

Response of Green Beans to Acidity Factors in Six Tropical Soils^{1,2}

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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

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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 \times 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/cm ³
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 \times 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				pH	Yields of green beans pounds/acre	Composition of bean leaves				
Percent aluminum saturation		Percent base saturation				Ca (per-cent)	Mg (per-cent)	P (per-cent)	N (per-cent)	Mn (ppm)
NH ₄ OAC method	Summa-tion of cations	NH ₄ OAC method	Summa-tion of cations							
<i>Humatas (Ultisol)</i>										
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	1.10	0.23	0.49	6.55	210
<i>Corozal topsoil (Ultisol)</i>										
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
<i>Corozal subsoil (Ultisol)</i>										
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
<i>Corozal level (Ultisol)</i>										
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
<i>Los Guineos (Ultisol)</i>										
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	50-66	4.3	9,040	1.34	0.46	0.16	5.58	149
<i>Coto (Oxysol)</i>										
— ¹	— ¹	88-98	— ¹	5.4	6,150	2.12	0.30	0.32	5.14	211
— ¹	— ¹	77-87	— ¹	4.8	5,920	1.91	0.29	0.31	5.13	231
— ¹	— ¹	66-76	— ¹	4.8	5,706	1.89	0.32	0.31	5.05	258
— ¹	— ¹	55-65	— ¹	4.4	4,530	1.69	0.34	0.30	5.21	267
— ¹	— ¹	44-54	— ¹	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.

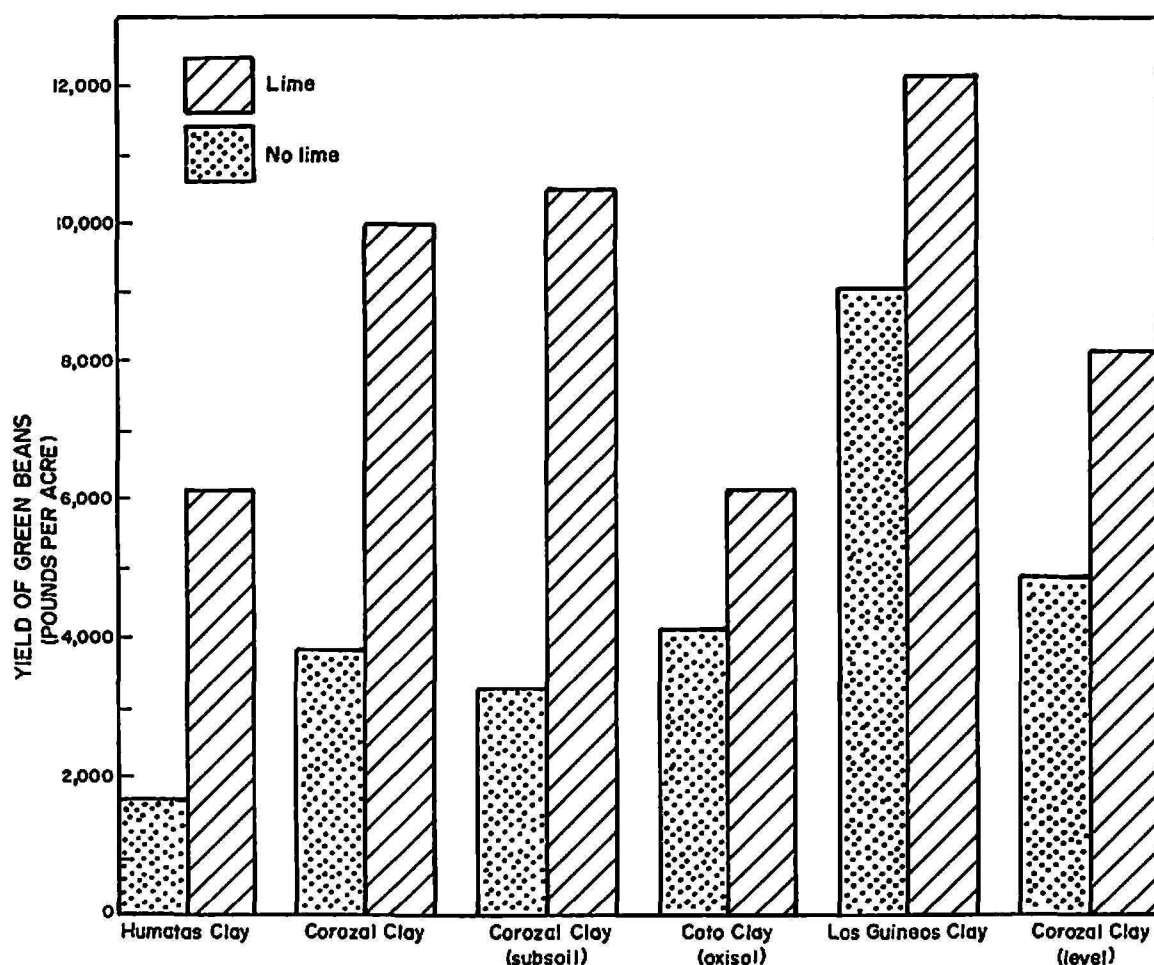


FIG. 1.—Effect of liming on yields of green beans growing on five typical Ultisols and one Oxisol under humid tropical conditions in Puerto Rico.

