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

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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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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
				Percent	*Meq/100 g*	*G/cm*
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	16.0	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.

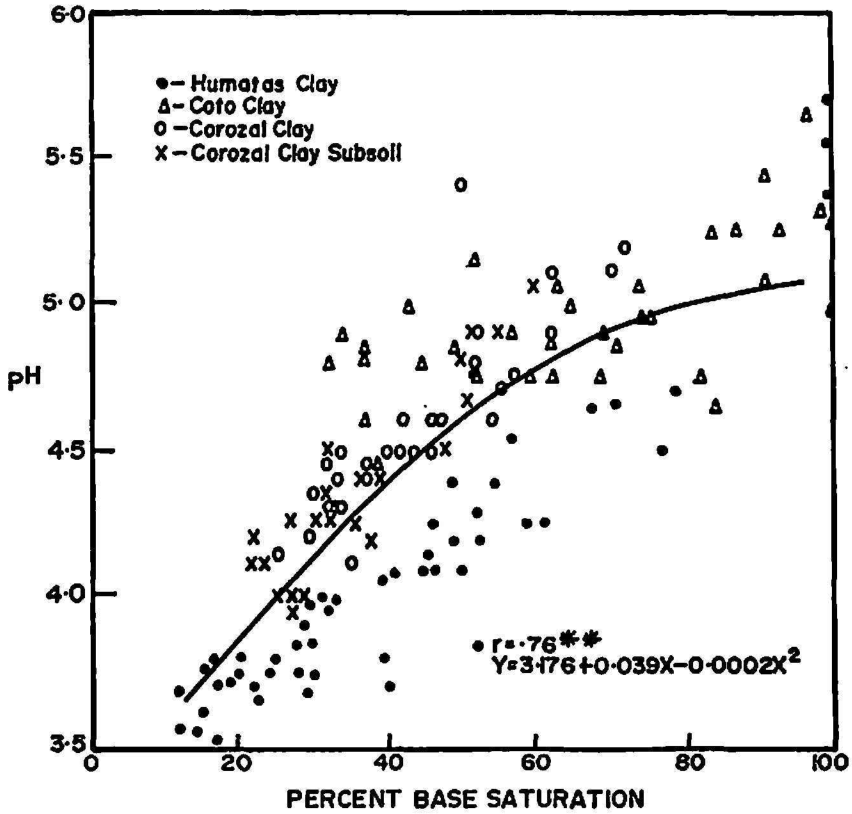

FIG. 1.—Relationship between pH and percent base saturation based on cation exchange capacities determined by the ammonium acetate method of three typical Ultisols and an Oxisol of the Humid Tropics.

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-

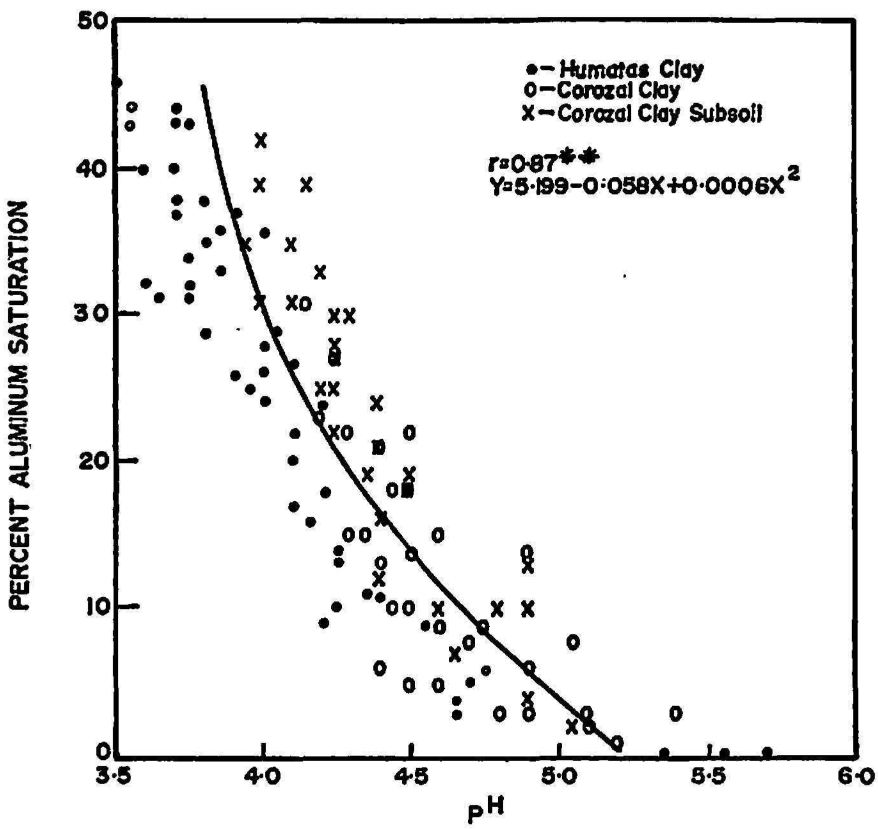

FIG. 2.—Relationship between pH and percent aluminum saturation based on cation exchange capacities determined by the ammonium acetate method of three typical Ultisols of the Humid Tropics.

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: Percent aluminum saturation, NH₄OAC method	Soil properties: Percent aluminum saturation, Summation of cations	Soil properties: Percent base saturation, NH₄OAC method	Soil properties: Percent base saturation, Summation of cations	pH	Yields of corn (bu/acre)	Composition of corn leaves: Ca (percent)	Mg (percent)	P (percent)	K (percent)	Mn (ppm)
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)

