

# PHOSPHORUS FRACTIONS AND AVAILABILITY IN A HAPLIC PLINTHOSOL UNDER NO-TILLAGE SYSTEM IN THE BRAZILIAN CERRADO

## Frações e disponibilidade de fósforo em um plintossolo haplico sob sistema de plantio direto no cerrado

Leonardo Ricardo Rotta<sup>1</sup>, Helder Barbosa Paulino<sup>2</sup>, Ibanor Anghinoni<sup>3</sup>,  
Edicarlos Damacena de Souza<sup>4</sup>, Guilherme Lopes<sup>5</sup>, Marco Aurélio Carbone Carneiro<sup>5</sup>

### ABSTRACT

Soil use and fertilizer management as well as cropping systems influence phosphorus (P) availability in the soil. This study evaluated P fractions and availability in a chronosequence of anthropic influence in a Haplic Plinthosol, in sites under no-till for different time periods: seven (NT7), eleven (NT11), and sixteen (NT16) years. Labile P concentrations in the soil accounted for 10%, 8%, and 9% of the total P for treatments NT7, NT11, and NT16, respectively. The labile P values ranged between 99 and 122 mg dm<sup>-3</sup> and indicated no time in no-tillage influence on labile P under in the studied Plinthosol. However, moderately labile P contents increased with time: NT7 < NT11 < NT16 (237, 341, and 375 mg dm<sup>-3</sup>, respectively). This increased followed the elevation in iron oxide contents, indicating a relationship between mineralogy and P accumulation. Regardless of no-tillage period, P contents extracted by Mehlich-1 were lower, underestimating the available P content, when compared with the extraction using a P selective resin. The stocks of labile P were sufficient to maintain high crop yields, according to the recommendations for the Cerrado region. Even if labile P contents are reduced, when adopting no-till system, the contents and stocks of P in the soil after several years were high enough to provide for adequate crop yields.

**Index terms:** Phosphorus adsorption; available phosphorus; tillage system.

### RESUMO

Uso do solo e manejo da adubação, bem como sistemas de cultivo influenciam fósforo (P) disponíveis no solo. Neste estudo, avaliaram-se as frações de P e disponibilidade em cronossequência de interferência antrópica em um Plintossolo Háptico com sete (NT7), onze (NT11) e dezesseis (NT16) anos de sistema de plantio direto. Concentrações lábeis de P, no solo, foram responsáveis por 10, 8 e 9 % do total de P para os tratamentos NT7, NT11 e NT16, respectivamente, variando entre 99 e 122 mg dm<sup>-3</sup>, indicando que não houve influência do tempo em plantio direto. No entanto, os teores de P moderadamente lábil aumentou com o tempo: NT7 < NT11 < NT16 (237, 341, e 375 mg dm<sup>-3</sup>, respectivamente), seguindo a elevação dos teores de óxidos de ferro, indicando uma relação entre mineralogia e acúmulo de P. Independentemente do período de plantio direto, os teores de P extraídos por Mehlich<sup>-1</sup> foram menores, subestimando o teor de P disponível, quando comparado com a extração com resina. Os estoques de P lábil são suficientes para manter rendimentos elevados, de acordo com as recomendações para a região do Cerrado. Mesmo que os teores de P lábil tenham sido reduzidos, ao adotar sistema de plantio direto, o conteúdo e as reservas de P, no solo, após vários anos, são altos o suficiente para fornecer o rendimento das culturas adequadas.

**Termos para indexação:** Adsorção de fósforo; fósforo disponível; sistema plantio direto.

### INTRODUCTION

The soils of the Cerrado biome in the state of Goiás, in Brazil, are predominantly Oxisols (Sepin, 2012). Depressional areas associated with these Oxisols are occupied by Aquox or Plinthosols. These depressional area soils differ in several aspects from Oxisols; however, they have been utilized for crop productions without any changes in management practices, which have implications for productivity and

environmental sustainability. These soils often occur in micro reliefs called termite hillocks. They are formed under conditions of restricted water percolation, leading to the formation of a plinthic horizon (Empresa Brasileira de Pesquisa Agropecuária-Embrapa, 2013). Large flow channels, built for lowering the water table level, are necessary to use soils for agricultural production. This anthropic action changes the physical, chemical, and biological features of the soil, which may affect nutrient dynamics.

