THE JOURNAL OF AGRICULTURE
OF THE UNIVERSITY OF PUERTO RICO

Issued quarterly by the Agricultural Experiment Station of the University of Puerto Rico, for the publication of articles by members of its personnel, or others, dealing with any of the more technical aspects of scientific agriculture in Puerto Rico or the Caribbean Area

Vol. LXIV JANUARY 1980 No. 1

An Approach to Minimize Al Toxicity in Ultisols through Organic Matter Additions[1, 2]

Abdul Wahab and M. A. Lugo-López[3]

ABSTRACT

Exploratory studies were conducted to determine the mode of action of organic matter on the immobilization of Al in an acid Ultisol. Ground coffee leaves and pangola grass were evaluated against various rates of $Ca(OH)_2$. Regression analyses showed correlation coefficients of over 0.91 when $Ca(OH)_2$ was the independent variable and exchangeable Al, pH and dry matter production were the dependent variables. An overall examination of the data reveals that acid Ultisols high in exchangeable Al inhibit plant growth and limit yields. The addition of coffee leaves decreased soil acidity and soil exchangeable Al. Coffee leaves were apparently more effective than pangola grass in inhibiting Al toxicity.

INTRODUCTION

The work herein reported was undertaken in an effort to determine the role of organic matter in the alleviation and/or inhibition of Al toxicity in an Ultisol. The main objective was to determine the effect of organic matter on the immobilization of active Al in an acid Ultisol. To determine the mode of action of organic matter on Al, requires a deep study of possible chemical bonds between the two agents.

The approach was to neutralize exchangeable soil Al to approximately the same extent by addition of different rates of $Ca(OH)_2$ and two organic matter sources. From earlier studies[4] it was found that 1 meq/100 g

[1] Submitted to Editorial Board September 26, 1977.

[2] Joint contribution from the Department of Agronomy, Cornell University, Ithaca, New York, and the Agricultural Experiment Station, University of Puerto Rico, Mayagüez Campus, Río Piedras, Puerto Rico. This study was part of the investigations supported by the USAID under research contract ta-c-1104 entitled "Soil fertility in the humid tropics."

[3] Former Assistant Soil Scientist, now Agricultural Research Specialist, Inter American Institute of Agricultural Sciences, OAS, Kingston, Jamaica, and Professor-Soil Scientist, (Ret., now Consultant, Cornell University), Agricultural Experiment Station, University of Puerto Rico, Mayagüez, P. R. The authors wish to acknowledge the cooperation of Mr. E. J. Brenes, Associate Soil Scientist (Ret.), Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P.R.

[4] Santiago, Publio, The Role of Organic Matter in the Inhibition of Aluminum Toxicity in an Ultisol. Unpublished M.S. Thesis, University of Puerto Rico, Mayagüez Campus, 1972.

$Ca(OH)_2$ was approximately equivalent to 1% dried ground coffee leaves in Al neutralizing power.

MATERIALS AND METHODS

Growth rates of sorghum plants growing on soils amended with $Ca(OH)_2$, coffee leaves and Pangola grass were compared. All experimental work was carried out in the greenhouse and laboratories of the Agricultural Experiment Station at Río Piedras, Puerto Rico.

The soil has been classified as Humatas clay, an Ultisol from Orocovis having a pH of 3.80 and Al saturation (Al/Σ cations) of 69%. A blanket application of plant nutrients to the soil was made as follows, p/m: N, 300; P, 100; K, 127; S, 40; Mg, 20; Mn, 10; Zn, 5; B, 2.5; Fe, 0.5; and Mo, 0.1.

Treatments were as follows: Check; 1, 3, 5, and 7 meq $Ca(OH)_2$/100 g of oven dried soil; 1, 3, 5, and 7% finely ground partially decomposed coffee leaves; and 1, 3, 5, and 7% finely ground Pangola grass. After the application of treatment differentials, the soils were brought to field capacity and incubated for 14 days at 25° C.

