FORMS OF PHOSPHORUS IN AN OXISOL UNDER DIFFERENT SOIL TILLAGE SYSTEMS AND COVER PLANTS IN ROTATION WITH MAIZE[1]

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SUMMARY

Phosphorus fractions play a key role in sustaining the productivity of acid-savanna Oxisols and are influenced by tillage practices. The aim of this study was to quantify different P forms in an Oxisol (Latossolo Vermelho-Amarelo) from the central savanna region of Brazil under management systems with cover crops in maize rotation. Three cover crops (*Canavalia brasiliensis*, *Cajanus cajan* (L.), and *Raphanus sativus* L.) were investigated in maize rotation systems. These cover crops were compared to spontaneous vegetation. The inorganic forms $NaHCO_3$-iP and NaOH-iP represented more than half of the total P in the samples collected at the depth of 5-10 cm during the rainy season when the maize was grown. The concentration of inorganic P of greater availability ($NaHCO_3$-iP and NaOH-iP) was higher in the soil under no-tillage at the depth of 5-10 cm during the rainy season. Concentrations of organic P were higher during the dry season, when the cover crops were grown. At the dry season, organic P constituted 70 % of the labile P in the soil planted to *C. cajan* under no-tillage. The cover crops were able to maintain larger fractions of P available to the maize, resulting in reduced P losses to the unavailable pools, mainly in no-tillage systems.

Index terms: organic matter, available phosphorus, phosphorus sequential fractionation, organic phosphorus, inorganic phosphorus.

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RESUMO: *FORMAS DE FÓSFORO EM LATOSSOLO SOB DIFERENTES SISTEMAS DE MANEJO E DE PLANTAS DE COBERTURA EM ROTAÇÃO COM MILHO*

*Frações de P desempenham papel fundamental na manutenção da produtividade dos Latossolos ácidos do Cerrado e são influenciadas pelas práticas de manejo. O objetivo deste estudo foi quantificar as diferentes formas de P em um Latossolo Vermelho-Amarelo do Cerrado, sob sistemas de manejo com plantas de cobertura em rotação com milho. Três plantas de cobertura (*Canavalia brasiliensis, Cajanus cajan *(L.) e* Raphanus sativus *L.) foram estudadas. Essas plantas de coberturas foram comparadas com vegetação espontânea. As formas inorgânicas $NaHCO_3$-iP e NaOH-iP representaram mais da metade do P total nas amostras coletadas na profundidade de 5-10 cm, durante a estação chuvosa, quando o milho foi cultivado. A concentração de P inorgânico de maior disponibilidade ($NaHCO_3$-iP e NaOH-iP) foi maior no solo sob plantio direto na profundidade de 5-10 cm, durante a estação chuvosa. As concentrações de P orgânico foram maiores durante a estação seca, quando as plantas de cobertura foram cultivadas. Nessa estação, o P orgânico constituiu 70 % do P lábil no solo plantado com C. cajan, sob plantio direto. As plantas de cobertura foram capazes de manter maiores frações de P disponível para o milho, resultando em redução de perdas de P para compartimentos indisponíveis, principalmente em sistemas de plantio direto.*

Termos de indexação: matéria orgânica, fósforo disponível, fracionamento sequencial de fósforo, fósforo orgânico, fósforo inorgânico.

INTRODUCTION

The dominant soils in the Central region of Brazil are dystrophic Oxisols, and conventional agricultural practices, especially tillage systems, have led to erosion, with losses of organic matter (OM) and nutrients (Bayer et al., 2006). In this region, P is one of the elements whose scarcity most limits crop development. However, in more weathered soils, the decomposition and mineralization of forest litter and soil OM make up the primary sources of P since mineral P is retained mostly in less available forms (Vincent et al., 2010).

Chemical fractionation represents an approximation of the biological and geochemical compartments that regulate the dynamics of organic and inorganic P in the soil. In sequential analysis, P in solution and labile P are removed first; then the more stable (recalcitrant) forms of this nutrient in the soil are also removed. In sequential extraction, organic and inorganic P fractions are determined in soil samples subjected to the extractors with different levels of bioavailability, which makes it possible to establish the approximate ratio among labile, non-labile, and occluded P, and then infer P availability in the soil (Tiessen & Moir, 1994; Cardoso et al., 2003; Resende et al., 2010).

Hence, P availability is dependent on the production system used, including crop residue and fertilizer management, which is directly related to the type of tillage system used, conventional and no-tillage (Araújo et al., 1996; Neufeldt et al., 2000; Tiecher et al., 2012; Mishra et al., 2012; Wyngaard et al., 2012).