<sup>1</sup>Universidade Federal de Goiás/UFG – Campus Jataí – Jataí – GO – Brasil

<sup>2</sup>Universidade Federal de Goiás/UFG – Campus Jataí – BR 364 – Km 192 – 75804-020 – Jataí – GO – Brasil – helderlino51@yahoo.com.br

<sup>3</sup>Universidade Federal do Rio Grande do Sul/UFRGS – Departamento de Ciência do Solo – Porto Alegre – RS – Brasil

<sup>4</sup>Universidade Federal de Mato Grosso/UFMT – Instituto de Ciências Agrárias e Tecnológicas – Campus de Rondonópolis – Rondonópolis – MT – Brasil

<sup>5</sup>Universidade Federal de Lavras/UFLA – Departamento de Ciência do Solo/DCS – Lavras – MG – Brasil

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The expansion and consolidation of no-tillage production systems may cause changes in the dynamics of nutrients at the soil-plant-atmosphere interface (Anghinoni, 2007; Pavinato; Merlin; Rosolem, 2009). Thus, compared with conventional tillage, the no-tillage system should be analyzed differently (Nicolodi et al., 2008), with methods that account for differences in the dynamics of organic matter transformation and accumulation, and in nutrient cycling (Anghinoni, 2007). Taking into account that most changes due to the no-till systems occur gradually, the influence of time on nutrient cycling in these systems needs to be emphasized and evaluated (Calegari et al., 2008).

In no-till systems, P tends to accumulate on the soil surface due to fertilizer applications to the surface (0-5 cm) (Bayer; Mielniczuk, 1997). This affects the distribution of soil P into different fractions, increasing P lability when compared to a conventional tillage system. This increase is due to P accumulation on the surface layer by sorption reactions, cycling, and recycling of nutrients, as well as mineralization of the P-containing residues (Sá, 1999). It is important to note that in no-till systems, the contact between P fertilizer and the soil is decreased, which results in lower P fixation and an increase in P lability, especially in the surface layer (Bravo; Giraldez; Ordoñez, 2007). This fact can also be favored by the greater organic matter content found in the no-till soil surface, because the organic compounds are able to bind to the soil colloids, decreasing P fixation, especially in the oxide rich soils, such as the Oxisols and Plinthosols, which have high capacity to retain P (Pinto et al., 2013).

Regardless of soil type, tillage system, crop rotation or soil layer examined, the labile and moderately labile pools of P would be the reserve of available P in soil (Selles et al., 1997; Gatiboni et al., 2007; Pinto et al., 2013). In the context of a system in which P accumulation occurs in less recalcitrant forms with steady increases in its lability, due to repeated fertilizations, plant-available P may decrease with time under no-till system.

Therefore, this study had as an objective to assess the lability of P fractions in a Haplic Plinthosol as a function of time under no-till system.

## MATERIAL AND METHODS

The study was conducted in areas of the Boa Vista Farm, located in the western portion of the Jataí county (17°57'11" S 52°04'45" W), near the Ariranha River (a right bank tributary in the Claro River drainage basin), state of Goiás, Brazil. The selected area represents a no-tillage chronosequence of 7, 11, and 16 years (NT7, NT11

and NT16, respectively) in a Haplic Plinthosol (Embrapa, 2013), with clayey texture in the 0-20 cm layer (450, 50, and 500 g kg<sup>-1</sup> of clay, silt, and sand, respectively).

A 44 ha area to evaluate the no-till system was established in the year 2003/2004, so that it had been under no-till for seven years when sampled for this study. This area received 5.0 Mg ha<sup>-1</sup> of dolomitic lime, 2.0 Mg ha<sup>-1</sup> of agricultural gypsum, and 550 kg ha<sup>-1</sup> of phosphate (33% P<sub>2</sub>O<sub>5</sub>), which were all incorporated through disking. The area received new liming applications using 1.5 Mg ha<sup>-1</sup> of dolomitic lime on the soil surface in 2005 and 2006. In the 2007/08 growing season, the area was cultivated with soybean in the summer and was fertilized with 450 kg ha<sup>-1</sup> of a 2-20-18 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O). After a fallow period, the area received 1.0 Mg ha<sup>-1</sup> of dolomitic lime, surface applied without incorporation. In the 2008/09 growing season, corn was grown during the summer, and the area was fertilized with 420 kg ha<sup>-1</sup> of a 10-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), with an off-season fallow period. In the 2009/2010 growing season, soybean was fertilized with 350 kg ha<sup>-1</sup> of the 2-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 100 kg ha<sup>-1</sup> of potassium chloride. Corn was cultivated during the off-season period, fertilized with 300 kg ha<sup>-1</sup> of 12-15-15 (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 200 kg ha<sup>-1</sup> of ammonium sulfate.