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 magnesium 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,

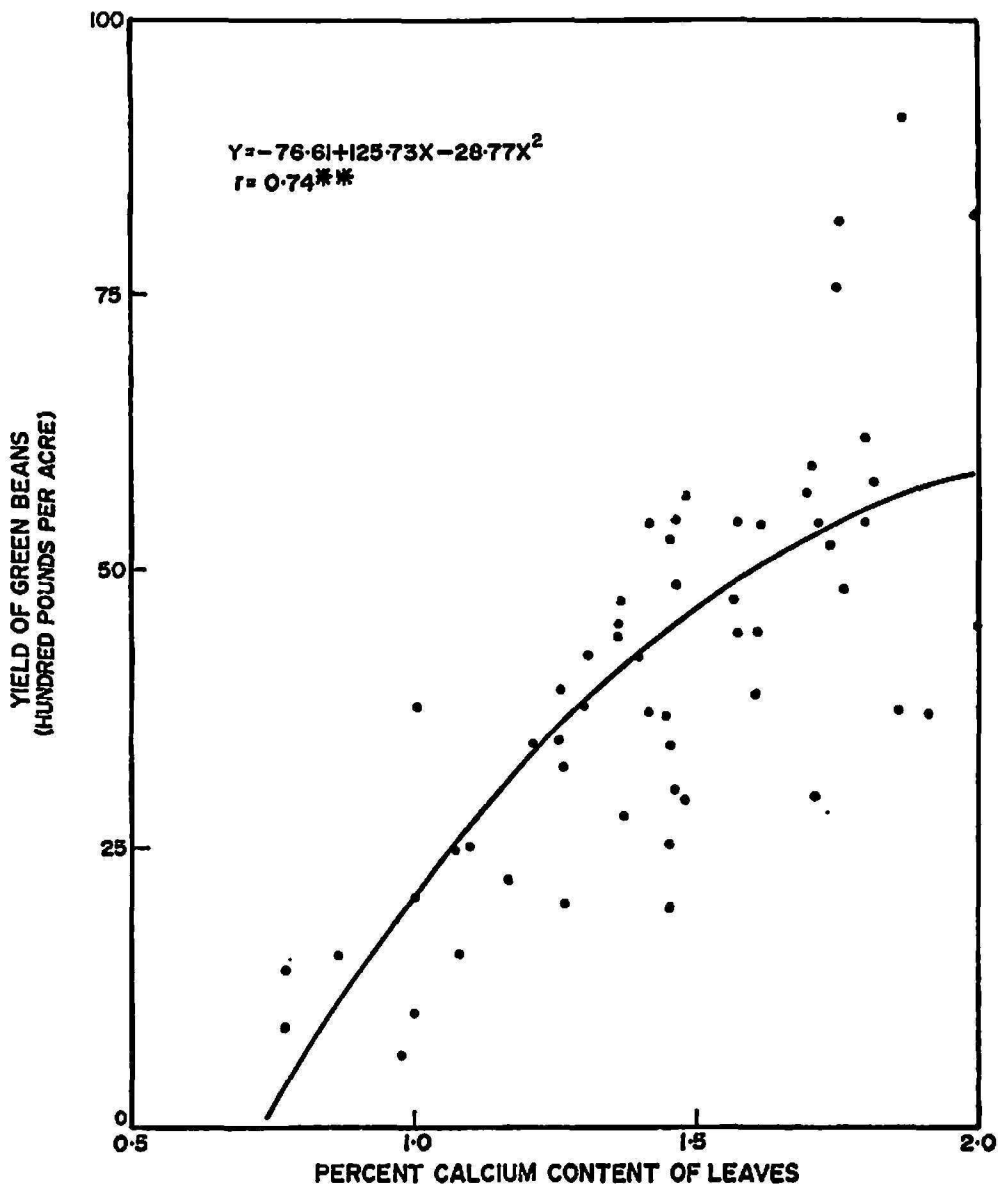


FIG. 3.—Relationship between yields and calcium content of leaves of beans growing on a Humatas clay at Orocovis.

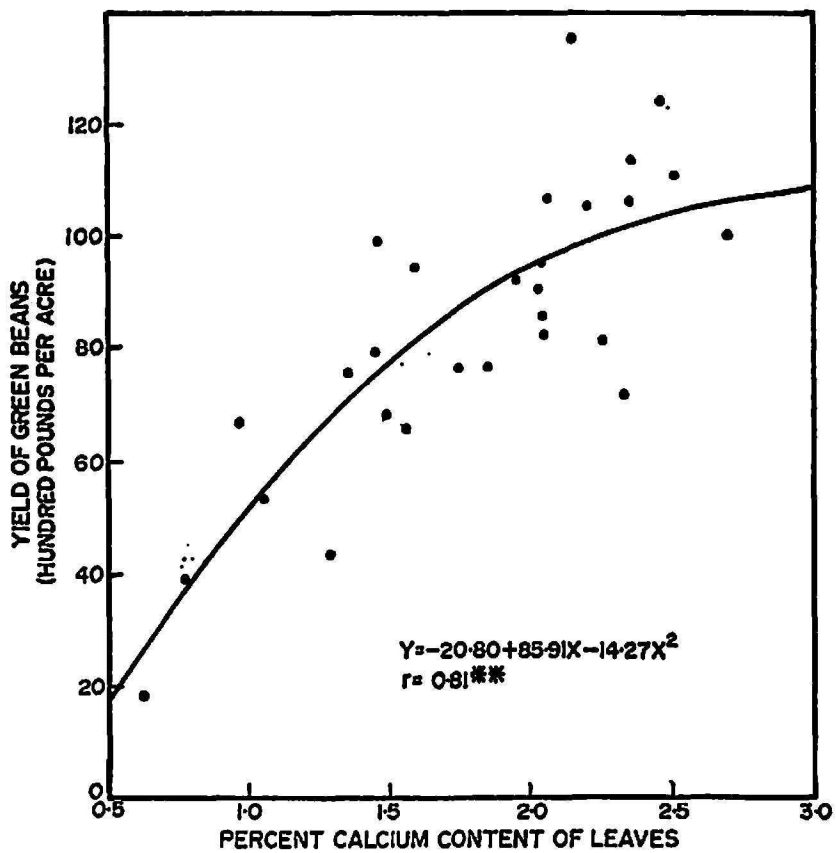


FIG. 4.—Relationship between yields and calcium content of leaves of green beans growing on Corozal clay.

