arranged in a completely randomized design. Increments of limestone were added as required to provide a wide range in soil acidity and percent base saturation. The limestone was thoroughly worked into and mixed with the upper 6 inches of soil.

TABLE 1. *Characteristics of the soils at the various experimental sites*

Soil type	Location	Classification	Origin	Organic matter	Cation exchange capacity	Bulk density of undisturbed soil
				Percent	*M eq 100 g*	*G cm³*
Humatas clay	Orocovis	Typic tropohumults	Volcanic tuffs	3.0	15	1.1
Corozal clay	Corozal	Aquic tropudult	Tuffaceous material	4.0	19	1.2
Corozal clay subsoil	Corozal	Aquic tropudult	Tuffaceous material	2.5	16	1.3
Coto clay	Isabela	Tropeptic haplorthox	Limestone quartzitic sand deposits	2.0	5	1.1
Los Guineos clay	Jayuya	Epiaquic tropohumults	Tuffaceous material	8.1	16	1.1
Corozal clay level	Corozal	Aquic tropudult	Tuffaceous material	4.7	19	1.2

The soil in all plots of all experiments was sampled 6 months after liming to determine its acidity status. Twelve cores were taken in each plot at 0 to 6-inch depths, composited, air dried, and screened through a 20-mesh sieve. Cation-exchange capacity was determined by both the ammonium acetate extraction procedure and by sum of cations. Calcium and magnesium were determined by the Versenate titration method using Calcein as calcium indicator and Calmagite as Ca-Mg indicator. Potassium was determined by flame photometry. Exchangeable aluminum was extracted with 1 *N* potassium chloride and determined by the aluminum method. Soil reaction was measured with a glass-electrode pH-meter using a 1:1.5 soil-water suspension.

Beans of the Bountiful variety were planted at 3 inches × 24 inches and

TABLE 2.—*Effect of various soil acidity factors on yields and composition of beans growing on a typical Oxisol and Ultisols under humid tropical conditions in Puerto Rico*

Soil properties						Composition of bean leaves				
Percent aluminum saturation		Percent base saturation		pH	Yields of green beans pounds acre	Ca (per cent)	Mg (per cent)	P (per cent)	N (per cent)	Mn (ppm)
NH_4OAC method	Summation of cations	NH_4OAC method	Summation of cations							
Humatas (Ultisol)										
0-9	0-14	60-79	86-100	5.3	6,190	1.83	0.27	0.36	5.75	110
10-19	15-29	50-59	71-85	4.7	5,010	1.56	0.25	0.34	5.76	160
20-29	30-44	40-49	56-70	4.5	4,350	1.49	0.21	0.44	5.94	160
30-39	45-59	30-39	41-55	4.2	3,050	1.26	0.21	0.36	5.95	190
40-59	60-74	20-29	26-40	3.9	1,620	1.16	0.23	0.49	6.55	210
Corozal topsoil (Ultisol)										
0-10	0-19	60-79	81-100	5.4	9,970	2.18	0.34	0.35	5.87	121
11-21	20-39	45-59	61-80	4.7	7,940	1.57	0.29	0.30	6.11	152
22-32	40-59	30-44	41-60	4.6	7,260	1.45	0.24	0.31	6.32	169
33-43	60-79	15-29	21-40	4.3	3,850	0.95	0.27	0.32	6.70	184
Corozal subsoil (Ultisol)										
0-8	0-13	59-68	87-100	5.4	10,450	2.00	0.33	0.31	5.97	122
9-17	14-27	49-58	73-86	4.8	8,780	1.61	0.36	0.32	6.14	123
18-26	28-41	39-48	59-72	4.6	7,820	1.34	0.27	0.30	6.28	132
27-35	42-55	29-38	45-58	4.3	4,950	1.07	0.24	0.30	6.25	150
36-44	56-69	19-28	31-44	4.2	3,240	0.88	0.25	0.30	6.78	157
Corozal level (Ultisol)										
0-9	0-12	84-100	88-100	5.2	8,140	3.08	0.24	0.21	5.29	165
10-19	13-25	67-83	75-87	4.7	7,500	2.92	0.25	0.18	5.37	234
20-29	26-38	50-66	62-74	4.6	4,960	2.44	0.25	0.20	5.67	263
Los Guineos (Ultisol)										
0-8	0-16	55-69	84-100	5.3	12,140	2.39	0.31	0.17	5.79	50
9-17	17-33	40-54	67-83	4.7	11,390	1.72	0.40	0.16	5.62	124
18-26	34-50	25-39	50-56	4.3	9,040	1.34	0.46	0.16	5.58	149
Coto (Oxysol)										
[1]	[1]	88-98	[1]	5.4	6,150	2.12	0.30	0.32	5.14	211
		77-87		4.8	5,920	1.91	0.29	0.31	5.13	231
		66-76		4.8	5,706	1.89	0.32	0.31	5.05	258
		55-65		4.4	4,530	1.69	0.34	0.30	5.21	267
		44-54		4.2	4,190	1.63	0.29	0.30	5.28	267

[1] No exchangeable aluminum at acidity levels studied.

fertilized with 150 pounds of nitrogen, 150 of phosphoric acid, 150 of potassium, 50 of magnesium, and 30 of zinc per acre in one application at planting. The beans were protected against insects and diseases by spraying periodically.

Leaf samples were taken in each plot following accepted procedures and analyzed for N, P, Ca, Mg, and Mn.

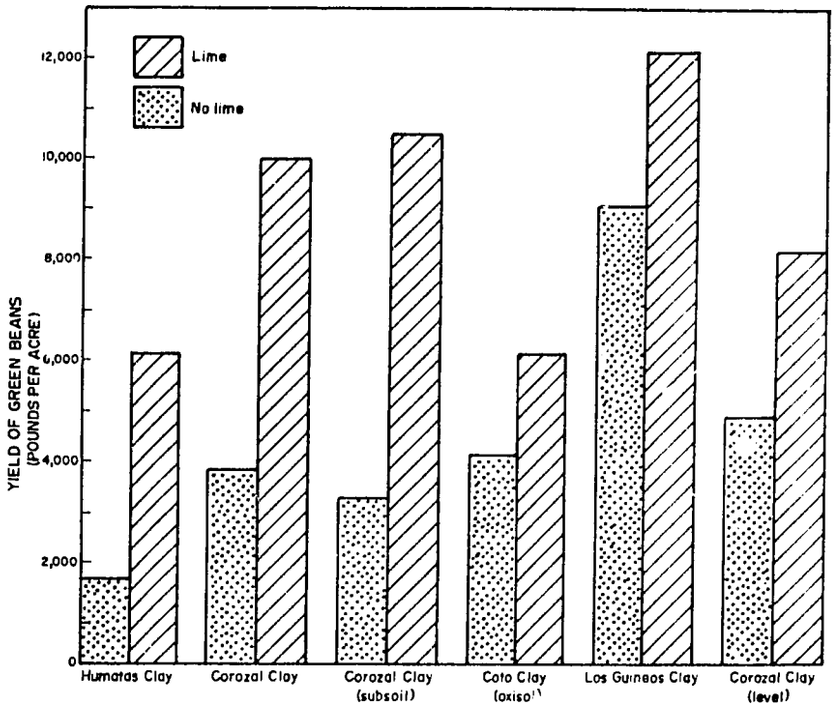

FIG. 1.—Effect of liming on yields of green beans growing on five typical Ultisols and one Oxisol under humid tropical conditions in Puerto Rico.

The beans were harvested at the proper stage for consumption as green beans and yields produced by each plot determined. Yields were related by regression analysis to soil pH, exchangeable aluminum, and exchangeable bases and to foliar composition of the beans.

RESULTS AND DISCUSSION

With proper liming, high yields of green beans were obtained in all the experiments (table 2 and fig. 1). Highest yields ranged from about 6,000 pounds per acre on Coto and Humatas clay to over 12,000 pounds on Los Guineos. Yields on the other soils ranged from about 8 to 10,000 pounds per acre.

FIG. 2.—Effect of liming a very acid Ultisol (Corozal clay) on growth of otherwise intensively managed, well fertilized beans. Plot in foreground had a pH of 4.2 with 40-percent aluminum and 25-percent base (Ca + Mg) saturation of the exchange complex. Plot in background was limed to pH 5.4 with no exchangeable aluminum and 70-percent base saturation.

The large increases in yield resulting from liming all soils are shown in figure 1. The response of beans to liming Corozal clay is illustrated in figure 2.

Calcium content of the bean leaves increased markedly with increasing soil base content, i.e., lime rates, and with yields in all soils (table 2). The close relationship between bean yields and calcium content of the leaves on Humatas and on Corozal soil and subsoil are shown in figures 3, 4, and 5. Calcium content of about 2 percent or more in the leaves was associated with high yields. The decrease in calcium content of the leaves with in-

creasing exchangeable soil aluminum suggests that calcium absorption by the plant was curtailed perhaps through a restrictive effect of aluminum on root development, or on uptake of this nutrient.

Manganese content of the bean leaves increased with increased acidity of all soils (table 2). On most soils, nitrogen content of the bean leaves also tended to increase slightly with acidity. However, neither magnesiumn or phosphorus contents of the bean leaves were affected by liming.

Table 2 shows that the Ultisols had high contents of exchangeable aluminum when acid while the Oxisol (Coto) contained only traces of exchangeable aluminum even when very acid.