Compared to other major nutrients, P is by far the least mobile and available to plants in most soil conditions, particularly in Oxisols, and is therefore likely to be greatly affected by tillage. Mechanical manipulation of soil during tillage may increase the chance of contact between soil solution or fertilizer-derived P and exposed soil particles, facilitating the formation of stable insoluble P compounds (Picone et al., 2003). Tillage, notably 'no-tillage', affects some chemical characteristics related to soil acidity that may influence P availability, plant growth, and yield (Ernani et al., 2002). Organic matter and P in greater quantities accumulate in the top few centimeters under no-tillage, compared to conventional tillage (Basamba et al., 2006; Mishra et al., 2012).

In crop rotation systems with cover crops, if residue production is high and if the soil is not revolved, the availability of P is strongly associated with the C cycle (Rheinheimer et al., 2000). The release of this nutrient from crop residues is dependent on the quantity and quality of OM, the decomposition process, and environmental conditions. Organic acids (oxalic, malonic, and piscidic) exuded by the roots of some plants such as *Cajanus cajan* can also remove adsorbed P from Fe and Al of the soil (Ae et al., 1991).

In a long-term experiment with six winter crops, the application of phosphate fertilizer in no-tillage rows increased inorganic P in the labile and moderately labile forms; and soil disturbance in conventional tillage redistributed the applied P to the deeper layers, increasing the moderately labile P concentration in the subsurface layers. Black oat and blue lupin were the most efficient P-recyclers, and under no-tillage they increased the labile P content in the soil surface layers (Tiecher et al., 2012).

The aim of this study was to evaluate the effect of different soil tillage systems (conventional and no-tillage) and the effect of different cover crops with maize rotation on the P forms in an Oxisol in the central savanna region of Brazil.

MATERIAL AND METHODS

The study was conducted at the Embrapa Cerrados experimental station, Planaltina, DF, Brazil (15º 36' 37" S and 47º 44' 36" W). The soil was classified as a Latossolo Vermelho-Amarelo (Embrapa, 2006) or Typical Acrustox (Soil Survey Staff, 2006). The texture and chemical characterization of the soil are shown in table 1. The climate is Aw (tropical with rainy summer) according to the Köppen classification. During the period under study, monthly pluvial precipitation ranged from null (July 2002) to 252 mm (January 2003). The monthly mean average temperature oscillated from 19 ºC (June 2003) to 27 ºC (March 2003).

At the beginning of the experiment (January 1997), the area was fertilized with 180 kg ha^{-1} of P_2O_5 (79 kg ha^{-1} de P) as fertilization for soil amendment. Before sowing, maintenance fertilization of 178 kg ha^{-1} of P_2O_5 (78 kg ha^{-1} of P) was applied in the form of single superphosphate, 49.8 kg ha^{-1} of K as potassium chloride, and 50 kg ha^{-1} of a micronutrient source (7 % Zn, 2.5 % Bo, 1 % Cu, 4 % Fe, 4 % Mn, 0.1 % Mo, and 0.1 % Co). Maintenance fertilization was repeated every year in accordance with soil analysis (CFSG, 1988), from the beginning of the experiment until 2002. The experiment was set up in a randomized complete block design with a split plot arrangement with three replications. Cover crops were sown into whole plots (12 × 30 m) at the end of each rainy season following by a maize crop in both conventional tillage (with incorporation of plant residues using a disk plow and harrow) and no-tillage subplots (12 × 15 m). Plots and subplots were separated by a 1 m border. Fertilizers were incorporated with the plant residues before sowing the maize, using a disk harrow in subplots under tillage or applied to the soil surface under no-tillage. The experiment was conducted from 1997 to 2002, and the cover crops were sown in the same area (plot) every year.

