Open Access Library Journal
2024, Volume 11, e11318
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Study of Organic and Inorganic Forms of Phosphorus in the Soil under Management Systems and Cropping Successions

Bianca Souza Selhorst[1], Jairo André Schlindwein[2], Wilson Sacchi Peternella[2*]

[1]Department of Agronomy, Federal University of Rondônia, Campus de Rolim de Moura, Rondônia, Brazil
[2]Department of Chemistry, Federal University of Rondônia, Porto Velho, Brazil
Email: *wpeternella@yahoo.com

How to cite this paper: Selhorst, B.S., Schlindwein, J.A. and Peternella, W.S. (2024) Study of Organic and Inorganic Forms of Phosphorus in the Soil under Management Systems and Cropping Successions. *Open Access Library Journal*, **11**: e11318.
https://doi.org/10.4236/oalib.1111318

Received: February 16, 2024
Accepted: March 24, 2024
Published: March 27, 2024

Abstract

The forms of organic "Po" and inorganic "Pi" phosphorus in the soil, in addition to being influenced by phosphate fertilization, can also be influenced by different soil management systems and cover crops. Therefore, the objective of this work was to evaluate the influence of soil management systems, cultivated with successions of crops in the forms of "Po" and "Pi". The experiment consisted of two soil preparation systems (Direct Planting System—SPD and Traditional Planting—PRT) and two crop successions (soy/beans and Corn/corn + brachiaria), being evaluated in two layers (0 - 10 and 10 - 20 cm). The use of crop successions promoted the greatest accumulation of total phosphorus in organic forms, both in SPD and PRT. There was no difference between systems for total Po forms in the two layers and labile "Po" in the 0 - 10 cm layer. However, in the 10 - 20 cm layer, the PRT obtained the highest levels of labile "Po". The inorganic forms of total phosphorus were higher in the 0 - 10 cm layer compared to the 10 - 20 cm layer in both systems evaluated. The SPD promoted higher levels of labile "Pi" in the 0 - 10 cm deep layer. As for PRT, there are higher levels of labile "Pi" in the 10 - 20 cm layer of the soil compared to SPD.

Subject Areas

Soil Science

Keywords

Direct Planting System, Traditional Planting and Phosphorus Lability

1. Introduction

The phosphorus element "P" is one of the main nutrients of the plant and is normally present in the soil in quantities available below the plants' needs, where it participates in the structures and processes vital for the development of plants. (LOPES, 1998 [1]; FAQUIM & ANDRADE, 2004 [2]).

The "P" content present in most soils can be relatively high, however, phosphorus is the element that most limits productivity in tropical soils, due to its ability to transform this element into stable, fixed forms, or combined with other elements. such as calcium, iron or aluminum, forming compounds that cannot be assimilated by plants. Therefore, even if the total levels in the soil are high in relation to those needed by plants, only a small fraction of it has a low binding energy that makes it available to plants. Under these conditions, the cycling of more labile organic forms can be accelerated, being more important in highly weathered tropical soils (SILVA & MENDONÇA, 2007 [3]).

The chemical element phosphorus "P" in soil can be found in organic "Po" and inorganic "Pi" forms, depending on the nature of the compound to which it is linked. The availability of "P" to plants depends on the capacity to replace phosphate ions in the soil solution, and can be divided into labile, moderately labile and non-labile. Labile and moderately labile forms support "P" uptake by plants. With the decrease in the support capacity of inorganic and organic forms of intermediate lability, the more recalcitrant forms of "P" begin to be buffered from the system (GATIBONI *et al.*, 2007 [4]).

Forms of "Po" and "Pi" can be influenced by several factors, including phosphate fertilizer, soil management system and cover crops (TIECHER *et al.*, 2012a [5]; LEITE *et al.*, 2016 [6]). According to GATIBONI *et al.*, 2013 [7], when the soil is not fertilized and plant residues are added, the organic fraction buffers the phosphorus in the soil solution. However, when there is fertilization, pho-sphorus accumulates in inorganic forms, which buffer the solution. Thus, organic phosphorus is used on a smaller scale, which allows its accumulation. With phosphate fertilization, phosphorus is redistributed in all soil fractions, with accumulation being more evident in labile inorganic fractions. However, over time, the adsorption energy increases and phosphorus gradually passes into less lable forms. (RHEINHEIMER *et al.*, 2008 [8]).