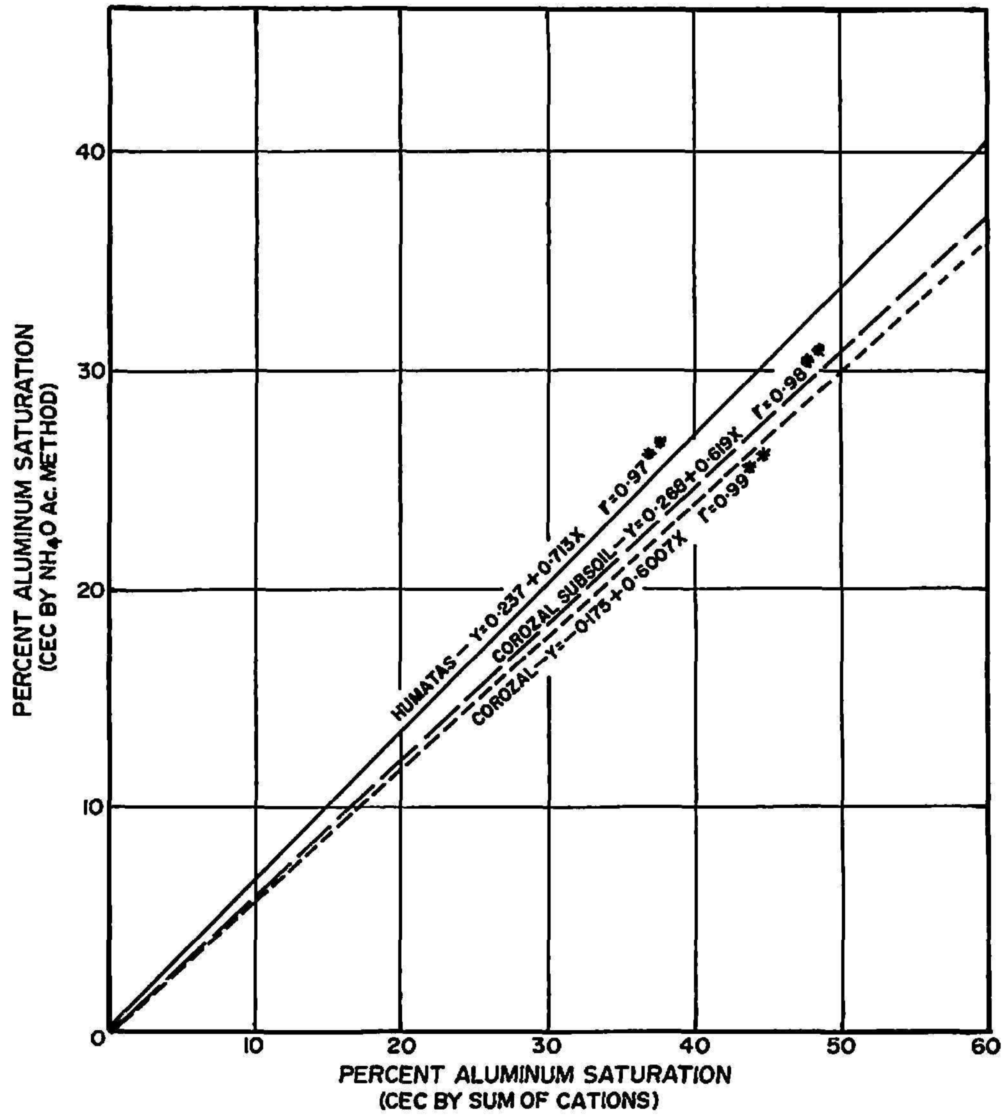

FIG. 3.—Relationship between percent aluminum saturation as determined by two methods on two typical Ultisols.

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.

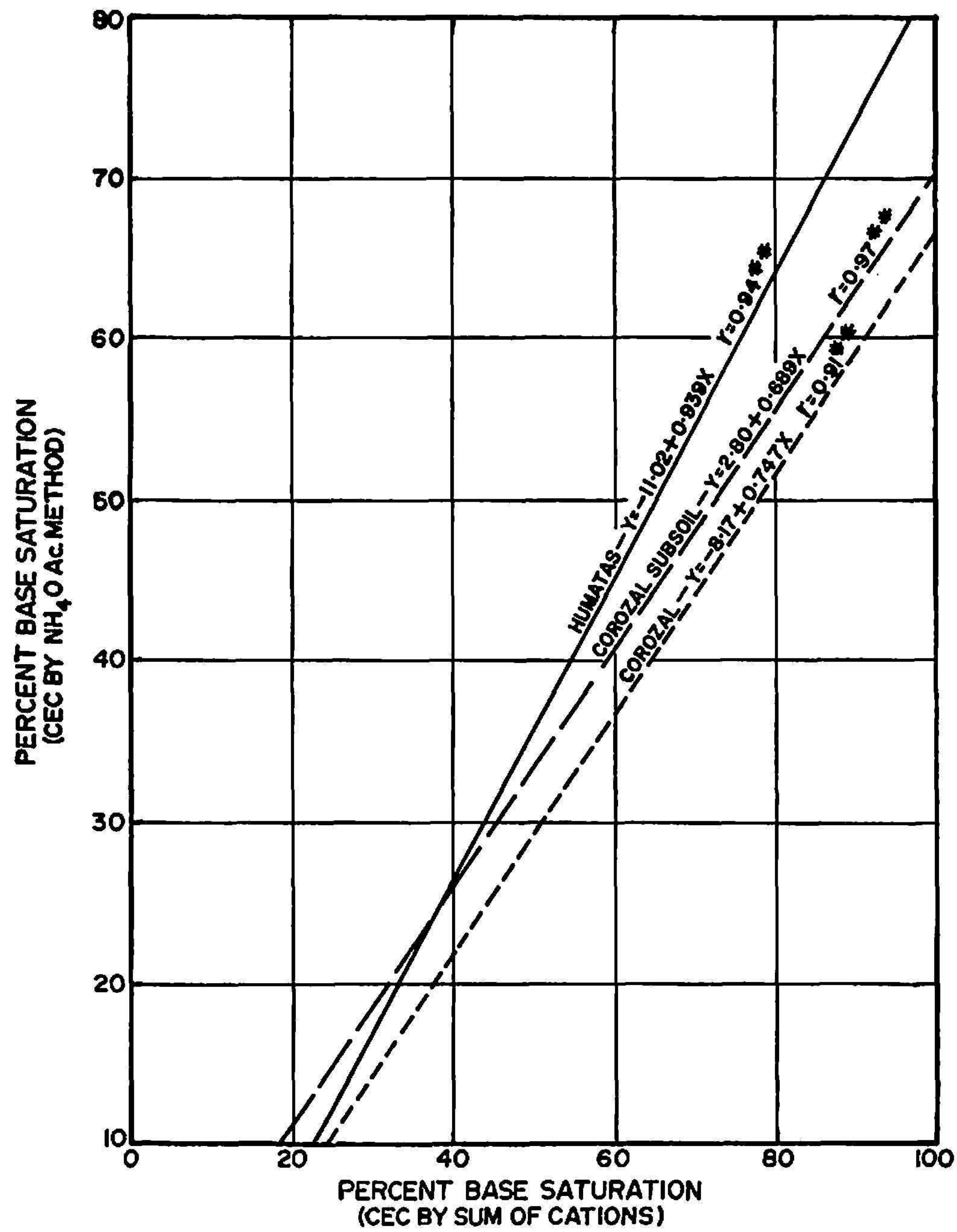

FIG. 4.—Relationship between percent base saturation as determined by two methods on two typical Ultisols.