Table 1. Soil physical and chemical characteristics for the 0-20 cm depth of a Typical Acrustox in the Cerrado region of Brazil (mean for *n* = 20 samples)

Characteristic	Mean
Clay (g kg^{-1})	513
Loam (g kg^{-1})	186
Sand (g kg^{-1})	301
pH (H_2O) (1:2,5)	6.20
Organic matter (g kg^{-1})	23.60
Al^{3+} (cmol$_c$ kg^{-1})	0.01
H + Al (cmol$_c$ kg^{-1})	3.34
Ca^{2+} + Mg^{2+} + K^+ (cmol$_c$ kg^{-1})	3.40
CEC (cmol$_c$ kg^{-1})	6.80
Base saturation (%)	50
P (mg kg^{-1})	3.40

Cover crops/maize systems and soil sampling

The following cover crop species were used in rotation with maize: *Canavalia brasiliensis* M. and Benth (Leguminosae), *Cajanus cajan* (L.) Millsp cv. Caqui (Leguminosae) and *Raphanus sativus* L (Brassicaceae). The control treatment consisted of natural fallow. Cover crops were planted in March (end of rainy season). Seeds were distributed (3 cm deep) in rows (spaced at 0.5 m) using a no-till planter.

Cover crops were cut at flowering and remained on the soil surface until sowing maize at the beginning of the rainy season. In the tilled subplots, plant residues were incorporated with a disk plow (20 cm depth). Maize was sown at the beginning of the rainy season (Nov 7, 2002) at a density of 55,000 plants ha^{-1} and a row spacing of 0.9 m.

In 2002, four years after the beginning of the experiment, during the dry season, soil samples were collected at the depth of 0-5 cm in trenches measuring 45 × 3 × 5 cm. At the depth of 5-10 cm, samples were collected at three points, from the bottom to the top of the trenches. The samples consisted of the homogenization of eight sub-samples (trenches) in each subplot, at the depth of 5-10 cm. The three points collected from the eight trenches added up to 24 sub-samples per subplot. The soil samples were then dried, ground, and sieved to 2 mm for sequential analysis of P.

Analysis of soil P fractions

A sequential extraction of P (Tiessen & Moir, 1994) was carried out in duplicate with extractors in the following order: 0.5 mol L^{-1} $NaHCO_3$ (pH = 8.5), 0.1 mol L^{-1} NaOH, hot concentrated HCl, and residue digestion with H_2SO_4 (residual fraction). Resin extraction was not performed, so resin P is included in the $NaHCO_3$ fraction. The 1 mol L^{-1} HCl step was also skipped because weathered soils such as those at this site generally do not contain P as part of the primary minerals extracted with 1 mol L^{-1} HCl. Phosphorus concentrations in all fractions were determined with molybdenum blue chemistry (Murphy & Riley, 1962). Certified Aldrich Phytic acid and ERA Nutrients, and PotableWatR with Orthophosphate P were used as quality control standards for determinations of the organic and inorganic P solution, respectively. NIST Montana Soil, Standard Reference material 2711, was used as the soil total P quality control standard.

Centrifuge tubes with the remaining soil were placed to dry and one part of the weighed dry soil was added to tubes for digestion. Then, 5 mL of sulfuric acid (with salicylic acid as a catalyzer) and 4 mL of H_2O_2 were added to these tubes, which were placed inside a block digester at 320 °C for 30 min. The supernatant was analyzed for concentration of residual P. Concentrations of organic P were calculated by the difference between total P and inorganic P.

Labile P was considered the sum of the organic (oP) and inorganic (iP) forms extracted with $NaHCO_3$ and NaOH. Recalcitrant P was represented by the organic and inorganic fractions extracted with HCl (heated and concentrated) and obtained by sulfuric acid/hydrogen peroxide digestion (Neufeldt et al., 2000; Cardoso et al., 2003).

Statistical analysis

An analysis of variance was performed for the study with data repeated over space and time to evaluate the effects of the cover crops (plots), types of residue management (subplots), soil depths (sub subplots) and the seasons of collection (sub sub subplots). These analyses and their respective deployments of significant interactions were performed using the SAS program (SAS, 2002), applying the PROC MIXED procedure.

RESULTS

The inorganic fraction in conventional and no-tillage systems with cover crops

Average content of the $NaHCO_3$-iP fraction was higher in soil subjected to the no-tillage system at the depth of 5-10 cm and in the samples collected in the rainy season (Table 2). The soil under conventional and no-tillage systems yielded higher concentrations in the samples collected from the depth of 5-10 cm, with the management system presenting differences in relation to the content of the $NaHCO_3$-iP fraction only at this depth ($p<0.001$).

Higher concentrations of the NaOH-iP fraction were observed in the rainy season and at the depth of 5-10 cm (Table 2). The types of management systems led to differences in respect to the high contents of the NaOH-iP fraction ($p<0.07$), which were found only in the soil samples from the 5-10 cm layer and in the samples collected during the rainy season.