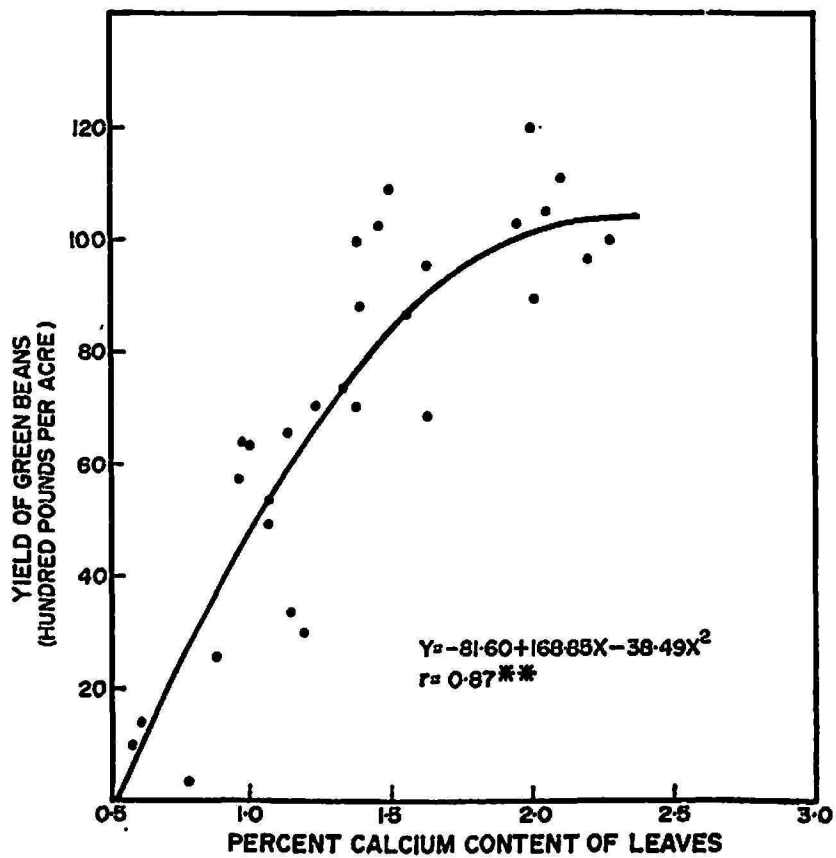


FIG. 5.—Relationship between yields and calcium content of leaves of green beans growing on Corozal subsoil.

