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Phosphorus fractions in Brazilian Cerrado soils as affected by tillage

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ABSTRACT

No-tillage systems lead to physical, chemical and biological changes in soil. Soil fertility is responsive to changes in tillage as it depends on nutrient status, soil water content and biological characteristics. This work aimed to determine long term changes in phosphorus forms and availability in the profile of two tropical soils under conventional and no-till systems, and to discuss the significance of these changes on plant growth and demand for P fertilizers. Undisturbed soil cores with 20 cm in diameter were collected to a depth of 40 cm, accommodated in PVC tubes and taken to a greenhouse, where the experiment was conducted. Two soils were collected in Central Brazil, in areas under Cerrado. Both soils had been cropped for at least 10 years under conventional tillage and no-till. In the greenhouse, pots received phosphorus fertilization or not at 43.7 kg ha^{-1}, and soybean was grown for 60 days, when soil P fractions were determined. Labile P fractions in the soil profile were not affected by management systems, and there was no accumulation of available P under no-till. A large amount of P added as fertilizer was adsorbed in soil and remained in moderately labile fractions, mainly on uppermost soil layers. Therefore, the phosphate fertilizer has promoted P accumulation on less available fractions in soil, remaining P on the soil after crop harvest. Eventually this phosphorus could migrate to more labile fractions and be available for crops grown in succession.

1. Introduction

Cerrado areas are predominant in Central and Northeast Brazil. Soils on these areas normally present low natural fertility and poor water retention capacity. Agricultural techniques developed during the last 20 years allowed the adoption of no-till (NT) in these areas, but there are just a few long term experiments with conclusive results on the changes in soil fertility under NT in these tropical soils.

Available phosphorus and potassium usually accumulates in the uppermost soil layers under NT, especially on kaolinitic soils from Southern Brazil (Muzilli, 1983). In some cases, NT showed available phosphorus (P) levels four to seven times higher than conventional tillage (CT) in the soil near-surface layer (0–5 cm), leading to an inference that a reduction in P fertilization would be possible. Some studies have been published during the last 10 years on fertility management in NT systems (Caires et al., 2000; Oliveira et al., 2002; Gatiboni et al., 2007) in subtropical soils, where the type of soil and climate are very different from the tropical Cerrado region. However, little is known about tillage effects on phosphorus availability and fractions in tropical oxidic soils.

Low soil disturbance under NT causes nutrients of low mobility to accumulate close to the application site (Robbins and Voss, 1991). Hence, reduced tillage systems change the concentration and distribution of phosphorus in the soil profile, leading to the establishment of a P concentration gradient that decreases with soil depth (Selles et al., 1997). As a result of this management system, organic P concentrations increased in the surface layers of a soil with low clay and oxide contents (Conte et al., 2003). Conversely, under CT systems mixing of plant residues and soil within the soil arable layer increases the organic matter decomposition rate and reduces the storage of labile and moderately labile organic P fractions. However, in clay soils with high Fe oxide contents, adoption of NT did not change soil organic P and soil organic matter status over time (Conte et al., 2003). Other data from Santos and Tomm (2003), also in clay soil, showed that available P was increased in surface layers under NT.

Inorganic and organic P fractions can act as source or sink of soluble P for the soil solution, depending on soil mineralogy, environmental conditions, fertilizer use and management system (Novais and Smyth, 1999). In natural ecosystems, where there is no P addition, availability is closely related with the cycle of organic P forms. Changes can be induced in the system through introduction of new plant species or increases in biomass yield and fertilization, which results in increased microorganism activity and mineralization rate (Gatiboni et al., 2007; Condron et al., 1985). However, when fertilizer is applied, all inorganic P fractions are increased,

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and this effect is more important for labile and moderately labile forms, which are usually responsible for P buffering in soil solution (Gatiboni et al., 2007).

Soil P fractionation using different extractors has been a good tool to understand total soil P availability and solubility, and has been useful in studying soil P dynamics under different soil management systems. The P fractionation developed by Hedley et al. (1982) and adapted by Cross and Schlesinger (1995) has been the most applied procedure in the last 15 years. It extracts inorganic P (Pi) and organic P (Po) fractions, starting with labile P and ending with more resistant forms. The Pi fractions include P extracted with resin, sodium bicarbonate ($NaHCO_3$), sodium hydroxide (NaOH), hydrochloric acid (HCl) and residual. The Po fractions include P extracted by $NaHCO_3$, NaOH and residual. In an experiment on the effect of cover crops on soil P availability, it was observed that at high P supply plants acquired most of their P from the resin-extractable P fraction, but at low P supply $NaHCO_3$-Pi was more important. Organic P accumulated in the rhizosphere, which may reflect in high microbial activity and a buildup of more stable organic P fractions or a low Po use-efficiency by plants (Kamh et al., 1999).

The aim of this work was to determine long term changes in P fractions and availability in the profile of two different tropical soils under CT and NT systems, and to discuss the significance of these changes on plant growth and demand for P fertilizers.