During the dry season, lower contents of the HCl-iP fraction were obtained in the soil samples from plots planted to *C. cajan* and, subsequently, under spontaneous vegetation (Table 2). Soil planted to *C. brasiliensis* and *R. sativus* yielded higher concentrations of this fraction ($p<0.01$) during the dry season in relation to collection performed during the rainy season (181 and 175 mg kg^{-1} respectively). In the dry season, these concentrations were higher in the samples from the depth of 0-5 cm while, during the rainy season, higher levels of HCl-iP were obtained in the samples collected at the depth of 5-10 cm. Significant individual effects from plant species, from the types of management practices, and from the season of collection were also observed concerning this iP fraction.

In the plots subjected to the conventional system with *C. cajan*, the samples yielded the highest value of residual P during the dry season (Table 2). In the plots of the no-tillage system, residual P content was the highest in samples collected during the rainy season from areas planted to *C. brasiliensis*. Under conventional tillage, the soil presented the highest level of residual P in the 5-10 cm layer, and under the no-tillage system, in the 0-5 cm layer. The average value of residual P was higher in the soil samples collected in the rainy season, under both management types.

The organic fraction in conventional and no-tillage systems with cover crops

In general, concentrations of the $NaHCO_3$-oP fraction (Table 3) were low, with average contents ranging from 7.4 mg kg^{-1} (rainy season) to 26 mg kg^{-1} (dry season). In the conventional tillage system, the highest values of this fraction were obtained during the dry season from soil planted to *C. brasiliensis* and, in the no-tillage system, from areas planted to *R. sativus*.

Concentrations in the NaOH-oP fraction were higher in soil subjected to the conventional tillage system and spontaneous vegetation during the rainy season, as well as under the no-tillage system for *R. sativus* and *C. brasiliensis*, also during the rainy season (Table 3). Considering the average NaOH-oP content, samples collected during the rainy season resulted in higher values for this part of the oP fraction.

Contents of the HCl-oP fraction were low, with average values ranging from 19 to 32 mg kg^{-1} (Table 3). The lowest contents were found during the dry season in soil samples from areas planted to *R. sativus* and spontaneous vegetation subjected to no-tillage and conventional systems, respectively.

Labile P content

Higher average content of labile P (sum of the organic and inorganic P fractions, extracted by $NaHCO_3$ and NaOH) was obtained in the samples collected in the rainy season in relation to the dry season (Table 3). The highest value of labile P was determined at the depth of 5-10 cm during the rainy season.

When soil was collected in the dry season, the content of recalcitrant P (357 mg kg^{-1}) was 55 % of

Table 2. Concentrations of the inorganic phosphorus fractions and of residual phosphorus in a soil with a cover crop under conventional and no-tillage systems at two depths and two seasons (dry and rainy)

Cover crop	$NaHCO_3$-iP				NaOH-iP			
	Dry	Rainy	0-5 cm	5-10 cm	Dry	Rainy	0-5 cm	5-10 cm
	mg kg^{-1}							
Canavalia brasiliensis	51 aB	103 aA	45 aB	120 aA	140 aB	311 aA	184 aB	301 aA
Cajanus cajan	43 aB	103 aA	54 aB	104 aA	142 aB	297 aA	164 aB	306 aA
Raphanus sativus	72 aB	111 aA	70 aB	121 aA	158 aB	290 aA	186 aB	289 aA
Spontaneous vegetation	72 aB	105 aA	54 aB	130 aA	161 aB	317 aA	179 aB	330 aA
Conventional	48 bB	87 bA	50 aB	93 bA	144 aB	273 bA	167 aB	276 bA
No-tillage	71 aB	125 aA	62 aB	145 aA	157 aB	334 aA	189 aB	337 aA

	HCl-iP		Residual-iP			
			Conventional		No-tillage	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
			mg kg^{-1}			
Canavalia brasiliensis	222 aA	181 aB	112 bB	176 aA	102 aB	181 aA
Cajanus cajan	164 bA	163 aA	149 aA	121 aA	109 aA	115 bA
Raphanus sativus	218 aA	165 aB	98 bA	136 aA	117 aA	126 bA
Spontaneous vegetation	188 abA	175 aA	112 b	165 aA	135 aA	153 abA
Average			118 B	150 A	116 B	144 A
System						
Conventional	163 aB	193 aA				
No-tillage	198 aA	171 aB				
Depth						
0-5 cm	205 aA	161 bB	130 aA		140 aA	
5-10 cm	191 bA	181 aA	144 aA		125 aB	

Means followed by the same letter, lower case in the column and upper case in the row, in each fraction, are not significantly different at $p<0.05$ according to Tukey's test.