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.

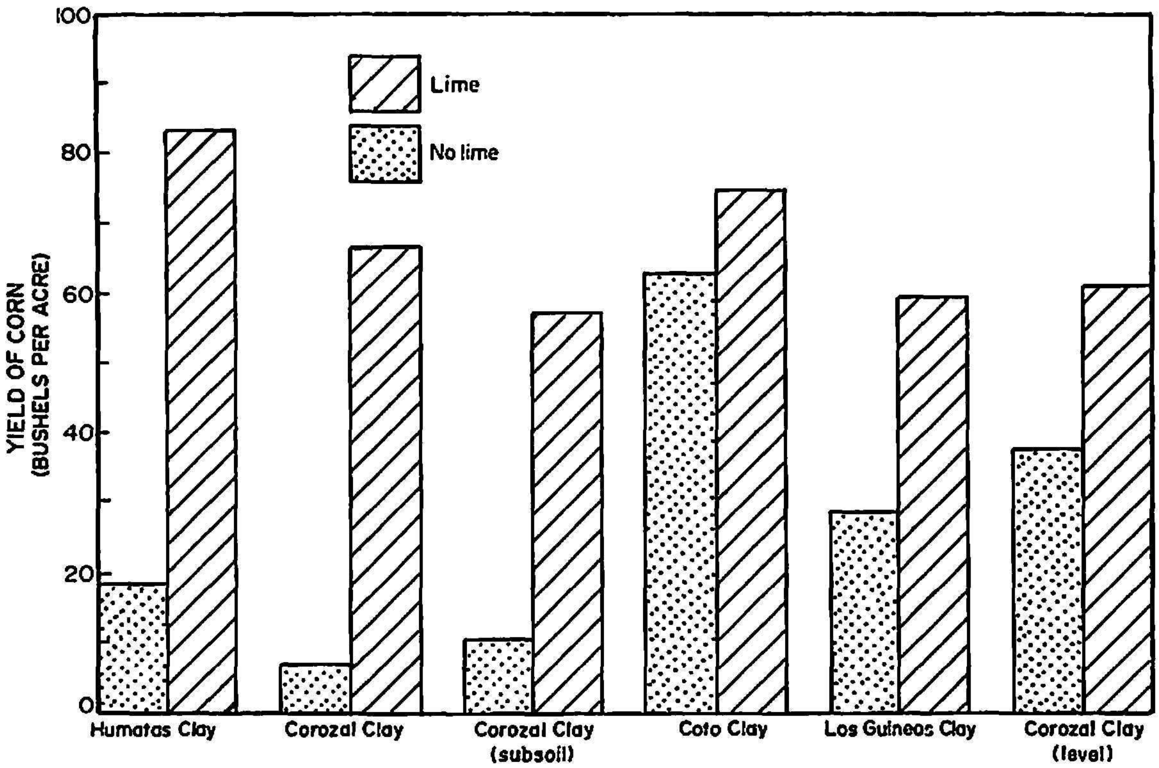

FIG. 5.—Effect of liming on yields of corn growing on five typical Ultisols and one Oxisol under humid tropical conditions in Puerto Rico.

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.

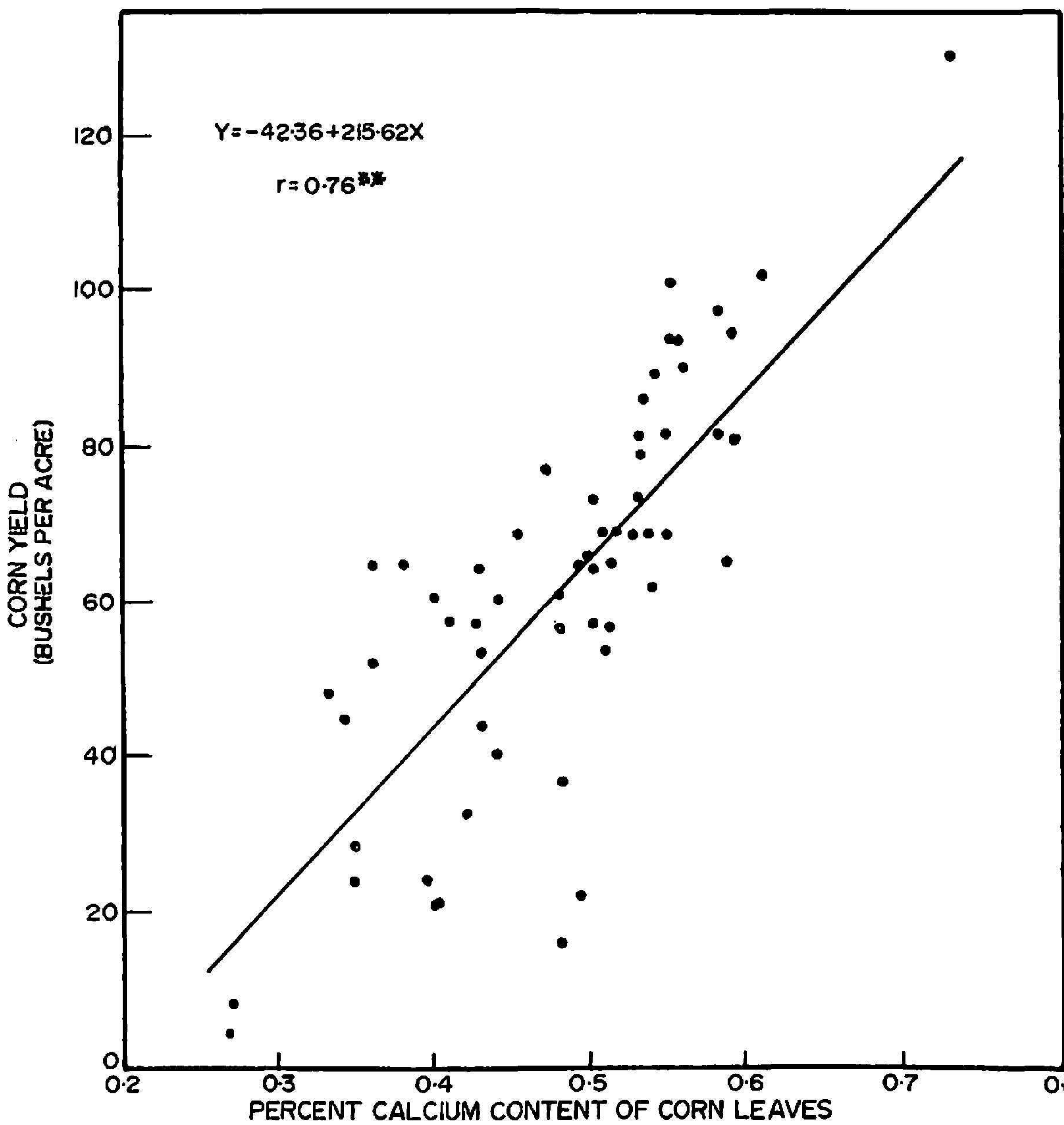

FIG. 7.—Relationship between yields and calcium content of leaves of corn growing on a Humatas clay at Orocovis.

