ORGANIC PHOSPHORUS FRACTIONS IN THE SOIL IN CHRONOSEQUENCE OF SUGARCANE CROPS MANAGED WITH PRE-HARVEST BURNING IN THE CERRADO BIOME OF THE STATE OF GOIÁS, BRAZIL

FRAÇÕES DO FÓSFORO ORGÂNICO NO SOLO EM CRONOSSEQUÊNCIA DE CANA-DE-AÇÚCAR QUEIMADA NO CERRADO GOIANO

Celeste Queiroz ROSSI[1]; Marcos Gervasio PEREIRA[2]; Paulo Roberto GAZOLLA[3]; Adriano PERIN[4]; Antonio Paz GONZÁLEZ[5]

1. Post-Doctoral Student, Agronomy Post-Graduate Course (Soil Science), Rural Federal University of Rio de Janeiro - UFRRJ, Seropedica, RJ, Brazil. Scholarship by Capes/Faperj. celesteqrossi@yahoo.com.br; 2. Professor, Department of Soils - UFRRJ, Scholarship by CNPq. mgervasiopereira01@gmail.com; 3. AGRODEFESA, Goiânia, GO, Brazil; 4. Professor D3I, Goiás Federal Institute, Supported by CPGA-CS / CAPES / PROEX; 5. Cathedratic Professor, University of Coruña, A. Zapateira campus, cod 15071, La Coruña, Spain, tucho@udc.es

ABSTRACT: Phosphorus (P) is an important macronutrient for plant development. The distribution of its forms in the soil depends on geochemical, biological and anthropogenic processes. The characterization of these compartments favors the understanding of this nutrient cycle. The objective of this work was to evaluate the total P contents and organic P fractions of Red Latosol samples in areas with different management systems in the State of Goiás, Brazil. The study was conducted in sugarcane areas in which the sugarcane harvest was performed with previous straw burning for 1 (CN1), 5 (CN5), 10 (CN10) and 20 (CN20) years, plus an area with native vegetation (NV) of the Cerrado biome, and an area with pasture (PA). Quantification of P fractions was performed by extraction with $NaHCO_3$, H_2SO_4 and NaOH. The CN20 area had the highest total P values up to 0.40 m deep compared with the others, while the CN5 area had values in the layer 0.40-0.60 m similar to those found for CN20. Regarding the inorganic labile P fraction, the largest contents were also found in the area CN20 up to 0.30 m deep. The P fraction extracted by NaOH had the highest proportions among the systems evaluated, although this fraction is considered little labile, it is quite dynamical in tropical soils.

KEYWORDS: Fractionation of phosphorus. Phosphorus forms. Inorganic phosphorus. *Saccharum officinarum.*

INTRODUTION

Phosphorus (P) is the most limiting nutrient for crop production in Brazil. Its content in the soil is dependent on several factors, including the source material and weathering level. Moreover, soil management causes soil chemical and biological transformations, acting directly on P form and availability.

The Brazilian natural ecosystems have low contents of P because the chemical properties of its soils. Plants and organisms use different mechanisms to increase the absorption efficiency of this element. These strategies may be morphologic, such as increasing root or shoot, increasing the amount of root hairs, or symbiotic, by the association with mycorrhizal fungi.

The organic P (Po) originates from plant residues added to the soil, microbial tissues and the decomposition of their products (RHEINHEIMER et al., 2000; CONTE et al., 2002 e 2003; MARTINAZZO et al., 2007). Biological processes regulate the dynamics and distribution of labile forms of P in the soil, and the recycling of its organic form is an important factor in make this nutrient available to plants (WHITELAW, 2000). The relative importance of Po in plant nutrition increases when there is a P deficiency, resulting from low total contents and/or strong adsorption of P by Fe and Al oxides and hydroxides in the soil (NOVAIS; MELLO, 2007).

The total phosphorus (Pt) of the soil consists of 15-80% of Po and is extremely relevant in tropical soils, since it actively participates in the P availability to plants and should be taken into account in studies involving its dynamics and bioavailability (STEVENSON, 1994; RHEINHEIMER; ANGHINONI, 2003).

Guerra et al. (1996), studying soils of the Brazilian Central Plateau, found total organic phosphorus (Pot) values accounting for 13-47% of Pt, increasing with the soil weathering level. These authors also found a positive correlation between the compartments Pt and labile Po and Pot and labile Po in less developed soils, but not in more weathered soils, possibly because the labile Po is used by organisms and plants due to the lack of labile inorganic P (Pi) in the soil.

The soil organic matter (SOM) dynamics in soils with high level weathering has an intense

Received: 14/04/15
Accepted: 20/01/16

cycling in tropical soils, therefore, it is an important source of nutrients for plants (MOREIRA; SIQUEIRA, 2002). Thus, the Po dynamics is directly related to the SOM dynamics (SOLOMON et al., 2002; CUNHA et al., 2007).

The objective of this work was to evaluate the total P contents and organic P fractions of Red Latosol samples in areas with different management systems in the State of Goiás, Brazil.