Table 3. Concentrations of the organic, labile, recalcitrant fractions and total phosphorus in a soil with cover crops under conventional and no-tillage systems over two seasons (dry and rainy)

Cover crop	$NaHCO_3$-oP				NaOH-oP				HCl-oP			
	Conventional		No-tillage		Conventional		No-tillage		Conventional		No-tillage	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
	mg kg^{-1}											
Canavalia brasiliensis	38 aA	11 aB	9.3 bA	8.3 aA	52 aA	77 aA	58 aB	137 aA	23 aA	21 aA	49 aA	8.8 aB
Cajanus cajan	23 abA	6.2 aB	26 abA	3.4 aB	40 aB	108 aA	45 aA	89 bA	68 aA	25 aA	44 aA	19 aA
Raphanus sativus	28 abA	4.9 aB	33 aA	6.9 aB	61 aB	113 aA	74 aB	153 aA	4 bA	18 aA	15 aA	26 aA
Spontaneous vegetation	16 bA	7.5 aA	25 abA	16 aA	64 aB	159 bA	44 aB	101 abA	34 aA	33 aA	2 bA	21 aA
Average	26 A	7.4 B	23 A	8.6 B	54 B	114 A	55 B	120 A	32 A	24 A	27 A	19 B

	Total P		Labile P				Recalcitrant P			
			Conventional		No-tillage		Conventional		No-tillage	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
				mg kg^{-1}						
Canavalia brasiliensis	544 aB	763 aA	263 aB	434 aA	276 aB	628 aA	351 aA	372 aA	368 aA	378 aA
Cajanus cajan	535 aB	742 aA	264 aB	459 aA	240 aB	548 aA	379 aA	297 bB	321 bA	309 bA
Raphanus sativus	744 aA	613 aB	267 aB	463 aA	391 aB	621 aA	420 aA	316 abA	357 aA	321 abA
Spontaneous vegetation	615 aB	761 aA	296 aB	579 aA	318 aB	558 aA	331 aA	364 aA	329 bA	357 aA
System										
Conventional	550 B	693 A								
No-tillage	603 B	812 A								
Depth										
0-5 cm	571 aB	640 bA	293 aA	367 bA			324 bB		349 aA	
5-10 cm	582 aB	865 aA	286 aB	706 aA			356 aA		336 bA	

Means followed by the same letter, lower case in the column and upper case in the row, in each fraction, are not significantly different at $p<0.05$ according to Tukey's test.

labile P. The level of recalcitrant P (297 mg kg^{-1}) was lower in soils planted to *C. cajan*, under the conventional system, and collected in the rainy season.

Total phosphorus

Total P obtained from sulfuric acid/hydrogen peroxide digestion varied from 550 to 865 mg kg^{-1}, corresponding to the dry and rainy seasons (Table 3). It varied from 617 mg kg^{-1} (dry season and depth of 0-5 cm) to 1,042 mg kg^{-1} (rainy season and depth of 5-10 cm).

The management system, soil depth and the season of collection exercised significant effects on the total P content. The total P content found in soil growing *R. sativus* was high during the dry season (p<0.01) while in soils planted to the other plant species, a higher total P content was observed in samples collected in the rainy season (Table 3). The highest total P concentrations were obtained in samples collected in the rainy season and at the depth of 5-10 cm in the no-tillage system.

Validation of the results obtained from sequential fractionation

The difference between the total P from sequential extraction and total P from sulfuric acid/hydrogen peroxide digestion was less than 10 % for most of the samples analyzed. The most accentuated variations between these two extractions were observed in few soil samples (<10 %), collected in the rainy season. This allowed for validation of the results obtained from the sequential fractionation in this study.

DISCUSSION

Effect of conventional tillage and no-tillage systems on the P fraction

The highest concentrations of the $NaHCO_3$-iP and NaOH-iP fractions were found in the soil samples collected in the rainy season at the depth of 5-10 cm under no-tillage systems. These results could be related to the season and to how the fertilizer was applied. The no-till planter used to sow the maize has a mechanism to insert fertilizer under the seed, resulting in an application (at the rate of 65.5 kg ha^{-1} of P) below the 5-cm layer, concentrating this element at the depth of 5-10 cm. After five years, localized application of a high quantity of P led to saturation of the adsorption sites, resulting in a high compartment of labile P in the no-tillag e system, especially in the 5-10 cm soil layer (Rheinheimer et al., 2000; Wyngaard et al., 2012; Tiecher et al., 2012).

