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Presence of The Exchangeable Aluminium in Lowland Soils Collected in The Maranhão State

Presença de Alumnío Trocável em Solos de Região de Baixada Coletados no Estado do Maranhão

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Abstract

The region includes from the Baixada Maranhense soils with high fertility and large agricultural potential. Although there is not adequate to increase productivity management system. This work aims to characterize chemically four soils (Vertisols) collected in the region and compare with a control soil (Argisolo). In a greenhouse-cultivated maize seedlings in the four soils. Analysis revealed high levels of nutrients and Al contents when compared with the ground control. At the same time, there was a high root growth, a common situation for plants grown in soils with low levels of aluminum. However, even at high levels of aluminum plant growth (the four soils) was not affected. This behavior can be explained by the presence of calcium and magnesium, which inhibit the aluminum toxicity in plants

Keywords: *Region of Baixada, corn, analysis, toxicity, aluminum.*

Resumo

A região da Baixada Maranhense inclui solos com alta fertilidade e largo potencial agrícola. Embora não exista sistema de manejo adequado para aumentar a produtividade. Este trabalho pretende caracterizar quimicamente quatro solos (Vertisolos) coletados na região e comparar com um solo controle (Argisolo). Em casa de vegetação, cultivou-se milho nos quatro solos estudados. Análises revelaram altos níveis de nutrientes e teores de Al, quando comparados com o solo controle. Ao mesmo tempo, foi verificado um alto crescimento de raiz, situação comum para plantas cultivadas em solos com baixos níveis de alumínio. Entretanto, mesmo com altos níveis de alumínio o crescimento da planta (nos quatro solos) não foi afetada. Este comportamento pode ser explicado pela presença de cálcio e magnésio, que inibem a toxidez de alumínio nas plantas

Palavras-chave: *Região de Baixada, milho, análise, toxicidade, alumínio.*

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1 Introdução

The toxicity of exchangeable aluminium (Al^{3+}) is probably one of the most important factors limiting plant growth in acid soils. The acidity by Al^{3+} it is an important component of the potential of tropical soils, exerts toxic effects on plant growth, mainly on the root system, reducing the absorption and translocation of nutrients in the plant and consequently crop productivity. According to FOY (1974), the elongation of the roots is prevented by virtue of the reduction of mitotic activity caused by aluminum, with subsequent increased susceptibility of the plant to water stress.

The species Al^{3+} occurs in high quantities in many regions of Brazil, among them is the region known as "Baixada Maranhense" in north of the country. This region has characteristics that differ from the other regions, mainly because of its wide variation in rainfall. The soils of the region were classified as Vertisoils, in hydromorphic environmental complexes and show a high spatial variability. About 2000 mm rainfall occur during the rainy season, 80% of which are substantially concentrated between January to May, become the soil anaerobic, which causes anaerobic conditions and reduction of soil ions e.g. Fe^{3+} Fe^{2+} (SILVA and MOURA, 2004). This situation favors the desorption of aluminum, which in its free form can be accumulated in the plant roots, where it interferes in the assimilation and redistribution of nutrients such as N, P, Ca and Mg (SALAMANCA et al., 2002).

In region exist un cycle of the humidity and dried caused by rainy period. During the dry season, a high evapotranspiration and low rainfall reduce the water availability to critical levels and cause the previously reduced soil elements to oxidize. Repeated year after year, this cycle changes the sorptive complex of the soil and at the same time is perceived increases acidity and levels of Ca and Mg as well as exchangable levels of Al (MEURER and ANGHINONI, 2002). The interpretation of soil chemical analyses, in these conditions, is prejudiced mainly when it is observed the growth and productivity of sensitive crops to the Al in soils with levels up to tenfold above the threshold values limit considered for the plants growth (KIRK, 2004).