Addition of fertilizers in the form of phosphate to the soil has been used to overcome "P" deficiency, however, when added in soluble form, that is, being found in the soil solution in the forms of H_3PO_4, $H_2PO_4^{-1}$, HPO_4^{-2} and PO_4^{-3}, where the concentrations of these anions are dependent on the pH of the medium, these species can be adsorbed on the surface of organic and inorganic colloids, or even converted to poorly soluble compounds complexed with Fe and Al oxides and hydroxides (BRADY & WEIL, 1996 [9]).

Microorganisms present in the soil, such as bacteria and fungi, solubilize unavailable inorganic forms of "P" (Xin *et al.*, 2002 [10]; Son *et al.*, 2006 [11]). These microorganisms use biochemical pathways, such as the production of organic acids, or even a mechanism that involves microbial development and that favors the secretion of protons (H^+) (Illmer *et al.*, 1995 [12]).

In Brazil, soils in agricultural areas generally present acidic soil conditions and the presence of aluminum and iron [$AlPO_4$ and $FePO_4$] in greater quantities. Based on the work carried out, as reported by (BARROSO & NAHAS, 2005 [13]), among the phosphorus fractions found in soils under conditions: 1) pasture, 2) forest, 3) forest and 4) corn crops the most abundant was iron phosphate [$FePO_4$], followed by aluminum phosphate [$AlPO_4$] and calcium phosphate [$Ca_3(PO_4)_2$]. It is known that the solubility of these phosphates is very low and decreases in the following order: Ca-P > Al-P > Fe-P.

As reported by (RICHARDSON, 1994 [14]), the amount of "P" present in the soil, in the order of 1% to 10%, is immobilized in the microbial biomass. This amount is not necessarily available to plants, but acts as a component of the dynamic process "P" cycle" in soils, being strongly influenced by fertility, seasonality and different agricultural practices.

Management systems that promote soil disturbance through tillage can expose new active adsorption sites, favoring the adsorption of orthophosphate ions to inorganic colloids, making these ions increasingly less available to crops. However, these effects can be minimized with the use of direct planting systems using cover crops that allow greater accumulation of organic matter, as the accumulation of organic matter in the soil allows greater soil aggregation, in addition to contributing to the reduction of losses. of "P" by erosion and to increase quantities of labile organic "Po" (GATIBONI *et al.*, 2007 [4]; LEITE *et al.*, 2016 [6]). The use of conservation systems combined with crop succession can promote the accumulation of plant residues, and thus contribute to the increase in organic forms of "P". In intensive cultivation systems, without the use of crop rotations that favor greater deposition of plant residues, with low "P" replacement, there is a decrease in "Po" (PARTELLI *et al*, 2009 [15]; TIECHER *et al.*, 2012a [5]).

Due to the influence of management systems on the forms of "P" in the soil, this work had as objective evaluate the effect of two management systems Direct Planting System (SPD), Traditional Planting (PRT), and crop successions on inorganic forms and organic content of the phosphorus element "P" in the soil.

2. Methodology

In this study, soil samples were used from an experiment with soil management systems and crop sequences, implemented in 2007 at the Experimental Farm of the Federal University of Rondônia, located on line 184 Norte, km 15 (Rodovia RO 479) in the municipality of Rolim de Moura/RO (11˚34'57"S and 61˚46'21"W).

The experimental design was factorial [(2 × 2) × 3] × 2, with two soil management systems, two crop successions, three replications, at two depths. The soil in the area is classified as a Red-Yellow Oxisol with a clayey texture (SANTOS, *et al.*, 2013 [16]).

The treatments were composed of two soil preparation systems: direct planting system (SPD) and traditional tillage (PRT), as shown in Table 1, with two successions of harvest/off-season crops: Soy/Beans and Corn/Corn + *Brachiaria spp*., as shown in Table 2.

The area was fertilized every year at sowing for annual harvest crops, using doses verified in soil analyzes as recommended in the "Manual of recommendations for the use of correctives and fertilizers in Minas Gerais—5th approximation".

Soil preparation for crop implementation, for the PRT system, starting in September/October of each year with two intermediate harrow passes. In the SPD system, only the plants were desiccated using herbicides.

In the off-season, direct planting was carried out in both soil preparation systems, due to the rainy season, where in this region it normally rains practically every day, making new soil preparation in the PRT system unfeasible.