On the Ultisols, which contained considerable exchangeable aluminum,

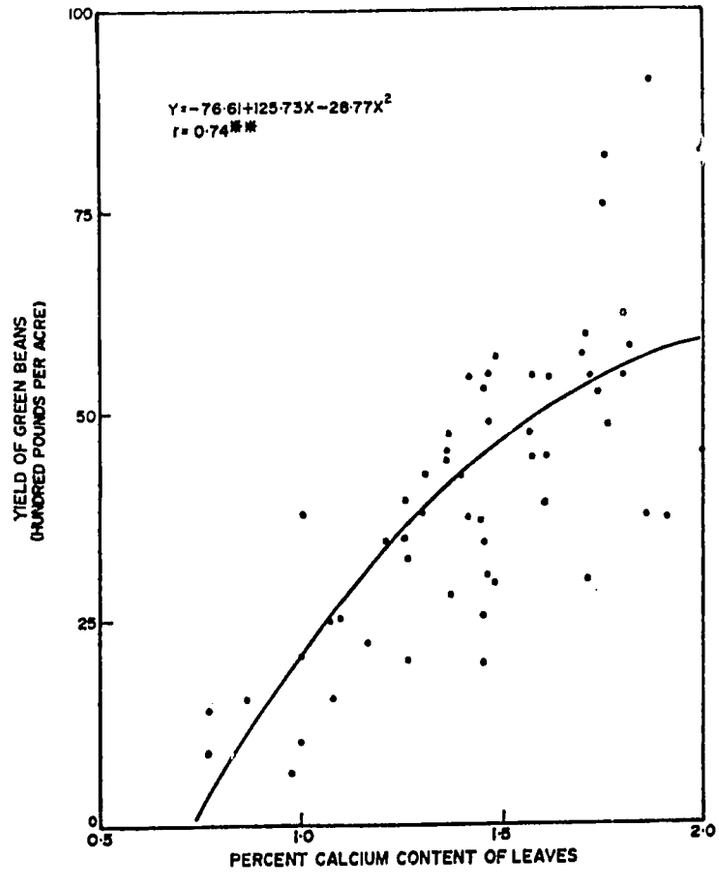

FIG. 3.—Relationship between yields and calcium content of leaves of beans growing on a Humatas clay at Orocovis.

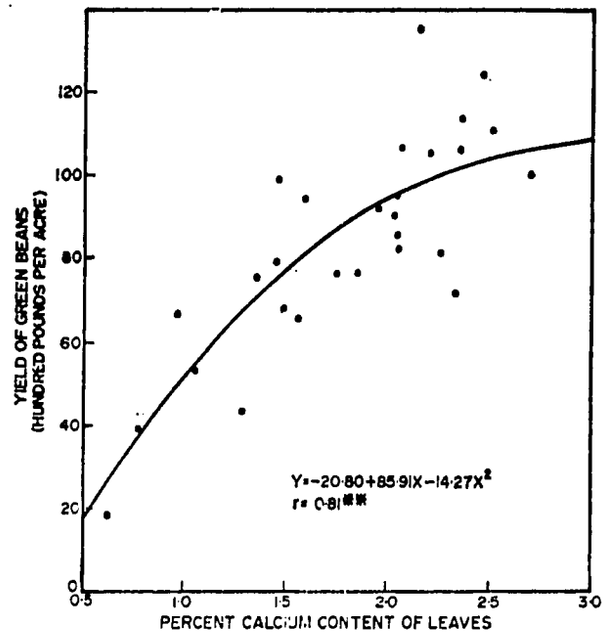

FIG. 4.—Relationship between yields and calcium content of leaves of green beans growing on Corozal clay.

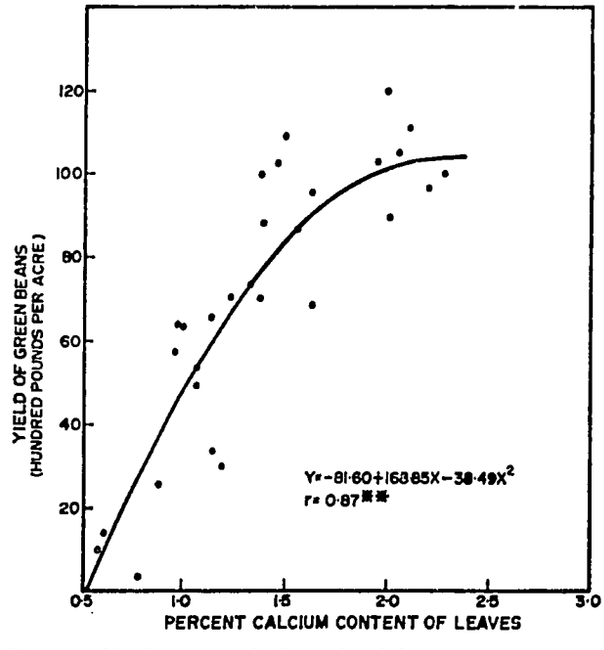

FIG. 5.—Relationship between yields and calcium content of leaves of green beans growing on Corozal subsoil.

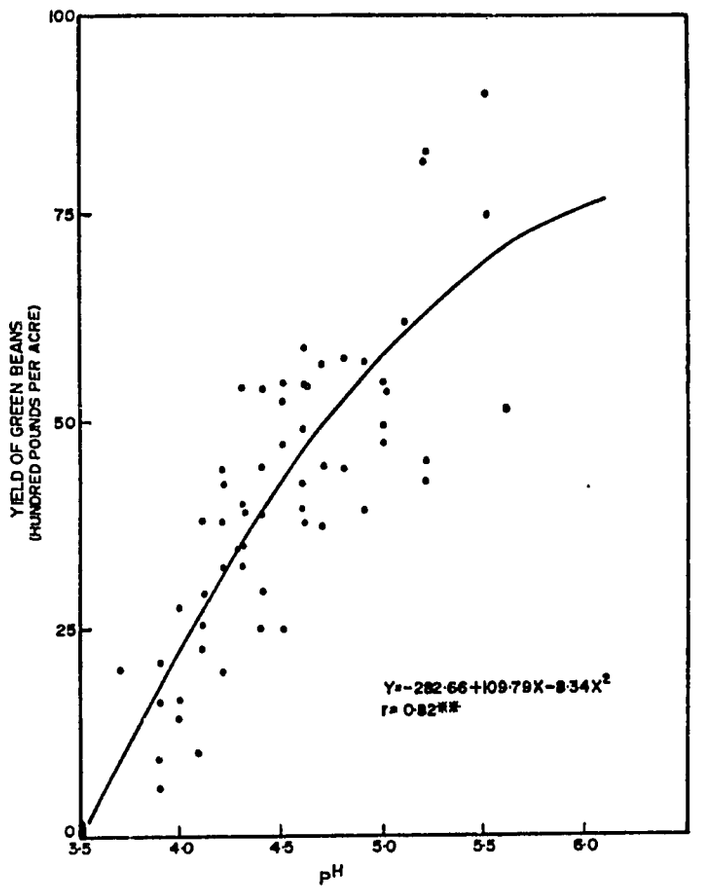

FIG. 6.—Relationship between yields of green beans and pH of a Humatas clay at Orocovis.

bean yields increased with increasing pH up to somewhat above 5.0 (table 2 and figs. 6, 7, and 8). On the Oxisol (Coto), which contains essentially no exchangeable aluminum but considerable manganese to which beans are sensitive, yields also increased with pH to about this level.

The close relationship between pH and yields of beans on Humatas, and on Corozal soil and subsoil, are illustrated in figures 6, 7, and 8.

Table 2 shows that bean yields increased with exchangeable base contents on all soils. The close relationship between percent base saturation and bean yields on Humatas and on Corozal soil and subsoil are shown in figures 9, 10, and 11. The rate of increase in yields dropped off at about 70-percent base saturation based on cation exchange capacities as determined by the ammonium acetate method.

Bean yields increased with decreasing exchangeable aluminum content to approximately 0 on all soils (table 2). The close relationship between exchangeable aluminum content and bean yields on Humatas and on Corozal soil and subsoil are shown in figures 12, 13, and 14. Almost no beans were produced when aluminum saturation approached 50 percent.

Exchangeable bases and aluminum thus provide excellent criteria for

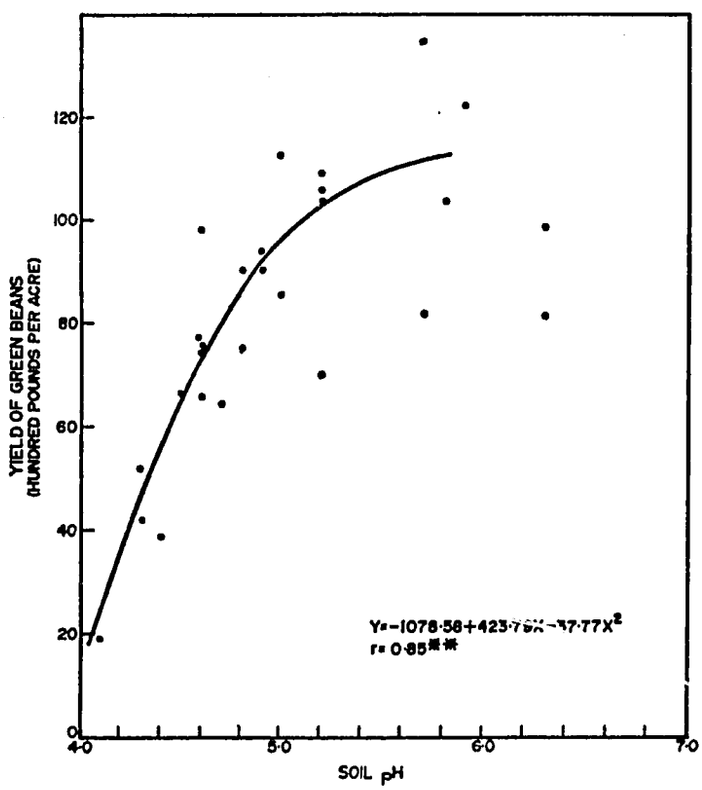

FIG. 7.—Relationship between yields of green beans and pH of a Corozal clay.

determining the need for liming for bean production on the typical Oxisols and Ultisols of the Humid Tropics. To obtain high bean yields, the soils should be limed to about pH 5.2 or 70-percent base saturation based on total exchange capacities determined with ammonium acetate, at which level these soils contain essentially no exchangeable aluminum and little manganese.

