Comparative Response of Three Crop Species to Liming Several Soils of the Southeastern United States and of Puerto Rico[1, 2]

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ABSTRACT

Yield response of three plant species to liming was determined in pot tests using soils typical of the humid upland region of Puerto Rico and of the southeastern United States. Three general response patterns were observed, but they were not clearly related to either crop species or soil category: 1) Increasing yield with increasing soil pH to a maximum between 5 and 6, followed by little or no change at higher pH values; 2) no clear response; and 3) increasing yield with increasing pH to a maximum between 5 and 6, followed by a decrease at higher pH values.

These results support the concept that satisfactory plant growth can be made on acid soils of tropical regions at somewhat lower pH levels than on soils of temperate regions. They also suggest that liming experience gained in temperate zones could be used with caution for acid soils of tropical regions.

INTRODUCTION

Judicious applications of lime are necessary for effective agricultural use of highly-weathered acid soils of both temperate and tropical regions. In temperate regions liming is probably as old as organized agriculture, but in the tropics it is being adopted much more slowly. There are several reasons for this. Availability and cost of lime are frequently limiting factors. Furthermore, liming recommendations in the tropics have often been strongly influenced by, if not derived from, results reported from less weathered and leached soils in temperate climates.

A number of workers (19, 25, 29) have pointed out the dangers of assuming similar responses to liming of soils of temperate and tropical regions. Yet, soil characteristics in humid-temperate and humid-tropical regions overlap extensively. Among all the soil orders, only Oxisols are restricted to the tropics (32). Useful extrapolation of liming experience to tropical soils should, therefore, be possible as better insight is

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gained into the specific underlying causes of acid-soil infertility and how they differ among broad groups of soils.

The purpose of the series of experiments presented in this report was to compare the response to lime of several plant genotypes common to the regions in question when grown on Oxisols and Ultisols typical of the upland soils of the southeastern United States where extensive liming research results are available, and of Puerto Rico, where 9 of the 10 soil orders (Soil Taxonomy) are found. A further objective was to attempt to identify the specific causes of any reduced plant growth associated with either a deficiency or excess of applied lime.

Several reviews provide up-to-date summaries of available information on liming of highly weathered soils and rationalization of observed effects (3, 9, 14, 17, 23). Due to the wide differences in response to lime among soils of any climatic region, many exceptions to generalizations regarding response of tropical and temperate region soils to liming should be expected. However, several points of difference appear to be fairly consistent. For example, crop yields are usually better in the tropics at lower soil pH levels than would be expected with similar crop species in temperate regions (7, 28). It is not known to what extent crop adaptation may contribute to this behavior. Several crops adapted to the tropics, such as tea, coffee, and peanuts, are highly tolerant to Al toxicity, but some varieties of these crops (12, 13, 28) differ widely in tolerance. Furthermore, maximum response to lime applications has been observed to occur at lower rates in the tropics than in other areas (28), suggesting that supplying Ca and Mg as nutrients may often be involved in response by the former soils. Also, the more highly weathered and leached soils of the humid tropics repeatedly have been reported to be susceptible to overliming, whereas such effects have not been of any consequence in temperate region soils (23, 25).

Thus, previous work suggests that in dealing with acid soils of the humid tropics, acidity may be less injurious and less lime is probably required for adequate correction than in soils of the temperate regions.

EXPERIMENTAL METHODS

GENERAL

The study was conceived as a means of identifying any outstanding differences between typical upland soils developed under humid-temperate and humid-tropical conditions as shown by response of identical plant genotypes to variations in soil pH. Location effects were minimized by the use of pot experiments (1-gal size) in a glass house in Río Piedras, Puerto Rico, and in a growth chamber in Auburn, Alabama. The soils from Puerto Rico were used in the Río Piedras experiment and those from the southeastern United States were used in the Auburn experiment. No attempt was made to maintain identical temperatures in the two locations, but they were similar, ranging around 30° C maximum during the day. Test plants were planted from the same lot of seed in all experiments, using an acid-sensitive, an intermediate-sensitive, and an acid-tolerant species. The plants were grown for 3 to 4 weeks before harvesting and determination of total dry weight of the aboveground material.

In carrying out these experiments, two problems were a constant source of concern. The first was maintaining an adequate supply of water without having at times an excess in the fine-textured soils or leaching the coarse-textured ones. This was finally settled by the use of large, woven fiber glass wicks placed in firm contact with the soil through the center of the pots and dipping in a reservoir of water beneath. This procedure gave much more uniform water levels in the soils than could be attained by additions to the pots as need appeared by either observation or weighing. The second problem was the tendency of the soils to shift in pH with time due to fertilizer reactions and accumulation of salts. In the poorly buffered soils, especially, the problem was serious and could not be solved satisfactorily. Soil pH could be determined in each pot only at the beginning of each experiment.

ANALYTICAL METHODS

Soil pH was determined with the glass electrode using 1:2.5 soil-water suspension. Soil solutions were displaced from soil samples taken at time of potting and after equilibration for 24 hr at the $^1/_3$-atm H_2O content. The solutions were analyzed for Ca, Mg, K, Al, and Mn, using the following procedures: EDTA titration for Ca and Mg, flame photometry for K, Eriochrome Cyanine R method (15) for Al; and colorimetric determinations of Mn following oxidation to $KMnO_4$. Exchangeable cations were determined using the same procedures after ammonium acetate extraction of the basic cations and KCl extraction of Al.

Plant material from selected treatments of each crop at harvest was spectrographically analyzed for both major and micronutrient contents by the Soil Testing and Plant Analysis Laboratory at Athens, Georgia. Plants grown under highly acid, intermediate, and "overlimed" conditions were included in the samples analyzed.