MATERIAL AND METHODS

The study was conducted in Rio Verde, State of Goiás, Brazil, in areas that had commercial crops of sugarcane (Decal Industry, Catanduva Distillery), conducted with pre-harvest burning for 1 (CN1), 5 (CN5), 10 (CN10) and 20 (CN20) years. Adjacent areas under native vegetation (NV) of the Cerrado biome, and pasture (*Brachiaria* sp.) (PA) were sampled to represent the soil's natural condition. The use history of the areas is presented in Figure 1.

The region climate is Aw (Köppen), tropical, with rainfall concentrated in the summer and a dry season well defined during the winter. Its average annual rainfall ranges from 1500 to 1800 mm year^{-1}, and its average annual temperature is 23°C. The soil of the area was classified as sandy loam Red Latosol (SANTOS et al., 2013).

Undisturbed samples were collected in May 2010 with a Kopeck ring in the layers 0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40 and 0.40-0.60 m, with six replications, opening transversal trenches to the sowing lines.

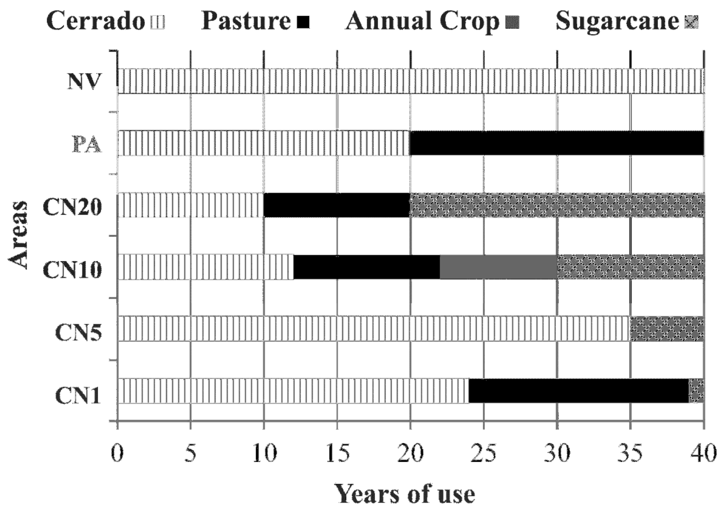

Figure 1. Use history of the studied areas.

The sugarcane areas were fertilized with 500 kg ha^{-1} of NPK (5-30-20) at planting and 500 kg ha^{-1} of NPK (18-00-27) at ratoon. The CN10 area had the first renovation in 2010, and the CN20 had the first renovation in 2000 with a second renovation after the 2010 harvest. The yield of the sugarcane areas was 113 (CN1), 111 (CN1), 85 (CN1) and 96 (CN1) Mg ha^{-1} in the 2009/2010 harvest. The CN20 area had applications of 60 m³ ha^{-1} year^{-1} of vinasse, containing C (0.03 mg L^{-1}), P (29 mg L^{-1}), K (225 mg L^{-1}), Ca (70 mg L^{-1}), and Mg (87 mg L^{-1}), and pH (H_2O) of 3.5, according to the Decal Industry.

The total phosphorus (Pt) was quantified according to Tedesco et al. (1995). The quantification of moderately resistant and resistant labile phosphorus fractions, was performed according to Bowman (1989) with the adaptation suggested by Duda (2000). The active carbon powder was purified using acid (HCl, 6 mol L^{-1}), sodium bicarbonate ($NaHCO_3$, 0.5 mol L^{-1}) and alkaline (NaOH, 0.5 mol L^{-1}) solutions. P contents were evaluated with a spectrophotometer in the blue range (660 nm), by the blue color formation of phosphate-molybdate complex in a sulfuric medium in the presence of ascorbic acid as a reducing agent (EMBRAPA, 1997).

The results were subjected to normality (Lilliefors), and homoscedasticity (Cochran & Barttlet) tests, and subsequently to analysis of variance, applying the means test (Scott Knott at 5% probability), using the statistical program SAEG 9.0 (Statistics and Genetics Analysis System, UFV).

RESULTS AND DISCUSSION

The largest values of total phosphorus (Pt) were found in sugarcane areas, which can be attributed to the fertilization in the crop areas over the years. Pt values were different between sugarcane areas in the depths evaluated (Table 1). The largest Pt values were found in the CN20 area, in the layer 0.30-0.40 m, which may be due to the vinasse application in this area. As for the layer 0.40-0.60 m, the CN5 area had values similar to those found for the CN20 area.

Studying phosphorus content in various Brazilian soils, Guerra et al. (1996) found Pt values ranging from 87 to 267 mg kg^{-1}, up to 0.20 m deep for sandy soils, and for Latosols with medium and clayey textures, from 132 to 557 mg kg^{-1}. Duda (2000) studied the microbial, organic and bioavailable phosphorus contents in different soil types and found for a sandy Argisol under sugarcane crop in Carpina, State of Pernambuco, Pt values of 71.4 (A horizon) and 17.6 mg kg^{-1} (Bt horizon), differing from the results found in the present study. Cunha et al. (2007) found Pt levels ranging from 585 to 515 mg kg^{-1} in the layer 0-0.10 m, in sandy loam soils (Haplic Cambisol and Red Latosol) under pasture in the Santa Maria Madalena region, State of Rio de Janeiro. Total P values ranging from 585 to 736 mg kg^{-1} in the layer 0.00-0.05 m was found in clayey Latosols under a cocoa agro-systems in Itajuípe, State of Bahia (ZAIA et al., 2008).