Abruña et al. (5) using combined data for these soils found that pH values increased from about 3.8 with a base saturation of about 20 percent to

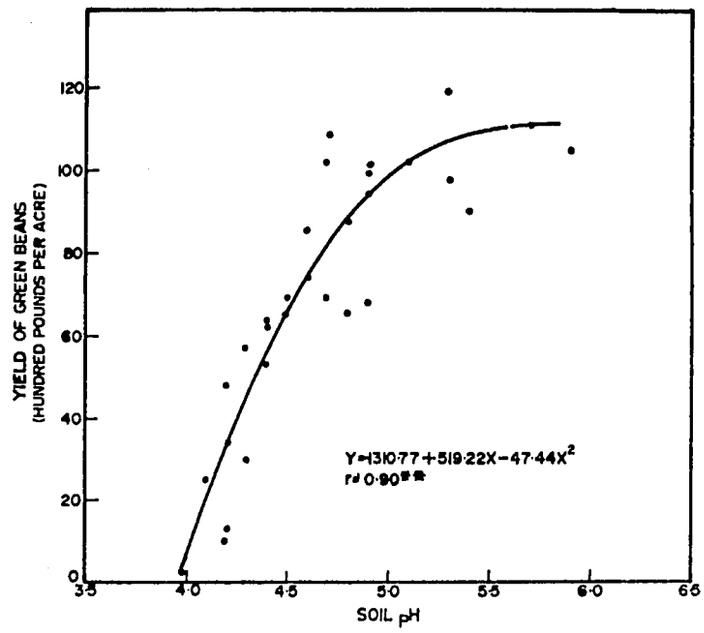

FIG. 8.—Relationship between yields of green beans and pH of a Corozal subsoil.

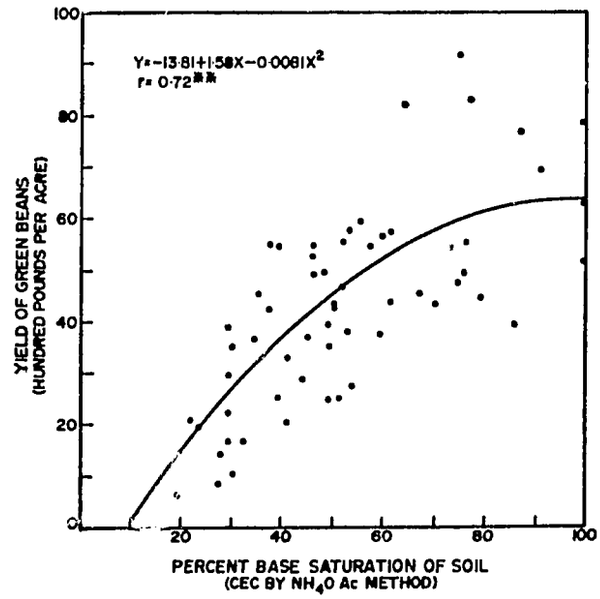

FIG. 9.—Relationship between yields of green beans and percent base saturation of a Humatas clay at Orocovis.

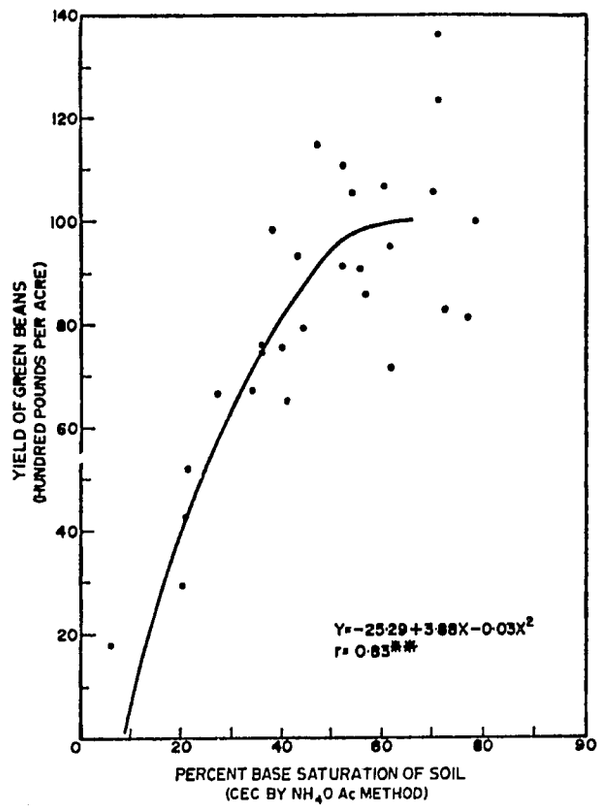

FIG. 10.—Relationship between yields of green beans and percent base saturation of a Corozal clay.

about pH 5.0 with a base saturation of about 70 percent based on cation exchange capacities determined by extraction with ammonium acetate.

The low pH values in relationship to exchangeable base content of these soils is explained by the probable presence of free salts resulting from heavy fertilization.

These authors also showed that the level of aluminum saturation in these soils, based on total exchange capacities determined with ammonium acetate, decreased from about 40 percent at pH values of about 3.9 to essentially no exchangeable Al at pH's of about 5.2. Thus, by liming to about pH 5.2, equivalent to around 70-percent base saturation, exchangeable aluminum and manganese contents of these soils was reduced to non-toxic levels.

These authors showed further that with these soils there is a very close

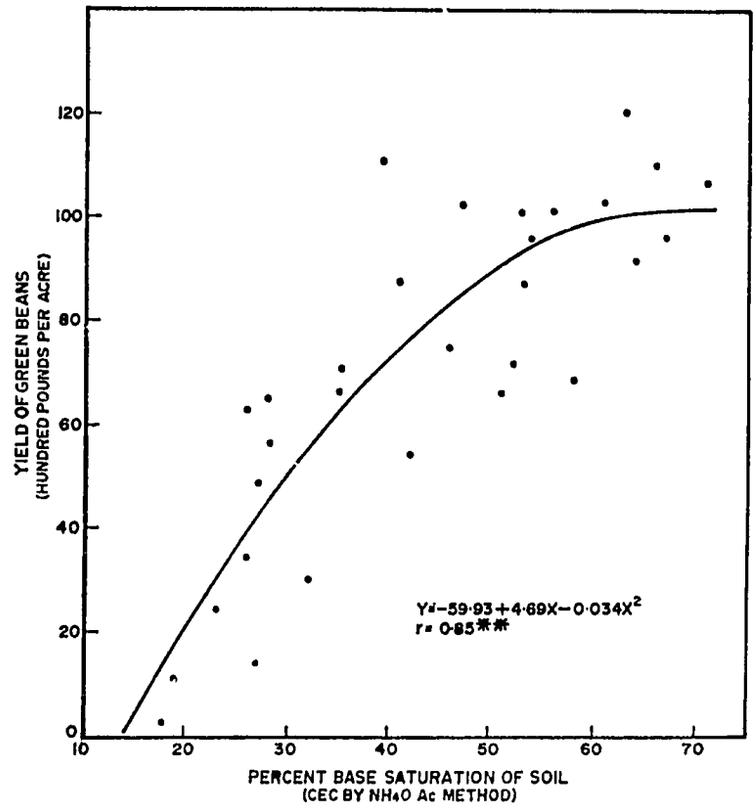

FIG. 11.—Relationship between yields of green beans and percent base saturation of a Corozal subsoil.

relationship between both percent exchangeable aluminum and percent exchangeable base content based on cation exchange capacities determined by either sum of cations at a given pH or with ammonium acetate at pH 7. Through this relationship, values based on either method of determining cation exchange capacity can be accurately converted to the other.

SUMMARY

The effect of soil acidity factors on yields and foliar composition of intensively managed green beans was determined in Ultisols and an Oxisol typical of the Humid Tropics.

Beans responded very strongly to liming on all six soils. Calcium content of the bean leaves increased and manganese content decreased with increasing lime rates and with yields.

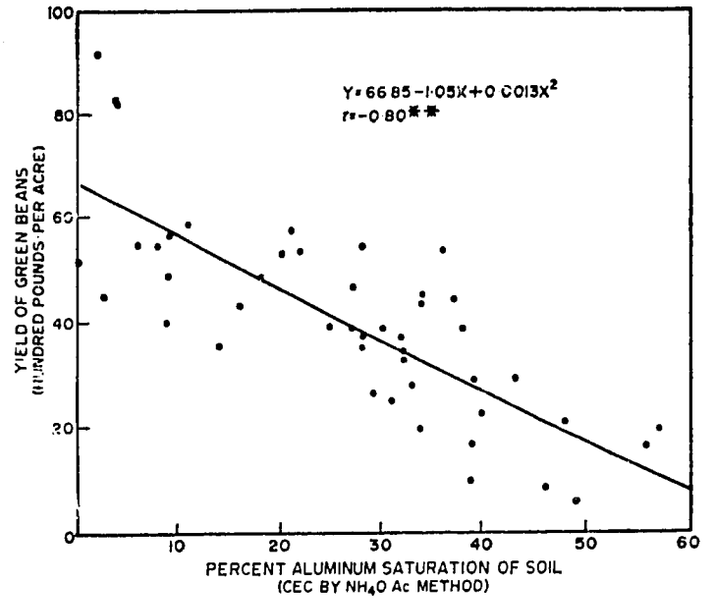

FIG. 12.—Relationship between yields of green beans and percent aluminum saturation of a Humatas clay at Orocovis.

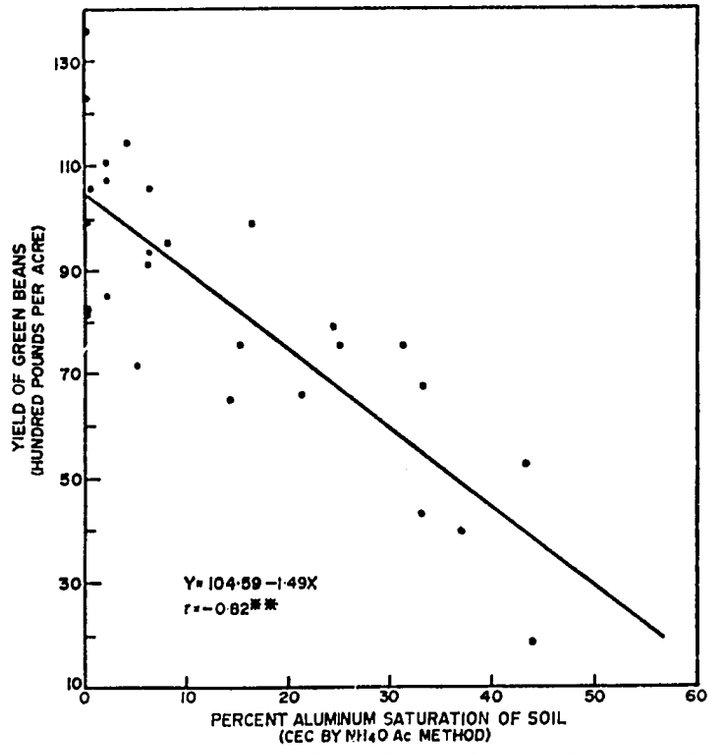

FIG. 13.—Relationship between yields of green beans and percent aluminum saturation of a Corozal clay.

