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Nutrient retention in an Amazonian Ultisol: implications for sustainable land use

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Abstract

Knowledge about cation and anion exchange and pH buffering in soils is essential for developing an efficient nutrient management system, especially in tropical soils where nutrient retention capacity may be low. Sorption characteristics and pH buffering of an Amazonian Ultisol were studied in sequential batch experiments. Objectives were to gain additional information on the cation and anion exchange and pH buffer properties of this soil by using a coupled equilibrium model.

The cation exchange capacities in the surface soil and subsoil were below 30 mmol_c kg⁻¹, indicating that the soil is highly limited in retaining nutrient cations against leaching. The anion exchange capacity of the soils for both depths was small (1 to 4 mmol_c kg⁻¹), indicating insignificant retention of NO₃ and its enhanced losses in seepage water following non-adapted management practices such as high doses of fertilization. More protons could be buffered in the surface soil than in the subsoil. Addition of protons to the surface soil released equivalent amounts of M_b (Ca, Mg, K, Na) cations because of CEC reduction, and an insignificant amount of Al. However, input of protons to the subsoil released large amounts of Al. The model satisfactorily predicted the sorption values for various elements in both depths, indicating that the main processes are understood.

The results indicated a very poor capacity of the soil for nutrient retention and pH buffering and a high risk of Al toxicity. Management options should substitute 'slash and burn' practices (which result in further nutrient losses) with mulch producing technologies and strive for only small additions of fertilizer (to reduce nutrient losses and avoid further soil acidification). A useful nutrient management strategy would include intercropping with legumes, but compensation for the increased acidification may be required.

2 Introduction

Knowledge about cation and anion exchange and pH buffering in soils is essential for developing an efficient nutrient management system, especially in tropical soils where nutrient retention capacity may be low. The cation exchange capacity (CEC) in soil samples from sub-Saharan Africa ranged from 4 to 254 mmol_c kg⁻¹ and depended mainly on the organic matter content; the contribution of clay to the CEC was considerable in the subhumid zone and that of silt in the non-humid zone (Asadu et al., 1997). Van Ranst et al. (1998) examined the charge characteristics of humid tropical soils from Western Cameroon and reported that anion exchange capacities can range from 4 to 11 mmol_c kg⁻¹ at ambient soil pH. Any increase in soil acidification may result in

decreased CEC owing to protonation of variable charges, reduced nutrient retention, and increased danger of Al and Mn toxicity to plant roots (Ludwig et al., 1997). Objectives were to gain additional information on the cation and anion exchange and pH buffer properties of an Amazonian Ultisol by using a coupled equilibrium model.

3 Materials and Methods

Surface soil (0-10 cm) and subsoil (30-50 cm) were collected from a cropping fallow site near Belém, (Pará, Brazil). The site was under a 2-year-old fallow and had already undergone two or more cycles of slash and burn agriculture.

Bulk soil samples were collected for this study from a profile. In order to test how representative these samples were for the site, additional soils were collected with an auger (diameter 18 mm) from five different points located 15 m apart in the angles of a square and in its centre. In the vicinity of each sampling point five individual auger samples were taken and bulked to form one composite sample. After sampling, soils were dried, homogenized and sieved through 2 mm. The texture of the surface soil was 84 % sand, 5 % silt and 11 % clay and that of the subsoil was 67 % sand, 7 % silt and 26 % clay. The soil was classified as a typic Kandiodult. Bulk density was 1.4 g cm⁻³ at both depths. Cation exchange capacity was low in soils from both depths (Table 1). In the surface soil, Ca was the dominant exchangeable cation, whereas Al was dominant in the subsoil (Table 1). Total C, N and P contents were 11.6 g kg⁻¹, 0.9 g kg⁻¹ and 47.8 mg kg⁻¹ in the surface soil and 4.8 g kg⁻¹, 0.4 g kg⁻¹ and 63.9 mg kg⁻¹ in the subsoil.

Table 1: Exchangeable cations (mmol_c kg⁻¹) and soil solution composition (step 0 of the batch experiments) of the surface soil and subsoil. Units for element concentrations are mmol l⁻¹, except for dissolved organic carbon (DOC) which is given in mmol l⁻¹. Mn concentrations are <0.01 mmol l⁻¹. nd: not determined.