Table 1. Total phosphorus (P total) in the soil (mg kg $^{-1}$), evaluated through sulfuric acid digestion in areas of chronosequence of sugarcane, pasture and native vegetation in the Cerrado biome of the State of Goiás.

Systems	Layers (m)					
	0-0.05	0.05-0.10	0.10-0.20	0.20-0.30	0.30-0.40	0.40-0.60
	P total (mg kg^{-1})					
CN1	234.05 d	261.76 c	267.31 b	206.34 d	218.54 c	222.97 b
CN5	272.86 c	263.37 c	273.91 b	358.27 b	375.14 b	419.43 a
CN10	358.41 b	304.72 b	265.52 b	262.96 c	207.57 c	210.13 b
CN20	420.49 a	437.36 a	435.25 a	403.62 a	405.72 a	428.92 a
NV	155.08 e	100.26 d	179.92 c	113.10 e	136.23 d	128.52 c
PA	272.43 c	249.30 c	271.58 b	269.86 c	237.31 c	220.18 b
CV %	9.42	9.49	7.53	7.72	8.87	8.1

Means followed by the same letter do not differ between the systems evaluated by the Scott Knott test at 5% probability. CN1 (1-year sugarcane crop harvested with previous straw burning), CN5 (5-years sugarcane crop harvested with previous straw burning), CN10 (10-years sugarcane crop harvested with previous straw burning) CN20 (20-years sugarcane crop harvested with previous straw burning), NV (native vegetation) and PA (pasture).

The relative proportion of organic P (Po) and inorganic P (Pi) had a heterogeneous pattern among the studied areas (Figure 2), except for the most superficial layer, which had more homogenous proportions. A long-term study on sugarcane crop under Haplic Cambisol in northwestern Rio de Janeiro State by Busato et al. (2005) found predominance of Pi fraction over Po fraction in sugarcane areas without burning compared with the burnt ones. These authors attributed this result to the mineralization of crop residues or humified organic matter of the soil, favoring mainly the available compartment. Moreover, an increment of 277% of P was found in the soil where the straw was preserved compared with the soil where the straw was burning before harvesting.

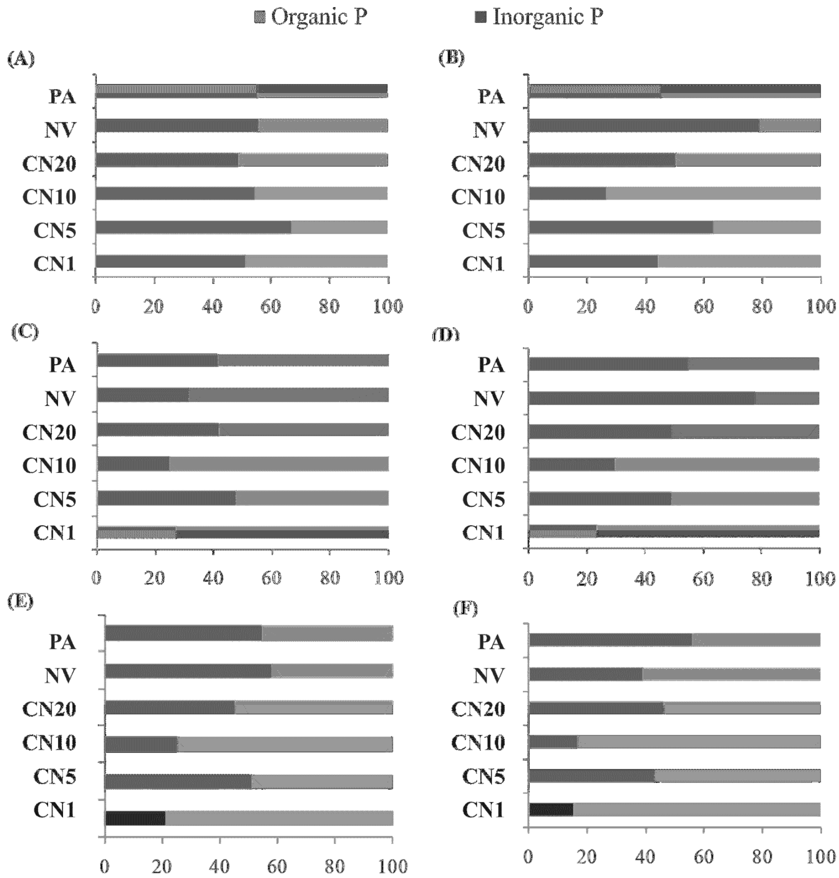

Figure 2. Relative distribution of organic and inorganic P of Red Latosols in areas of chronosequence of sugarcane, pasture and native vegetation in the Cerrado biome of the State of Goiás. (A) 0-0.05 m; (B) 0.05-0.10 m; (C) 0.10-0.20 m; (D) 0.20-0.30 m; (E) and 0.30-0.40 m (F) 0.40-0.60 m. CN1 (1-year sugarcane crop harvested with previous straw burning), CN5 (5-years sugarcane crop harvested with previous straw burning), CN10 (10-years sugarcane crop harvested with previous straw burning) CN20 (20-years sugarcane crop harvested with previous straw burning), NV (native vegetation) and PA (pasture).