SOILS

Six different acid soils, three from the humid region of Puerto Rico and three from the southeastern United States, were selected to provide a wide range in degree of weathering and difference in response to lime applications (1, 4, 23). The soils, listed in table 1, were four Ultisols and two Oxisols. All were strongly acid, and ranged in texture from loamy sand to clay. Bulk samples of each soil were taken from unlimed plots in field experiments. These soils had all been used for row crop production for many years, during which time residually acid fertilizers had been used. Even so, the pH range, between 4.3 and 4.6, is probably not unusually low for unlimed soils of these series (22, 27).

TEST PLANTS

The test plant varieties selected were Sudangrass (*Sorghum sudanensis*, [Piper] Stapf, corn (*Zea mays* L. var. Funk SX 4949), and soybean (*Glycine max.* [L] Merr. var. Hardee). All were chosen in consultation with research workers familiar with general performance of the crops in both temperate and tropical climates. Sudangrass is widely recognized as a very acid-sensitive crop, having an especially low tolerance for Al (26). The soybean plant, on the other hand, has relatively high tolerance of acidity. Although it may be somewhat more Mn-sensitive than many species (21), it is relatively tolerant of solution Al (26). Corn, in the authors' experience, has been intermediate in its tolerance of soil acidity (1, 3). Of course, wide variations in tolerance are expected among varieties of any crop, as has been demonstrated for both temperate and tropical conditions (5, 28).

TABLE 1.—*Description of soils included in liming experiments*

Soil series	Classification	Location	Initial pH
Bladen clay loam	Typic Albaquults clayey, mixed, thermic	Fleming, Ga.	4.6
Norfolk loamy sand	Typic Paleudults fine-loamy, siliceous, thermic	Headland, Ala.	4.4
Lucedale sandy loam	Rhodic Paleudults	Thorsby, Ala.	4.4
Catalina clay	Tropeptic Haplorthox clayey, oxidic, isohyperthermic	Barranquitas, P. R.	4.3
Humatas clay	Typic Tropohumults clayey, kaolinitic, isohyperthermic	Orocovis, P. R.	3.9
Coto clay	Tropeptic Haplorthox clayey, kaolinitic, isohyperthermic	Isabela, P. R.	4.3

LIME AND FERTILIZER TREATMENTS

Bulk lots of each soil (25 kg) were treated with finely-ground (100-mesh) dolomitic limestone at a number of rates to provide a final soil pH ranging from that of the unlimed sample up to at least pH 7.0. These bulk samples were equilibrated at the 1/3-atm H_2O percentage for about 1 week before potting. The soils were fertilized with P and K according to soil test, N was added at the rate of 120 p/m as NH_4NO_3 in solution when the soil moisture level was adjusted just prior to potting and planting. No micronutrients were included in the fertilization.

RESULTS AND DISCUSSION

SOIL PROPERTIES

Exchangeable cations in the unlimed soils and at an intermediate and a relatively high pH are shown in table 2. Cation exchange capacity, as

TABLE 2.—*Some soil chemical properties at several pH levels resulting from differential lime applications*

Soil	Soil pH	Exchangeable cations, meq/100g				Σ cations
		Ca	Mg	K	Al	
Norfolk sandy loam	4.4	0.26	0.13	0.39	0.33	1.1
	4.8	.34	.15	.38	.23	1.1
	6.4	.80	.50	.38	.0	1.7
Lucedale sandy loam	4.4	.76	.63	1.10	1.23	2.7
	4.8	1.70	.83	.07	.87	3.5
	5.8	2.28	.98	.06	.0	3.3
Bladen clay loam	4.6	3.30	4.90	.11	5.66	14.0
	5.2	6.20	11.20	.12	1.12	18.6
	6.4	10.00	6.00	.18	.0	16.2
Humatas clay	3.9	3.49	.62	ND[1]	5.30	9.41
	4.2	4.70	1.21	ND	3.48	9.39
	6.0	7.70	2.25	ND	.0	9.95
Catalina clay	4.3	5.52	4.14	ND	1.95	11.61
	4.4	4.73	3.97	ND	1.72	10.42
	5.7	5.80	3.07	ND	.0	8.87
Coto clay	4.3	1.87	.18	ND	1.53	3.58
	4.5	2.58	.31	ND	.90	3.79
	6.7	3.64	1.51	ND	.0	5.15

[1] Exchangeable K was not determined on these soils, but soil tests results indicated no abnormal deviations from commonly occuring levels which range around 0.1 meq/100 g.

indicated by Σ cations, ranged from only about 1 meq/100 g in the Norfolk to around 18 in the Bladen. This was not quite as wide as the range among the Puerto Rican soils (about 4 to 11 meq/100 g). Exchangeable Al was relatively high in all unlimed soils, amounting to around 50% of the exchangeable cations in all but the Catalina soil. In this soil it tended to conform to levels expected for an Oxisol. None of the unlimed soils had a ratio Σ cations:Ca below those previously reported as growth limiting (11), nor did Mg approach levels considered phytotoxic.

The concentration of various cations in the displaced soil solution at several soil pH levels, and the calculated molar activity of the potentially toxic Al and Mn ions are listed in tables 3 and 4. Here again, the Ca level should have been adequate in all cases, and Mg was usually not excessive. However, Al was present at toxic levels in all the soil solutions at pH levels below about 5.0, and Al activity was very high at the lowest pH values. The relationship between soil solution pH and chemical activity of the soluble Al is shown in figure 1. Any increase in chemical activity of Al in the soil solution above zero reportedly decreases cotton root extension (2). Figure 1 also shows that when all six

TABLE 3.—*Soil solution cation composition—soils from southeastern United States*