TABLE 1.—*Effect of different rates of $Ca(OH)_2$ on soil pH, soil exchangeable Al, dry matter production and plant height at 31 days*

$Ca(OH)_2$ added to soil	pH	Al saturation of soil (Al/Σ cations)	Dry matter/ plant	Plant height
Meq/100 g		%	*Mg*	*Cm*
0	3.80	69	14	5.2
1	3.90	65	29	8.3
3	4.15	40	80	14.5
5	4.35	20	511	41.5
7	4.75	13	1,330	57.9

A randomized complete block design consisting of 4 blocks and 13 soil treatments was followed. Fifty-two pots were used, each one containing 1,350 g of oven-dried soil. Sorghum, variety RS671, was used as indicator plant. Germination was 80% at planting. Twenty seeds were planted per pot; and after germination, seedlings were randomly thinned to 10 per pot. Throughout the experimental period (31 days), the soil was watered twice daily. Spectracide (Diazinon) was applied frequently to control the armyworm.

Measurements of plant height were made at weekly intervals beginning 14 days after seeds were planted. At the conclusion of the experiment the aerial portions of the plants were dried at 70° C for 48 h, then weighed.

After an incubation period of 14 days at 25° C, soils were analyzed for the following: pH, Ca + Mg, CEC, K, P, Mn, and Al. At the end of the experiment (31 days), composites of dried leaves were obtained by mixing materials from the four replicates of each treatment. Each sample was analyzed for the following: P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, Al, Mo, Sr, Ba and Na. Regression analyses were made.

RESULTS AND DISCUSSIONS

Table 1 shows that the percentage of exchangeable Al saturation of the soil was at a minimum at the highest lime application rate, while soil pH value and dry matter production were increased by the lime application.

Regression analyses showed correlation coefficients of over 0.91 in all cases with $Ca(OH)_2$ as the independent variable. The analyses of variance for the regression reveal highly significant F values in pH, percentage of

TABLE 2.—*Effect of different rates of coffee leaves on soil pH, soil exchangeable Al, dry matter production and plant height at 31 days*

Coffee leaves added to soil	pH	Al saturation of soil (Al/Σ cations)	Dry matter/ plant	Plant height
%		%	*Mg*	*Cm*
0	3.80	69	14	5.2
1	3.85	61	30	8.4
3	4.10	29	304	28.4
5	4.20	18	1,894	60.1
7	4.40	8	2,409	61.3

TABLE 3.—*Effect of different rates of pangola grass on soil pH, soil exchangeable Al, dry matter production and plant height at 31 days*

Pangola grass added to soil	pH	Al saturation of soil (Al/Σ cations)	Dry matter/ plant	Plant height
%		%	*Mg*	*Cm*
0	3.80	69	14	5.2
1	3.70	61	27	7.6
3	3.80	54	30	7.9
5	4.05	48	167	24.4
7	4.15	34	582	41.4

Al saturation and plant height. F values for dry matter were significant. Thus, the values of the dependent variables can be predicted with a high degree of precision on the basis of the independent variable, i.e., $Ca(OH)_2$ added to the soil.

Table 2 shows that the greatest increases in dry matter production and plant height occurred when coffee leaves were increased from 3 to 5%. Soil pH increased with each increment of coffee leaves. The greatest increase in soil pH (0.25 unit) occurred as the organic matter was increased from 1 to 3%. Accompanying this pH increase was a 32% reduction in the percentage of Al saturation of the soil and a 10-fold increase in dry matter production. Highest pH values and plant growth were obtained in the treatment receiving 7% coffee leaves. Regression analyses of the data also reveal a very high degree of correlation. F values were highly significant, respectively, just as in the case of $Ca(OH)_2$ (table 1).

Table 3 shows that the percentage of aluminum saturation of the soil was appreciably decreased by the addition of Pangola grass; the regression was highly significant. Soil pH was also affected; the regression was significant. Significant increases in plant height occurred as the percentage of Pangola grass in the soil was increased from 3 to 5 and from 5 to 7%. Analysis of variance for the regression of Pangola additions on dry matter production was not significant.