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

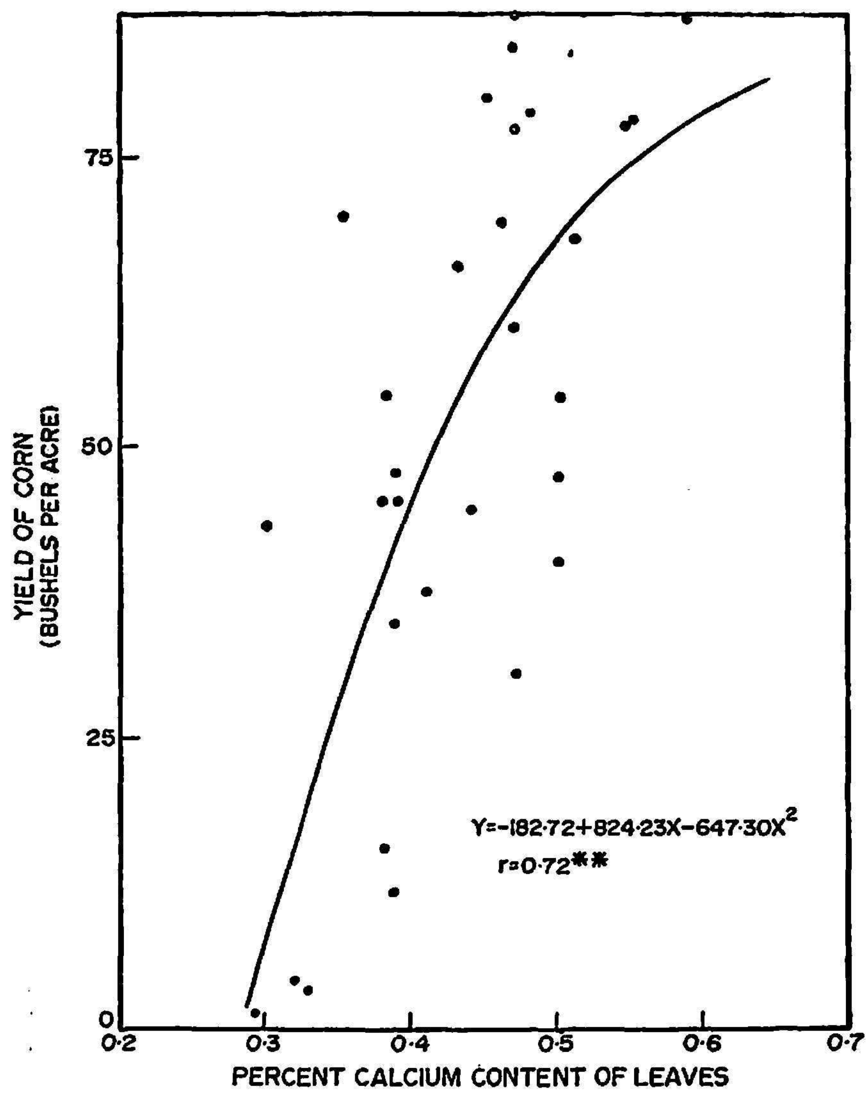

FIG. 8.—Relationship between yields and calcium content of corn growing on Corozal clay.

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

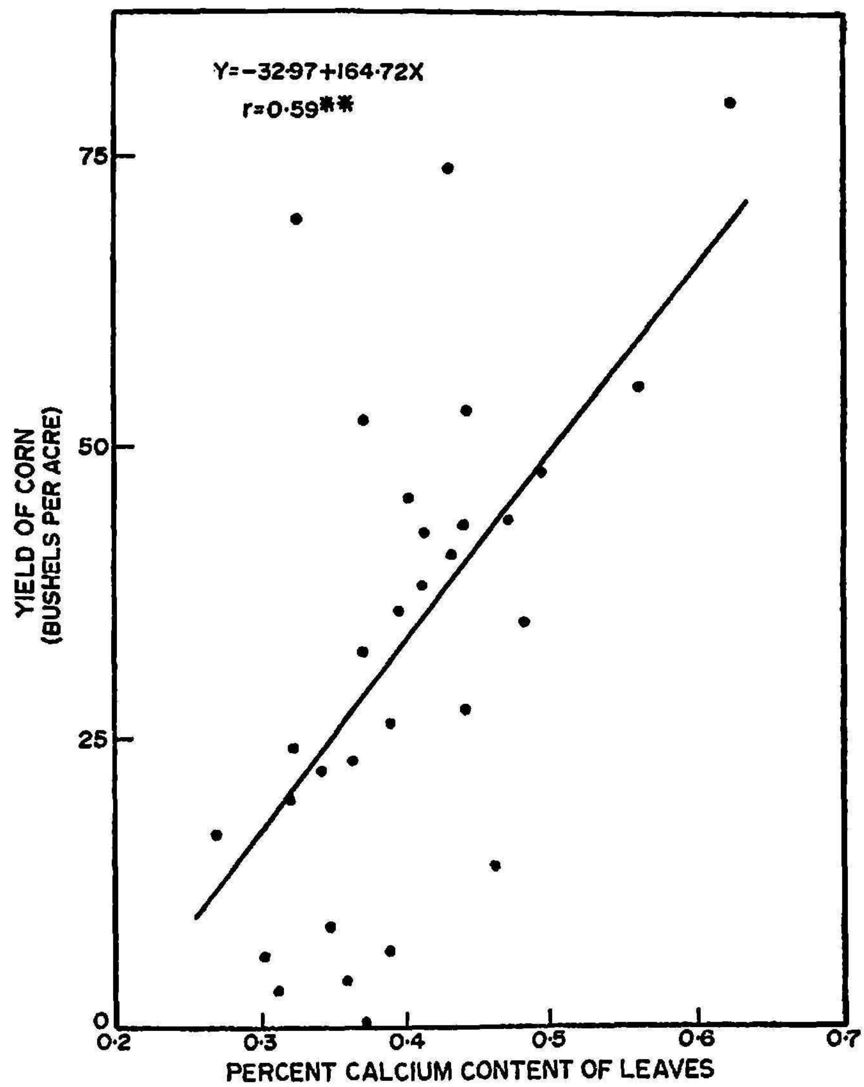

FIG. 9.—Relationship between yields and calcium content of leaves of corn growing on Corozal clay subsoil.