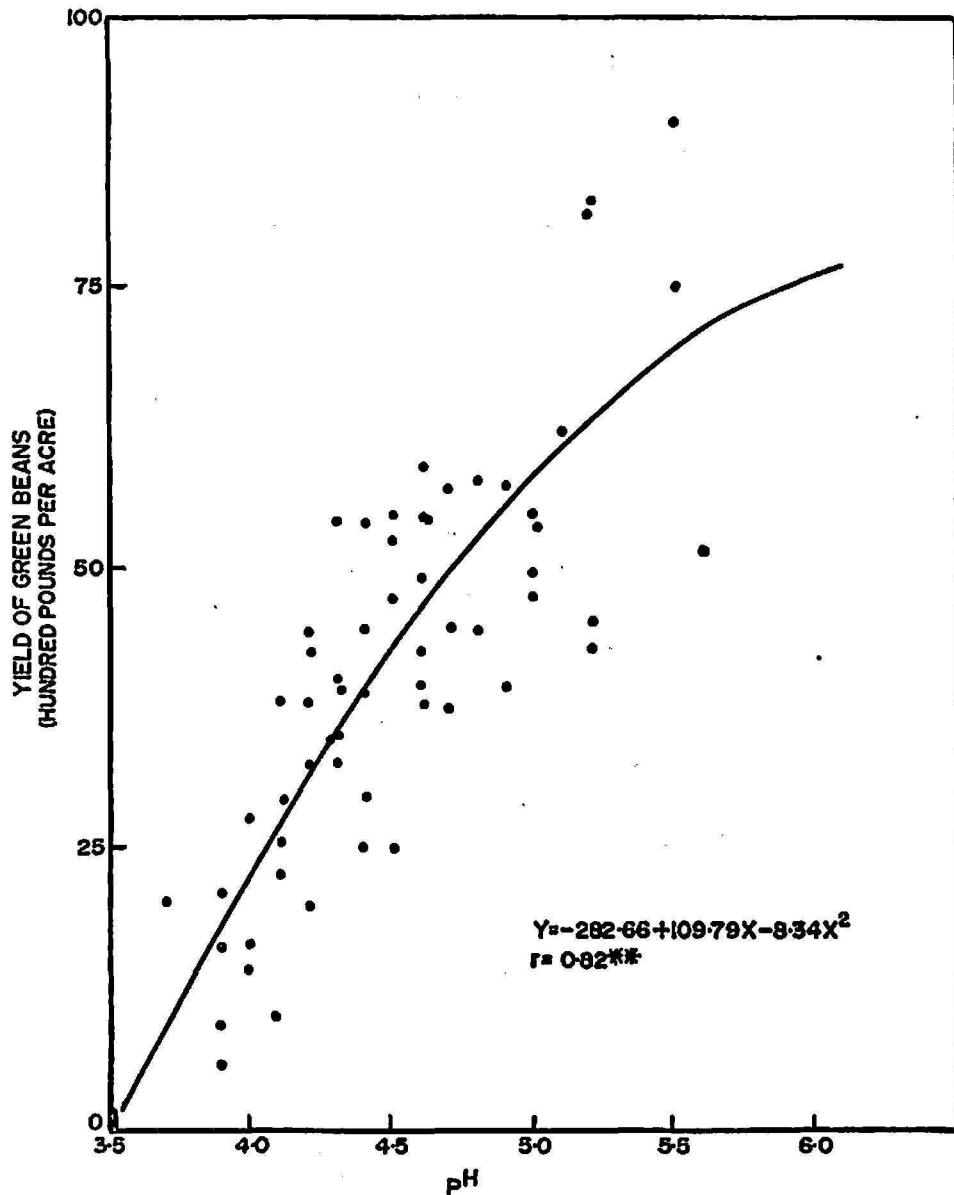


FIG. 6.—Relationship between yields of green beans and pH of a Humatas clay at Orocovis.

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

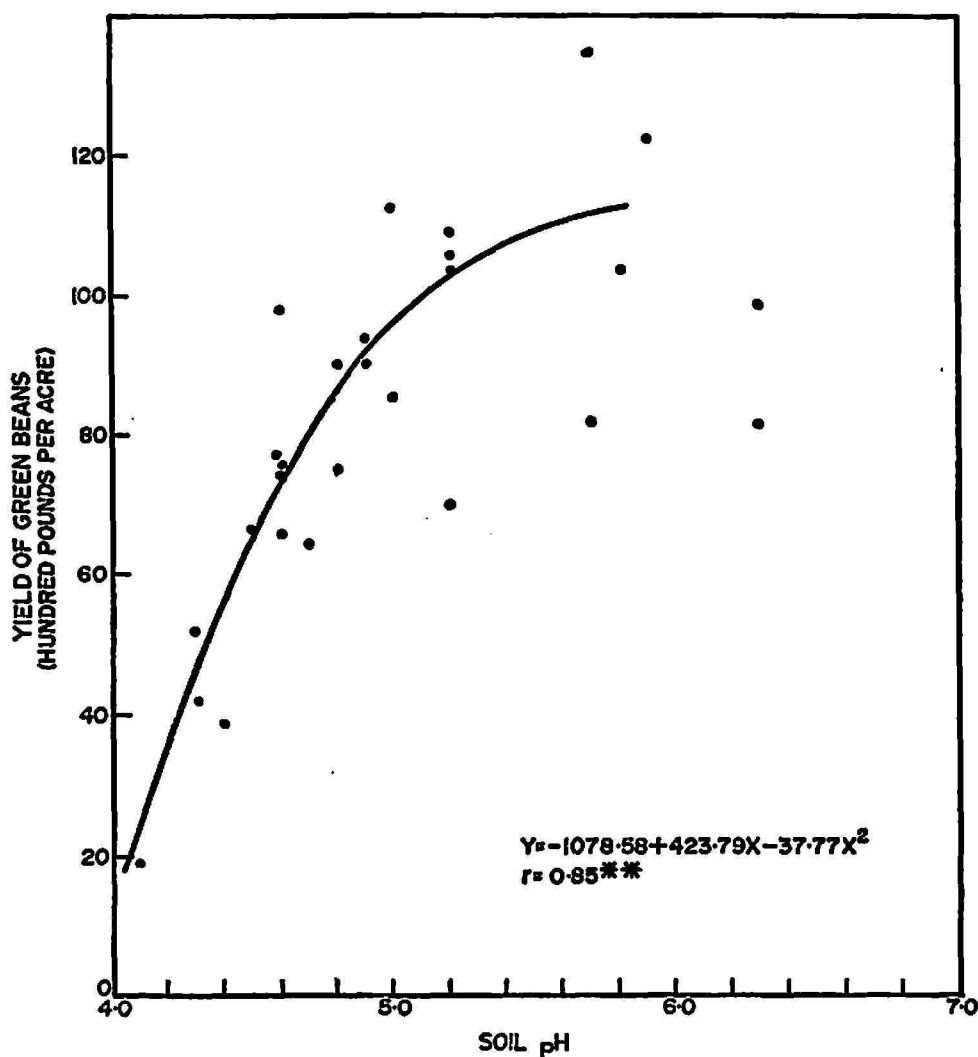


FIG. 7.—Relationship between yields of green beans and pH of a Corozal clay.