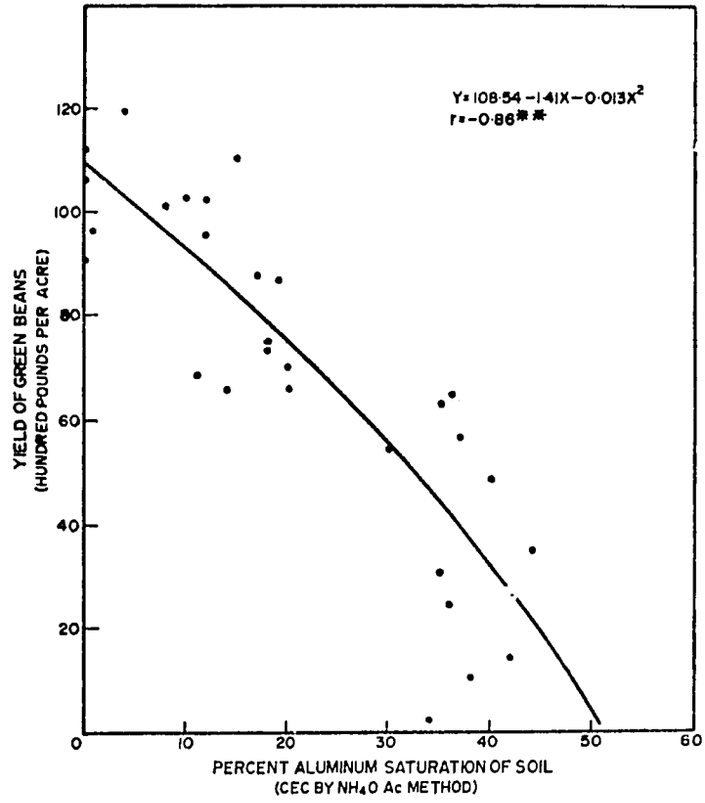

FIG. 14.—Relationship between yields of green beans and percent aluminum saturation of a Corozal subsoil.

Bean yields increased with increasing soil pH to about 5.2 at which level these soils contained essentially no exchangeable aluminum.

Bean yields increased with increasing exchangeable soil base content to about 70-percent saturation based on cation exchange capacities as determined with ammonium acetate at pH 7.

Bean yields increased with decreasing exchangeable soil aluminum to essentially 0.

Soil pH and exchangeable base and aluminum contents were effective criteria for liming these soils.

RESUMEN

Se determinó el efecto de distintos factores asociados con la acidez en Ultisols y un Oxisol típicos de extensas regiones de los Trópicos Húmedos, en la producción y composición foliar de las habichuelas.

Las habichuelas respondieron al encalado en experimentos de campo realizados en seis suelos. El contenido de calcio en las hojas de las habichuelas aumentó y su contenido de manganeso disminuyó con el nivel de cal y la producción de habichuelas.

La producción de habichuelas aumentó con el pH hasta aproximadamente 5.2, a cuyo nivel esto suelos apenas contenían aluminio intercambiable.

La producción de habichuelas aumentó con el contenido de bases intercambiables hasta alcanzar un 70 por ciento de saturación basado en la capacidad total de cambio, determinado ésta con acetato amónico a pH 7.0.

La producción de habichuelas aumentó según disminuyó el aluminio intercambiable en el suelo, lográndose la mayor producción cuando el valor de aquél fue approximadamente 0.

El pH y el contenido de bases y de aluminio intercambiables en el suelo constituyeron criterios adecuados para determinar la necesidad de encalar estos suelos, típicos de regiones extensas en los Trópicos Húmedos para la producción de habichuelas.

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Response of Corn to Acidity Factors in Eight Tropical Soils[1,2]

Fernando Abruña, Raúl Pérez-Escolar, José Vicente-Chandler, Robert W. Pearson, and Servando Silva[3]

INTRODUCTION

Major factors causing low crop yields in much of the Humid Tropics, where lies the world's greatest potential for increased food production, are associated with high soil acidity such as toxic concentrations of aluminum and manganese, deficiencies of calcium and magnesium, and fixation of phosphorus. Little information is available, however, on the specific factors of acid soil infertility influencing yield and composition of tropical crops grown under intensive management.

The natural high acidity of the Ultisols and Oxisols which prevail in much of the Humid Tropics can be increased rapidly by heavy fertilization with residually acid fertilizers. For example, Abruña et al. (1) found that the application of 800 pounds of nitrogen as ammonium sulfate per acre yearly over a 2-year period sharply increased acidity and loss of bases in typical soils of the humid region of Puerto Rico.

Under these conditions, the response of crops to liming can be very strong. In Puerto Rico, Abruña et al. (4) found that yields of heavily fertilized Napier grass growing on an acid Ultisol were doubled by liming. Abruña and Vicente-Chandler (2) found that yields of heavily fertilized sugarcane growing on a typical Ultisol increased from 1 to 47 tons per acre yearly with increasing exchangeable base and decreasing exchangeable aluminum content of the soil but that foliar composition of the cane was not affected. Abruña et al. (3) reported that intensively managed coffee responded strongly to liming on acid soils high in manganese but did well at very high acidity and exchangeable aluminum levels in soils low in manganese. Abruña et al. (5) found that tobacco responded strongly to liming on 3 Ultisols and an Oxisol and that response was closely related to the exchangeable aluminum and manganese content of the soils.

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[3] Soil Scientist, ARS, USDA, Soil Scientist, Agricultural Experiment Station, and Soil Scientists and Agricultural Technican, ARS, USDA, respectively.

The present study determined the effect of various factors associated with soil acidity on yields and foliar composition of corn grown on eight Ultisols and Oxisols typical of the Humid Tropics.

MATERIALS AND METHODS

Field experiments were conducted with corn grown on the eight soils the main characteristics of which are shown in table 1.

Experimental sites were divided into from 30 to 60 plots of 12 feet × 12 feet each, arranged in a completely randomized design. Increments of

TABLE 1.—*Characteristics of the soils at the various experimental sites*

Soil type	Location	Classification	Origin	Organic matter content	Cation exchange capacity	Bulk density of undisturbed soil
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Los Guineos clay	Jayuya	Epiaquic tropohumults	Tuffaceous material	8.1	16.0	1.1
Corozal clay (level)	Corozal	Aquic tropudult	Tuffaceous material	4.7	19.0	1.2
Piña loamy sand	Manatí	Typic haplorthox	Quartzitic sand deposits	0.5	1.3	1.3
Catalina clay	Barranquitas	Typic haplorthox	Andesitic tuffs	2.3	11	1.0

limestone were added as required to provide a wide range in soil acidity and percent base saturation. The limestone was thoroughly worked into and mixed with the upper 6 inches of soil.

The soil in all experimental plots was sampled 6 months after liming to determine its acidity status. Twelve cores were taken in each plot at 0 to 6-inch depths, composited, air dried, and screened through a 20-mesh sieve. Cation-exchange capacity was determined by both the ammonium-acetate extraction procedure and by sum of cations. Calcium and magnesium were determined by the Versenate titration method using Calcein as calcium indicator and Calmagite as Ca-Mg indicator. Potassium was determined by flame photometry and manganese colorimetrically after oxidation with

periodate. Exchangeable aluminum was extracted with 1 *N* potassium chloride and determined by the aluminum method. Soil reaction was measured with a glass-electrode pH meter using a 1:1.5 soil-water suspension.

Corn of the hybrid Pioneer 306 variety from Jamaica was planted at 18 inches × 18 inches, fertilized with 150 pounds of nitrogen, 80 of phosphoric acid (P_2O_5), 150 of potash (K_2O), 50 of magnesium, and 30 of zinc per acre and protected against insects by periodic spraying.

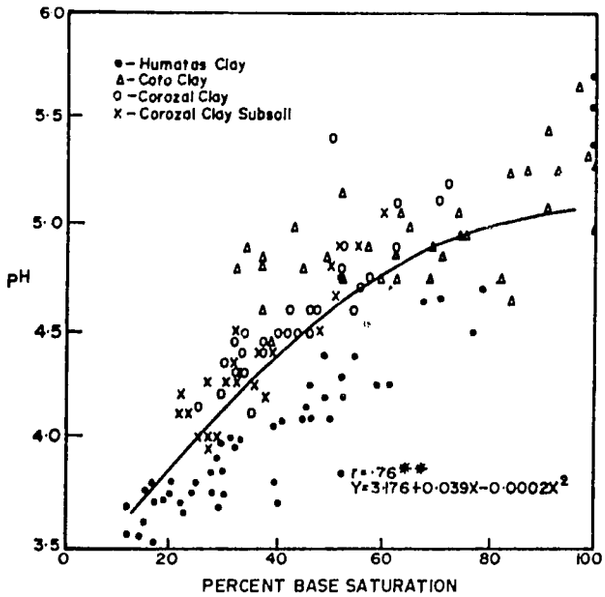

FIG. 1.—Relationship between pH and percent base saturation based on cation exchange capacities determined by the ammonium acetate method of three typical Ultisols and an Oxisol of the Humid Tropics.

Leaf samples were taken in each plot just before tasseling and analyzed for P, K, Ca, Mg, and Mn using standard procedures.

Yields of corn produced by each plot were determined and related by regression analysis to soil pH, exchangeable aluminum and exchangeable bases, and to foliar composition of the corn plant.

RESULTS AND DISCUSSION

Data for four soils combined show that pH values increased from about 3.8 with a base saturation of about 20-percent to about pH 5.0 with a base saturation of around 70-percent based on cation exchange capacity determined by extraction with N-neutral ammonium acetate (fig. 1). The low

pH values in relation to exchangeable base content of these soils is explained by the probable presence of free salts resulting from heavy fertilization causing displacement of exchangeable aluminum which hydrolyzes to produce an acid reaction.