The site established in 1998/1999 was 94 ha in area and had been under no-tilled for 11 years at the time of soil sampling. This site received 6.0 Mg ha<sup>-1</sup> of dolomitic lime and 560 kg ha<sup>-1</sup> of reactive rock phosphate, with 32% P<sub>2</sub>O<sub>5</sub>. Liming was applied to the soil surface in 2001 and 2007, using 3.0 and 2.0 Mg ha<sup>-1</sup> of dolomitic lime, respectively. In the 2007/08 growing season, corn was grown in the summer, fertilized with 400 kg ha<sup>-1</sup> of the 10-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 100 kg ha<sup>-1</sup> potassium chloride and 300 kg ha<sup>-1</sup> of ammonium sulfate. Liming was done before corn sowing. In the 2008/2009 growing season, soybean was grown in the summer, with 300 kg ha<sup>-1</sup> of the 2-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 100 kg ha<sup>-1</sup> of potassium chloride, followed by off-season corn cultivation fertilized with 300 kg ha<sup>-1</sup> of the 12-15-15 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 200 kg ha<sup>-1</sup> of ammonium sulfate. In the 2009/10 growing season, the area was cultivated with soybean and fertilized with 300 kg ha<sup>-1</sup> of the 2-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 100 kg ha<sup>-1</sup> of potassium chloride. Corn was cultivated in the off-season period with 300 kg ha<sup>-1</sup> of the 12-15-15 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 200 kg ha<sup>-1</sup> of ammonium sulfate.

The third site, 151 ha in area, was under no-till for 16 years at the time samples were collected. Until the 1995/96 growing season, the area was cultivated using

conventional tillage and received 3.0 Mg ha<sup>-1</sup> of dolomitic lime. At the beginning of planting, 1.0 Mg ha<sup>-1</sup> of reactive rock phosphate (33% P<sub>2</sub>O<sub>5</sub>) and 2.0 Mg ha<sup>-1</sup> of gypsum were applied. Liming was done in 2005, with 2.5 Mg ha<sup>-1</sup> of dolomitic lime. In the 2007/08 growing season, the area was cultivated with soybean and fertilized with 400 kg ha<sup>-1</sup> of the 2-20-18 NPK formulation. Corn was grown in the off-season period using 300 kg ha<sup>-1</sup> of the 12-15-15 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 200 kg ha<sup>-1</sup> of ammonium sulfate. In the 2008/09 growing season, soybean was grown with 300 kg ha<sup>-1</sup> of the 2-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 100 kg ha<sup>-1</sup> of potassium chloride and corn was cultivated in the off-season, fertilized with 300 kg ha<sup>-1</sup> of the 12-15-15 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 200 kg ha<sup>-1</sup> of ammonium sulfate. In the 2009/10 growing season, soybean was grown in the summer, which was fertilized with 300 kg ha<sup>-1</sup> of the 2-24-12 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 100 kg ha<sup>-1</sup> of potassium chloride and corn in the off-season period, fertilized with 300 kg ha<sup>-1</sup> of the 12-15-15 formulation (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O), plus 200 kg ha<sup>-1</sup> of ammonium sulfate.

Using Surfer® software, the studied areas were divided into 100x100 m polygons, forming a grid. In this context, five subsamples were collected from five different polygons, which were randomly chosen. Because the areas under study are located in the same soil type, we chose to randomize the sampling points within each area, test for homogeneity of variance between them, and analyze as a completely randomized design with five pseudo-replicates. Pseudo-replicates are used in studies involving relatively large areas, where is not possible to use blocks, according to the procedure described by Hurlbert (1984). The studied areas are all located near each other, presenting similar topography, climate, soil and management systems, differing only in cultivation time.

Soil samples were divided into six layers: 0 to 2.5; 2.5 to 5; 5 to 7.5; 7.5 to 10; 10 to 15; and 15 to 20 cm, and were collected in September 2011, during the dry season. Soil samples were transported to the Laboratory of Soil Science at the Federal University of Goiás, Campus Jataí, Brazil and were oven-dried at 40 °C and sieved through a 2 mm – mesh sieve. Total organic carbon (C), exchange able calcium (Ca), magnesium (Mg), and aluminum (Al) were extracted with 1.0 mol L<sup>-1</sup> KCl, pH, potential acidity (H + Al), and available P and K (Mehlich<sup>-1</sup> extractant) (Table 1) were determined according to Embrapa (2009).

Total iron (Fe) (Fey; Dixon, 1983), Fe-oxalate (Schwertmann, 1964; McKeague; Day, 1966), and Fe-dithionite (Holmgren, 1967) are shown in Table 2.