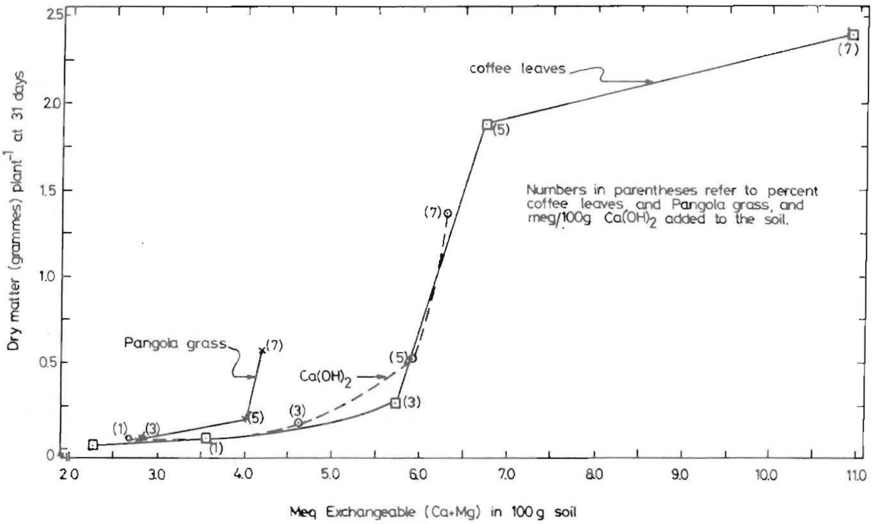

FIG. 1.—Relationship between plant growth and soil exchangeable bases (Ca + Mg) following application of 1, 3, 5, and 7% coffee leaves and pangola grass, and 1, 3, 5, and 7 Meq/100g Ca $(OH)_2$.

Figure 1 shows that at any given number of meq. of $Ca(OH)_2$/100 g soil, coffee leaves or Pangola grass, added to the soil, the coffee leaves resulted in the highest percentage of soil exchangeable bases. Pangola grass resulted in the lowest increase in soil exchangeable bases. The addition to the soil of 7% plant material or 7 meq $Ca(OH)_2$/100 g followed by a 2-week incubation period at 25° C resulted in 10.91, 4.19 and 6.30 meq exchangeable bases for coffee leaves, Pangola grass and $Ca(OH)_2$, respectively. Plant growth was essentially the same with treatments of $Ca(OH)_2$ and coffee leaves, which resulted in 2.3 to 6.3 meq exchangeable bases. Increase in plant growth beyond 6.3 meq exchangeable bases was probably due to the concurrent increase of Ca and Mg and possibly K also in the soil as coffee leaves were increased from 5 to 7%.

Figure 2 shows that within the pH range of 3.7 to 4.4, plant growth was greatest in soils amended with coffee leaves. The soil pH increased from 3.80 to 4.75 by the addition of 7 meq $Ca(OH)_2$. However, growth rates at the latter pH value were markedly lower than those obtained at pH 4.4 when coffee leaves were added to the soil.

From figure 3 it is evident that at a given level of exchangeable Ca + Mg, the soil treated with coffee leaves exhibited a lower pH than the one treated with $Ca(OH)_2$.