Figure 2 shows that the level of Al saturation based on exchange capacity determined with ammonium acetate decreased from about 40 percent at about pH 3.9 to 0 at pH values of around 5.2. Thus, by liming to about pH 5.0, equivalent to around 70 percent base saturation, exchange-

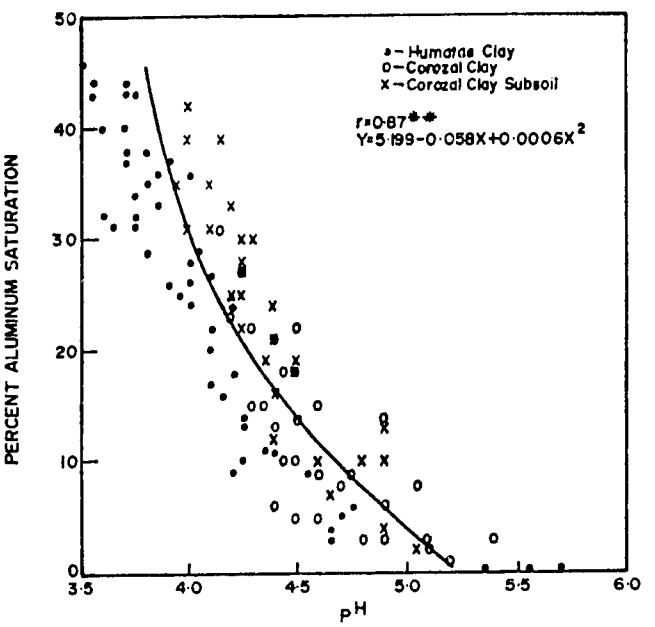

FIG. 2.—Relationship between pH and percent aluminum saturation based on cation exchange capacities determined by the ammonium acetate method of three typical Ultisols of the Humid Tropics.

able aluminum content of these soils was reduced to non-toxic levels. With Ultisols, a very close relationship between percent Al saturation and pH is indicated by the r value of 0.87.

Table 2 shows that the Humatas, Corozal, and Los Guineos clay soils (Ultisols) had a high content of exchangeable aluminum when acid. But the Oxisols (Coto sandy clay, Catalina clay and Piña loamy sandy), even when very acid, contained only traces of exchangeable aluminum, indicating a very advanced stage of weathering. Reeve and Sumner (7) reported no relationship exists between exchangeable aluminum and pH on Natal Oxisols. Unpublished data obtained by the authors show that the

TABLE 2.—*Effects of various soil acidity factors on yields and composition of corn growing on typical Ultisols and Oxisols under humic tropical conditions in Puerto Rico*

Soil properties				pH	Yields of corn (bu/acre)	Composition of corn leaves				
Percent aluminum saturation		Percent base saturation				Ca (percent)	Mg (percent)	P (percent)	K (percent)	Mn (ppm)
NH_4OAC method	Summation of cations	NH_4OAC method	Summation of cations							
Humatas (planted May 18)										
0–9	0–14	60–79	86–100	5.3	83.8	0.57	0.11	0.36	2.00	
10–19	15–29	50–59	71–85	4.7	70.5	0.51	0.10	0.36	1.95	
20–29	30–44	40–49	56–70	4.5	65.3	0.49	0.12	0.37	1.89	
30–39	45–59	30–39	41–55	4.2	44.6	0.42	0.11	0.35	1.85	
40–59	60–74	20–29	26–40	3.9	18.4	0.36	0.11	0.34	1.78	
Corozal (topsoil) (planted March 5)										
0–10	0–19	60–79	81–100	5.4	66.5	0.48	0.10	0.46	1.37	
11–21	20–39	45–59	61–80	4.7	46.4	0.41	0.09	0.48	1.64	
22–32	40–59	30–44	41–60	4.6	35.5	0.41	0.09	0.49	1.66	
33–43	60–79	15–29	21–40	4.3	6.7	0.33	0.10	0.42	1.94	
Corozal (subsoil) (planted March 5)										
0–8	0–13	59–68	87–100	5.4	56.9	0.47	0.10	0.43	1.35	
9–17	14–27	49–58	73–86	4.8	40.7	0.41	0.10	0.43	1.68	
18–26	28–41	39–48	59–72	4.6	35.8	0.40	0.10	0.43	1.75	
27–35	42–55	29–38	45–58	4.3	15.1	0.33	0.11	0.37	1.75	
36–44	56–69	19–28	31–44	4.2	10.4	0.33	0.12	0.41	1.85	
Corozal (level) (planted July 2)										
0–9	0–12	84–100	88–100	5.2	60.5	0.31	0.10	0.47	2.03	92
10–19	13–25	67–83	75–87	4.7	50.0	0.28	0.12	0.45	2.13	98
20–29	26–38	50–66	62–74	4.6	37.4	0.28	0.07	0.47	2.16	97
Los Guineos (planted July 8)										
0–8	0–16	55–69	84–100	5.3	59.5	0.30	0.11	0.44	2.68	31
9–17	17–33	40–54	67–83	4.7	42.3	0.28	0.12	0.46	2.77	35
18–26	34–50	25–39	50–66	4.3	28.3	0.27	0.12	0.43	2.87	40

TABLE 2.—*Continued*

Soil properties				pH	Yields of corn (bu/acre)	Composition of corn leaves				
Percent aluminum saturation		Percent base saturation				Ca (percent)	Mg (percent)	P (percent)	K (percent)	Mn (ppm)
NH_4OAC method	Summation of cations	NH_4OAC method	Summation of cations							
Coto (Oxisol) (planted March 8)										
[1]	[1]		[1]							
—	—	88-98	—	5.4	74.6	0.44	0.09	0.20	1.81	59
—	—	77-87	—	4.8	67.0	0.40	0.09	0.20	1.82	80
—	—	66-76	—	4.8	67.0	0.40	0.09	0.18	1.84	104
—	—	55-65	—	4.4	65.8	0.38	0.10	0.21	1.85	92
—	—	44-54	—	4.2	63.0	0.38	0.08	0.18	1.95	116
Piñas (planted April 21)										
[1]	[1]		[1]							
—	—	76-88	—	5.5	44.5	0.58	0.16	0.44	2.00	80
—	—	63-75	—	4.8	47.2	0.55	0.15	0.42	1.90	103
—	—	50-62	—	4.7	44.0	0.48	0.14	0.45	2.06	121
—	—	37-49	—	4.6	27.2	0.41	0.15	0.42	1.96	114
Catalina[1] (Oxisol) (planted May 5)										
[1]	[1]		[1]							
—	—	80-89	—	5.6	73.0	0.33	0.10	0.43	2.23	74
—	—	70-79	—	5.3	82.1	0.33	0.08	0.42	2.14	86
—	—	60-69	—	5.2	78.9	0.30	0.08	0.41	2.07	66
—	—	50-59	—	4.8	70.1	0.29	0.09	0.42	2.12	104

[1] No exchangeable aluminum at acidity levels studied.

Oxisols of Puerto Rico rarely contain much aluminum but can have rather high contents of exchangeable and easily reducible manganese. Ultisols in Puerto Rico, however, rarely are high in exchangeable or easily reducible manganese but are high in exchangeable aluminum when acid.

In the Ultisols, there is a close correlation between aluminum and base saturation values based on cation exchange capacities determined either by sum of cations or by N ammonium acetate at pH 7.0 (figs. 3 and 4). Thus with these soils cation exchange capacity values determined with NH_4OAC, a widely used value, can be converted to cation exchange values determined by sum of cations extracted with an unbuffered salt (6). Such a relationship does not exist with the Oxisols (Coto, Piñas and Catalina)

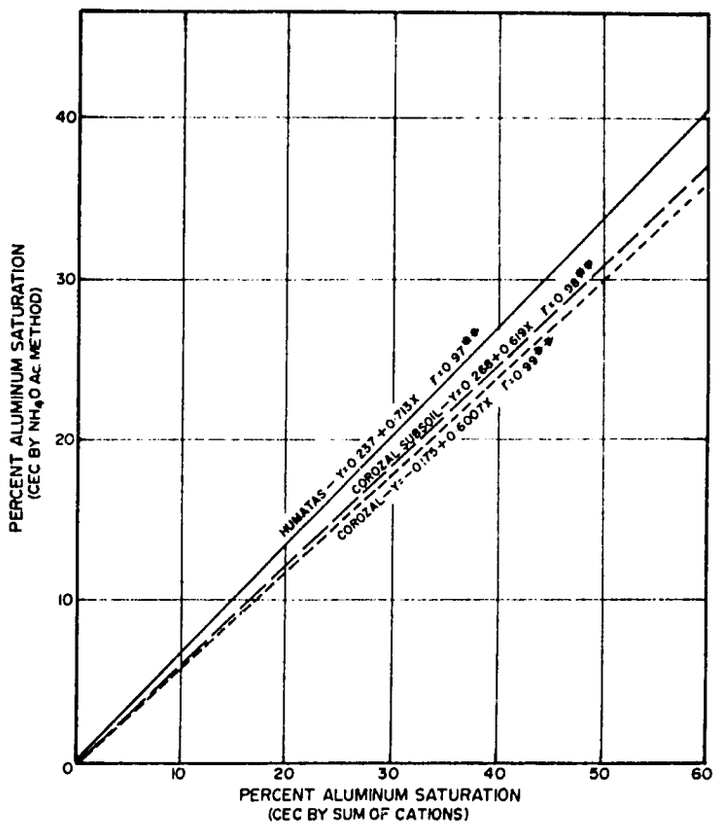

FIG. 3.—Relationship between percent aluminum saturation as determined by two methods on two typical Ultisols.

which contain only traces of exchangeable Al. Reeve and Sumner (7) working with Oxisols from Natal conclude these soils contain small amounts of exchangeable aluminum but large amounts of aluminum extractable with NH_4OAC at pH 4.0.

Despite the lack of a higher yielding hybrid, rather high yields of corn were obtained in all the experiments when the soil was properly limed (table 2 and fig. 5). Highest yields at the various sites ranged from 44.5 bushels per acre on Piñas sand where moisture was frequently limiting, to 83.8 bushels on the steep Humatas clay, with yields on the other soils generally ranging from 60 to 70 bushels or so per acre.