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.

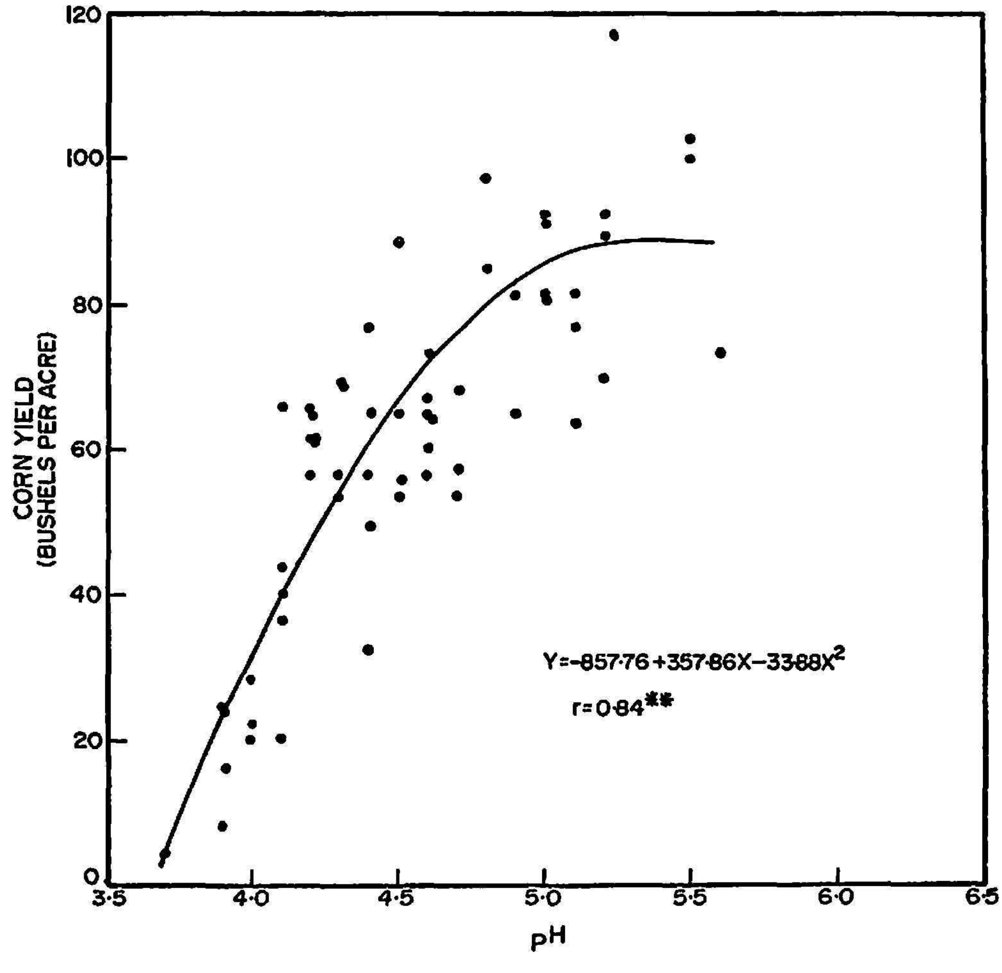

FIG. 10.—Relationship between corn yields and pH of a Humatas clay at Orocovis.

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.

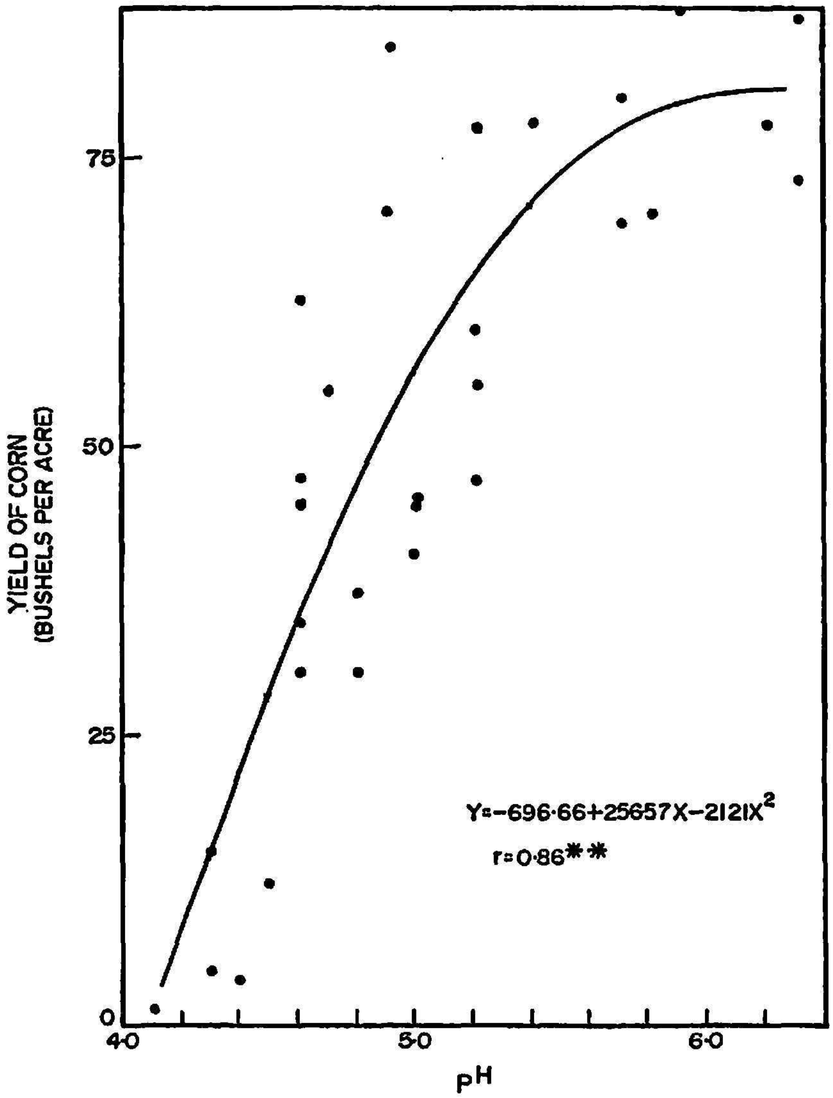

FIG. 11.—Relationship between corn yields and pH of a Corozal clay.