The sequential fractionation of P (Tables 2, 3 and 4) showed that the resistant fraction (P OH^-), extracted by NaOH was the most representative of all the areas evaluated. The lowest values were found in the moderately resistant fraction (P H^+), which was considered up to 0.40 m deep, since deeper P contents were below the detection level by spectrometry. Souza et al. (2007) found little contribution of labile P fraction in the P total pool, with predominance of non-labile P in Latosols and Neosols of the State of Minas Gerais, which had a wide variation in clay, mineralogy and soil organic matter (SOM) contents. Fernandes et al. (2002), studying lowland soils of the south of Minas Gerais.

Regarding the phosphorus total labile fraction (Table 2), the highest levels were found in the NV area, resulting in greater proportions of labile organic P in relation to the total labile P. The CN20 area had the highest values of total labile P. This result may be influenced by the addition of vinasse (29 mg P L^{-1}) in this area (Table 2). Regarding the inorganic labile P fraction, the largest contents were also found in the area CN20 up to 0.30 m deep, while the organic labile P fraction in this area had the lowest proportions in relation to the total labile P, showing that with the application of P from external sources cause a decrease in the contribution of organic P in the soil.

Tiessen et al. (1984) found a Po contribution of 14% of plant nutrition in little weathered soils, while in very weathered soils it reached 80%. Beck; Sanches (1994) found a Po contribution of 9% in soils with phosphorus fertilization and 34% in unfertilized systems. Likewise, Gatiboni et al. (2007) report a Po contribution in fertilized soils of 6%, and 43% in soils without mineral fertilizers.

Table 2. Labile P fractions extracted by $NaHCO_3$ in areas of chronosequence of sugarcane, pasture and native vegetation in the Cerrado biome of the State of Goiás.

Systems	Layers (m)					
	0-0.05	0.05-0.10	0.10-0.20	0.20-0.30	0.30-0.40	0.40-0.60
			Total Labile P (mg kg^{-1})			
CN1	35.6 c	35.1 b	40.9 a	37.3 a	31.4 b	33.0 a
CN5	36.2 c	32.8 c	26.2 c	35.2 a	32.0 b	23.6 c
CN10	37.4 c	24.1 d	25.9 c	20.5 c	18.8 d	17.1 d
CN20	41.7 b	45.9 a	39.5 a	36.1 a	17.5 d	19.5 d
NV	65.5 a	53.2 a	42.3 a	35.7 a	34.0 a	28.7 b
PA	43.2 b	38.0 b	30.5 b	31.3 b	27.4 c	27.8 b
CV %	5.7	7.0	9.5	9.32	7.04	14.14
			Labile Inorganic P (mg kg^{-1})			
CN1	19.3 b	17.7 c	18.2 b	22.3 a	21.6 a	15.7 a
CN5	10.0 d	15.7 c	9.8 c	11.7 d	8.8 d	6.1 d
CN10	17.4 c	13.9 d	14.2 d	6.8 e	7.0 e	7.8 c
CN20	26.1 a	24.3 a	22.7 a	20.7 b	4.3 f	6.2 d
NV	19.7 b	20.1 b	19.4 b	17.2 c	16.7 b	16.4 a
PA	17.6 c	16.3 c	17.4 b	16.8 c	13.8 c	14.6 b
CV %	9.7	11.0	11.3	8.2	9.9	9.6
			Labile Organic P (mg kg^{-1})			
CN1	16.3 d	17.4 c	22.8 a	15.0 c	9.8 d	19.0 a
CN5	26.2 b	17.1 c	16.5 b	23.5 a	23.2 a	17.5 a
CN10	19.9 c	10.2 d	11.8 c	13.6 c	11.8 c	9.2 c
CN20	15.6 d	21.6 b	16.8 b	15.4 c	13.2 c	13.3 b
NV	45.9 a	33.1 a	22.8 a	18.4 b	17.3 b	12.3 b
PA	25.6 b	21.6 b	13.1 c	14.6 c	13.5 c	13.1 b
CV %	12.6	10.6	16.6	15.3	13.9	20.9

Means followed by the same letter do not differ between the systems evaluated by the Scott Knott test at 5% probability. CN1 (1-year sugarcane crop harvested with previous straw burning), CN5 (5-years sugarcane crop harvested with previous straw burning), CN10 (10-years sugarcane crop harvested with previous straw burning) CN20 (20-years sugarcane crop harvested with previous straw burning), NV (native vegetation) and PA (pasture).

Busato et al. (2005) evaluated the P extracted by $NaHCO_3$ in a Cambisol in Campos dos Goytacazes, State of Rio de Janeiro, and found, in areas without pre-harvest burning, average values of labile P fractions in the soil of 115 mg kg^{-1}, representing 14% of the extracted phosphorus content, and in areas with pre-harvest burning, average values of 16 mg kg^{-1}, representing 5%, showing the importance of organic matter preservation to increase more available forms of P in the soil. These results confirm those found in the present study for the sugarcane areas with pre-harvest burning.