Figure 5 and table 2 show the large increases in corn yields resulting from liming, particularly on the Ultisols. The response of corn to liming on Humatas clay is illustrated dramatically in figure 6.

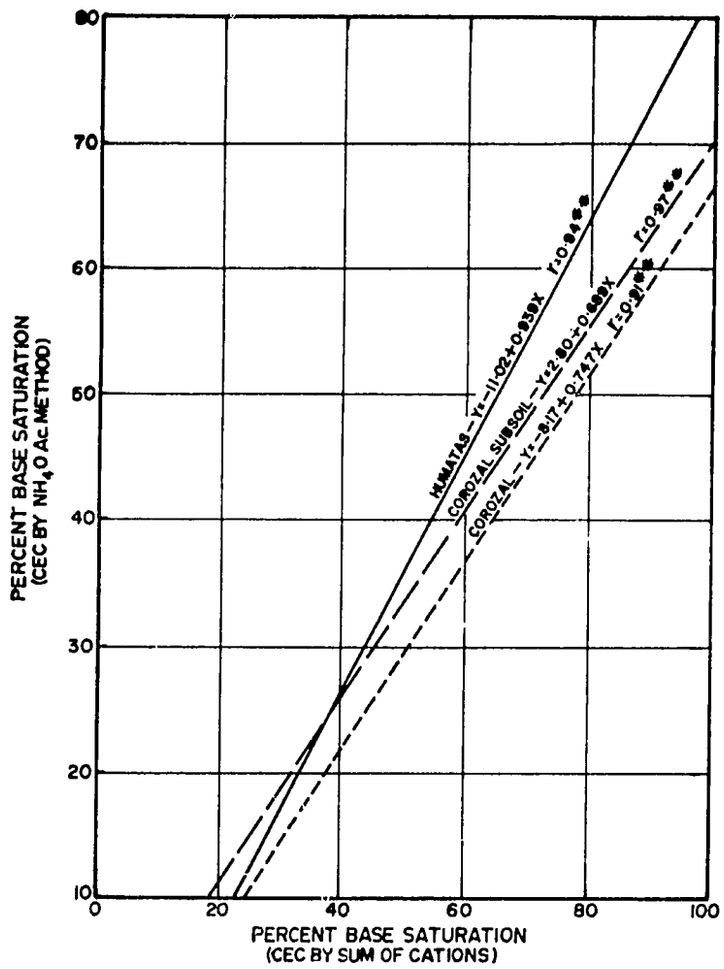

FIG. 4.—Relationship between percent base saturation as determined by two methods on two typical Ultisols.

Calcium content of the corn leaves increased with yields and with soil base content, i.e., lime rates, on all soils (table 2). The relationship between corn yields and calcium content of the leaves was particularly close on Humatas and on Corozal soil and subsoil as shown in figures 7, 8 and 9.

Magnesium, phosphorus, potassium, or manganese content of the corn leaves were not affected by liming (table 2). Magnesium content generally was low while phosphorus content generally was high on all soils except Coto. Contents generally were within normal ranges in most instances.

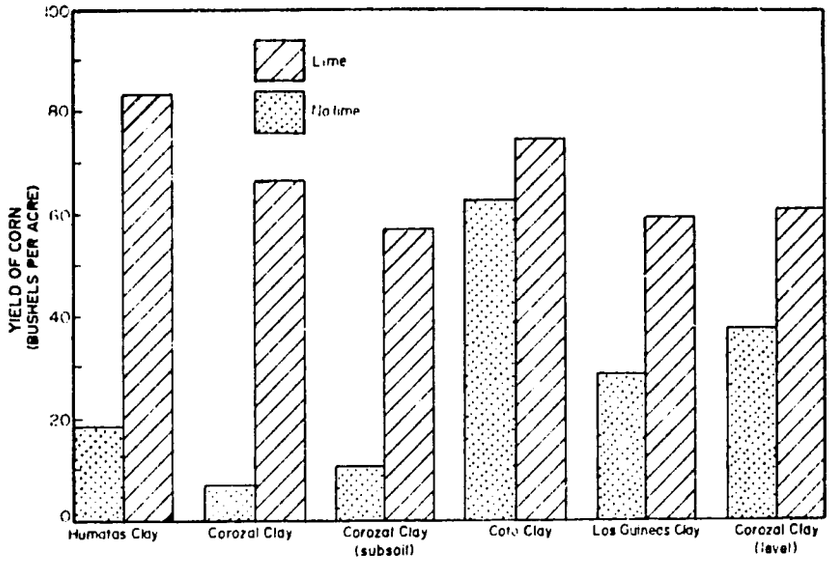

FIG. 5. Effect of liming on yields of corn growing on five typical Ultisols and one Oxisol under humid tropical conditions in Puerto Rico.

FIG. 6.—Effect of liming a very acid Ultisol (Humatas) clay at Orocovis on growth of otherwise intensively managed, well fertilized corn. Plot in foreground had a pH of 3.9 with 55-percent aluminum and 25-percent base (Ca + Mg) saturation of the exchange complex. Plot in background was limed to pH 5.3 with no exchangeable aluminum and 75-percent base saturation.

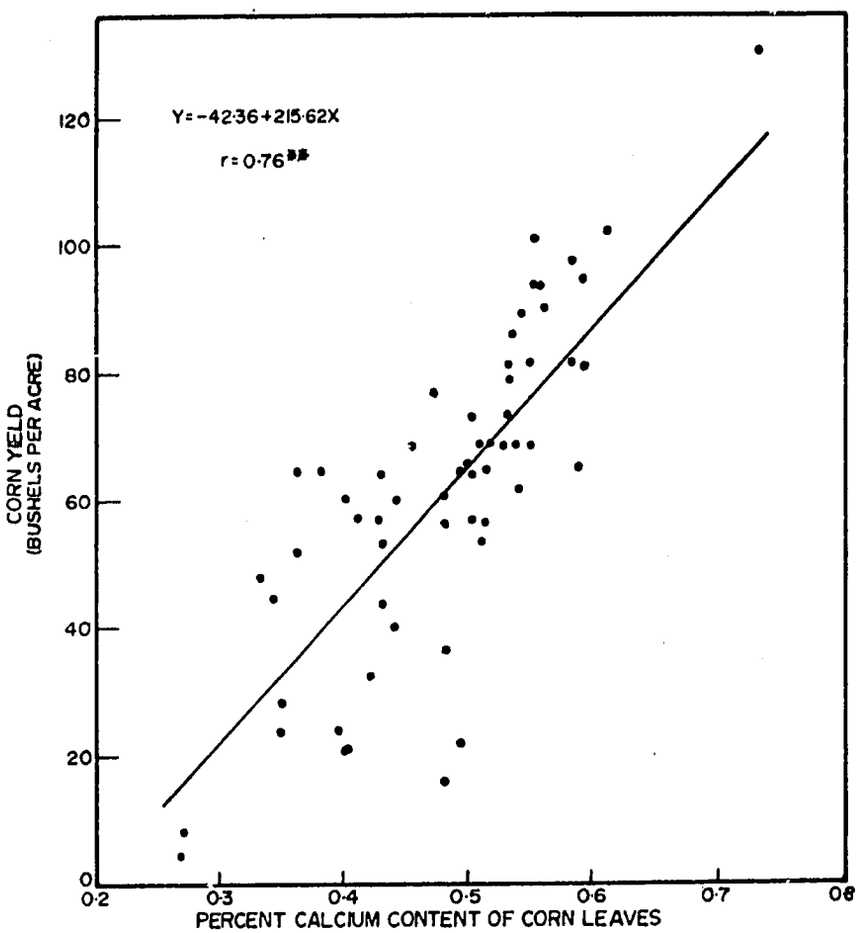

FIG. 7.—Relationship between yields and calcium content of leaves of corn growing on a Humatas clay at Orocovis.

The decrease in calcium content of the corn leaves with increasing aluminum saturation can be explained by the restrictive effect of aluminum on root development or there was less Ca in the soil solution in relation to Al ions. This relationship is not apparent with the other nutrients (P, K, Mg) the uptake of which by corn was not related to decreased aluminum in the soil. The much less marked uptake of calcium with increased liming on the Oxisols which contain essentially no exchangeable aluminum further suggests such a relationship.

On the Ultisols (Humatas, Corozal, and Los Guineos) which contained exchangeable aluminum, yields increased sharply with increasing pH to

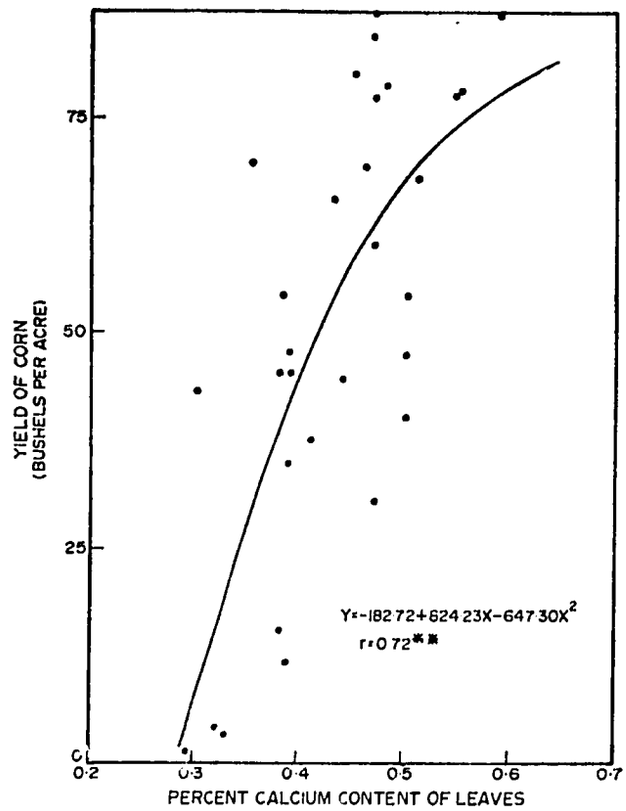

FIG. 8.—Relationship between yields and calcium content of corn growing on Corozal clay.

slightly above 5.0 (table 2 and figs. 10, 11 and 12). There is essentially no exchangeable aluminum in these soils (fig. 2) at such pH levels.