The predominance of inorganic forms (NaOH-iP fraction) in total P from the soil collected during the rainy season (Table 2), represented 28 and 40 % at the depths of 0-5 and 5-10 cm, respectively. These results were also observed in other studies (Araújo et al., 1996; Conte et al., 2003; Wyngaard et al., 2012), in which this fraction was also considered to be predominant in cultivation systems with fertilization. The high quantities of iP extracted with the NaOH extractor indicate the P applied that was not promptly absorbed by the plants. At the depth of 5-10 cm and in the soil collected at the maturation stage of the maize (rainy season), the two most available fractions ($NaHCO_3$-iP, NaOH-iP) represented 55 % of the total Ps. In soil collected during the dry season, the $NaHCO_3$-iP and NaOH-iP fractions make up 35 % of the total P, thus acting as an available source of P 10 months after application of the fertilizer. Lilienfein et al. (2000) observed that the NaOH-iP fraction was the most concentrated fraction in the soy/maize rotation under the no-tillage system. Conte et al. (2003) also verified that, in the no-tillage system, the moderately labile iP fraction (NaOH-iP) was the major sink for the applied P, and that participation of the labile fractions of iP was in direct relation to the quantity of P added to the soil.

The high concentration of iP in the fractions of rapid availability (Table 2), such as the $NaHCO_3$-iP fraction and, especially, the NaOH-iP fraction, indicates that there was no effect of the cover crops on increasing the availability of this element in the soil. The soil adsorption sites were saturated mainly in the samples from the no-tillage plots collected during the rainy season, reducing the impacts of the chemical and biological mechanisms (Ae et al., 1990; Reinheimer et al., 2000; Cardoso et al., 2003; Tiecher et al., 2012) that act to release adsorbed P to the constituents of the clay. The action of the cover crops was more accentuated in relation to the iP-concentrated HCl fractions and residual P when the level of P in the soil was low, i.e., in the samples collected during the dry season, after the export of nutrients in the form of maize grain and ten months after fertilizer application (Table 2).

Basamba et al. (2006) showed that the P fractions were also generally higher in no-till treatments. Results from this study indicate that the rotational systems (maize-soybean-green manure and maize-pastures) improved the soil conditions for implementing no-till or minimum tillage systems in a savanna Oxisol.

Effect of cover plants on P fraction

The highest level of extracted oP in the $NaHCO_3$-oP fraction in the soil samples collected from plots subjected to the conventional system increased biomass production (Carvalho et al., 2009). Greater decomposition of these plants (Carvalho et al., 2008) may have favored the synthesis of oP compounds and the availability of this element in its organic forms. However, in the no-tillage system, the formation of organic compounds may have been inhibited in the samples planted to *C. brasiliensis* (9.0 mg kg^{-1} P) due to the limited contact of its residues with the soil, in agreement with Rheinheimer et al. (1999), who related soil oP availability to the incorporation of biomass. The higher level of the $NaHCO_3$-oP fraction under the no-tillage system and *R. sativus* is possibly due to the capacity of this cover crop in concentrating nutrients in its tissue, especially P (Carvalho et al., 2008). Wyngaard et al. (2012) indicated that oP is affected by management practices, and Qiao (2012) reported that the percentage of total P present as iP was affected by the crop in the agrosystem. Tiecher et al. (2012) observed that black oat and blue lupin were the most efficient P-recyclers and, in no-tillage, they increased the labile P content in the soil surface layers. Thus, with the accumulation of crop residues on the soil surface, as observed in the present study, the release of labile P was favored, due to the high level of decomposition of this cover crop in the no-tillage system (Carvalho et al., 2008; 2009). The higher concentration of this organic fraction in the samples collected in the dry season (26 mg kg^{-1} P) in relation to the samples collected in the rainy season (8 mg kg^{-1} P) is in agreement with the inverse relationship obtained between oP and the quantities of phosphate fertilizers added to the soil (Araújo et al., 1996; Conte et al., 2003).