Phosphorus fraction action was performed at the Laboratory of Soil Fertility at the Federal University of Rio

Grande do Sul, Brazil. We used 0.5 g of soil samples, which were subjected to different extractants in a sequential scheme proposed by Hedley, Stewart and Chauhan (1982) with modification described by Condron, Goh and Newman (1985). Molybdate-reactive P, from alkaline extracts of sodium bicarbonate and sodium hydroxide, was analyzed according to the Dick and Tabatabai method (1977), and was designated as “inorganic P” (Pi) for this study. In the alkaline extracts, total P (Pt) was determined by digestion with ammonium persulfate + sulfuric acid in autoclave (United States Environmental Protection Agency - USEPA, 1971). Molybdate-unreactive P was determined as the difference between Pt and Pi, and was considered to be organic P (Po) for this study. Phosphorus from acid extracts was determined by the Murphy and Riley method (1962).

The fractions of Pi extracted by resin method, plus the Po and Pi contents extracted by sodium bicarbonate were considered as labile P. The P contents extracted using sodium hydroxide were considered as moderately labile, while residual and the contents of P extracted with hydrochloric acid were considered as poorly labile. The labile P stocks were calculated based on soil equivalent quantities, according to the method proposed by Ellert and Bettany (1995).

The data were subjected to analysis of variance, and the means compared by the Fisher's least significant difference test (LSD) at 5% using the statistical SAS (2007).

## RESULTS AND DISCUSSION

The labile P levels at the 0-20 cm layer were slightly greater in the treatments NT7 and NT16 compared to NT11 (Figure 1). The lowest concentration of labile P found for the treatment NT11 which can be attributed to the soil disking performed in 2007. This action may have led to the disruption of aggregates, increasing the contact surface area between adsorption site and the phosphate ions, and as a result, the P fixation increased, which caused a reduction in labile P in the surface layer (Figure 2).

This result has been reported elsewhere (Selles et al., 1997; Rheinheimer and Anghinoni, 2003). For NT7 and NT16, the cultivation time had little influence on the content of readily available P in soil, despite the addition of differential cumulative amounts of this nutrient (NT7= 495 and NT16= 645 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>). This aspect was also observed with the labile P stocks (Figure 3), suggesting that, in these no-till systems, the P supply from the labile fraction to the soil solution can be kept constant after a certain time or quantity of P added.

The negative correlation between labile P and Fe-oxalate (Table 3) suggests that poorly-crystalline iron oxides play a role in adsorbing P from the soil solution at these sites, which agrees with Nwoke et al. (2003). However, as can be seen in Table 3, clay content is positively correlated ( $p < 0.05$ ) with labile P, probably due to the greater amount of Lewis acid sites, thus promoting P adsorption that initially increases the potential to have labile P, according Novais and Smyth (1999) and Pinto et al. (2013).