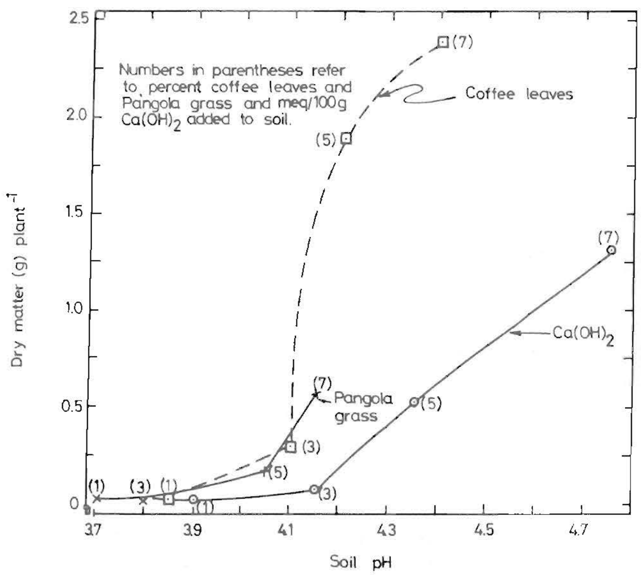

FIG. 2.—Relationship between dry matter accumulation and soil pH as adjusted by equivalent rates of coffee leaves and pangola grass, and $Ca(OH)_2$ respectively.

In general, plant growth was less inhibited as the exchangeable soil Al decreased below 4 meq/100 g. Maximum plant growth occurred in the treatment receiving 7% coffee leaves resulting in 1.02 meq/100 g exchangeable Al. By comparison, addition to the soil of 7% Pangola grass or 7 meq $Ca(OH)_2$, lowered the soil exchangeable Al content to 3.3 and 0.92 meq/100 g, respectively.

Tables 4, 5 and 6 show the relation between soil pH and foliar composition. Upon inspection of the data it appears as one characteristic feature that Al, Fe and Na accumulation were highest in the control and in treatments containing 1% coffee leaves, 1% Pangola grass and 1 meq

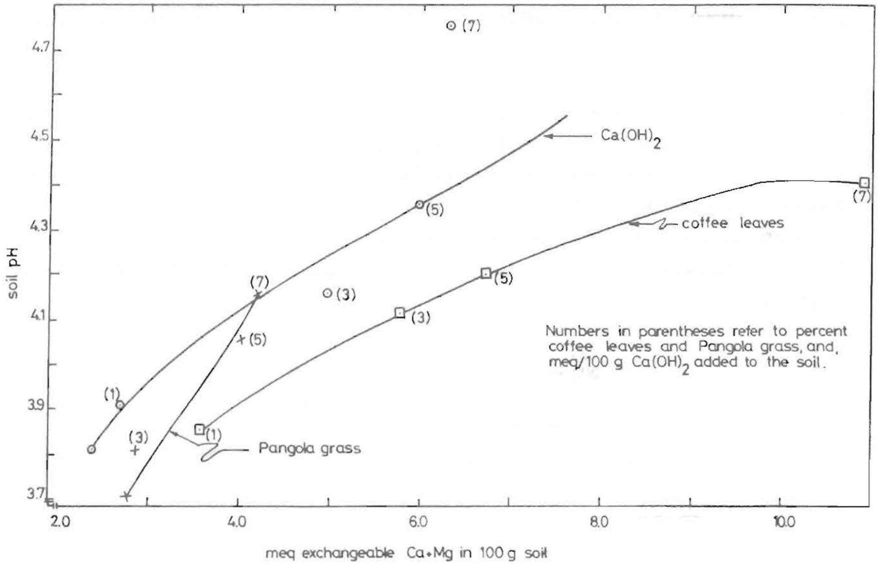

FIG. 3.—Relation between soil pH and exchangeable Ca + Mg at different rates of application to the soil of Ca $(OH)_2$ coffee leaves and pangola grass.

TABLE 4.—*Effect of different rates of $Ca(OH)_2$ on soil pH and foliar composition of sorghum*

$Ca(OH)_2$ added to soil	Soil pH	Foliar composition							
		P	K	Ca	Mg	Mn	Al	Na	Fe
Meq/100 g				%				*P/m*	
0	3.80	0.34	1.21	0.24	0.21	234	852	1,120	356
1	3.90	0.23	1.16	0.40	0.16	191	1,525	804	689
3	4.15	0.11	0.85	0.32	0.05	93	538	168	548
5	4.35	0.18	2.15	0.51	0.09	164	202	150	153
7	4.75	0.19	2.10	0.54	0.15	173	133	94	117