Soil	Solution pH	Soil solution composition					Al activity	Mn activity
		Ca	Mg	K	Al	Mn		
				mM			*μM*	*μM*
Norfolk	4.0	5.1	2.1	15.1	0.95	0.7	134.1	349
	4.5	6.6	6.2	13.6	.21	.4	26.2	189
	4.7	6.8	7.2	13.4	.12	.6	13.9	279
	4.8	7.1	9.6	12.1	.04	.3	3.8	136
	6.7	8.3	20.1	8.3	–	tr	–	–
	7.1	11.6	28.2	8.6	–	tr	–	–
Lucedale	3.9	9.3	4.2	5.6	1.33	.5	184.5	234
	4.0	11.4	5.5	5.4	1.02	.4	132.5	181
	4.1	16.3	4.9	5.5	.75	.2	90.2	87
	4.2	19.4	9.5	5.3	.36	.1	39.2	41
	4.8	27.3	21.3	2.5	.09	.1	7.0	36
	6.7	24.4	28.2	1.2	–	tr	–	–
Bladen	4.2	6.1	3.3	.4	.64	.1	177.1	53
	5.0	6.6	5.6	.3	.27	.1	25.6	51
	5.7	12.1	12.3	.3	.14	tr	16.4	–
	6.1	10.1	10.0	.3	–	tr	–	–
	6.5	13.2	12.2	.4	–	tr	–	–
	7.5	21.4	18.5	.4	–	tr	–	–

soil solution Al contents were expressed in terms of chemical activity, they had essentially the same pattern as soil solution pH was varied from 3.5 to 7.0. This observation agrees with those of other workers (7) that "critical" soil pH for plant growth is often lower in Puerto Rican soils than in those of the southeastern U.S. Chemical activity of soil-solution Al includes factors not represented adequately in a simple soil pH measurement. Figure 1 emphasizes the close relationship between pH of the true soil solution and the chemical activity of its Al content.

Figure 2 shows that there is a general relationship between soil suspension and displaced soil-solution pH, with the latter around 0.5 unit lower than the former. The soils did not seem to differ consistently in this relationship.

Tables 3 and 4 also show the concentration and chemical activity of Mn in the displaced soil solution at varying pH levels. Generally, soluble Mn level decreased as pH increased, reaching extremely low values near pH 7. However, Bladen soil solutions contained little more than traces of Mn even at very low pH, whereas Catalina solutions had extremely high concentrations when pH was below about 5. Manganese solubility in soils is a highly labile property, making it difficult to

TABLE 4.—*Soil solution cation composition—soils from Puerto Rico*

Soil	Solution pH	Soil solution composition					Al activity	Mn activity
		Ca	Mg	K	Al	Mn		
				mM			*µM*	*µM*
Humatas clay	3.5	13.1	3.2	0.8	2.3	0.6	471	287
	3.6	13.9	4.8	1.0	2.6	.8	500	339
	3.7	11.2	3.7	.3	1.4	.6	331	309
	3.8	8.3	1.9	.3	.7	.5	179	229
	4.1	13.6	4.7	.2	.4	.6	85	289
	4.7	7.0	1.0	1.3	.1	.4	20	200
	5.0	12.2	2.2	1.2	0	.3	0	125
	6.5	2.6	1.7	.1	0	0	0	0
Coto clay	4.1	8.4	1.2	.5	.8	1.9	196	901
	4.2	5.4	.5	.1	.3	1.3	101	717
	4.3	3.2	—	.3	.3	.8	91	702
	4.5	5.1	.6	.1	.2	1.0	56	578
	5.8	1.8	.9	.1	0	0	0	0
	6.7	3.2	2.2	.1	0	0	0	0
Catalina clay	4.1	18.8	1.8	.8	.5	20.8	74	8355
	4.2	15.2	2.7	.5	.4	19.8	59	7441
	4.3	16.5	4.6	.5	.3	20.6	46	7526
	4.4	26.0	2.3	.5	.2	22.3	24	7777
	5.0	8.4	2.8	.1	0	.3	0	148
	6.4	2.2	1.0	.1	0	0	0	0

establish relationships to plant growth that may occur over a period of several weeks, as illustrated by the results in figure 3. At the same pH level, soil solution Mn activity in the Coto clay decreased sharply between potting and a sampling after the third test crop had been harvested. Such changes are known to be influenced by drying, wetting, temperature changes, and other factors.

The plant composition results listed in tables 5 through 7 show that Ca level did not drop below 0.2% in any of the plant materials, regardless of soil type or liming treatment. This level should have been adequate for normal plant growth (30). This conclusion is also supported by the soil-solution cation composition results (tables 3 and 4).

Similarly, P content of the plant materials appeared normal, usually around 0.2%. This agrees with previously reported effects of Al on P uptake and translocation, which varied from increases (24) through no effect (20, 8) to decreases (12, 13), depending on plant species and environmental factors.

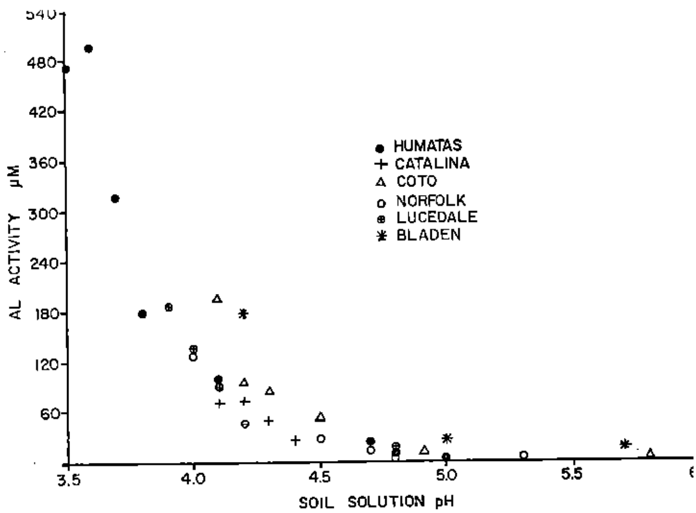

FIG. 1.—Relationship of Al activity to soil solution pH among several soils of tropical and temperate climatic regions.