The markedly higher levels of the NaOH-oP fraction in the soil samples collected in the rainy season in relation to those collected in the dry season for the no-tillage system with the use of *C. brasiliensis* and *R. sativus*, and under no-tillage and conventional systems of spontaneous vegetation, are attributed to the biomass produced by the occurrence of regrowth, especially in the case of *C. brasiliensis* and spontaneous vegetation (Sodré Filho et al., 2004). The decomposition of plant residues in these species (Carvalho et al., 2008; 2009) in the presence of moisture may have favored this organic form of P. Chemical fertilization also affected the level of NaOH-oP obtained from the samples collected during the rainy season (three months after the sowing of the maize) with relative participation of 10 % of the total fractions of samples from the 0-5 cm layer in the soil under the no-tillage system and with spontaneous vegetation, and up to 25 % with the use of *R. sativus*. In relation to the samples collected at the depth of 5-10 cm, the variation of this proportion was 8% in the no-tillage system with growth of *C. cajan,* and up to 19 % in soils subjected to the conventional system and spontaneous vegetation. According to Rheinheimer et al. (1999), the oP may occur linked to organic colloids by highly stabilized Fe and Al bonds; however, Makarov et al. (1997) questioned the importance of P-Fe(Al)-humus linkages since the synthetic complex (P-Fe-humus) is stable at pH 1.5.

CONCLUSIONS

1. The inorganic forms of greater availability ($NaHCO_3$-iP and NaOH-iP) represented more than half of the total P in samples collected at the depth of 5-10 cm, and were highest in the soil at the depth of 5-10 cm subjected to the no-tillage system, both during the rainy season.

2. In the dry season, organic P constitutes 70 % of the labile P in the soil planted to *C. cajan* under no-tillage (0-5 cm) and conventional systems (5-10 cm).

3. The results obtained indicate that the use of cover plants, especially under adequate conditions for plant biomass production and synchronization between their decomposition and the use of P by the following crop, can promote the desorption of this element which accumulates in recalcitrant forms.

4. Phosphorus appears to be more efficiently and gradually reduced in the soil when applied as fertilizer, which is a non-renewable and exhaustible resource.

5. The cover plants were able to maintain larger fractions of P available to agricultural crops, thereby reducing P losses to the unavailable pools, especially in the no-tillage system.

LITERATURE CITED

AE, N.; ARIHARA, J. & OKADA, K. Phosphorus uptake mechanism of pigeon pea grown in Alfisols and Vertisols. In: JOHANSEN, C.; LEE, K. & SAHRAWAT, K.L., eds. Phosphorus nutrition of grain legumes in the semi-arid tropics. Patancheru, ICRISAT, 1991. p.91-98.

ARAÚJO, A.G.; AYARZA, M.A.; FRIESEN, D.K. & VILELA, L. Frações orgânicas e inorgânicas de fósforo em um solo de Cerrado sob diferentes sistemas de preparo. In: PEREIRA, R.C. & NASSER L.C.B., eds. Biodiversity and sustainable production of food and fibers in the tropical savannas'. Brasília, Embrapa-CPAC, 1996. p.319-322.

BASAMBA, T.A.; BARRIOS, E.; AMÉZQUITA, E.; RAO, I.M. & SINGH, B.R. Tillage effects on maize yield in a Colombian savanna Oxisol: Soil organic matter and P fractions. Soil Till. Res., 91:131-142, 2006.

BAYER, C.; MARTIN-NETO, L.; MIELNICZUK, J.; PAVINATO, A. & DIECKOW, J. Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil Till. Res., 86:237-245, 2006.

CARDOSO, I.M.; JANSSEN, B.H.; OENEMA, O. & KUYPER, T.W. Phosphorus pools in Oxisols under shaded and unshaded coffee systems on farmers' fields in Brazil. Agrofor. Syst., 58:55-64, 2003.

CARVALHO, A.M.; BUSTAMANTE, M.M.C.; GERALDO JUNIOR, J. & VIVALDI, L.J. Decomposition of plant residues in Latosol under corn crop and cover crops. R. Bras. Ci. Solo, 32:2831-2838, 2008.

CARVALHO, A.M.; BUSTAMANTE, M.M.C.; ALCÂNTARA, F.A.; RESCK, I.S. & LEMOS, S.S. Characterization by solid-state CPMAS 13C NMR spectroscopy of decomposing plant residues in conventional and no-tillage systems in Central Brazil. Soil Till. Res., 101:100-107, 2009.

COMISSÃO DE FERTILIDADADE DE SOLOS DE GOIÁS - CFSG. Recomendações de corretivos e fertilizantes para Goiás: 5ª aproximação. Goiânia, 1988. 101p.

CONTE, E.; ANGHINONI, I. & RHEINHEIMER, D.S. Phosphorus accumulation fractions in a clayey Oxisol in relation to phosphate doses under no-tillage. R. Bras. Ci. Solo, 27:893-900, 2003.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa em Solos. Sistema brasileiro de classificação de solos. Rio de Janeiro, 2006. 306p.