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

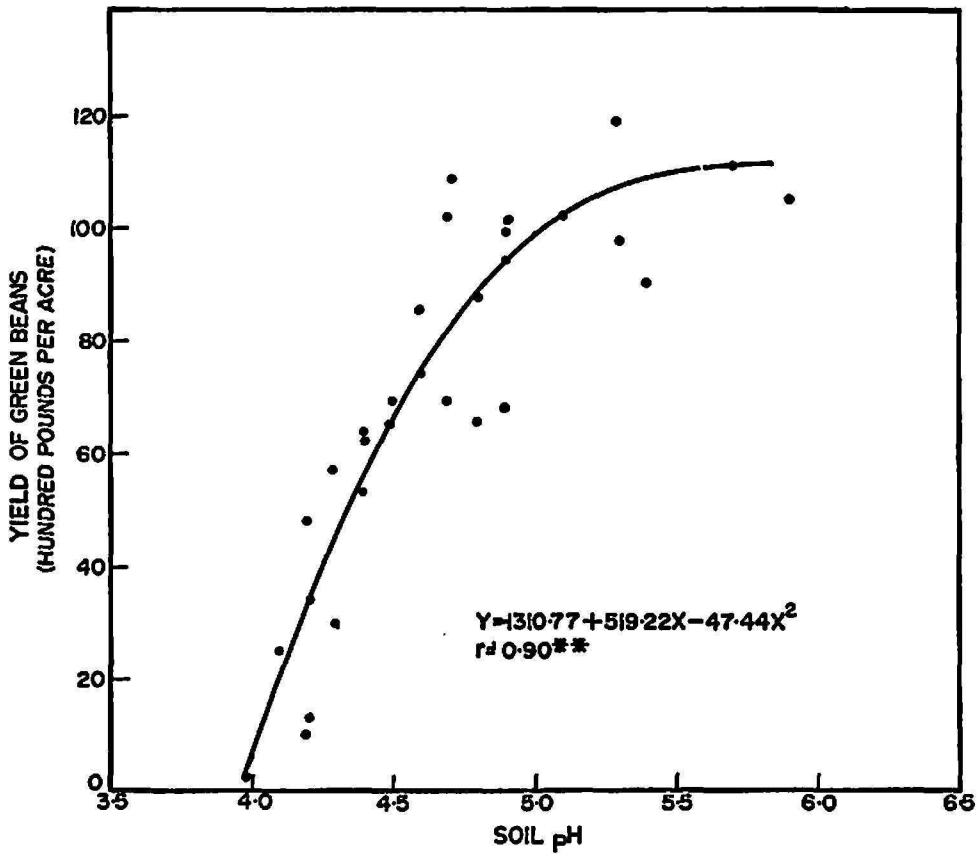


FIG. 8.—Relationship between yields of green beans and pH of a Corozal subsoil.

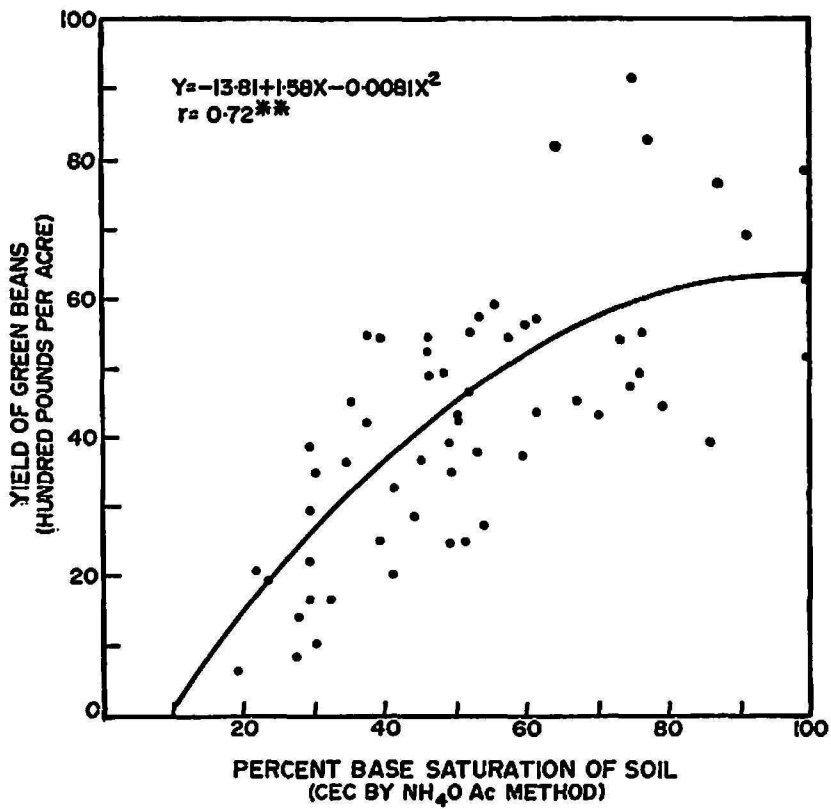


FIG. 9.—Relationship between yields of green beans and percent base saturation of a Humatas clay at Orocovis.