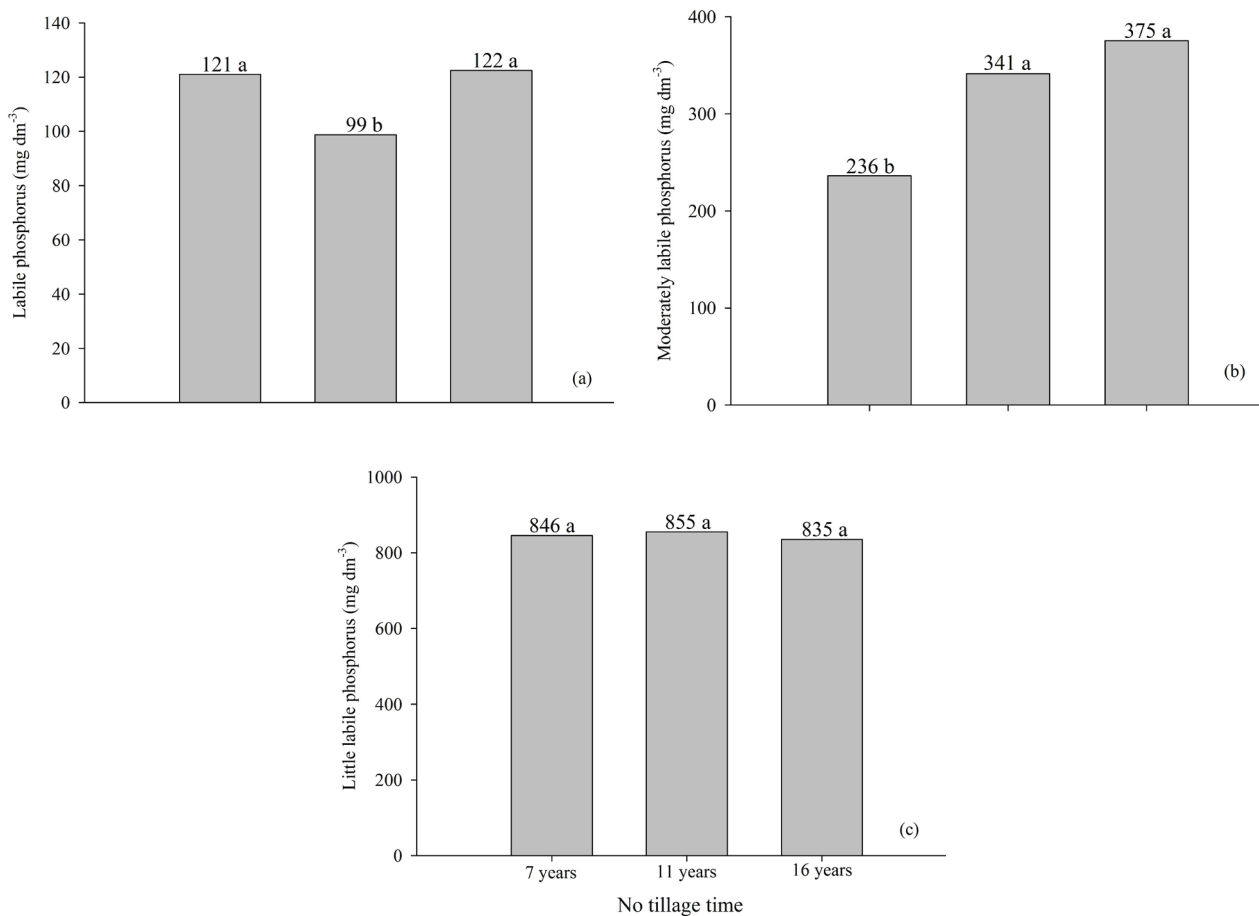
**Table 1:** Chemical attributes at layers of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops.

NT <sup>1</sup> time Years	Layers cm	pH	H+Al	Al	Ca	Mg	K	P	SOM	SB	CEC	BS
			----- cmol <sub>c</sub> dm <sup>-3</sup> -----				- mg dm <sup>-3</sup> -		g kg <sup>-1</sup>	-cmol <sub>c</sub> dm <sup>-3</sup> -		%
7	0.0 - 2.5	6.8	5.0	0.1	4.5	2.1	74.7	6.3	32	6.9	11.9	58
	2.5 - 5.0	7.0	4.2	0.1	4.4	2.0	33.2	5.8	31	6.6	10.8	61
	5.0 - 7.5	6.6	5.2	0.1	3.7	0.8	27.2	12.4	27	4.7	9.9	47
	7.5 - 10.0	6.2	6.2	0.1	2.3	0.8	21.1	4.0	21	3.3	9.5	34
	10.0 - 15.0	5.7	8.1	0.2	1.2	0.7	21.1	2.5	20	2.2	10.3	21
	15.0 - 20.0	5.2	8.7	0.5	0.6	1.2	24.1	1.2	21	2.4	11.1	21
11	0.0 - 2.5	6.4	2.1	0.2	4.2	1.6	97.6	4.5	37	6.3	8.4	75
	2.5 - 5.0	6.3	2.0	0.1	3.4	1.8	50.4	3.0	30	5.4	7.4	73
	5.0 - 7.5	6.2	2.2	0.1	2.7	1.0	27.9	5.0	29	3.9	6.1	64
	7.5 - 10.0	6.0	2.7	0.1	2.3	1.1	26.4	6.8	21	3.6	6.3	57
	10.0 - 15.0	5.7	2.2	0.2	1.8	0.9	22.4	3.8	24	3.0	5.2	57
	15.0 - 20.0	5.7	2.0	0.3	0.8	0.7	23.8	0.7	25	1.9	3.9	48
16	0.0 - 2.5	6.3	1.7	0.1	4.3	2.3	102.2	4.2	42	7.0	8.7	80
	2.5 - 5.0	6.3	1.9	0.1	3.7	1.9	70.2	3.9	31	5.9	7.8	76
	5.0 - 7.5	6.1	2.4	0.1	3.5	1.8	49.4	14.1	29	5.5	7.9	70
	7.5 - 10.0	6.0	5.9	0.1	1.1	0.5	44.7	12	32	1.8	7.7	23
	10.0 - 15.0	5.9	5.9	0.1	0.7	0.5	29.8	2.5	24	1.4	7.3	19
	15.0 - 20.0	5.5	4.6	0.1	0.5	0.8	25.8	0.9	19	1.5	6.1	24