Depth (cm)	Solid phase							
	H	Na	K	Ca	Mg	Al	Mn	Total
0-10*	0.0	0.0	0.2	17.3	3.0	0.4	0.3	21.2
30-50*	0.4	0.1	0.1	3.1	1.5	7.4	0.0	12.6
	Solution phase							
	pH	Na	K	Ca	Mg	Al	DOC	SO ₄
0-10	6.28	111	122	105	46	18	4.8	42
30-50	5.29	49	8	11	5	0	nd	20

*NH₄Cl extractable amounts minus the water soluble amounts

Spatial variability of exchangeable cations was low and the contents for the additional soil samples were very similar to the ones of the bulk soil sample shown in Table 1. Mean values (n=5) and standard deviations (in parentheses) of cations (mmol_c kg⁻¹) in two depths of additional soils were:

For 0 - 10 cm - Ca: 16.7 (3.9), Mg: 2.7 (0.4), K: 0.4 (0.1), Na: 0.0 (0.0), Al: 1.4 (0.7), Mn: 0.2 (0.1), H: 0.1 (0.2) and,

for 30 - 50 cm - Ca: 2.6 (1.1), Mg: 0.6 (0.2), K: 0.1 (0.1), Na: 0.0 (0.0), Al: 8.2 (1.5), Mn: 0.0 (0.0), H: 0.6 (0.3).

Sorption characteristics and pH buffering of the soil were studied in sequential batch experiments using 1 mM HCl, NaOH or CaCl₂. Additionally, cation and anion exchange capacities were determined in the pH range from 3 to 9 (Ludwig et al., 2001).

The coupled equilibrium model PHREEQC which included inorganic complexation, multiple cation exchange and the solubility of Al(OH)₃ was used (Ludwig et al., 2001).

4 Results and Discussion

The cation exchange capacities in the surface soil and subsoil were below $30 \text{ mmol}_c \text{ kg}^{-1}$, indicating that the soil is highly limited in retaining nutrient cations against leaching. The anion exchange capacity of the soils for both depths was small (1 to $4 \text{ mmol}_c \text{ kg}^{-1}$), indicating insignificant retention of NO_3 and its enhanced losses in seepage water following non-adapted management practices such as high doses of fertilization.