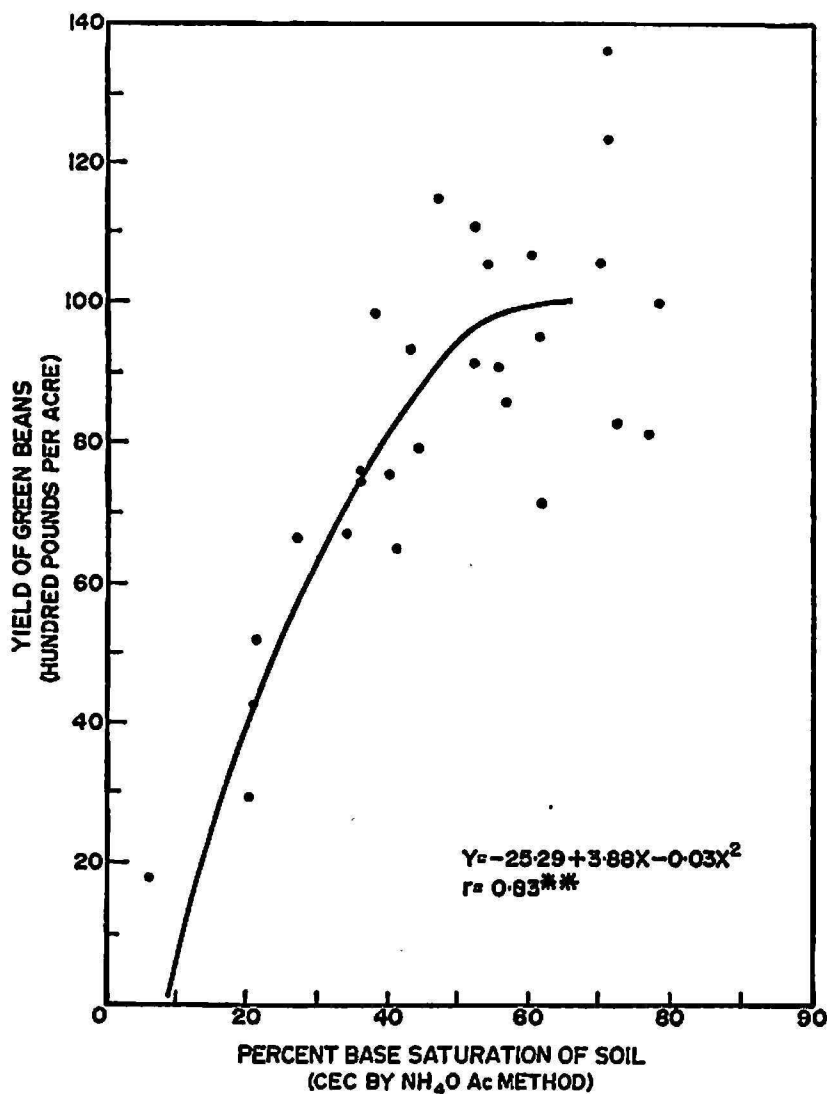


FIG. 10.—Relationship between yields of green beans and percent base saturation of a Corozal clay.

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

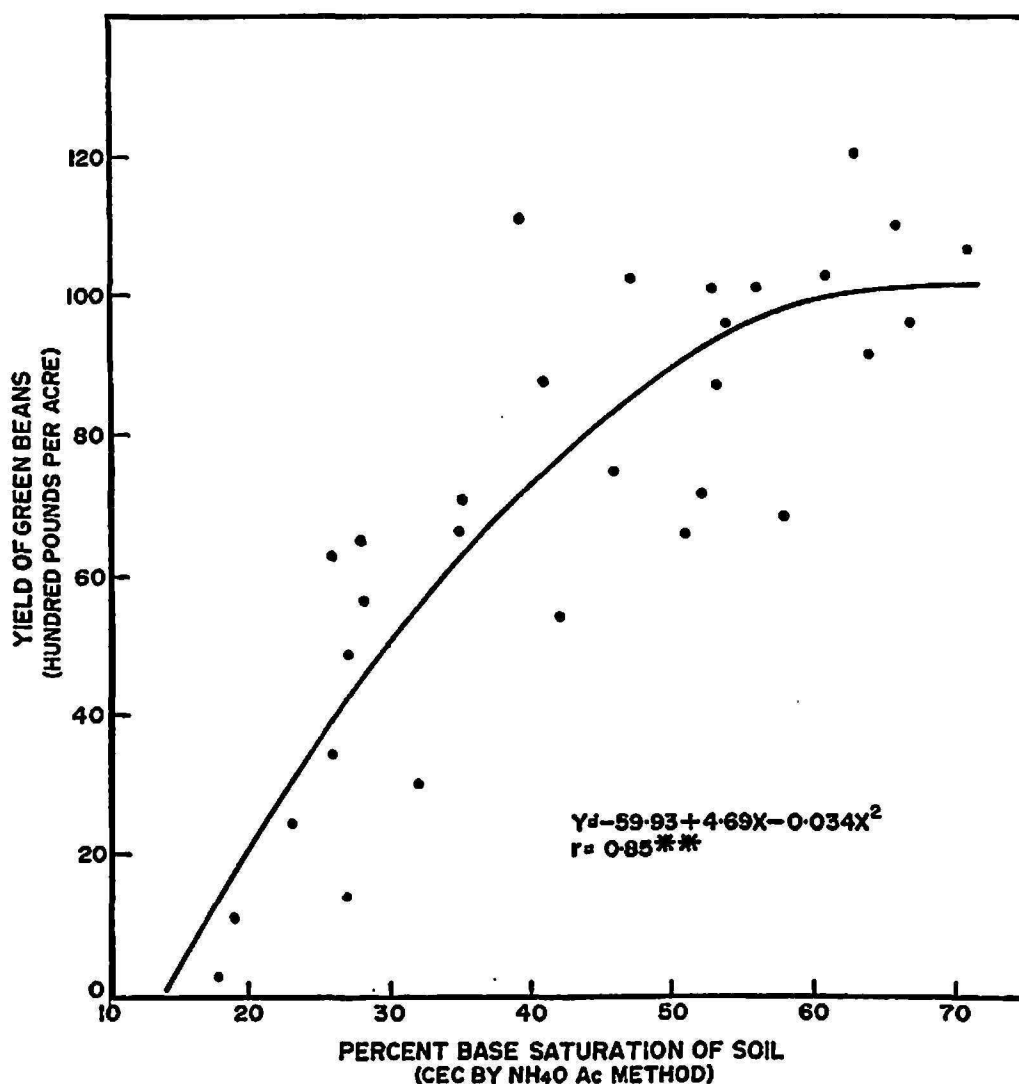


FIG. 11.—Relationship between yields of green beans and percent base saturation of a Corozal subsoil.

