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Organic matter and its relation to maize crops on acid soils of Colombia

L. A. Rojas[1)], J. E. Baquero[2)], M. Ramírez[1)], F. Rodriquez[1)] and G. Roveda[1)]

[1)] *Colombian Corporation of Agricultural Research, CORPOICA A.A. 240142 Bogotá , Colombia, lrojas@corpoica.org.co*

[2)] *Colombian Corporation of Agricultural Research, CORPOICA A.A. , A.A. 3129, Villavicencio-Meta, Colombia, jbaquero@corpoica.org.co*

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Abstract

To examine genotype by environment interactions with respect to the adaptation of maize (*Zea mays* L.) cultivars on acid soils of the tropics characterised by aluminium toxicity and low availability of nitrogen and phosphorus, a long term field experiment was carried out on an Oxisol of the Eastern plains of Colombia. Treatments applied were as follows: two sources of organic matter (OM; chicken manure and cowpea shoots at 5 t ha^{-1} each), two phosphorus rates (25 and 50 kg P ha^{-1}), two levels of limestone (0 and 1.5 t ha^{-1}) and three maize varieties with differential tolerance to soil acidity. The experimental results showed that grain yields remained fairly stable with time at all treatment levels. The application of OM combined with lime and P produced the highest yield increment compared to the unamended control. The maize cultivar Sikuani by far out-yielded the other cultivars in the unamended control treatment. Particularly the soil acidity-sensitive cultivar ICA had very low yields in the check treatment. On the other hand, cultivar ICA had the largest grain-yield response to lime, P and OM applications followed by the cultivars Clavito and Sikuani. Application of lime produced the greatest yield increase in cultivar ICA. Application of OM further significantly enhanced maize yields, whereas the effect of Cowpea green manure was rather small. Mean grain yields over the five seasons at the highest level of soil amendments (combination of lime, P and OM) were 4843, 3879, and 4741 kg ha^{-1} for ICA, Clavito, and Sikuani, respectively. With combined lime/organic matter application the available P and the exchangeable aluminium in the soil changed from 6 to 32 mg kg^{-1} and from 2.1 to 0.2 $cmol_c$ kg^{-1}, respectively, whereas the Al, Ca, and Mg saturation percentages changed from 73 to 6%, 10 to 35%, and 3.7 to 9%, respectively.

Introduction

The Eastern Plains (Llanos Orientales) of Colombia comprise an area of about 26 million hectares. The most suitable area for agriculture has an extension of about 4.6 million hectares. Maize has been a suitable crop for both, large and small farmers of this region because it can be used by humans and animals at a low level of mechanisation and industrial processing (Valencia, 1992). However, the main consequences of low soil fertility, such as clay minerals with low cation exchange capacity (CEC), high acidity, high Al, low organic matter (OM) content, and low availability of plant nutrients, particularly of phosphorus (P; Salinas, 1984), require the application of lime and mineral fertilisers thereby increasing the production costs for maize in that region. The introduction of soil acidity-tolerant maize cultivars like ICA-Sikuani V-110 (Sikuani) has allowed to reduce lime applications, providing a partial solution to soil acidity as a restriction to crop growth. However, this approach did not solve the P fixation problem. It is also unclear whether the long-term use of soil acidity-tolerant and/or P-efficient cultivars will enhance soil acidification or allow sustainable crop production on these soils. The main objective of this research was to evaluate agronomic practices, such as the application of lime, mineral P and OM on soil Al and P availability in a long term experiment with different maize cultivars.

Materials and methods

The field experiments were carried out on a Tropeptic Haplorthox soil from the piedmont of the Eastern acid plains of Colombia, at 320 m.a.s.l., with a mean temperature of 27^{o} C and a relative humidity of 70-90%. The soil characteristics are shown in Table 1. Treatments were as follows: three organic matter rates (no OM, chicken manure and cowpea shoots at 5 t ha^{-1} each, incorporated into the soil), two levels of P (25 and 50 kg P ha^{-1} applied as calcium superphosphate), two limestone levels (0 and 1.5 t ha^{-1}) and three maize varieties with a different Al resistance (Sikuani, an improved soil acidity-tolerant cultivar), Clavito (a local cultivar) and ICA V-109 (an acid-soil sensitive cultivar, ICA). The experimental design was factorial with randomised complete blocks of 36 treatments and 4 replications totalling 144 plots. A basic fertilisation was performed by adding N, K, Ca, Mg, Zn and B (at levels of 100, 70, 60, 30, 1.3 and 0.3 kg ha^{-1}) to the soil. Maize was grown during five consecutive semesters, from 97a season through 99a season. In each year soil chemical parameters were determined at the anthesis stage of the crop and grain yield was measured at harvest.