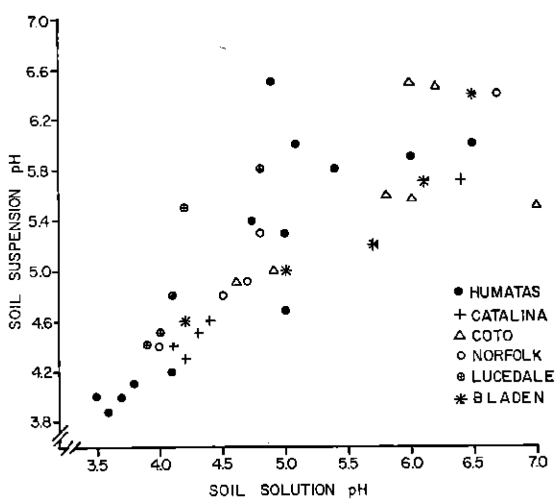

FIG. 2.—Relationship of soil suspension pH to that of the displaced soil solution.

Magnesium content of some plant materials varied much more with liming than did Ca content. For example, for all soil types sudangrass had much higher Mg contents at high pH levels than in the unlimed or lightly limed treatments, yet Ca content varied little with treatment (tables 5, 6, and 7). Jackson (14) has emphasized the complex relationships involved in Mg uptake and translocation by plants, including interactions of Mg with Al, Mn, and P. The present data do not support any clear conclusions concerning relationships between liming and Mg uptake or plant yield.

YIELD RESPONSE

Yield responses of the three crop species to liming are shown in figures 4 through 9. Often the same crop was grown several times and

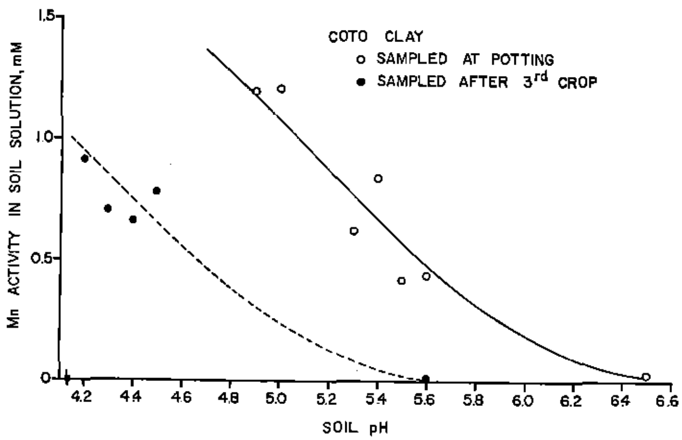

FIG. 3.—Changes in soil solution Mn level with cropping over a wide soil pH range.

the data were combined. Field experiment results were available from the Bladen clay loam site and are shown on the same graphs to compare responses (figure 4). Soybeans and corn grown on the Bladen soil responded similarly to liming in both field and pot tests.

Three general response patterns were observed, but they are not clearly related to either crop species or soil. These are, in the order of frequency of occurrence: 1) Increasing yield with increasing soil pH to a maximum between pH 5 and 6, followed by little or no change at higher pH levels; 2) no yield response to increasing pH; and 3) increasing yield with increasing pH to a maximum between pH 5 and 6, followed by a tendency to decrease at higher pH values.

Bladen Clay

All three crops responded to liming the Bladen soil, and they appeared to differ little in the soil pH required for maximum yield (figure 4). None

TABLE 5.—*Composition of sudangrass with respect to several essential elements and soil pH level*[1]

Soil reaction	P	Ca	Mg	Mn	B	Zn
pH	%	%	%	*P/m*	*P/m*	*P/m*
			Norfolk sandy loam			
4.1	0.4	0.2	0.2	796	9	>300
4.7	.6	—	—	829	15	>300
6.5	.4	.3	1.3	108	8	91
7.5	.3	.4	1.3	64	4	47
			Lucedale sandy loam			
4.0	.2	1.2	.8	401	12	>300
4.6	.2	1.1	1.8	128	5	>300
6.4	—	.7	1.0	65	6	167
7.5	—	1.0	1.8	61	5	115
			Bladen clay			
4.5	.3	.6	.5	89	18	211
4.9	.2	.3	.4	57	18	91
5.5	.2	.4	.6	37	9	44
7.2	.5	.8	1.1	3	8	34
			Catalina clay			
4.7	.2	.3	.1	>898	10	41
4.9	.2	.4	.3	>898	8	50
5.3	.2	.4	1.0	146	4	34
6.0	.2	.5	1.6	113	2	21
			Humatas clay			
4.3	.2	1.3	.3	722	21	50
4.7	.2	.5	.6	368	8	45
5.6	.2	.5	.9	53	6	39
6.7	.2	.6	1.6	22	2	36
			Coto clay			
4.5	.2	.6	.2	>898	15	43
5.0	.1	.7	.3	>898	16	48
5.4	.2	.6	.5	598	10	63
6.0	.2	.5	.7	327	9	59

[1] All plant analyses were performed spectrographically in a routine plant analysis laboratory which did not vary dilution of solutions analyzed to fit individual sample concentrations of Mn or Zn except by special request on samples when resubmitted. For this reason, when Mn or Zn are reported as >898 or >300, respectively, readings were off scale at standard routine dilution, and samples of the particular plant tissue were no longer available for reruns.

responded to an increase in pH above about 5.5. This was a direct reflection of soil solution Al activity, which reached a low level at pH 5.7. Also, soluble Mn was very low at all pH values (table 3).

Sudangrass yield decreased as soil pH increased to values above about 6. This detrimental effect of high pH seemed to be due to Mn deficiency, based on both plant symptoms and composition. At pH 7.0 the plant material contained only 3 p/m Mn as compared with about 60 p/m or more at pH levels below 5.5. However, Mn content of both soybean and corn plants was this low at high soil pH values (tables 6 and 7), yet there were no visible symptoms of Mn deficiency in either crop, nor was there indication of yield depression of soybeans. Corn yield, nevertheless, seemed to decrease somewhat as soil pH increased above 7.