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.

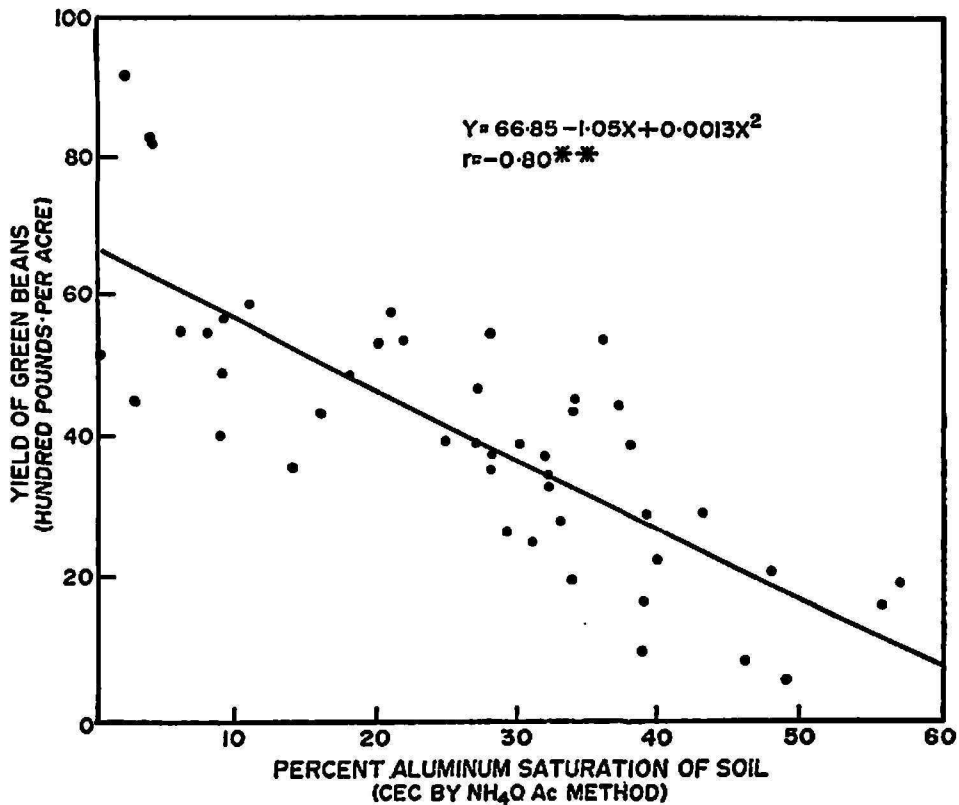


FIG. 12.—Relationship between yields of green beans and percent aluminum saturation of a Humatas clay at Orocovis.

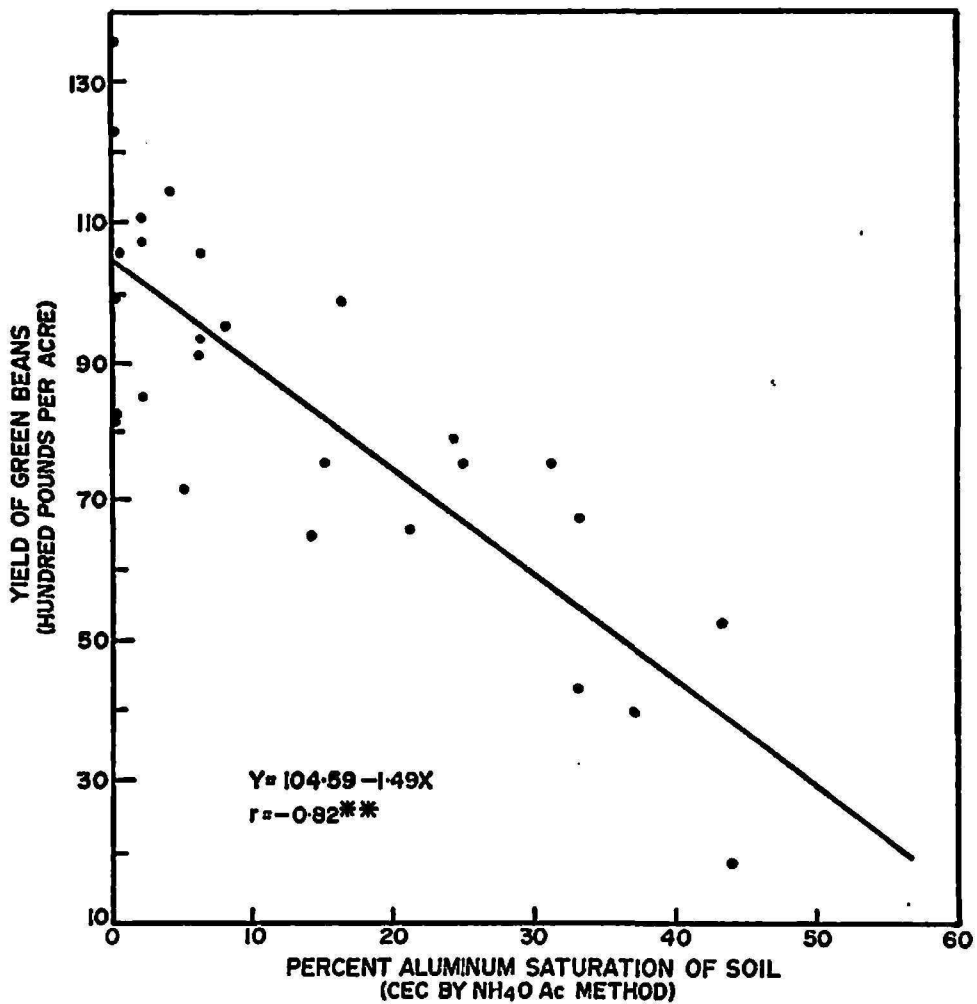


FIG. 13.—Relationship between yields of green beans and percent aluminum saturation of a Corozal clay.