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

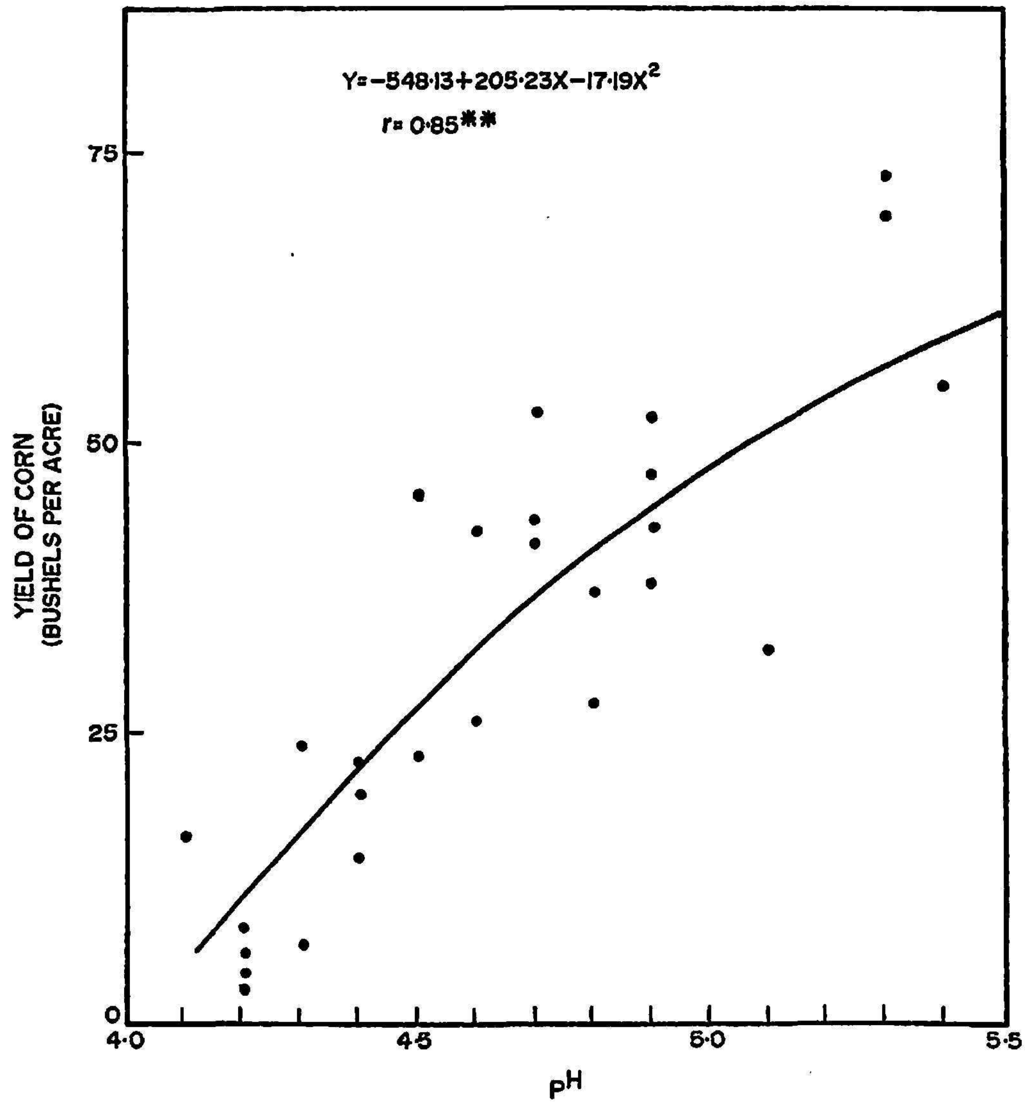

FIG. 12.—Relationship between corn yields and pH of a Corozal clay subsoil.

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.

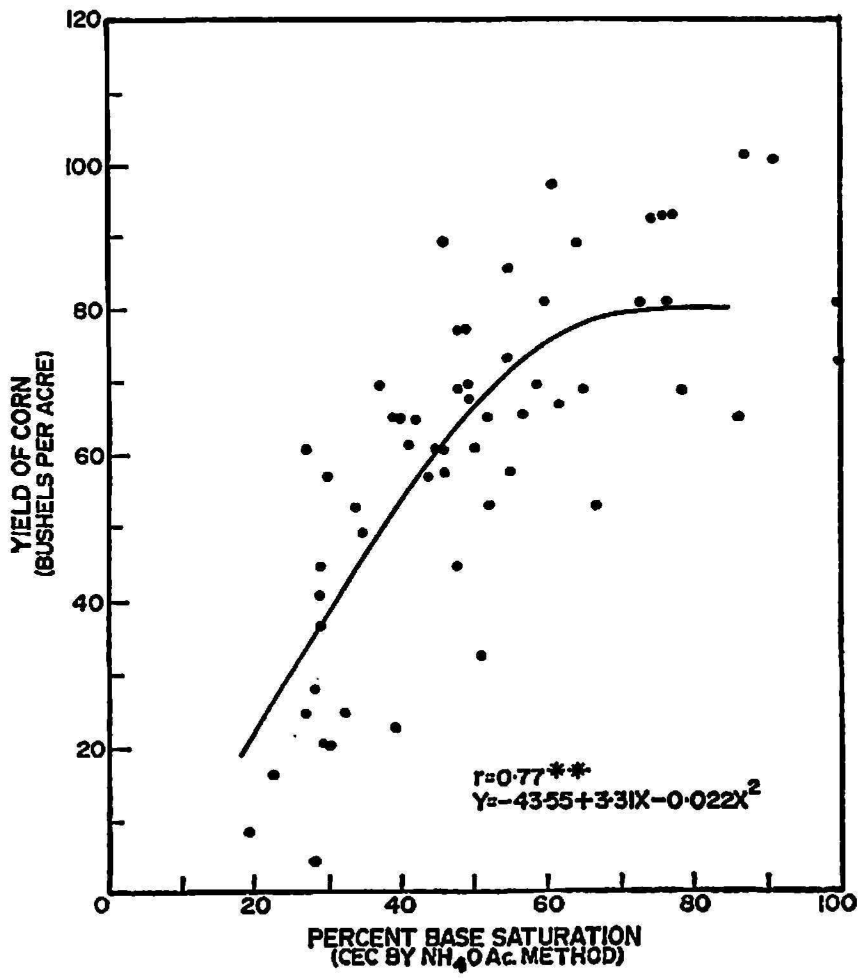

FIG. 13.—Relationship between yields of corn and percent base saturation of a Humatas clay.