<sup>1</sup> No-tillage. Extractants: pH in water 2:1; Al and Ca extracted by KCl 1 mol L<sup>-1</sup>; K and P extracted by Mehlich-1. Organic carbon extracted by the Walkley-Black method as described by Allison (1965). SOM obtained by multiplying the organic carbon content by 1.72 (Van Bemmelen factor). SB: sum of bases; BS: base saturation.

**Table 2:** Iron forms and some ratios between them of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops.

No-tillage time years	Layers cm	Total iron (Fe <sub>t</sub> )	Iron-dithionite (Fe <sub>d</sub> )	Iron-oxalate (Fe <sub>o</sub> )	Fe <sub>d</sub> /Fe <sub>t</sub>	Fe <sub>o</sub> /Fe <sub>d</sub>
		----- g kg <sup>-1</sup> -----				
7	0.0 - 10.0	35		26	0.67	0.73
	10.0 - 20.0	43		28	0.74	0.65
11	0.0 - 10.0	50		41	0.82	0.81
	10.0 - 20.0	53		48	0.79	0.92
16	0.0 - 10.0	60		43	0.73	0.72
	10.0 - 20.0	62		46	0.74	0.74

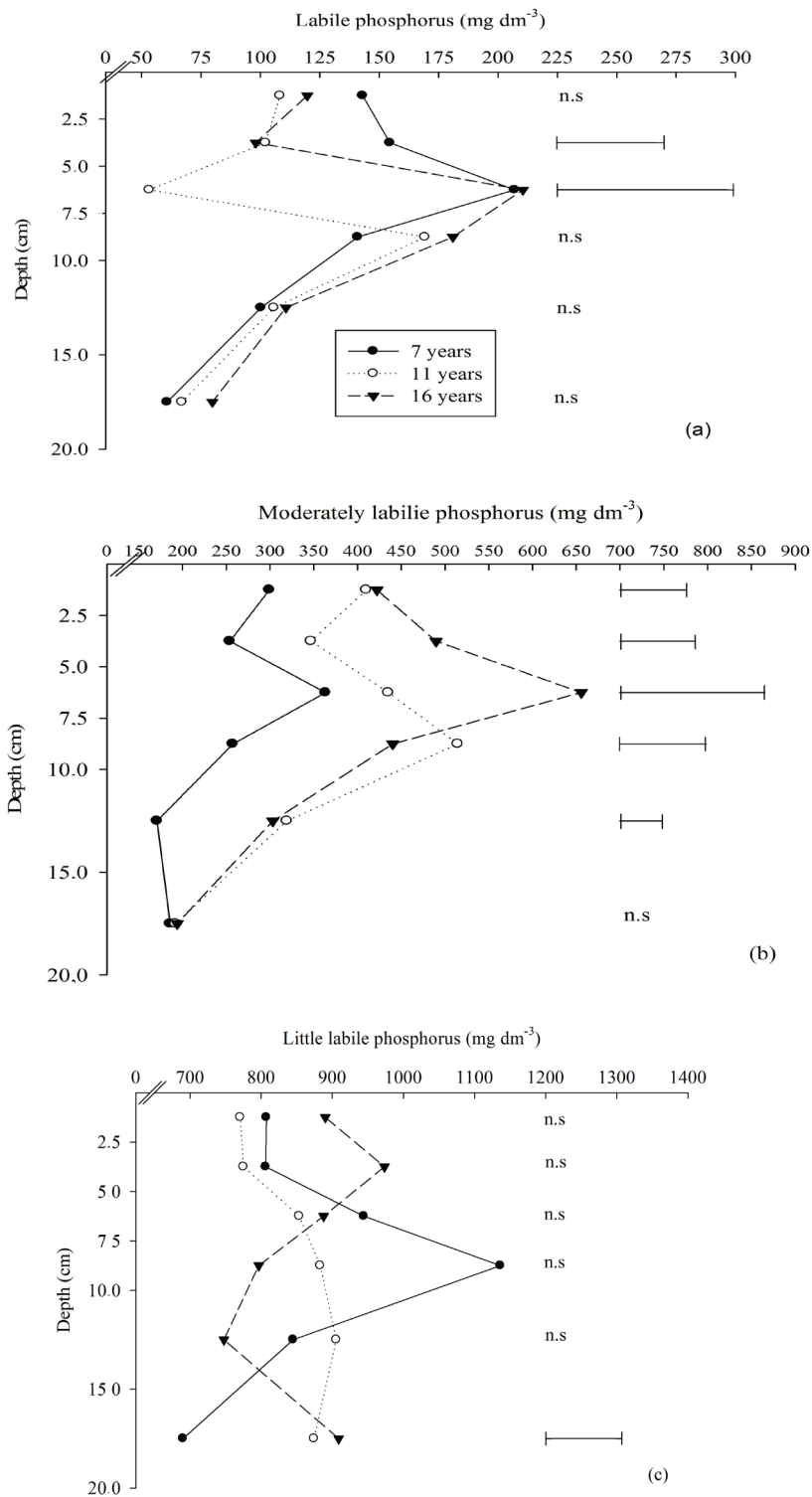


**Figure 1:** Levels of labile P (a), moderately labile P (b), and little labile P (c) ( $\text{mg dm}^{-3}$ ) at the 0 to 20 cm layer of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops.

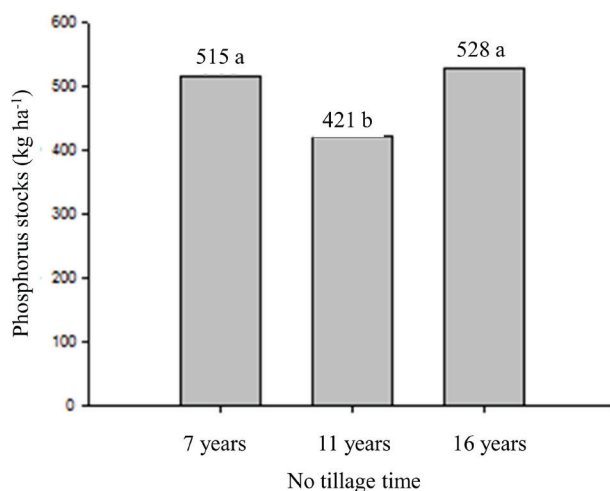
It should be noted that labile P stocks are considered high in the three studied areas, reaching values around  $500 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$  (Figure 3). These values are much greater than crop requirements for corn and soybean, which are usually cultivated in these areas, receiving  $120$  and  $80 \text{ kg ha}^{-1}$  of  $\text{P}_2\text{O}_5$ , respectively (Sousa; Lobato, 2004). In this context, the Mehlich<sup>-1</sup> extracting adopted in state Goiás (Brazil) may be under estimating P available to plants. On average, among the evaluated