The highest values of total P H^+ (Table 3) were found in the CN20 area in the first two layers. The PA and NV areas had the highest proportions of organic P H^+ in relation to the total P H^+, with values over 70% in all depths (Figure 3).

Duda (2000) found highest values of P extracted by acid compared with other extractors, however, he found values of P similar to those found in the present study for sandy Argisols in Carpina, State of Pernambuco, with values 40 mg kg^{-1} (total P H^+ fraction) and 8 mg kg^{-1} (organic P H^+). The author emphasizes this fraction importance in soil fertility studies, since it is related to non-humic substances and fulvic acids (SEQUI et al., 1986), and the microorganisms and plants accessibility to this compartment can be easier compared to P forms related to humic acids, which are organic substances with higher humification level (FARES et al., 1974).

Table 1. Moderately resistant phosphorus fractions (P H^+) extracted by H_2SO_4 in areas of chronosequence of sugarcane, pasture and native vegetation in the Cerrado biome of the State of Goiás.

Systems	Layers (m)

	0-0.05	0.05-0.10	0.10-0.20	0.20-0.30	0.30-0.40
			Total P H^+ (mg kg^{-1})		
CN1	19.8 c	18.1 d	14.0 c	10.3 c	5.4 e
CN5	22.3 c	20.7 c	16.7 b	12.9 b	8.2 d
CN10	38.4 b	23.4 b	11.8 d	9.5 d	5.0 e
CN20	41.8 a	30.8 a	17.6 b	10.7 c	10.1 c
NV	18.3 c	18.3 d	20.4 a	22.0 a	18.6 a
PA	14.6 d	12.9 e	13.6 c	10.7 c	13.0 b
CV %	10.8	4.6	10.4	14.5	9.5
			Inorganic P H^+ (mg kg^{-1})		
CN1	17.6 d	16.1 c	12.8 b	8.1 b	4.1 d
CN5	19.3 c	17.7 b	14.4 a	9.8 a	6.1 b
CN10	29.1 a	19.6 a	9.5 c	7.5 b	3.7 d
CN20	28.5 b	17.6 b	11.9 b	7.7 b	7.4 a
NV	4.9 e	4.9 d	5.5 d	6.3 c	4.7 c
PA	2.9 f	2.6 e	2.8 e	1.9 d	2.5 e
CV %	1.9	5.6	9.7	11.2	14.5
			Organic P H^+ (mg kg^{-1})		
CN1	2.2 c	2.0 d	1.2 d	2.2 c	1.3 d
CN5	3.0 c	3.0 c	2.2 d	3.2 c	2.1 c
CN10	9.2 b	3.8 c	2.3 d	2.1 c	1.3 d
CN20	13.3 a	13.2 a	5.7 c	2.9 c	2.7 c
NV	13.4 a	13.5 a	14.9 a	15.7 a	13.8 a
PA	11.6 a	10.3 b	10.8 b	8.8 b	10.5 b
CV %	31.8	13.3	21.6	23.1	14.0

Means followed by the same letter do not differ significantly between the systems evaluated by the Scott Knott test at 5% probability. CN1 (1-year sugarcane crop harvested with previous straw burning), CN5 (5-years sugarcane crop harvested with previous straw burning), CN10 (10-years sugarcane crop harvested with previous straw burning) CN20 (20-years sugarcane crop harvested with previous straw burning), NV (native vegetation) and PA (pasture).

Nogueira et al. (2008) studied P forms in an orthic chromic Luvisol under agroforestry systems in Sobral, State of Ceara, and found a predominance of P extracted in acid over the P extracted in an alkaline medium. The Pt (H^+) content ranged from 69.9 to 414.5 mg kg^{-1}, with average content of 141 mg kg^{-1}, higher than those found in the present study. According to Novais; Smith (1999), P extraction in acid medium solubilize P forms linked to calcium, which confirms the results of soil chemical composition of Nogueira et al. (2008). According to Mota (1997), hornblende, feldspar and biotite, which are potential sources of P, are among the predominant primary minerals in Luvisols of this region.

P values extracted in alkaline medium in the CN20 area differed from other areas, with greater values for the total, organic and inorganic fractions. The mineralization of the soluble P fraction extracted in alkaline medium may be slower, since it is associated with more stable forms of organic matter, such as humic and humin acids, which have high mineralization resistance (STEVENSON, 1994).

The NaOH is more efficient in extracting P forms of low lability and with restricted availability to plant absorption, these P forms are associated with phosphate of low and high crystallinity of Al and Fe oxides (NOVAIS; SMYTH, 1999; RHEINHEIMER; ANGHINONI, 2001), therefore, the amount of P extracted with NaOH is justified by the type of soil in the studied area.

The less labile P forms (Pi and Po-NaOH), which have availability restricted to plant absorption, had levels of P higher than the fractions extracted with bicarbonate and sulfuric acid in a study on soil phosphorus forms under influence of liming and organic fertilization in soils with different textures (SOUZA et al., 2007). According to these authors, the highest content found in this P fraction indicates the importance of application of organic residues, since it is an important compartment in cycling of P in the soil (TATE; SALCEDO, 1988).