Although there are large hopes and many expectations that the Maranhão lowlands may become a major food supplier capable of dealing with the nutritional deficiency of the local rural population, the farming system, based solely on maize and rice cropping produces yields far below expectations. This holds true especially in areas cropped for several years before field abandonment. The consequences of such land use (slash and burn practices) on soil fertility are still largely unknown which impedes founded recommendations concerning improved land-use practices. This situation is very unfortunate in a region exhibiting one of the lowest indices of human development in Brazil, in spite of its rich environmental resources (SILVA and MOURA, 2004).

The present study, aimed at filling this knowledge gap by investigating the multiple relationships of chemical soil fertility indicators both amongst themselves and with the growth of maize as an indicator crop.

2 Methodology

The study region are located in the northern mid-western state (Maranhão), lowlands constitute a transition zone between humid Amazonia and dry Northeast provinces of Brazil, covering large amplitude in soil and rainfall regimes. Situated between the 4o and the 1o of south latitude and 26° and 44° west longitude. show a homogeneous topography with elevations ranging from 0 to 80m, relative humidity near 90% and that climate ranked according Köeppen as Aw, with average air temperature always above the 18th Celsius and a rainfall with two seasons: a rainy and a dry (EMPRAPA, 1986).

Topsoil samples of four (I, II, III and IV) lowland soils classified by Vertisoils, with varying degrees of hydromorphism were collected at 0 to 20 cm depth in the dry season. A fifth soil (V) classified by Oxisoil was included as control for illustrative comparison. The soils (I, II, III, IV and V) were collected in Ap horizon, after were air dried and subsequently crushed to pass a 2-mm sieve. In the laboratory the samples were submitted the physical and chemical analyses according to Embrapa (1997): a) pH in H_2O and $CaCl_2$ in the relationship 1:2,5 (soil: liquid); b) Ca^{2+} and Mg^{3+} extracted by KCl 1 mol L^{-1} (proportion 1:20) and dosed by Atomic Absorption Spectrophotometer, AAS, Perkin Elmer; c) Available Na and K extracted by HCl 0,05 mol L^{-1} (proportion 1:10) and dosed by flame photometry; d) Al^{3+} extracted by KCl 1 mol L^{-1} (proportion 1:20) and dosed by titration, with NaOH 0,025 mol L^{-1}; e) Potential acidity (H + Al) extracted with $Ca(OAc)_2$ 1 mol L^{-1} to pH 7,0 (proportion 1:15) and dosed by titration; f) Available P extracted by Mehlich - 1 (HCl 0,05 mol L^{-1} + H_2SO_4 0,0125 mol L^{-1}) in the proportion 1:20 and dosed by calorimetric and g) Organic carbon for digestion obtains by $K_2Cr_2O_7$ and dosed by titration.

The exchangable levels of the Al were obtained by the following five methods: a) extraction through solution of KCl 1 mol L^{-1} and determination through titration with solution of NaOH 0,02 mol L^{-1}; b) extraction through solution of KCl 1 mol L^{-1} and determination through spectrometry of atomic emission for plasma (ICP-OES, Perkin Elmer, optima 3000); c) extraction through solution of $Na_2P_2O_7$ 0.025 mol L^{-1}, with subsequent determination through ICP; d) extraction of Al through solution of $CuCl_2$ 0.5 mol L^{-1}, with subsequent determination through ICP and e) extraction of Al through solution of NH_4Cl 1 mol L^{-1}, with subsequent determination through ICP.

The fertility of these soils was evaluated in a greenhouse experiment using maize (Zea mays L., cultivar AG 1051) planted in 2 dm^3 pots as bio-indicator. The investigation was carried out in a completely randomized bi-factorial design involving the five soils with and without a basic fertilization (N, P, K) with three replications each. Soil humidity was daily corrected to field capacity throughout the experiment. After 45 days, shoots and roots from maize crop were completely harvested and dried at 70°C to evaluate dry matter and nutrients levels (soil samples after maize havest no were analised). The report data were submitted to analysis of variance and post-hoc comparison of means with the Tukey test ($p < 0.05$).