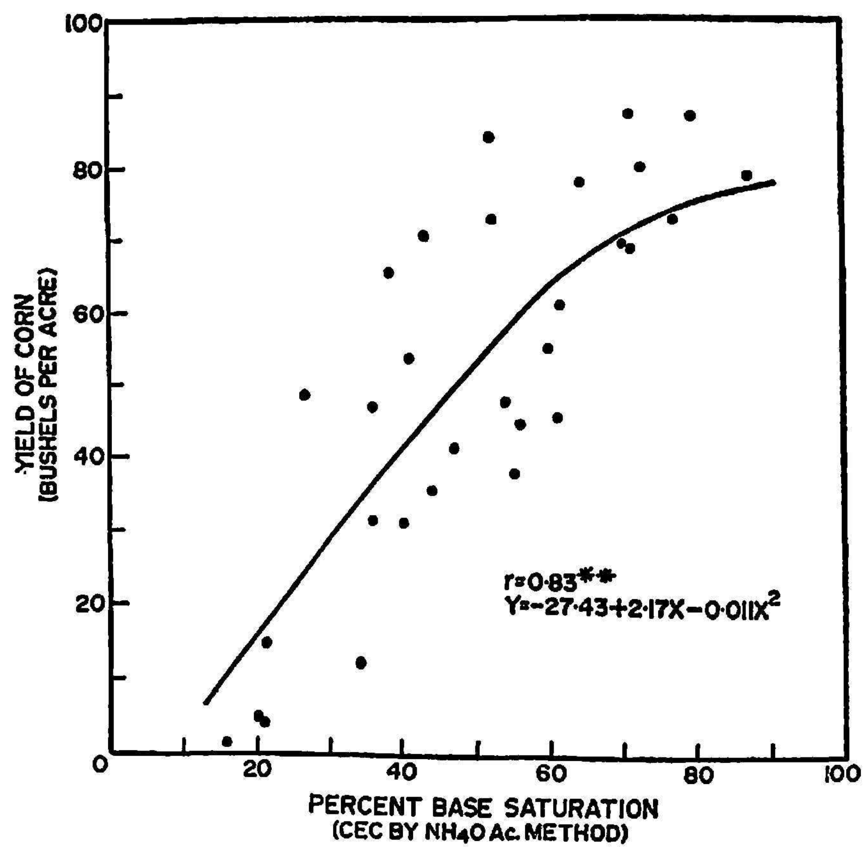

FIG. 14.—Relationship between yields of corn and percent base saturation of a Corozal clay.

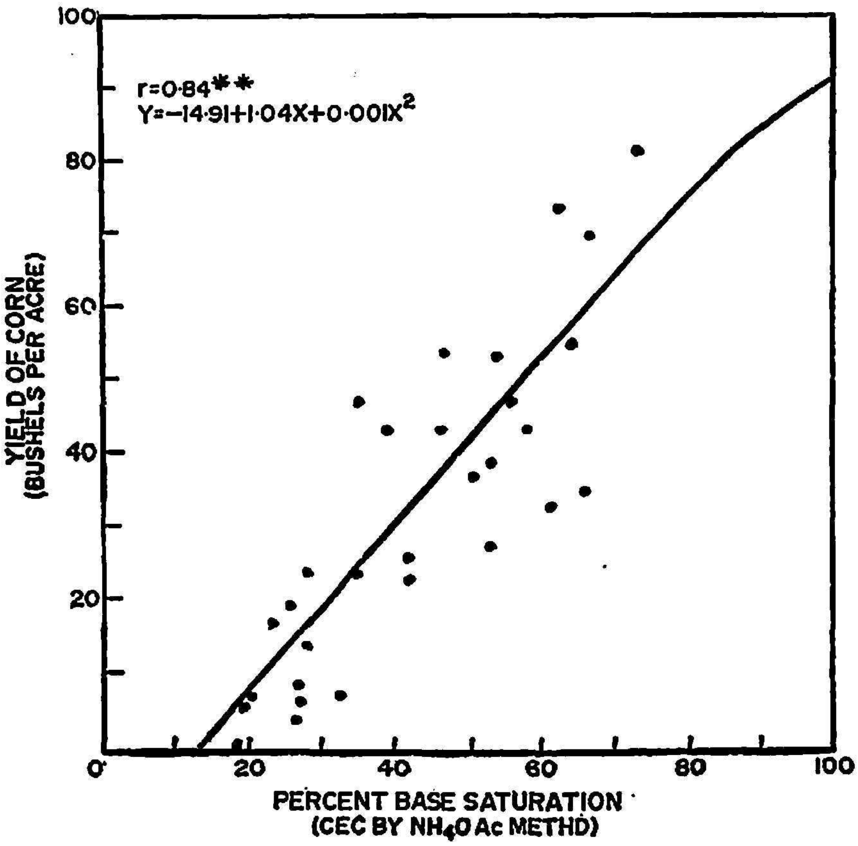

FIG. 15.—Relationship between yields of corn and percent base saturation of a Corozal clay subsoil.