Busato et al. (2005) found P fraction extracted by NaOH representing a major portion of the total content of P on all areas and depths evaluated, especially in the ones that received vinasse. They also found lower contribution (11%) to the total content of P up to 0.40 m deep for areas with sugarcane without pre-harvest burning. According to these authors, the management of sugarcane without burning for long time reduce pollutants emissions into the atmosphere and contribute to higher levels of P in the soil surface and subsurface.

Table 4. Phosphorus resistant fractions (P OH^-) extracted by NaOH in areas of chronosequence of sugarcane, pasture and native vegetation in the Cerrado biome of the State of Goiás.

Systems	Layers (m)					
	0-0.05	0.05-0.10	0.10-0.20	0.20-0.30	0.30-0.40	0.40-0.60
	Total P OH^- (mg kg^{-1})					
CN1	134.6 d	129.9 d	75.6 d	56.7 d	55.2 f	41.5 e
CN5	191.0 b	187.6 b	148.8 b	185.0 b	201.7 b	202.0 b
CN10	257.2 a	149.7 c	98.8 c	111.3 c	91.6 d	72.6 d
CN20	269.1 a	302.1 a	258.6 a	261.3 a	241.1 a	248.5 a
NV	66.3 e	68.1 e	39.8 e	80.9 d	74.6 e	74.0 d
PA	163.0 c	131.8 d	137.8 b	166.1 b	148 c	144.3 c
CV %	8.4	9.0	13.9	14.5	7.6	6.8
	Inorganic P OH^- (mg kg^{-1})					
CN1	34.1 e	35.4 e	27.7 d	25.8 f	23.8 f	26.6 f
CN5	39.9 d	41.0 d	37.2 c	39.7 d	36.9 d	39.7 c
CN10	91.9 b	83.3 b	47.6 b	49.2 b	52.9 b	47.4 b
CN20	98.0 a	128.3 a	98.5 a	83.7 a	73.5 a	66.0 a
NV	33.5 e	27.8 f	33.7 c	34.3 e	28.8 e	37.1 d
PA	45.6 c	47.2 c	54.4 b	43.4 c	40.4 c	30.5 e
CV %	6.5	4.2	11.5	4.8	4.6	5.1
	Organic P OH^- (mg kg^{-1})					
CN1	97.2 d	94.6 c	48.0 d	32.5 d	31.4 c	14.9 e
CN5	151.1 b	146.6 b	111.6 b	145.3 b	164.8 a	162.4 b
CN10	165.0 b	66.5 d	51.1 d	62.1 c	38.8 c	25.1 e
CN20	171.0 a	173.8 a	160.1 a	177.6 a	167.6 a	182.5 a
NV	32.8 e	40.3 e	14.7 e	46.6 d	45.8 c	37.0 d
PA	124.1 c	84.6 c	83.4 c	149.4 b	107.5 b	113.8 c
CV %	9.7	14.5	17.2	13.1	10.3	10.6

Means followed by the same letter do not differ between the systems evaluated by the Scott Knott test at 5% probability. CN1 (1-year sugarcane crop harvested with previous straw burning), CN5 (5-years sugarcane crop harvested with previous straw burning), CN10 (10-years sugarcane crop harvested with previous straw burning) CN20 (20-years sugarcane crop harvested with previous straw burning), NV (native vegetation) and PA (pasture).

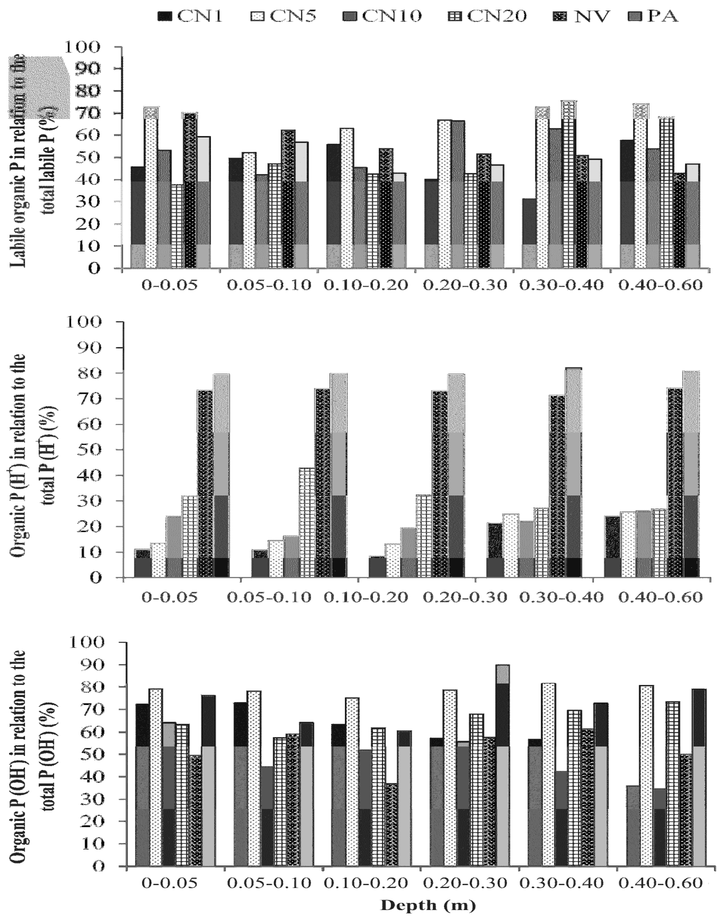

Figure 3. Percentage of labile, moderately resistant and resistant organic P, extracted with $NaHCO_3$, H_2SO_4 and NaOH, in relation to their total P.