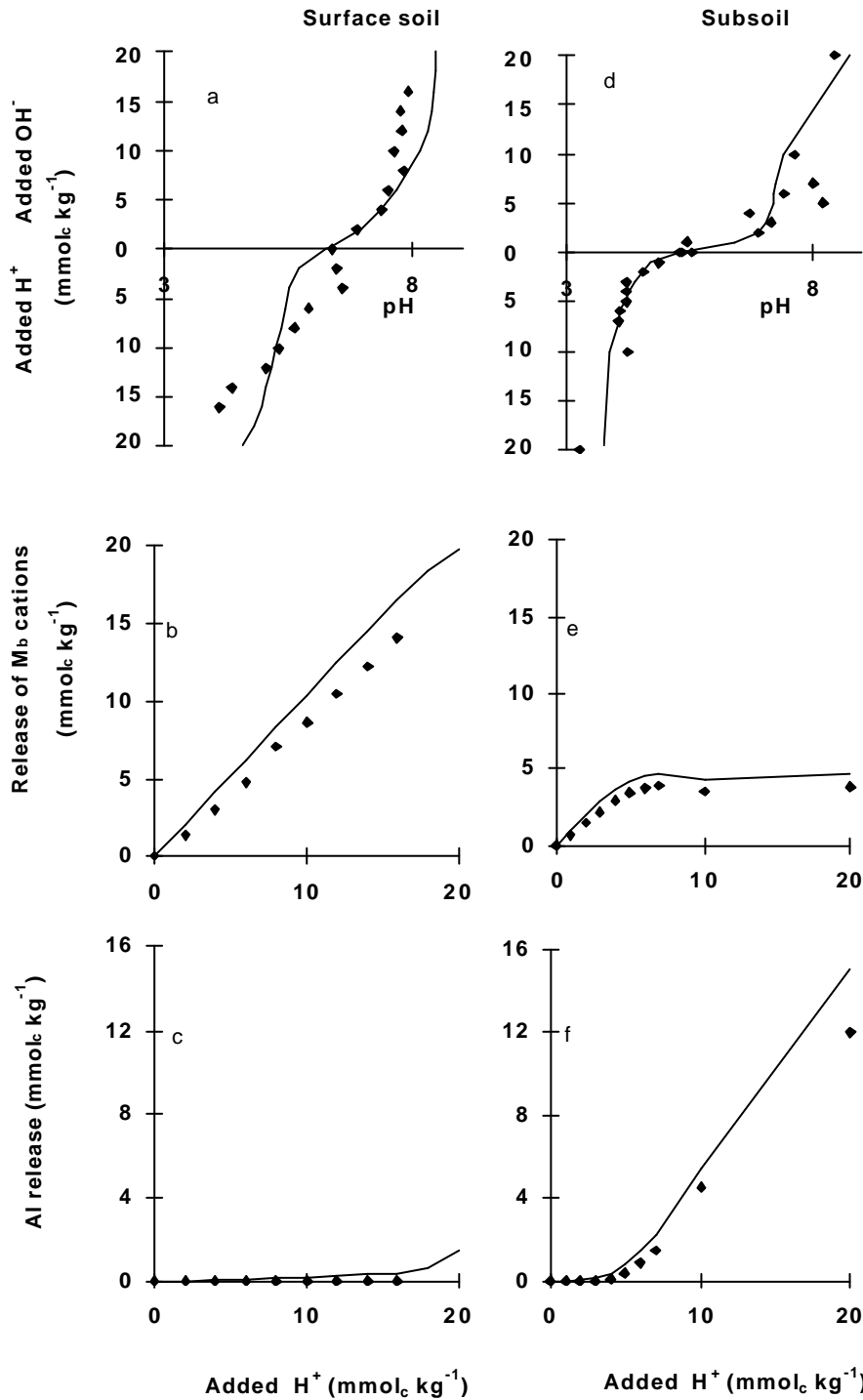


Fig. 1: Measured (diamonds) and modeled (lines) titration curves for the surface soil (1a) and subsoil (1d). Measured and modeled sorption of M_b (Mg, Ca, K, Na) cations (1b) and Al (1c) against added H^+ for the surface soil and sorption of M_b cations (1e) and Al (1f) against added H^+ for the subsoil.

More protons could be buffered in the surface soil than in the subsoil (Figs. 1a & 1d). Addition of protons to the surface soil released equivalent amounts of M_b (Ca, Mg, K, Na) cations because of CEC reduction, and an insignificant amount of Al (Figs. 1b & 1c). However, input of protons to the subsoil released large amounts of Al (Fig. 1f). The model satisfactorily predicted the sorption values for various elements in both depths, indicating that the main processes are understood (Fig. 1).

The main source of acid input in these soils is through the application of N fertilizers, especially ammonium sulfate, but also ammonium nitrate and urea. For instance, Stumpe and Vlek (1991) showed in 2-yr column experiments that repeated additions of 50 or 100 kg N ha⁻¹ as urea, ammonium sulfate or calcium ammonium nitrate to an Ultisol (Onne, Nigeria), Oxisol (Carimagua, Colombia) and Alfisol (Egbeda, Nigeria) resulted in increases of exchangeable Al and Mn. A decrease of the CEC for the Alfisol was also observed. Cahn et al. (1993) showed in split-plot field experiments for an Oxisol (near Manaus, Brazil) that in plots treated with 300 kg urea-N ha⁻¹ high rates of NO₃ leaching accelerated the loss of Ca and Mg. In their study, leaching of NO₃ and acidification were low in plots which received legume green manure as N sources. The low AEC and CEC of the Ultisol reported in our study indicate options such as replacing most or part of N input through leguminous green manuring should be considered.

The moderately high soil pH, lack of exchangeable Al and relatively high content of Ca and Mg suggest that the surface soil still shows the effect of ash from slash burning. It therefore has higher capacity to buffer protons both due to exchangeable content of M_b cations and high pH. The subsoil is more acid and has high amount of exchangeable Al. Only small amounts of additional protons can be buffered by this soil without releasing Al to the solution phases and this buffering will occur mainly by exchange with M_b cations. The results of this study indicated a low capacity of the soil for nutrient retention and pH buffering and a high risk of Al toxicity. Thus, 'slash and burn' practices (which result in further nutrient losses) should be substituted with mulch producing technologies. Additionally, high rates of N fertilizer should be avoided. If nitrate has to be applied for faster N uptake by plants, the rates should be small, but frequently applied to match uptake. Application of slow release N fertilizers may be another possibility. Application of N in the ammonium or urea form will cause proton formation and should be accompanied by liming materials (containing both Ca and Mg) and K fertilizer. A useful nutrient management strategy would include intercropping with legumes, but compensation for the increased acidification may be required.

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