soil layers, P concentrations extracted by Mehlich<sup>-1</sup> were low, ranging from  $4.0$  to  $6.3 \text{ mg dm}^{-3}$  for the evaluated treatments (Table 4). When using P selective resin as an extractant, these values were  $53$ ,  $61$ , and  $53 \text{ mg dm}^{-3}$ , representing  $44$ ,  $50$ , and  $54 \%$  of the labile P concentrations for NT7, NT11, and NT16 areas, respectively. This lesser Mehlich<sup>-1</sup> efficiency in the evaluation of available P is probably due to the

exhaustion of the mixture of diluted acids ( $\text{HCl } 0.05 \text{ mol L}^{-1}$  and  $\text{H}_2\text{SO}_4 \text{ } 0.0125 \text{ mol L}^{-1}$ ) with increasing concentrations of the clay fraction, especially oxides, and the soil weathering-leaching conditions (Novais; Smyth, 1999). Motta et al. (2002), Gatiboni et al. (2002) and Pinto et al. (2013) also found greater values when using resin as an extractant in Oxisols.

The contents of moderately labile P at 0-20 cm depth (Figure 1b) were considered equal for NT11 and NT16 ( $341$  and  $375 \text{ mg dm}^{-3}$ , respectively), being greater than NT7 ( $236 \text{ mg dm}^{-3}$ ). This fraction accounted for  $20$ ,  $26$ , and  $28 \%$  of the total P in soil, in the treatments NT7, NT11, and NT16, respectively. Moreover, the moderately labile P was positively correlated with Fe-dithionite, total Fe, silt, organic matter, and base saturation, and negatively correlated with pH (Table 3).



**Figure 2:** Levels of labile P (a), moderately labile P (b), and little labile P (c) ( $\text{mg dm}^{-3}$ ) at different depths of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops. Horizontal bar compares the treatments within each depth, Tukey ( $P < 0.05$ ).