On these soils, corn yields generally increased with increased exchangeable base content as determined with ammonium acetate to about the 70-percent level (table 2 and figs. 13, 14, and 15) or to levels approaching 100-percent base saturation determined by the sum of cations at the various pH levels (table 2).

Yields of corn growing on the Ultisols increased with decreasing exchangeable aluminum content to essentially 0 (table 2 and figs. 16, 17, and 18). On Humatas and on Corozal soil and subsoil almost no corn was produced when percent exchangeable aluminum saturation based on cation exchange capacity determined with ammonium acetate exceeded 40-percent or 60-percent when based on summation of bases.

On Oxisols, however, (Piñas, Coto, and Catalina) which contained essentially no exchangeable aluminum, corn responded much less to liming than on the Ultisols, thus indicating aluminum toxicity to be the main factor affecting response of corn to liming in these experiments.

On Oxisols, therefore, crops such as corn which are not sensitive to manganese toxicity can produce high yields with less lime than required

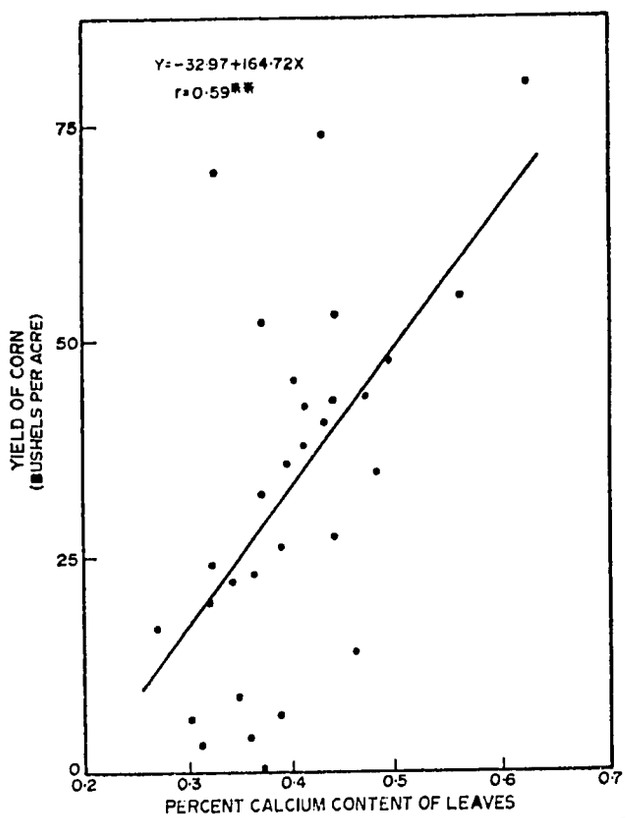

FIG. 9.—Relationship between yields and calcium content of leaves of corn growing on Corozal clay subsoil.

on Ultisols which have high exchangeable aluminum content at low pH's. Such is not the case with tobacco and coffee which are sensitive to high manganese levels in the soil as shown by Abruña et al. (3, 5).

The data presented in this paper show that exchangeable bases and aluminum provide excellent criteria for determining the need for liming for corn production on typical Oxisols and Ultisols of the Humid Tropics.

The data also show that near maximum yields of corn can be produced on these typical soils of the Humid Tropics by liming to about pH 5.2, or

to about 70-percent base saturation based on cation exchange capacities as determined with ammonium acetate, at which level the soils contain essentially no exchangeable aluminum.

SUMMARY

The effect of soil acidity factors was determined on yields and foliar composition of corn grown on Ultisols and Oxisols typical of the Humid Tropics.

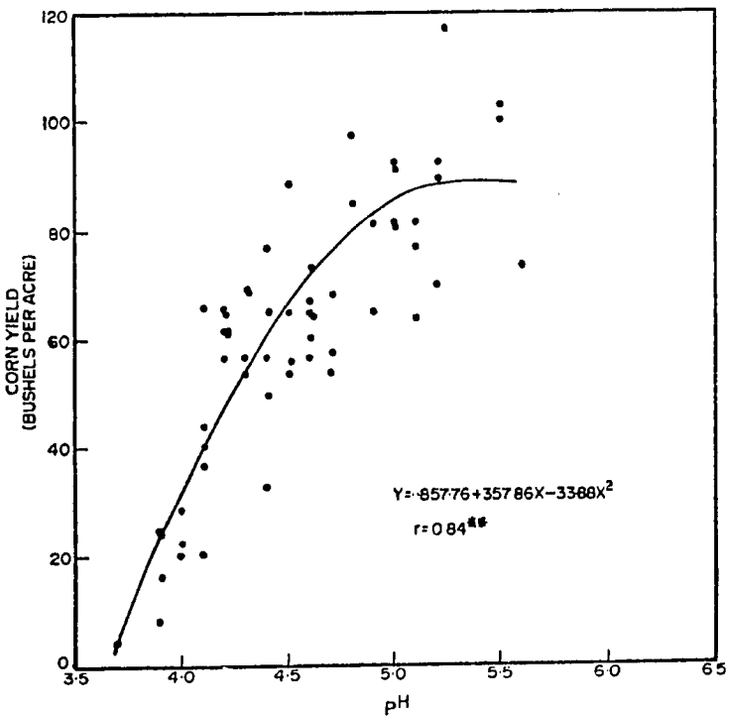

FIG. 10.—Relationship between corn yields and pH of a Humatas clay at Orocovis.

Soil pH values increased from about 3.8 with a base saturation of around 20 percent to about pH 5 with a base saturation of around 70 percent based on cation exchange capacities determined with neutral ammonium acetate. The low pH values in relation to exchangeable base contents are explained by the presence of free salts.

The level of aluminum saturation of the soil based on exchange capacities as determined with ammonium acetate decreased from 40-percent at about pH 3.9 to 0 at about pH 5.2.

The Ultisols had a high content of exchangeable aluminum when acid but the more weathered Oxisols contained little aluminum.

A very close relationship exists between exchangeable base (Ca + Mg) and aluminum values based on total exchange capacities determined either with ammonium acetate at pH 7.0 or by the sum of cations at a given pH permitting conversion of one value to another.

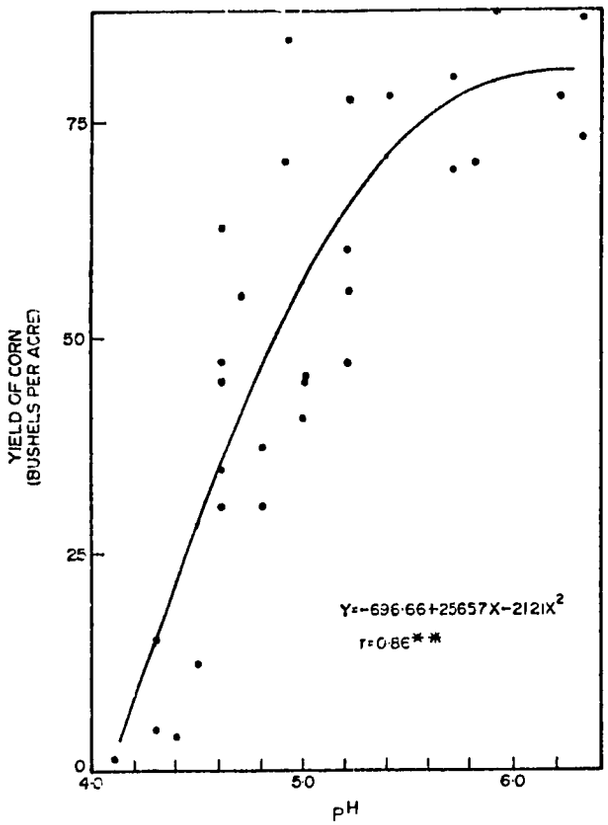

FIG. 11.—Relationship between corn yields and pH of a Corozal clay.

Corn responded strongly to liming particularly on the Ultisols which had high exchangeable aluminum content when acid.

Calcium content of the corn leaves increased with soil base content and with yields but foliar composition was not otherwise affected by liming.

Corn yields increased with pH to about 5.2 at which pH level these soils contained essentially no exchangeable aluminum, with exchangeable base content as determined with ammonium acetate to about the 70-percent

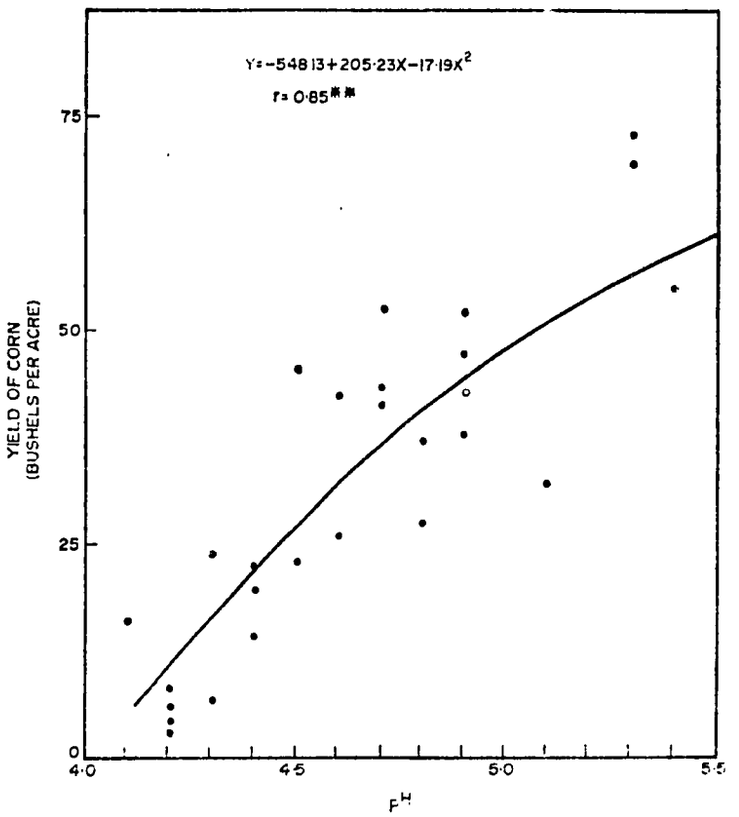

FIG. 12.—Relationship between corn yields and pH of a Corozal clay subsoil.

saturation level, and with decreasing exchangeable aluminum in the soil to essentially 0.