ERNANI, P.R.; BAYER, C. & MAESTRI, L. Corn yield as affected by liming and tillage system on an acid Brazilian Oxisol. Agron. J., 94:305-309, 2002.

LILIENFEIN, J.; WILCKE, W.; AYARZA, M.A.; VILELA, L.; LIMA, S.D.C. & ZECH, W. Chemical fractionation of phosphorus, sulphur, and molybdenum in Brazilian savannah Oxisols under different land use. Geoderma, 96:31-46, 2000.

MAKAROV, M.I.; MALYSHEVA, T.I.; HAUMAIER, L.; ALT, H.G. & ZECH, W. The forms of phosphorus in humic and fulvic acids of Alpine Soils in the Northern Caucasus. Geoderma, 80:61-73, 1997.

MISHRA, A.; CABRERA, M.L. & REMA, J.A. Phosphorus fractions in poultry litter as affected by flue-gas desulphurization gypsum and litter stacking. Soil Use Manage., 28:27-34, 2012.

MURPHY, J. & RILEY, J.P. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27:31-36, 1962.

NEUFELDT, H.; SILVA, J.E.; AYARZA, M.A. & ZECH, W. Land-use effects on phosphorus fractions in Cerrado Oxisols. Biol. Fertil. Soils, 31:30-37, 2000.

PICONE, L.I.; ZAMUNER, E.C.; BERARDO, A. & MARINO, M.A. Phosphorus transformations as affected by sampling date, fertilizer rate and phosphorus uptake in a soil under pasture. Nutr. Cycl. Agroecosyst., 67:225-232, 2003.

QIAO, S.M.Y. Distribution of inorganic and organic phosphorus fractions in two phosphorus-deficient soils as affected by crop species and nitrogen applications. Commun. Soil Sci. Plant Anal., 43:631-644, 2012.

RESENDE, J.C.F.; BUSTAMANTE, M.M.C.; MARKEWITZ, D.; KLINK, C.A. & DAVIDSON, E.A. Phosphorus cycling in a small watershed in the Brazilian Cerrado: Impacts of frequent burning. Biogeochemistry, 105:105-118, 2010.

RHEINHEIMER, D.S.; ANGHINONI, I. & KAMINSKI, J. Depletion of inorganic phosphorus fractions by successive extraction with resin in different soils and management systems. R. Bras. Ci. Solo, 24:345-354, 2000.

RHEINHEIMER, D.S.; CASSOL, P.C.; KAMINSKI, J. & ANGHINONI, I. Fósforo orgânico do solo. In: SANTOS, G.A. & CAMARGO, F.A.O., eds. Fundamentos da matéria orgânica do solo ecossistemas tropicais e subtropicais. Porto Alegre, Metrópole, 1999. p.227-244.

SAS Institute. SAS User's guide Statistics. 5.ed. Cary, 2000. 943p.

SODRÉ FILHO, J.; CARDOSO, N.A.; CARMONA, R. & CARVALHO, A.M. Phytomass and soil cover of sequential crops after maize in Cerrado region. Pesq. Agropec. Bras., 39:327-334, 2004.

SOIL SURVEY STAFF. Keys to soil taxonomy. 10 ed. Washington, DC, USDA-Natural Resources Conservation Service, 2006.

TIECHER, T.; RHEINHEIMER, D.S.; KAMINSKI, J. & CALEGARI, A. Forms of inorganic phosphorus in soil under different long term soil tillage systems and winter crops. R. Bras. Ci. Solo, 36:271-281, 2012.

TIESSEN, H. & MOIR, J.O. Characterization of available P by sequential extraction. In: CARTER, M.R. & GREGORICH, E.G., eds. Soil sampling and methods of analysis, Boca Raton, CRC Press, 1994. P.75-86.

VINCENT, A.G.; TURNER, B.L. & TANNER, E.V.J. Soil organic phosphorus dynamics following perturbation of litter cycling in a tropical moist forest. Eur. J. Soil Sci., 61:48-57, 2010.

WYNGAARD, N.; ECHEVERRÌA, H.E.; VIDAURRETA, A.; PICONE, L.I. & DIVITO, G.A. Carbon and phosphorus in soil particulate fraction: Effect of continuous agriculture, tillage and fertilization. Geophys. Res. Abstr., 14:3377-3390, 2012.