Results and discussion

The results did not show any effect of the varieties on soil characteristics during the five semesters of maize cropping (Table 1). It was observed that individual treatments of lime and organic matter (especially chicken manure) decreased the exchangeable Al in the soil diminishing therefore both, soil acidity and Al saturation percentage. The latter parameter decreased from 72 to 4.2%. The combination of lime and chicken manure led to a decrease of exchangeable Al to undetectable levels.

Table 1. Soil chemical parameters of the experimental soil over time.

Time	pH	OM %	Al	Ca	Mg	K	Na	CEC
					cmol$_c$ kg^{-1}			
I.T.[1)]	4.5	1.8	2.1	0.4	0.15	0.09	0.13	2.90
A.T.[2)]	5.2	1.9	0.2	1.1	0.29	0.17	0.14	3.15

	Al	Ca	Mg	K	P	sand	silt	Clay
	Saturation %			mg kg^{-1}			%	
I.T.[1)]	73	10.0	3.7	2.2	6.0	50	30	20
A.T.[2)]	6	35.0	9.0	5.4	32.0			

[1)] I.T.: Initial time at the onset of the experiment
[2)]A.T.: After five growing seasons and combined treatment applications

Lime and organic matter increased the exchangeable Ca and Ca saturation percentage from 14 to 36% and of Mg from 3.7 to 9%. According to ICA (1992), the adequate mean values of these parameters in the soil should be 30-50% for Ca and 15-25% for Mg. CEC increased from 2.90 to 3.15 cmol$_c$ kg^{-1}.This may still be classified as very low. However, the colloidal complex of the soil became saturated mainly with Ca and Mg instead of toxic Al. Lime (1.5 t ha^{-1}) and P application (50 kg ha^{-1}) did not increase plant available soil P. Phosphorus availability was increased with either chicken manure (with or without lime) or cowpea with lime: soil P concentration increased from 6 to 32 mg kg^{-1} after five semesters of treatment application.

Possibly due to their fast mineralisation, the organic materials used in the present study did not lead to increases in soil organic matter, however, the decrease in Al and the increase of exchangeable bases and P led to an overall increase in soil fertility.

Mean grain yields of the three varieties across all treatments were in the order Sikuani > ICA > Clavito with values of 3586, 3220 and 2645 kg ha^{-1}, respectively. Cultivar Sikuani by far out-yielded the other cultivars in the unamended control (‘check’) treatment (data not shown). Particularly the soil acidity-sensitive cultivar ICA had very low yields in the check treatment (Fig. 1). On the other hand, cultivar ICA had the largest grain-yield response to lime, P and OM applications followed by the cultivars Clavito and Sikuani.

Application of lime produced the greatest yield increase in cultivar ICA. Application of OM further significantly enhanced maize yields, whereas the effect of cowpea green manure was rather small. Mean grain yields over the five seasons at full soil correction (combination of lime, P and OM applications) were 4843, 3879, and 4741 kg ha^{-1} for ICA, Clavito, and Sikuani, respectively. This clearly reflects the superiority of the improved *versus* the local cultivar (Clavito) and confirms that breeding for soil acidity-tolerance did not lead to a loss in productivity at the high input level (Sikuani)

Overall, the results clearly show that the breeding and use of soil acidity-tolerant cultivars in combination with moderate rates of lime, P and organic matter application represent an important component of the sustainable use of the acid soils of the Eastern plains of Colombia for maize production. Further research is needed to better understand the complex interactions between genotype, organic matter, and climate on plant nutrient uptake and soil chemical and physical parameters.

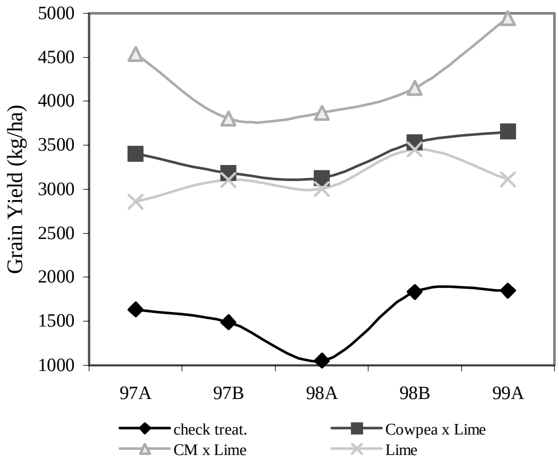

Figure 1. Effect of organic matter and lime applications on the grain yield of soil acidity-sensitive maize cultivar ICA V-109.

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