TABLE 5.—*Effect of different rates of coffee leaves on soil pH and foliar composition of sorghum*

Coffee leaves added to soil	Soil pH	Foliar composition							
		P	K	Ca	Mg	Mn	Al	Na	Fe
%				%				*P/m*	
0	3.80	0.34	1.21	0.24	0.21	234	852	1,120	356
1	3.85	0.29	1.02	0.32	0.19	282	1,530	493	1,000
3	4.10	0.22	2.25	0.31	0.11	246	132	75	134
5	4.20	0.17	1.65	0.48	0.29	374	226	64	205
7	4.40	0.19	1.77	0.38	0.34	365	214	162	176

$Ca(OH)_2$ respectively. Levels of Na, Fe and Al generally decreased as soil pH increased. Potassium levels increased as levels of $Ca(OH)_2$ increased. Manganese content declined appreciably following the application of $Ca(OH)_2$, remained essentially unchanged following the addition of Pangola grass, and increased appreciably in treatments receiving coffee leaves. However, the only statistically significant effects were as follows: $Ca(OH)_2$ treatments decreased foliar Na; coffee leaves decreased P levels; and Pangola grass treatments increased K and decreased Ca.

The results obtained thus far are in general agreement with those reported earlier. Acid Ultisols high in soil exchangeable Al inhibit plant growth and limit yields of many crops. However, soils could be amended to raise pH value to levels at which the solubility of Al is decreased. Liming is perhaps the most widespread method currently employed to neutralize soil acidity. The studies herein reported have shown that addition to the soil of organic matter, in the form of decomposed coffee leaves, results in decreased soil acidity and soil exchangeable Al. Further, coffee leaves were apparently more effective in inhibiting Al toxicity than were Pangola grass and $Ca(OH)_2$. It is possible that organic matter reduces the solubility of Al through complex formation resulting in less Al in soil solution. This may be one reason why plants accumulated more dry matter at a lower pH in soils amended with coffee leaves than in soils amended with lime.

TABLE 6.—*Effect of different rates of Pangola grass on soil pH and foliar composition of sorghum*

Pangola grass added to soil	Soil pH	Foliar composition							
		P	K	Ca	Mg	Mn	Al	Na	Fe
%		%				P/m			
0	3.80	0.34	1.21	0.24	0.21	34	852	1,120	356
1	3.70	0.23	1.16	0.25	0.20	273	1,565	2,248	956
3	3.80	0.22	1.26	0.20	0.20	247	538	2,434	238
5	4.05	0.22	2.20	0.15	0.21	218	182	142	149
7	4.15	0.24	3.22	0.13	0.22	228	272	204	172

Action of organic matter in the inhibition of Al toxicity requires further studies. However, the use of coffee leaves at 3 to 5% levels, could be recommended as a soil amendment, especially in Ultisols where this crop is grown and where liming is not economically feasible.

RESUMEN

Se realizaron estudios preliminares para determinar cómo actúa la materia orgánica en el proceso de inmovilización del aluminio en un Ultisol ácido. Se comparó el uso de hojas molidas de café y de yerba

pangola con diferentes cantidades de $Ca(OH)_2$. Los análisis de regresión revelaron coeficientes de correlación de más de 0.91 cuando el $Ca(OH)_2$ se consideró como la variable independiente, y el aluminio cambiable, el pH y la producción de materia seca como las variables dependientes. Un examen de los datos revela que en los Ultisols ácidos y ricos en aluminio cambiable se inhibe grandemente el crecimiento de las plantas y se limitan sus rendimientos. La adición de hojas de café baja tanto la acidez del suelo como el aluminio cambiable. El uso de hojas de café fue aparentemente más eficaz que el de la yerba pangola para reducir la toxicidad que puede atribuirse al aluminio del suelo. Se puede recomendar el uso de hojas de café para estos fines, si las hay disponibles en los Ultisols ácidos, donde no sea económicamente viable el uso de la cal.