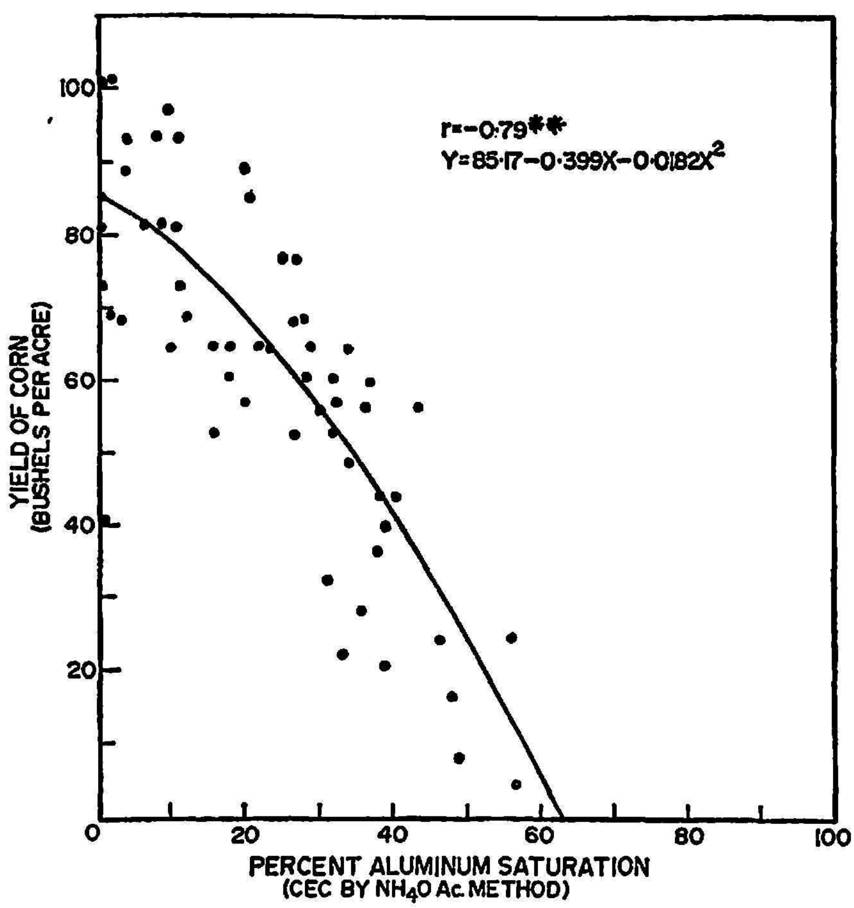

FIG. 16.—Relationship between yields of corn and percent aluminum saturation of a Humatas clay.

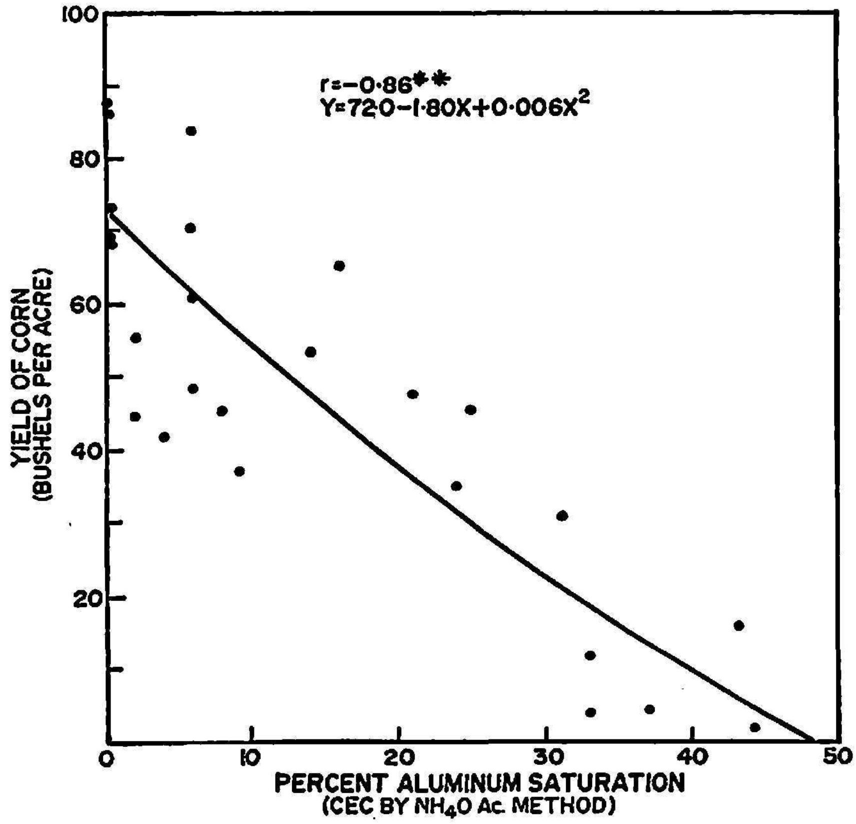

FIG. 17.—Relationship between yields of corn and percent aluminum saturation of a Corozal clay.

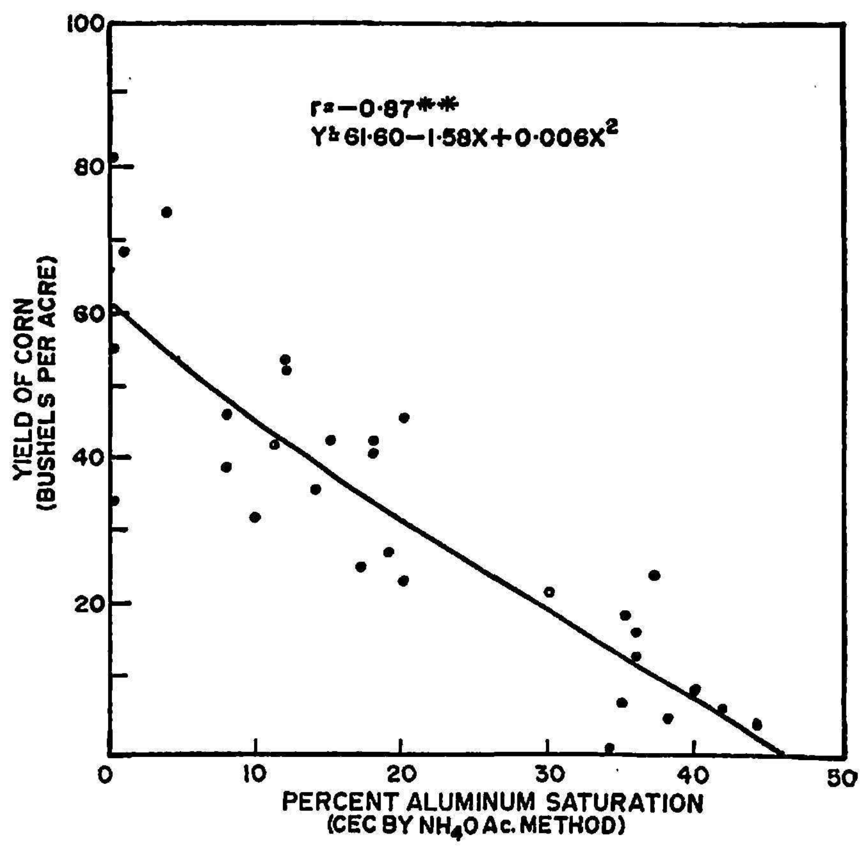

FIG. 18.—Relationship between yields of corn and percent aluminum saturation of a Corozal clay subsoil.

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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