Norfolk Sandy Loam

The three crops showed no clear difference in response patterns on the Norfolk soil (figure 5). Yield of all three crops increased as soil pH increased to between 5.5 and 6.5.

The response pattern corresponded very well with that of Al activity in the soil solution, which was probably the chief factor governing plant behavior with respect to acidity. Both corn and soybeans showed clear yield increases as soil pH was raised from 5.0 to 5.5, and sudangrass yield continued to increase up to at least pH 6.5.

TABLE 6.—*Composition of corn tissue with respect to several elements and soil pH level*

Soil reaction	P	Ca	Mg	Mn	B	Zn
pH	%	%	%	*P/m*	*P/m*	*P/m*
			Norfolk sandy loam			
4.3	0.8	0.2	0.1	>898	63	>300
4.6	.4	.6	.5	>898	40	>300
5.6	.4	.5	.6	714	40	>300
7.6	.4	.5	1.3	119	15	79
			Lucedale sandy loam			
4.3	.2	.7	.1	>898	50	>300
5.0	.4	.8	1.7	442	18	287
5.5	.3	.7	2.0	96	18	66
7.1	.2	.8	.2	71	12	129
			Bladen clay			
4.3	.2	.8	1.2	221	48	290
4.7	.1	.5	1.0	119	28	139
5.5	.3	.5	1.8	3	19	240
7.8	.2	1.0	2.0	1	6	70
			Catalina clay			
4.7	.2	.5	.1	>4490	42	38
5.1	.2	.5	.2	>4490	48	43
5.5	.1	.6	1.4	281	34	40
6.0	.1	.6	1.0	218	28	26
			Humatas clay			
4.0	.2	.5	.2	1140	78	49
4.8	.2	.7	.3	1320	73	51
5.4	.2	.8	.4	1445	56	40
6.0	.2	.7	1.4	77	30	33
			Coto clay			
4.5	.2	1.0	.4	3010	41	56
5.0	.2	.8	.3	2465	32	52
5.6	.2	.8	.5	1970	34	50
6.8	.1	.6	1.5	114	32	28

Besides the detrimental effects of Al, Zn toxicity could have been a factor in plant response to liming the Norfolk soil. While lime-induced Zn deficiency has been reported, especially on sandy soils (31), the possible toxic effects of this element at low soil pH has received little attention. Bennett (6) concluded that while extremely low concentrations of Zn (<1 p/m) usually injure plants, Zn toxicity would be economically significant only in special situations since it is rare for most soils. The bulk sample of Norfolk soil had been taken from a field on which peanuts had been grown for several years and fungicides containing Zn had been used. Plant material from all three test crop species grown at pH levels below about 5 contained very high (>300 p/m) levels of Zn compared to those present when the soil had been limed to pH values of 6 or higher (80 to 100 p/m) (tables 5 through 7).

TABLE 7.—*Composition of soybean plant material at several soil pH levels*

Soil reaction	P	Ca	Mg	Mn	B	Zn	Mo
pH	%	%	%	*P/m*	*P/m*	*P/m*	*P/m*
			Norfolk sandy loam				
4.5	0.7	0.5	0.3	>898	55	>300	4
4.8	.6	.7	.4	>898	48	>300	4
5.6	.5	1.1	.6	133	31	151	4
7.6	.5	1.3	1.1	33	33	44	4
			Lucedale sandy loam				
4.5	.3	1.6	.7	>898	51	>300	4
4.8	.3	1.8	.4	297	43	241	5
6.1	.3	1.9	1.5	131	33	87	5
7.7	.3	1.7	1.8	46	55	53	4
			Bladen clay				
4.3	.2	1.0	.7	77	34	244	4
4.7	.3	1.3	.9	49	37	123	4
5.4	.3	1.6	1.2	11	43	99	4
7.5	.4	1.9	1.7	1	43	66	5
			Catalina clay				
4.7	.3	1.6	.4	>898	100	42	4
4.9	.2	1.7	.5	412	103	36	4
5.5	.2	1.6	.7	155	85	33	4
6.0	.2	1.5	.8	119	75	38	4
			Humatas clay				
4.8	.2	1.6	.5	150	103	45	3
5.0	.2	1.7	.6	124	103	42	4
5.6	.2	1.5	.5	21	91	38	3
6.0	.2	1.5	.7	17	86	37	4
			Coto clay				
4.5	.2	1.4	.5	646	103	45	4
5.0	.2	1.3	.4	265	102	41	4
5.6	.2	1.5	.6	48	103	42	4
6.0	.2	1.5	.8	46	93	29	4

Manganese content of the plant material was relatively high at very low soil pH values, but there was no clear evidence of either Mn toxicity in the unlimed soil or of Mn deficiency in the highly limed soil.

Lucedale Sandy Loam

Sudangrass and soybeans responded sharply to increasing soil pH in the lower range (figure 6) but not above about pH 5.8. Soil solution Al activity was high at very low soil pH levels, but decreased rapidly as pH increased from about 4.7 (table 3). Since Mn level in the soil solution