**Figure 3:** Labile P stocks calculated as  $P_2O_5$  at the 0-20 cm layer of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops. Means followed by the same letter do not differ significantly by the Tukey test at 5%.

Similarly to labile P (Figure 2a), moderately labile P concentrations are greater in the superficial layers of the soil (0-10 cm) (Figure 2b). According to Rheinheimer and Anghinoni (2000), P initially accumulates in the less labile forms with consequent P saturation and then it accumulates in moderately labile fractions. This fraction can be considered as source or sink of available P, depending on the P input added as fertilizer. When P is applied in a greater quantity compared with the P exported by crops, P accumulates in moderately labile forms, and, in this case, it acts as a sink. On the other hand, when P is applied in low amounts, the moderately labile P can act as a source, supplying crop requirements (Conte; Anghinoni; Rheinheimer, 2003; Gatiboni et al., 2007). Taking into consideration the low values of Fe extracted with oxalate (Table 2), it is likely that the predominant forms of Fe in these soils are highly crystalline Fe-oxides. Hernández and Meurer (1998)

observed a direct relationship between adsorbed P concentration and the Fe-oxide concentrations in soil. Data from this study suggest that the crystalline Fe-oxides maybe holding the moderately labile P fraction, because the area with the largest reservoir of moderately labile P (Figure 1b) showed a higher correlation with the Fe content extracted with dithionite (Table 3). The results of the present study (Figure 1a and 1b) indicate that the labile P compartment may be saturated within a few years of cultivation whether high levels of P are applied.

Even though the P added over the years tends to accumulate in fractions of moderate lability, the poorly labile P concentrations or the P that is strongly retained in the soil were not affected after 16 years of no-tillage (Figure 1c and 2c). This P fraction represents 70, 66, and 63 % of the total P for NT7, NT11, and NT16, respectively. This accumulation in poorly labile or strongly adsorbed fractions was positively correlated with less crystalline Fe-oxide concentrations (Table 3), suggesting that this oxide form, even at lower concentrations in the soil, is the primarily sink responsible for P retention, regardless of cultivation time and P quantities added to the soil.

According to Walker and Syers (1976), in highly weathered-leached soils, most of the total P is found in the low labile fraction, which is confirmed by the data in this study. It is possible that this fraction was not significantly altered by the addition of annual fertilizers doses or this fraction may have reached its maximum P adsorption. As there is a constant maintenance of P concentrations in the more labile fraction along the cultivation years, it is possible that the P specifically adsorbed on these soils has reached saturation. This would suggest again that P fertilization requirements in the studied areas are quantitatively over estimated and fewer inputs are warranted. The change from the conventional to a no-till system raises the need for a new calibration of the Mehlich<sup>1</sup> extractant, so that phosphate fertilization in no-tillage systems can be more accurately and economically recommended.

**Table 3:** Pearson's correlation coefficient between P fractions and different attributes of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops.

Phosphorus fractions	Fe <sub>o</sub>	Fe <sub>d</sub>	Fe <sub>t</sub>	Clay	Silt	pH	SOM	BS
Labile	-0.93*	-0.46	-0.02	0.89*	-0.45	0.45	0.00	-0.89*
Moderately labile	0.55	0.97*	0.98*	0.23	0.97*	-0.97*	0.97*	0.65*
Little labile	0.66*	-0.01	-0.45	-0.99*	-0.02	0.02	-0.47	0.57

Fe<sub>o</sub>: iron-oxalate; Fe<sub>d</sub>: iron-dithionate; Fe<sub>t</sub>: total-iron; SOM: soil organic matter; BS: base saturation.

**Table 4:** Average contents of P extracted with resin, bicarbonate, and Mehlich-1 at the 0-20 cm layer of a Cerrado Haplic Plinthosol in a chronosequence of no-tillage crops.

No-tillage Time years	Resin	Bicarbonate	Mehlich <sup>-1</sup>
----- mg dm <sup>-3</sup> -----			
7	53	68	5.4
11	61	61	4.0
16	53	46	6.3

### CONCLUSIONS

Phosphorus predominantly accumulates in the soil in the poorly labile fraction. However, the added P preferentially accumulates in the moderately labile fraction, which increases in depth with time using no-till system.

Even though the labile P content is reduced by soil disturbance, concentrations and stocks of Pin the soil in the seventh year of implementation of no-till system are high enough to provide for high crop yields.

The high P lability of a chronosequence of Cerrado Plinthosols, under no-till is not detected by the Mehlich<sup>-1</sup> extractant, which may underestimate P availability to crops.

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