CONCLUSIONS

The area of sugarcane that had 20 years of management with pre-harvest burning had the highest content of total P in the soil among the areas evaluated.

Great contributions of P are found from the fraction extracted with alkaline solution and small contributions from the fraction extracted with acid solution.

The organic P greatly contributed to the total P content.

ACKNOWLEDGEMENTS

The authors acknowledge the support of CPGA-CS / UFRRJ, CNPq, Capes, Federal Institute of the State of Goiás - Campus Rio Verde and the Decal Industry.

RESUMO: O fósforo (P) é um importante macronutriente para o desenvolvimento vegetal. A distribuição de suas formas no solo está condicionada por processos geoquímicos, biológicos e ações antrópicas. A caracterização desses compartimentos favorece o entendimento do ciclo desse nutriente. O objetivo desse trabalho foi avaliar o teor de P total e das frações de P orgânico de amostras de Latossolo Vermelho em áreas com diferentes sistemas de manejo ao estado de Goiás. O estudo foi realizado em áreas de cana-de-açúcar, de 1 (CN1), 5 (CN5), 10 (CN10), 20 (CN20) anos, onde a colheita da cana é feita com a prática da queima prévia da palhada antes da colheita e adicionalmente uma área de cerrado (VN) e pastagem (PA). A quantificação das frações de P foram obtidas empregando-se extrações com $NaHCO_3$, H_2SO_4 e NaOH. A área CN20 apresentou os maiores valores de Pt quando comparadas as demais até 0,40 m de profundidade, já para a camada de 0,40-0,60 m a área CN5 apresentou valores semelhantes aos verificados para CN20. Para a fração lábil inorgânica os maiores teores de P também foram observados na área CN20 até 0,30 m de profundidade. A fração extraída com NaOH apresentou as maiores proporções de P entre os sistemas avaliados, apesar dessa fração ser considerada pouco lábil, em solos de regiões tropicais se apresenta como forma bastante dinâmica.

PALAVRAS-CHAVE: Fracionamento de fósforo. Formas de fósforo. Fósforo inorgânico. *Saccharum officinarum*.

REFERÊNCIAS

BECK, M. A.; SANCHES, P. A. Soil phosphorus fraction dynamics during 18 years of cultivation on a Typic Paleudult. **Soil Science Society and American Journal,** Madison, v. 58, p. 1424-143, 1994. http://dx.doi.org/10.2136/sssaj1994.03615995005800050021x

BOWMAN, R. A. A sequential extraction procedure with concetrated sulfuric acid and diluted base for soil organic phosphorus. **Soil Science Society and American Journal** , Madison, v. 53, n. 326-366, 1989.

BUSATO, J. G.; CANELLAS, L. P.; VELLOSO, A. C. X. Fósforo num Cambissolo cultivado com cana-de-açúcar por longo tempo: I - Fracionamento sequencial. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 29, n. 935- 944, 2005.

CONTE, E.; ANGHINONI, I.; RHEINHEIMER, S. D. Fósforo da biomassa microbiana e atividade de fosfatase ácida após aplicação de fosfato em solo no sistema de plantio direto. **Revista Brasileira de Ciência do Solo,** Viçosa, v. 2, p. 925-930, 2002.

CONTE, E.; ANGHINONI, I.; RHEINHEIMER, D.S. Frações de fósforo em Latossolo argiloso pela aplicação de fosfato no sistema plantio direto. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 27, p. 893-900, 2003.

CUNHA, G. M.; GAMA-RODRIGUES, A. C.; COSTA, G. S.; VELLOSO, A. C. X. Fósforo orgânico em solos sob florestas montanas, pastagens e eucalipto no norte fluminense. **Revista Brasileira de Ciência do Solo,** Viçosa, v. 31, p. 667-671, 2007.

DUDA, G. P. **Conteúdo de fósforo microbiano, orgânico e biodisponível em diferentes classes de solos.** 2000. 158f. Tese (Doutorado em Agronomia-Ciência do Solo) Universidade Federal Rural do Rio de Janeiro, Seropédica, 2000.

EMBRAPA. Centro Nacional de Pesquisa de Solos. **Manual de métodos de análise de solo.** 2.ed. Rio de Janeiro, 1997. 212p.

FARES, FL.; FARDEAU, J. C.; JACQUIN, F. Quantitative survey of organic phosphorus in differents soil types. **Phosphorus in Agriculture**, Paris, v. 28, p. 25-40, 1974.