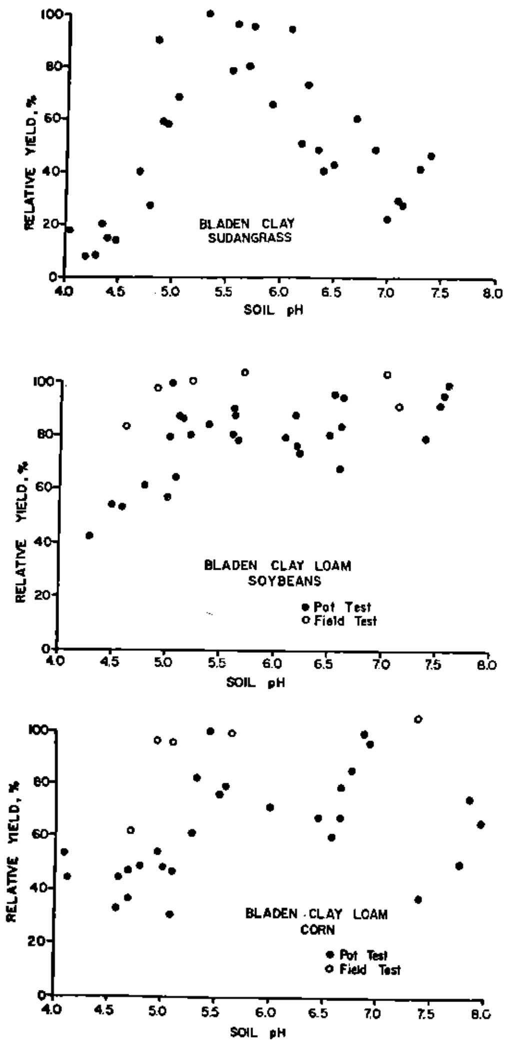

FIG. 4. – Relationship between soil pH and yield of three test crops on Bladen soil.

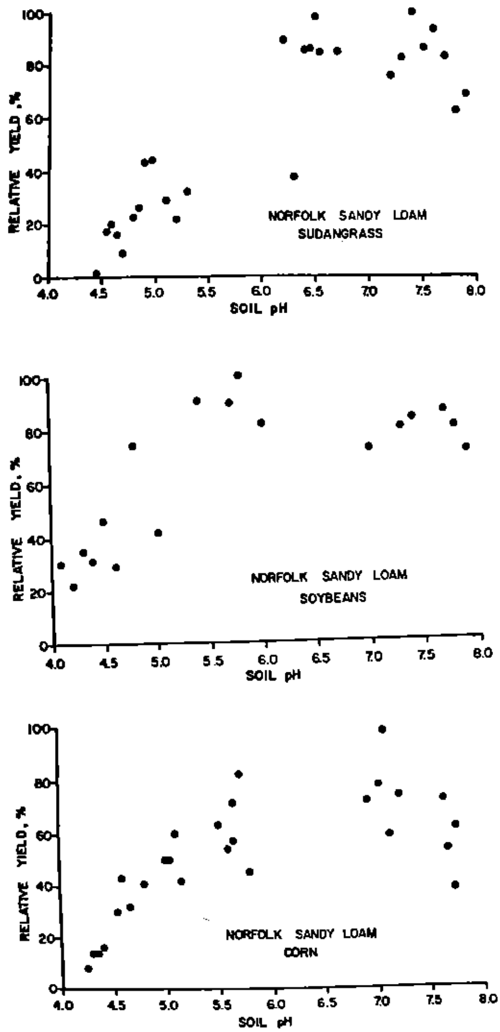

FIG. 5.—Relationship between soil pH and yield of three test crops on Norfolk soil.

was low except in the most acid treatments, and Mn content of the plant material did not appear excessive (tables 5, 7), possibly the observed response of sudangrass and soybeans to liming this soil was due to correcting Al toxicity.

Corn, however, had no clear response pattern. Experimental error was high, as shown by the data point scatter. Neither soil solution nor plant composition results adequately explain this behavior. Soil-solution Al activity was high at the lower pH levels, ranging up to 184 μM. At similar levels of activity, corn growth was severely limited in some of the other soils, e.g., Bladen. Both Mn and Zn contents of the plant material were unusually high (>898 p/m and >300 p/m, respectively) when grown on Lucedale soil at pH levels of about 4.0 (table 6), but were within the normal range when soil pH was about 5.0. Thus, the lack of corn response to liming Lucedale soil could be due to either 1) response being obscured by the high experimental error, or 2) some limiting growth factor that was not dependent upon soil pH.

Humatas Clay

Responses of the three test crops to liming Humatas soil are shown in figure 7. Sudangrass gave a tremendous yield increase, from no growth

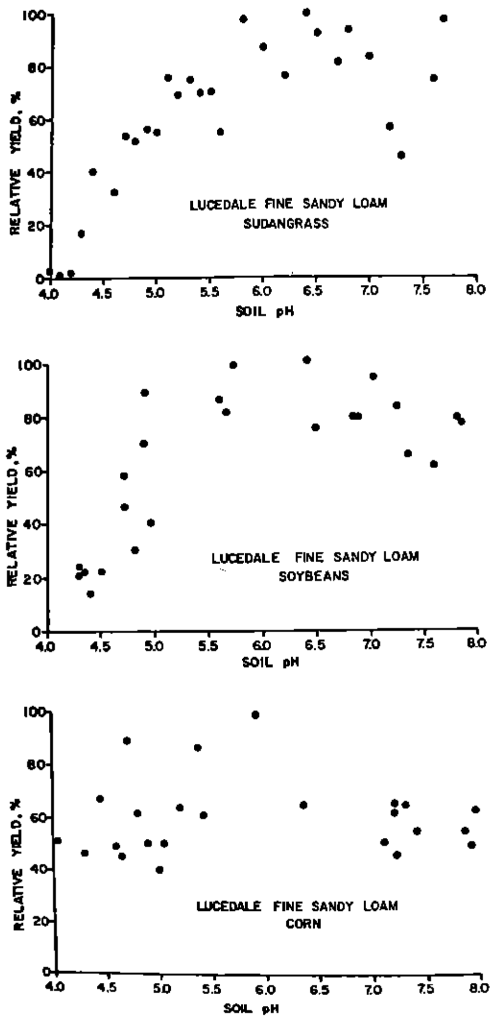

FIG. 6.—Relationship between soil pH and yield of three test crops on Lucedale soil.