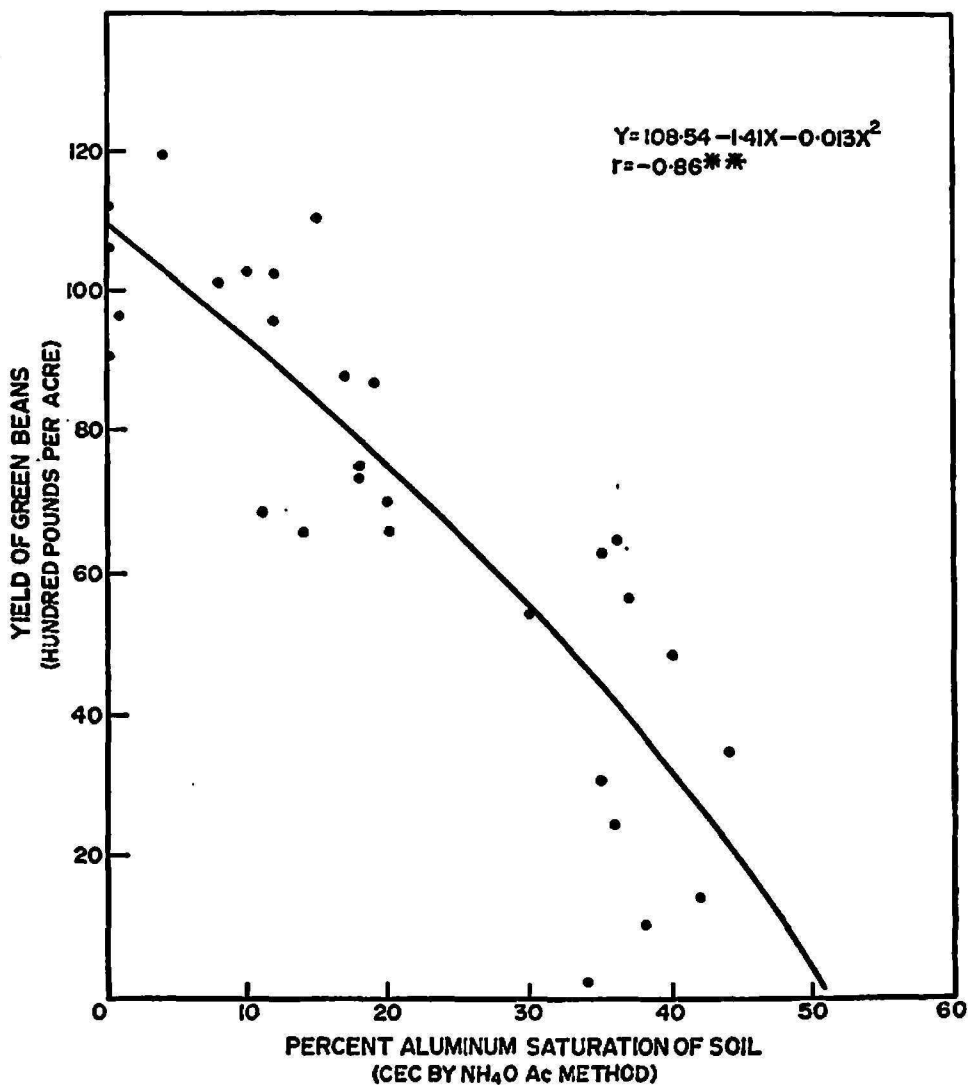


Fig. 14.—Relationship between yields of green beans and percent aluminum saturation of a Corozal subsoil.

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 estos 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 aproximadamente 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.

LITERATURE CITED

1. Abruña, F., and Vicente-Chandler, J., Sugarcane yields as related to acidity of a Humid Tropic Ultisol, *Agro. J.*, 59: 530-31, 1967.
2. —, —, Becerra, L., and Bosque-Lugo, R., Effects of liming and fertilization on yields and foliar composition of high yielding sungrown coffee in Puerto Rico, *J. Agr. Univ. P.R.* 49 (4): 413-28, 1965.
3. —, —, and Pearson, R. W., Effects of liming on yields and composition of heavily fertilized grasses and on soil properties under humid tropical conditions, *Soil Sci. Soc. Am. Proc.* 28: 657-61, 1964.
4. Abruña-Rodríguez, F., Vicente-Chandler, J., Pearson, R. W., and Silva, S., Crop Response to Soil Acidity Factors in Ultisols and Oxisols-Tobacco, *Soil Sci. Soc. Am. Proc.* 34 (4): 629-35, 1970.
5. —, Pérez-Escobar, R., Vicente-Chandler, J., Pearson, R. W., and Silva, S., Response of Corn to Acidity Factors in Eight Tropical Soils, *J. Agr. Univ. P.R.* 58 (1): 59-77, 1974.