FERNANDES , L. A.; FAQUIN, V.; FURTINI, A. E.; CURI, N. Formas de fósforo em solos de várzea e biodisponibilidade para o feijoeiro. **Pesquisa Agropecuária Brasileira**, Brasília, v. 37, p. 373-383, 2002. http://dx.doi.org/10.1590/S0100-204X2002000300019

GATIBONI, L. C. KAMINSKI, J.; RHEINHEIMER, D. S.; FLORES, J. P. C. Biodisponibilidade de formas de fósforo acumuladas em solo sob sistema plantio direto. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, p. 691-699, 2007.

GUERRA, J. G. M.; ALMEIDA, D. L.; SANTOS, G. A.; FERNANDES, M. S. Conteúdo de fósforo orgânico em amostras de solos. **Pesquisa Agropecuária Brasileira**, Brasília, v. 31, p. 291-299, 1996.

MARTINAZZO, R.; RHEINHEIMER, D.S.; GATIBONI, L.C.; BRUNETTO, G. KAMINSKI, J. Fósforo microbiano do solo sob sistema plantio direto afetado pela adição de fosfato solúvel. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, p. 563-568, 2007.

MOREIRA, F. M.; SIQUEIRA, J. O. **Microbiologia e bioquímica do solo**. Lavras: UFLA, 2002. 626 p.

MOTA, F. O. B. **Mineralogia de solos da região semi-árida do estado do Ceará**. 1997. 205 f. Tese (Doutorado em Agronomia). Universidade de São Paulo, São Paulo, 1997.

NOGUEIRA, R. S.; OLIVEIRA, T. S.; SÁ MENDONÇA, E.; FILHO ARAÚJO, J.A. Formas de fósforo em Luvissolo Crómico Órtico sob sistemas agroflorestais no município de Sobral-CE1. **Revista Ciência Agronômica,** Fortaleza, v. 39, p. 494-502, 2008.

NOVAIS, R. F.; MELLO, J. W. V. **Relação solo planta**. In: NOVAIS, R. F. et al. Fertilidade do solo. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, p. 276-374. 2007.

NOVAIS, R. F.; SMYTH, T. J. **Fósforo em solo e planta em condições tropicais**. Viçosa-MG: UFV, 1999. 399 p.

RHEINHEIMER, D. S. et al. Fósforo da biomassa microbiana em solos sob diferentes sistemas de manejo. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 24, p. 589-597, 2000.

RHEINHEIMER, D. S.; ANGHINONI, I. Distribuição do fósforo inorgânico em sistemas de manejo de solo. **Pesquisa Agropecuária Brasileira**, Brasília, v. 36, p.151-160, 2001. http://dx.doi.org/10.1590/S0100-204X2001000100019

RHEINHEIMER, D. S.; ANGHINONI, I.; CONTE, E. Sorção de fósforo em função do teor inicial e de sistemas de manejo de solos. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 27, p. 41-49, 2003.

SANTOS, H. G. dos; JACOMINE, P. K. T.; ANJOS, L. H. C. dos; OLIVEIRA, V. A. de; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A. de; CUNHA, T. J. F.; OLIVEIRA, J. B. de. **Sistema brasileiro de classificação de solos**. 3. ed. rev. e ampl. Brasília, DF: Embrapa, 2013. 353 p.

SEQUI, P.; NOBILI, M. ; LEITA, L.; CERCIGNANI, G. A new index of humification. **Agrochimica**, Pisa, v. 30, p. 175-179, 1986.

SOLOMON, D.; LEHMANN, J.; MAMO, T.; FRITZCHE, F.; ZECH, W. Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands. **Geoderma**, Amsterdam, v. 105, p. 21-48, 2002. http://dx.doi.org/10.1016/S0016-7061(01)00090-8

SOUZA, R. F. et al. Formas de fósforo em solos sob influência da calagem e adubação orgânica. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, p. 1535-1544, 2007.

STEVENSON, F. J. **Humus chemistry: genesis, composition, reactions**. New York: J. Wiley. 1994, 496p.

TATE, K. R.; SALCEDO, I. H. Phosphorus control of soil organic matter accumulation and cycling. **Biogeochemistry**, Kansas, v. 5, p. 99-107, 1988. http://dx.doi.org/10.1007/BF02180319

TEDESCO, M. J.; GIANELLO, C.; BISSANI, C. A.; BOHNEN, H.; VOLKWEISS, S. J. **Análises de solo, plantas e outros materiais.** 2.ed. Porto Alegre: UFRGS, 1995. 174p. (Boletim técnico de solos, 5).

TIESSEN, H.; STEWART, J. W. B.; COLE, C. V. Pathways of phosphorus transformation in soils of differing pedogenesis. **Soil Science Society of American Journal,** Madison, v. 48, p. 853-858, 1984.

WHITELAW, M. A. Growth promotion of plant inoculated with phosphate solubilizing fungi. **Advances in Agronomy,** San Diego, v. 69, p. 99-151, 2000. http://dx.doi.org/10.1016/S0065-2113(08)60948-7

ZAIA, F. C.; GAMA-RODRIGUES, A. C.; EMANUELA FORESTIERI DA GAMA-RODRIGUES, E. F.; MACHADO, R. C. R. Fósforo orgânico em solos sob agrossistemas de cacau. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 32, p. 1987-1995, 2008.