2. Materials and methods

Soils were collected in Luziânia, Goiás (16°15′10″S, 47°56′19″W), and Costa Rica, Mato Grosso do Sul (18°12′40″S, 53°12′13″W), Brazil. The soils are classified as Ferralsols by WRB-FAO (1998), the first is a Red-Yellow (FRY) and second is a Red (FRe). Both are Typic Hapludox (Soil Taxonomy, 1999) and in Brazilian classification the first is a Latossolo Vermelho-Amarelo and the other is a Latossolo Vermelho (EMBRAPA, 1999). FRY had been under CT and NT, where soybean and corn had been cropped in rotation since 1992, and FRe had been cropped to corn, oil seed radish, cotton and soybean in rotation, under CT and NT, since 1994. In January 2005, undisturbed soil cores were collected by inserting 42 cm long PVC tubes, with 20 cm of diameter, in the soil up to 40 cm depth, using a 13 kg metallic hammer. Then, the soil surrounding the tube was removed, the tube was taken out and the bottom was smoothed. A plastic net was fixed in the bottom to prevent soil loss and the pots were taken to a greenhouse at the Crop Science Department, College of Agricultural Sciences, São Paulo State University in Botucatu, São Paulo, Brazil. Plant residues present on soil surface in the field were maintained, and more soybean residue (equivalent to 6 Mg ha^{-1} dry weight) was placed on the soil surface in all pots. This was done to protect the soil and simulate field conditions in releasing nutrient and organic compounds during residue decomposition. Two soybean plants were grown in each pot for 60 days. Soil water was maintained near field capacity, by weighing the pots and adding water as required on a daily basis. Treatments consisted of two soils (FRY and FRe), two tillage systems (CT and NT), and two fertilizer rates (0 and 43.7 kg of P ha^{-1} as simple superphosphate—SSP) spread over the soybean straw immediately before seeding. Each tube was considered an experimental unit, and the experiment had 4 replicates. Soybean was harvested 60 days after plant emergence, oven dried at 65 °C for 72 h and weighed. Plant material was ground and shoot nutrient concentration was determined as described in Tedesco et al. (1995).

Immediately after soybean harvest, the columns were dismantled and samples were taken from the following soil layers: 0–5, 5–10, 10–15, 15–25 and 25–40 cm. Soil samples were oven dried at 40 °C for 72 h, ground and sieved through a 2 mm screen. Phosphorus pools were fractionated at each depth using Hedley et al. (1982) procedure with modifications (Cross and Schlesinger, 1995; Gatiboni et al., 2007) . The sequential extraction was anion exchange resin, 0.5 M $NaHCO_3$, 0.1 M NaOH; 1 M HCl; 0.5 M NaOH and residual digestion with concentrated $HCl + HNO_3 + H_2SO_4$. Inorganic and residual P of the extracts were analyzed using the blue molybdate–ascorbic acid method (Murphy and Riley, 1962). The organic fractions extracted by 0.5 M $NaHCO_3$, 0.1 M NaOH and 0.5 M NaOH were determined by digestion of the extract with ammonium persulfate and H_2SO_4, in autoclave at 120 °C for 2 h. Then, the organic P was determined in the same way as described for inorganic P.

The experimental design was a factorial $2 \times 2 \times 2$ with 4 replicates. All data were submitted to ANOVA (SAS Institute, 2001) and means were compared using LSD ($P < 0.05$). The factor depth was analyzed separately for each depth layer.

3. Results

Selected soil characteristics at the moment of field collection are presented in Table 1. Mehlich-1 P was higher in the uppermost soil layers in NT than in CT, in both soils, due to many years without soil mobilization. Comparing soils, FRY had much less total iron (DCB) than FRe, about 30 g kg^{-1} on FRY against 90 g kg^{-1} on FRe, which probably affected P adsorption dynamics.

There was no effect of tillage system on soybean dry matter yield, but it was increased by 76.5% with P fertilizer (Table 2). Both soils presented high levels of available P (Sousa and Lobato, 2002) in the 0–15 cm layer (Table 1). However, the amount of P originally available was not enough to support a good crop development, probably due to the small volume of the pot, and application of P fertilizer increased soybean leaf P concentration in both soils. Nitrogen concentration in soybean tissue was not affected by soil type or tillage system, but was increased by P fertilizer (Table 2). The foliar concentrations of potassium (K) were higher in the FRe, but there was no response to fertilizer or tillage system. The higher concentration of K in soybean in FRe resulted from the higher level of available K in that soil (Table 2). Concentrations of Ca and Mg were higher in FRY than in FRe, but were not affected by tillage or fertilizer application (Table 2).

In the absence of P fertilizer, FRY showed less Pi extracted by resin in plots under NT than under CT (Fig. 1 and Table 3), but for FRe this was true only on the surface layers, because Pi was increased in the 10–15 cm layer under NT. However, with fertilizer application, Pi resin was increased from 16.5 to 60.6 mg kg^{-1} in the surface layer, considering the average for both soils.

Inorganic and organic P fractions extracted by $NaHCO_3$ (Pi and Po bicarbonate) are considered available in the soil, even though they are bound to the soil mineral fraction and are not as readily available as the resin fraction (Cross and Schlesinger, 1995). Bicarbonate extracted Pi behavior was similar to Pi resin, however, actual contents were low (Fig. 2A). In the upper layer, $NaHCO_3$ Pi contents were similar in both soils, but lower values were found in other depths for FRY (Table 3). $NaHCO_3$ Pi increased with P fertilizer addition, but only in the 0–5 cm layer, similarly to what was observed for Pi resin. For $NaHCO_3$ Po, there was no effect of P fertilizer (Fig. 2B), however, high P concentrations were found in FRe under CT as compared with the levels considered ideal for plant development (Table 3).

The Pi extracted with 0.1 M NaOH (NaOH Pi) was increased by P fertilization in the uppermost soil layers (Fig. 3A). In both soils, higher NaOH Pi values were found in CT than under NT. Organic P extracted by 0.1 M NaOH (NaOH Po) was similar in both soils and management systems (Fig. 3B), with a gradual decrease from the surface to the deepest soil layer. A nominal increase in this fraction was observed in the 0–5 cm layer with P fertilizer application.