Soil pH, exchangeable base, and exchangeable aluminum content were effective criteria for liming these soils.

RESUMEN

Se estudió el efecto de distintos factores asociados con la acidez en ocho Ultisoles y Oxisoles típicos de los Trópicos Húmedos, sobre la producción y composición foliar del maíz.

El pH de los suelos aumentó de 3.8 con un contenido de bases intercambiables equivalente a un 20 por ciento de saturación a aproximadamente 5.0 con un 60 por ciento de bases intercambiables, a base de la capacidad de intercambio determinada ésta con acetato amónico normal neutral.

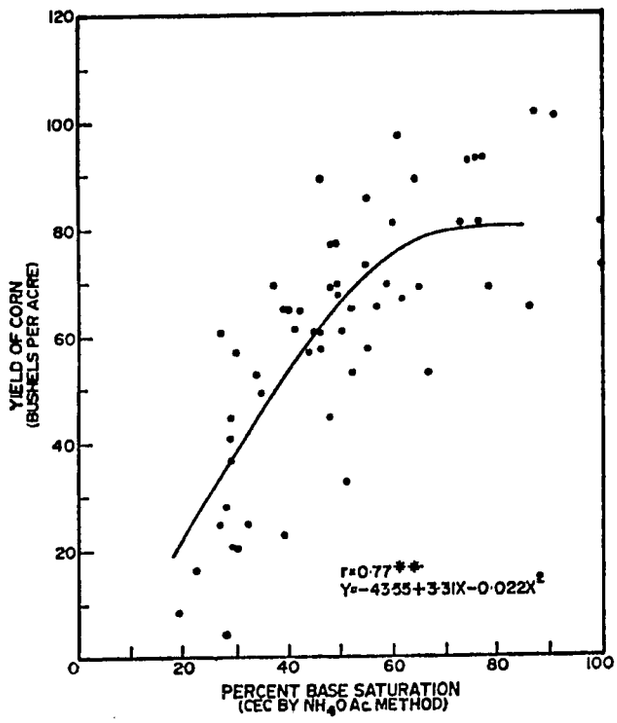

FIG. 13.—Relationship between yields of corn and percent base saturation of a Humatas clay.

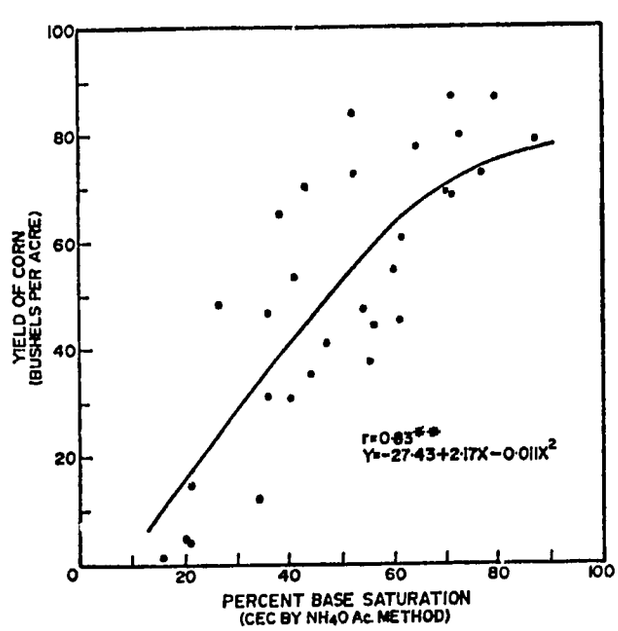

FIG. 14.—Relationship between yields of corn and percent base saturation of a Corozal clay.

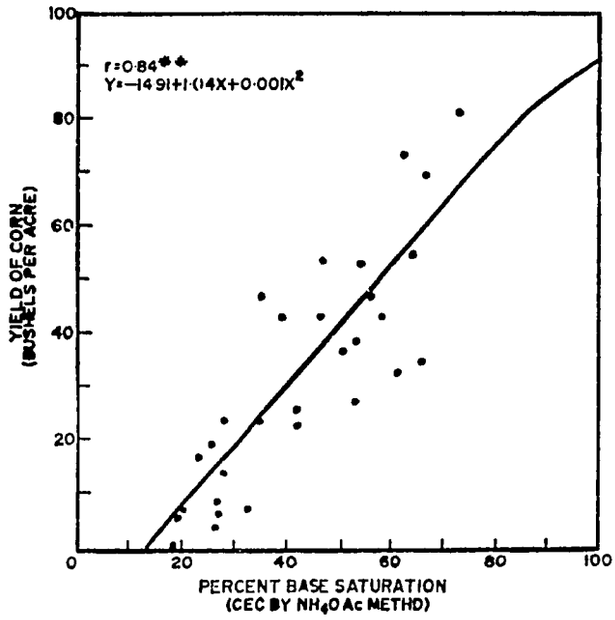

FIG. 15.—Relationship between yields of corn and percent base saturation of a Corozal clay subsoil.

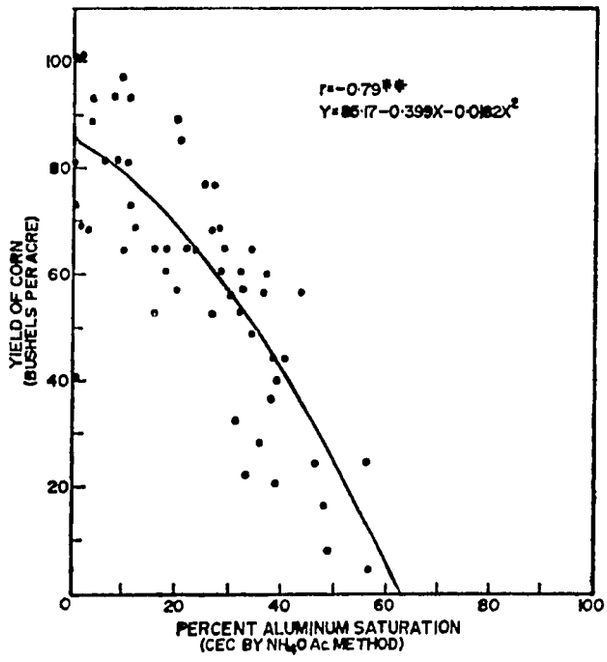

FIG. 16.—Relationship between yields of corn and percent aluminum saturation of a Humatas clay.

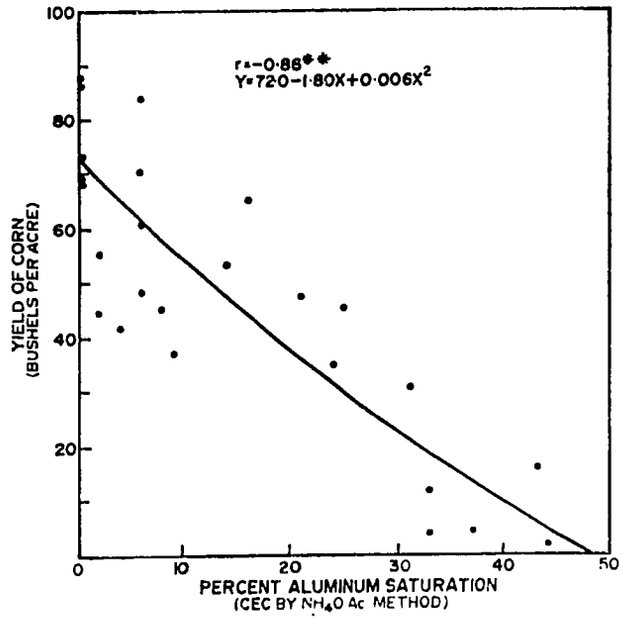

FIG. 17.—Relationship between yields of corn and percent aluminum saturation of a Corozal clay.

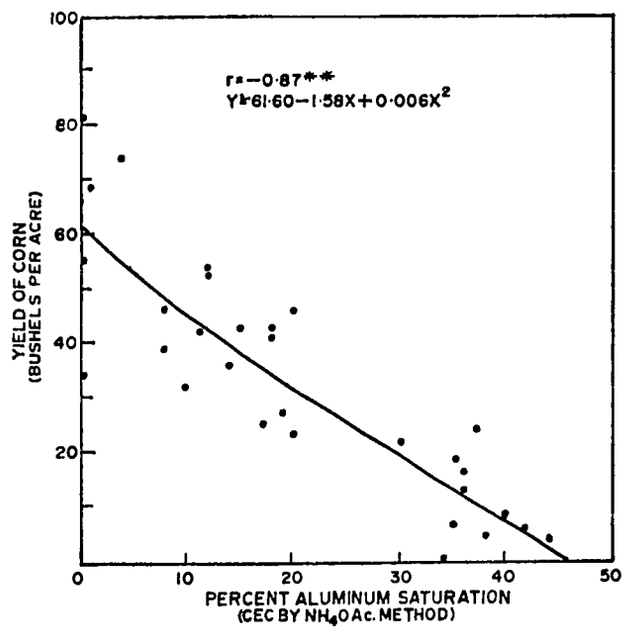

FIG. 18.—Relationship between yields of corn and percent aluminum saturation of a Corozal clay subsoil.

Los bajos niveles del pH en relación a las bases intercambiables se explican por la presencia de sales resultantes del abonamiento.

El contenido de calcio en las hojas de maíz aumentó con el contenido de bases intercambiables en el suelo y con la producción del grano, no así los demás constituyentes que permanecieron a niveles similares.

La producción de maíz aumentó al subir el pH del suelo hasta aproximadamente 5.2, a cuyo nivel de acidez los suelos apenas contenían aluminio intercambiable.

La producción de maíz aumentó con el contenido de bases intercambiables en los suelos hasta aproximadamente 70 por ciento de saturación, a base de la capacidad total de intercambio determinada con acetato amónico.

La producción de maíz aumentó según disminuyó el contenido de aluminio intercambiable en el suelo, lográndose la máxima producción cuando dicho contenido se aproximó a 0.

El pH así como el contenido de bases y de aluminio intercambiables en el suelo constituyeron criterios adecuados para determinar la necesidad de encalar estos suelos, típicos de regiones extensas en los Trópicos Húmedos, para la producción de maíz.

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