Adsorbed phosphorus partitioning in some benchmark soils from Northeast Brazil

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Abstract

The partitioning of adsorbed P between labile and non-labile pools by soils is fundamental to the residual effect of fertilizer-P added to soils. The main objective of the study was to determine the partitioning of adsorbed P between the labile and non-labile phases by some benchmark soils of northeast Brazil for which is little is known. Surface and subsurface samples of several soils: Non-Calcic Brown soil and Planosol (Haplustalfs), Cambisol (Ustropepts), Lithosols (Orthents) and Alluvial soil (Tropaquepts) were equilibrated with varying concentrations of KH$_2$PO$_4$. The readily exchangeable portion of the adsorbed P was determined by anion exchange resin (AER). Considerable hysteresis was observed between adsorbed P and AER-P. To quantify the extent of the hysteresis, a critical P concentration (P$_{crit}$), the amount of P adsorbed at zero desorption by AER, was defined. The P$_{crit}$ of the soils averaged across the soil depths followed the order: Non-Calcic Brown soil > Planosol > Alluvial > Cambisol > Lithosol. The P$_{crit}$ correlated with clay and oxalate Fe (Fe$_{ox}$). The P affinity index (K) estimated by Langmuir adsorption model accounted for 66% of the variance in P$_{crit}$. A sequential extraction with 0.5 M NaHCO$_3$, 0.1 M NaOH and 11.5 M HCl to remove the labile, moderately labile and non-labile P forms respectively, indicated that between 63 and 99% of adsorbed P was in the labile pool (AER-P + HCO$_3$-P + OH-P), suggesting that the soils might have high potential for residual fertilizer-P responses.

Introduction

Soils of the Brazilian cerrado, mainly Latosols or Oxisols, have high P fixation and sorption capacity; estimates of standard P requirements of these soils are over 700 mg kg$^{-1}$ (Goedert, 1983). However, the standard P requirements for some soils from northeast Brazil, used in the present study, are far below the reported estimates for cerrado soils (Agbenin and Tiessen, 1994b).

It is not simply enough that we know the P adsorption capacity of a soil without the complementary desorption capacity, and the partitioning of the adsorbed P between labile and non-labile pools of soil P. It is the rate of desorption and the partitioning of adsorbed P between labile and non-labile forms that usually constitutes the limiting step in its bioavailability, and the residual response to applied fertilizer-P (Barrow, 1980, 1985). Dilute salt solutions such as 0.01 M CaCl$_2$, Ca(NO$_3$)$_2$ and 0.1 M KCl and isotopic techniques have all been used to evaluate P desorption. Except for the greater quantity of water used, isotopic technique is quite valid as the condition for the measurement is closest to P release processes, but the method has two conceptual problems (Amer et al., 1955). First, the amounts of P exchanged by $^{32}$P is only valid at equilibrium that is rarely attained in soils. Second, the kinetic exchange of $^{32}$P for soil P may not be satisfactory as an unequivocal index of P availability because P supply to plants is a one way diffusive process not an exchange process. Consequently, the use of AER which functions as a P sink has been proposed (Amer et al., 1955). This is analogous to P diffusion to roots that is a one way process. Anion exchange resin is widely used to characterize the P desorption capacity of soils (Gunary and Sutton, 1967; Hislop and Cooke 1968; Vaidyanathan and Talibudeen, 1970).
If the purpose of P desorption is to assess the quantity of adsorbed P in the labile phase, it is unlikely that a single AER extraction will be able to quantify the reserve labile P in the short time involved. Any approach that quantifies the amounts of labile P in soils provides information on potential residual effectiveness of fertilizer-P applied to soils, (Barrow, 1980; Fixen and Ludwig, 1982; Muns and Fox, 1976; Russell et al., 1988). Thus the initial AER extraction has to be supplemented by selective extractants that remove labile and moderately labile P forms that may equilibrate with soil solution P on depletion by plant uptake or leaching losses. The objectives of the study were to determine the partitioning of adsorbed P between the labile and non-labile P pools and discuss the implication for fertilizer-P management strategy for crop production in these soils from northeastern Brazil for which little is known.