3 Results and Discussion

The root, is the part most sensitive plants to excess Al, presents short, thick, weak, with apex thick and brown, there is formation of lateral roots whose growth is also reduced. However, when soil samples from the Baixada Maranhense are analyzed to determine the Al^{3+} levels are well above the critical levels of toxicity (0.5 $cmolcdm^{-3}$) at pH values equal to 5.0, Al saturation of 30 %, and mean values (0.6 $cmolcdm^{-3}$) found in soil under Cerrado of Central Brazil (PONTES, et al., 2010). Research proven and shown that even with high levels of Al, some crops are sensitive to the presence of Al, such as corn and watermelon, but was perceived have reasonable productivity when cultivated in soils of the Baixada Maranhense, no symptoms of toxicity. This indicates that the levels detected by-routine methods do not determine the actual toxicity of Al in these soils.

In the lowlands soils of the region presented expandable clay and silt accumulate in the depression zones. Due to their typically slow hydraulic conductivity, there is a water-logging for large periods of the rainy

Table 1. Physical and chemical characterization of four lowland soils (I – IV) and an Oxisoil (V), arranged in decreasing order of clay contents

Soil	C_{org}	Ca	M	K	H	BS [a]	Al	CEC		Ph	sand	silt	Cla
	dag.k	----------------cmol$_c$.kg^{-1} -----------							mg.	CaC	------ g.kg^{-1}-----		
I	1.8	5.0	6.0	0.25	3.8	11.2	6.8	21.8	11	4.1	40	240	720
II	2.3	9.1	7.5	0.21	2.6	16.8	7.0	26.4	8.5	4.6	50	240	710
III	1.7	4.8	4.6	0.20	1.1	9.6	8.0	18.7	16	4.6	90	330	580
IV	2.2	3.5	3.3	0.31	2.3	7.1	6.1	15.5	12	4.3	60	540	400
V	2.0	2.4	2.1	0.16	0.4	4.6	0.8	5.9	5	3.9	100	700	200

Soils	SB +Al	m [b]	V [c]	Ca/CEC	Ca/A	Ca+Mg/	Ca/H	Ca+Mg/
		-------- % --------						
I	18.0	38	51	23	0.7	1.6	1.3	2.9
II	23.8	29	63	34	1.3	2.4	3.5	11.9
III	17.6	45	51	26	0.6	1.2	4.4	8.5
IV	13.2	46	46	22	0.7	1.3	1.5	2.9
V	5.4	15	78	40	3.0	5.6	6.0	11.2

a base sum. b aluminium saturation (Al/BS + Al). c base saturation (BS/CEC).

season. This explains the positive association between high clay contents and the elevated levels of Ca, Mg and Al^{3+} which constitute typical characteristics of the hydromorphic soils of the region, represented by soils I, II III and IV (see Table 1). Only the levels of K and Al^{3+} and pH values can be considered below or above critical levels as cited by Ribeiro et al. (1999). However, the complex relationships between the sorptive components at low pH values, ratios among the different elements are a more meaningful means for soil fertility evaluation than the single elements taken by themselves.

Due to their generally close correlations with plant growth, base and aluminum saturation are generally accepted as important fertility attributes in tropical soils. However, in the case of our hydromorphic soils, these variables do not indicate any limitation in soil fertility. The results of the root length it is presented in Table 2.

For root and shoot growth, the Ca/Al ratio (WRIGHT et al., 1987) is more correlated than the Ca and Al^{3+} saturation percentages by themselves. Foy (1992) suggested that the presence of Ca and Mg in the substrate can reduce the adverse effects of Al^{3+} on root development. On the other hand, excess H ions can increase plant requirements for Ca because of their effects on nutrient uptake kinetics and nutrient retention by plants roots. Silva et al. (2000) concluded that H ion toxicity was a major factor influencing the sorghum growth on soil with pH below 4.8. Since the toxicity of water soluble Al^{3+} is reduced by chelation of Al^{3+} with organic acids or other ligands, the evaluation of possible Al toxicity must also take the organic carbonic contents into account (KIRK, 2004).