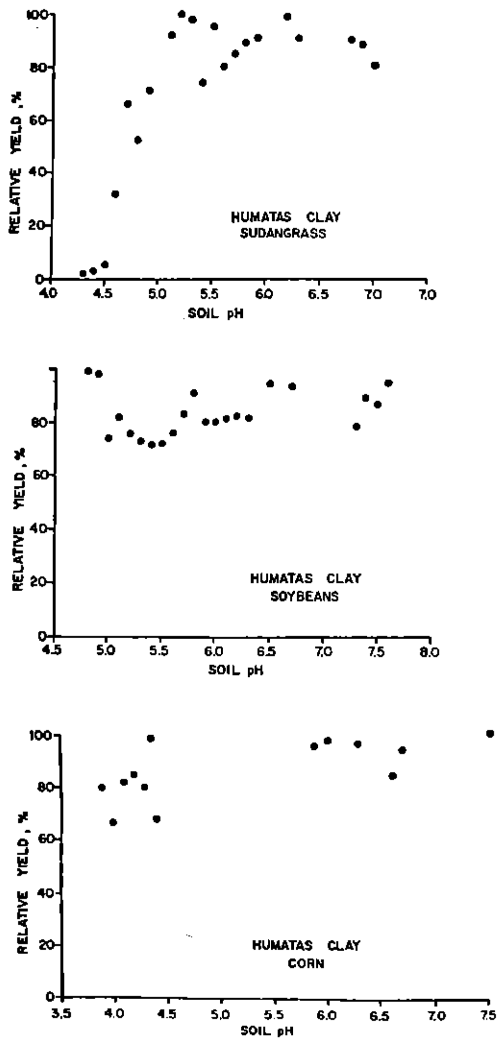

FIG. 7.—Relationship between soil pH and yield of three test crops on Humatas soil.

at soil pH of 4.4 to maximum yield at about pH 5.5. Corn and soybeans showed no clear response over the same pH range, although corn tended to respond. In this soil neither Mn nor Zn toxicities were possible limiting factors (tables 4 and 6) and Al nearly disappeared from the soil solution at pH 4.9 (table 4 and figure 1). Thus, observed yield responses are consistent with measured soil characteristics, and are attributed to neutralization of soluble Al.

Catalina Clay

Yield responses of the three test crops to lime application are shown in figure 8. Sudangrass and corn yields increased sharply as soil pH increased at the very low levels, after which there was no further effect of liming. The behavior of soybeans was more difficult to define due to the wide data point scatter.

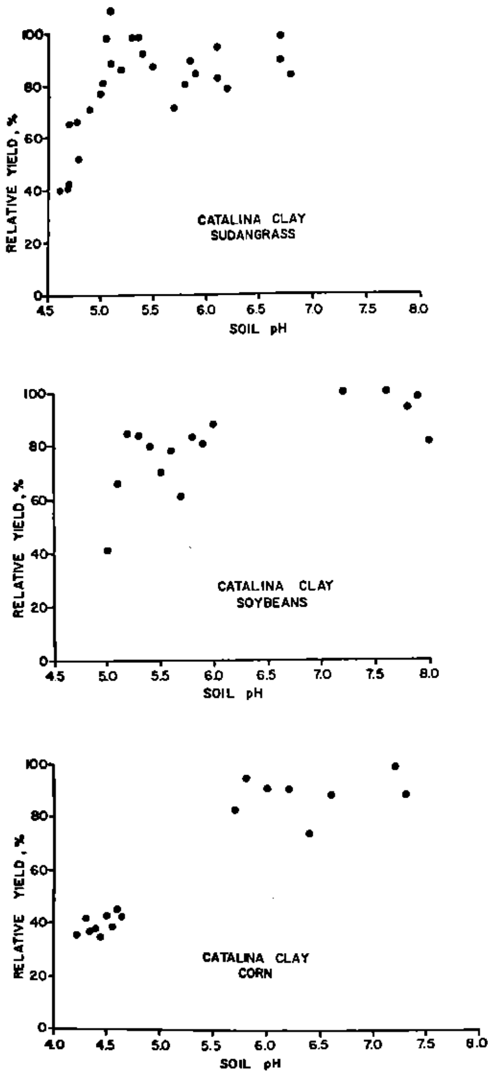

FIG. 8.—Relationship between soil pH and yield of three test crops on Catalina soil.

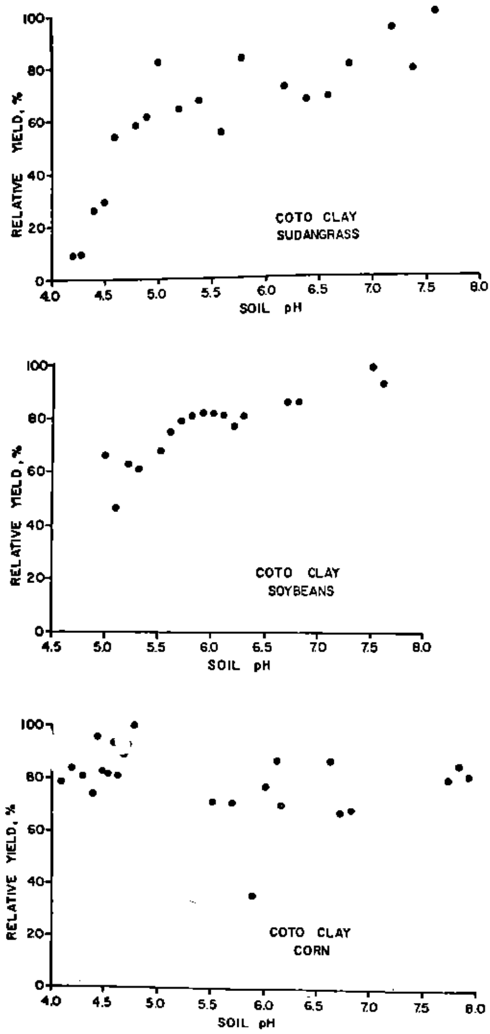

FIG. 9.—Relationship between soil pH and yield of three test crops on Coto soil.