Materials and Methods

The soils used for the study were taken from five soils: Non-Calcic Brown soil and Planosol (Haplustalfs), Cambisol (Ustropept), Lithosols (Orthents) and Alluvial soil (Tropaquept). Various soil depths were sampled for the study to provide a range of soil physico-chemical properties that can influence P desorption, and partitioning of adsorbed P. The methods used to determine the soil physico-chemical properties, and the soil native P fractions are given elsewhere (Agbenin and Tiessen, 1994b). Two grams of soil were equilibrated with 0 to 400 \( \mu g \) g\(^{-1}\) P as KH\(_2\)PO\(_4\) for six days in a supporting 0.01 M CaCl\(_2\) solution. At the end of the equilibration period the soil suspensions were centrifuged at 6000 g and decanted through a millipore filter. Amounts of entrained solution were determined. Phosphate remaining in the solution was determined colorimetrically (Murphy and Riley, 1962). Adsorption maxima and affinity constants were determined by fitting adsorption data to linear Langmuir isotherm (Eq. 1).

\[
\frac{X}{C} = \frac{1}{Kb} + \frac{C}{b} \quad (1)
\]

where \( X = \) P sorbed (mg P kg\(^{-1}\) soil ), \( C = \) equilibrium P concentration (mg P L\(^{-1}\)), \( b = \) adsorption maximum, and \( K = \) bonding energy. Langmuir adsorption parameters for the soils have been reported by Agbenin and Tiessen (1994b).

One chloride charged AER strip (9 \times 62.5 mm) was introduced into each tube with 30 ml of deionized water. The tubes were shaken for 16 hours and the resin strips were removed and the adhering soils were carefully washed back into the tube. The AER strips were placed in clean 50 mL centrifuge tubes and extracted with 20 mL of 0.5 M HCl for 16 hours to desorb P from the AER strips. The amount of P desorbed by AER was calculated from the difference between P in AER and P in entrained solution. To estimate the amount of adsorbed P in labile pool, the soil residue from the AER extraction was subjected to a sequential extraction 4 - 10 days later. For this purpose, only the soils that had been equilibrated with 400 \( \mu g \) P g\(^{-1}\) soil were used. The samples were refrigerated to minimize continuing reaction prior to sequential extraction. Labile inorganic P (Pi) forms were sequentially removed following AER extraction, first, by 0.5 M NaHCO\(_3\), then 0.1 M NaOH and 1.0 M HCl. The 0.5 M NaHCO\(_3\) and 0.1 M NaOH removed labile P and moderately labile P forms (Stewart and McKercher, 1982), while 1.0 M HCl removed Ca-bound P. Phosphorus not recovered in these successive extractions was assumed to be the residual P, supposedly non-labile P, and was extracted with hot 11.5 HCl (82 °C) and H\(_2\)SO\(_4\)-H\(_2\)O digestion. The detailed sequential extraction of P is described elsewhere (Agbenin and Tiessen, 1994a). A control treatment was included, and the difference between P in the treatment and control soils was attributed to adsorbed P.

Results

Relationship between P adsorption and desorption

At low adsorbed P, there was negligible P desorption by AER, but as the concentration of adsorbed P increased, the proportion of P desorbed increased (Fig. 1). The relationship between P adsorbed and desorbed was described by a general linear model:

\[
Y = A - BX
\]

\( Y = \) P desorbed, \( A = \) intercept, \( B = \) slope, and \( X = \) amount of P adsorbed.

To quantify the adsorption-desorption hysteresis, a critical P (P\(_{\text{crit}}\)) adsorbed below which P desorption by AER was zero was defined. Equating \( Y = 0 \) (when desorbed P by AER is zero), \( X = P_{\text{crit}}, \) is equal to the intercept \( A \) divided by the slope \( B \). The range of values of \( A, B \) and \( P_{\text{crit}} \) for the soils are given in Table 2. Soils with relatively high native labile P had low P\(_{\text{crit}}\) and some of them, especially surface samples of the