The soils under investigation showed large variations in their ratios of chemical indicators with their differential effects on root growth in accordance to literature data (BERNINI, 2010). A general analysis of the data perceives root growth was more positively related with the ratio between organic carbon and Al saturation both with and without fertilization (Table 1 and 2). This suggests that sustainable soil management must give priority to the maintenance or increase of soil organic matter. The decline in soil organic matter during successive years of cultivation and tillage, caused by the rapid mineralization under the prevailing warm-humid conditions is the main factor responsible for the drastic decline in soil fertility encountered in mechanized agriculture and continuous cultivation (CRITTER et al., 2002).

Various methods of the extraction for determination of Al^{3+} are shown in Table 3. None of these discriminate aluminum toxicity in these soils, since there was no relationship between extracted Al-levels and root growth for any extraction method. Neither the lightest extractor (KCl) or the strongest ones ($Na_4P_2O_7$ and $CuCl_2$) distinguished the soils (I to IV). According to the some researchers (Van HESS et. al., 2001) this aluminium form not presented toxicity to development of the plants, due formation of the organic complexes of the low molecular weight.

The several methods used for Al3+ determination (KCl, $Na_4P_2O_7$, $CuCl_2$ and NH_4Cl extractor's) did not discriminate the form real of the aluminium in soils. These forms of the Al^{3+} are related to the aluminum toxicity and your unbioavailable/bioavailable (Silva, et al. 2000). The table 3 showed Al^{3+} levels obtained by different extractors. There was no correspondence between the extracted contents of the soils and the growth of the plants in none of the methods. Nor the lightest extractor KCl nor the stronger, $Na_2P_2O_7$ and $CuCl_2$, were not revealed capable to separate the soils I and II as Al tenors that theoretically should be chelated in unequal amounts due its organic matter very different levels.

Table 2 – Root size (length in cm) obtained after 45 days of sowing; without 1 and with 2 addition of the fertilizers

Soils	Root maior [1]	Root maior [2]	Root menor [1]	Root menor [2]
I	0.83 cA	0.94 cB	0.21 bA	0.23 cB
II	0.50 bA	0.59 bB	0.12 cA	0.16 bB
III	0.60 bA	0.81 cB	0.09 dA	0.12 bB
IV	0.64 bA	0.82 cB	0.12 cA	0.15 bB
V	1.58 aA	1.76 aB	0.33 aA	0.39 aA

Means followed by similar letters are not significantly different ($p<0.05$) acording to the Tukey test.

Table 3. Aluminum concentrations obtained by different extractors.

Soils	KCl [a]	KCl [b]	$Na_4P_2O_7$ [C]	$CuCl_2$ [d]	NH_4Cl [e]
$cmol_c\ dm^{-3}$ -----			$cmol_c.dm^{-3}$		
I	6.8	8.1	147	42	9.0
II	7.0	8.5	150	44	9.7
III	8.0	9.2	176	50	10.2
IV	6.1	8.0	144	39	8.8
V	0.8	2.7	17	5.3	3.1

a Test 1, extraction by KCl 1 mol L-1 and determination by titration.
b Test 2, extraction by KCl 1 mol L-1 and determination by ICP-OES.
c Test 2, extraction by Na4P2O7 0.025 mol L-1 and determination by ICP-OES.
d Test 2, extraction by CuCl2 0.5 mol L-1 and determination by ICP-OES.
e Test 2, extraction by NH4Cl 1 mol L-1 and determination by ICP-OES

5 Final Discussion

Sustainability of agriculture under the humid equatorial conditions of the lowlands of Maranhão state can only be achieved if soil management adopts practices that maintain or increase the contents of soil organic matter and that also avoid the increase of H ion and Al saturation. This is because we found the ratios of Corg/Al saturation and Ca/H to be the most important factors affecting the plant growth in these soils. Heavy tillage and successive rice or maize monocultures must therefore be avoided and be substituted by more sustainable management practices such as reduced or no-tillage, green-manuring and crop rotations with legume cover crops during the dry season.

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