In this soil solution Al activity was relatively low, and Mn seems to have had a definite role. This agreed with plant composition results (tables 5 through 7), which show Mn content of all plant materials to be extremely high at soil pH levels of about 5.0 or lower.

Soybean yield responded to increasing soil pH at least through pH 6.0. Unfortunately, soil pH values of this soil had shifted when the soybean test crop was planted, and pH levels below 5.0 are not represented. However, the data cannot be correlated clearly with results reported by Martini et al. (18), who found that maximum soybean yield on five

Oxisols in southern Brazil was usually reached when soils were limed to pH 5.2 to 5.7. Their results are generally consistent with those reported by Hanh (Aluminum and manganese toxicity to soybeans [*Glycine max* L., Merrill] M. S. thesis, Auburn University, Auburn, Alabama, 1973) for highly weathered and leached soils of the southeastern U. S., and with the optimum soil pH range reported by Kamprath (16) for soybeans growing on Ultisols in North Carolina. In the field experiments in southern Brazil (18), soybeans responded to liming five Oxisols where initial soil pH ranged from 4.4 to 5.4. It was concluded from these results and from pot studies with two of the soils that both Al and Mn toxicities were probably involved in some of the soils. Their results indicated that 1,000 p/m Mn in the plant would be toxic. This approximate level was reported by Hanh, who found toxicity symptoms and depression of top growth when Mn content of leaves increased to 750 p/m.

Thus, in the Catalina soil Mn toxicity apparently was the primary cause of soybean yield depression at soil pH values below about 6.0. The problem of shifting soil pH is evident in the corn response curve of figure 8. The gap between soil pH values of about 4.8 and 5.8 makes it impossible to locate more than an approximate local maximum, which appears to lie at about pH 5.5. Here again, soil solution Al level cannot adequately explain the response of corn to liming, and Mn must have played a dominant role. This was supported by the Mn content of corn tissue grown at pH levels above 5.0 (table 6) where Al in this soil solution would be an insignificant factor.

Coto Clay

Like the other Oxisol (Catalina), sudangrass grown on Coto soil responded to liming, soybeans responded less and the increase persisted to a higher pH level, while corn gave no response (figure 9).

Sudangrass yield appeared to reach a maximum at a pH of about 5.3 after increasing very sharply with increasing pH from just above 4. Manganese content of the plant material was very high at soil pH values up to and slightly above 5 (table 5). Aluminum activity in the soil solution was relatively low even at soil pH levels where yield was depressed. It thus seems likely that Mn toxicity was important in sudangrass behavior on this soil, although Al toxicity probably was involved also at very low pH values.

Soybean yield on the Coto soil tended to increase at a relatively constant rate throughout the range tested. This response cannot be explained by Mn toxicity based on plant composition, and a full explanation for this response is not possible at this time.

Complete lack of response by corn to liming the Coto, even though pH values as low as 4.2 were measured, is also an enigma. At that value, Al activity should have been sufficiently high (196 μM) to depress yield. Also, Mn content of the corn tissue, even at pH 4.5, was high.

OVERLIMING

The results presented in figures 4 through 9 support the conclusion that overliming is not a common hazard among representative upland soils of Puerto Rico or the southeastern U. S. Only one crop, sudangrass, on only one soil, Bladen, showed a clear decline in yield as soil pH was increased above 6. This is consistent with previously reported results (23).

RESUMEN

El comportamiento de tres especies de plantas: yerba Sudán (sorgo sudanense), sojas y maíz, sembradas en suelos ácidos del sureste de los Estados Unidos y de Puerto Rico, se estudió en condiciones de invernadero. Las plantas se sembraron en tiestos. A los suelos se les administraron varios niveles de encalado para que el pH variara de 3.9 a 6.7, y el contenido en aluminio entre 0 y 5.66 miliequivalentes por 100 g. de suelo.

Se recolectaron datos de la producción de materia seca correlacionada con el pH. Este también se correlacionó con la actividad iónica del aluminio y el manganeso en la solución de los distintos suelos. De los seis suelos usados, dos (Catalina y Coto, de Puerto Rico), se clasificaron como Oxisols y los otros cuatro (Bladen, Lucedale y Norfolk, de Estados Unidos y Humatas, de Puerto Rico) como Ultisols.

Los datos relativos a los distintos suelos mostraron diferencias notables en la actividad iónica. Los Oxisols mostraron gran actividad iónica del manganeso, mientras que en el caso de los Ultisols el aluminio fue más activo. Los suelos de Puerto Rico arrojaron mayor actividad iónica, tanto del aluminio como del manganeso, al compararse con los del sureste de los Estados Unidos.

De las tres especies de plantas estudiadas, la yerba Sudán pareció ser la más sensitiva a los valores bajos de pH y a las altas concentraciones de aluminio. Por otro lado, las sojas y el maíz respondieron en forma parecida en algunos suelos, pero variaron en otros.

En términos generales puede decirse que se observaron tres patrones de respuesta, pero no fue posible establecer un patrón definido entre especies o entre suelos. A base de la frecuencia en que ocurrieron, los tres patrones de respuesta fueron los siguientes: 1) aumento en la producción a medida que ascendía el pH, lográndose el mayor aumento entre pH 5 y 6, seguido por una muy leve respuesta a pH superior a 6; 2) ninguna respuesta a ascensos en el pH; 3) aumento constante en la producción a medida que ascendía el pH hasta un máximo entre 5 y 6, seguido por una disminución en producción a pH que se aproxime a 7.

Los datos confirman la teoría de que el pH crítico para el crecimiento de las plantas es corrientemente más bajo en los suelos de Puerto Rico que en los del sureste de los Estados Unidos. También puede concluirse que la experiencia obtenida con el encalado en zonas templadas pudiera utilizarse en zonas tropicales si se toman las debidas providencias.

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