The sowing of the crop is generally carried out in the months of November and December, and the off-season between March and April. The harvests from 2014 to 2017 received sowing fertilizer using 350 kg·ha^{-1} of the commercial formulation 4-30-16 (NPK), and corn received top dressing using 120 kg·ha^{-1} of nitrogen, in the form of urea, when the plant presented an average of five expanded leaves.

Table 1. Description of soil management systems.

Soil Management	Symbol	Description
Traditional Preparation	PRT	Three harrowings using a plowing harrow and two more with a leveling harrow, with the operations carried out before planting in the harvest, once a year. In the off-season, direct sowing was carried out, with no soil preparation being carried out, due to the rainy season in the region, which made soil preparation at that time impossible.
Direct Planting System	SPD	Soil preparation before system implementation. Afterwards, there was no soil preparation, with the only disturbance being in the sowing line during the harvest and off-season.

Table 2. History of crop successions in different soil management.

Crop successions	Symbol	History
Soy x Caupi Beans	S/F	From 2007 to 2014, soybeans were sown in the harvest and common beans in the off-season. From 2015 onwards, soybeans were sown in the harvest and cowpeas in the off-season.
Corn x Corn + Brachiaria	M/M + B	From 2007 to 2014, corn was sown in the harvest and corn in the off-season. From 2015 onwards, corn was sown in the harvest and corn in the off-season in intercropping with Brachiaria ruziziensis, which was sown when the corn was 1.0 meters tall.

The soil samples for this study were collected in March 2018. In both systems (SPD and PRT), four subsamples were collected to form a single sample, for the 0 - 10 and 10 - 20 cm layers in depth.

The chemical analyzes were composed of the fractionation of "P", according to the methodology of Hedley *et al.*, (1982) [17] with the modifications proposed by Condron *et al.*, (1985) [18] and adaptations by Gatiboni (2003) [19].

The "P" from the soil samples was extracted sequentially with anion exchange resin (RTA) in a suspension of soil and water, $NaHCO_3$ 0.5 $mol \cdot L^{-1}$, NaOH 0.1 $mol \cdot L^{-1}$, HCL 1.0 $mol \cdot L^{-1}$ and NaOH 0.5 $mol \cdot L^{-1}$. After extractions, the remaining soil was dried in an oven and subjected to digestion with H_2SO_4 + $MgCl_2$ + H_2O_2 (Presidual fraction), as described by Brookes & Powlson (1982) [20]. The inorganic phosphorus "Pi" of the alkaline extracts of $NaHCO_3$ and NaOH was determined by the method of Dick & Tabatabai (1977) [21]. In these alkaline extracts, total "P" was determined by digestion with ammonium persulfate + sulfuric acid in an autoclave (USEPA, 1971) [22], with organic phosphorus "Po" being obtained by the difference between total "P" and "Pi". The "Pi" of the acid extracts was determined according to the method of Murphy & Riley (1962) [23]. Total phosphorus was obtained by summing the fractions of the chemical fractionation performed as (P-Total).

The results were interpreted using a 2 × 2 × 2 factorial analysis, with: 1) two soil management systems, 2) two crop successions and 3) two layers, with three replications, respectively. The data were subjected to analysis of variance (ANOVA), and when significant, the Tukey test ($P < 0.05$) was applied to compare the means using the statistical analysis computer program SISVAR (FERREIRA, 2011) [24].

3. Results and Discussion

Forms of the chemical element phosphorus, inorganic (Pi) and organic (Po), referring to the compartments: 1) labile (Pi_{RTA}, Pi_{bic}, and Po_{bic}), 2) moderately labile ($Pi_{Hid0.1}$, $Po_{Hid0.1}$ and Pi_{HCl}) and 3) non-labile ($Pi_{Hid0.5}$, $Po_{Hid0.5}$ and $P_{Residual}$), are presented in **Tables 3-5**, respectively.

Pi_{RTA} showed a difference between SPD and PRT systems, in the presence of succession (Corn/corn + brachiaria) in the 10 - 20 cm soil layer, being superior for the PRT system (**Table 3**). This higher content in the conventional system must be the result of soil disturbance, which allows the homogenization of "P" levels in the arable layer.

When evaluating the layers, the SPD system (soy/beans and corn/corn + brachiaria) showed higher levels in the 0 - 10 cm layer, compared to the 10-20 cm layer. In this system, all fertilizers applied to sowing during the years of consolidation are concentrated in the surface layer of the soil, which can lead to saturation of the adsorption sites, present in the organic and inorganic colloids of the soil, resulting in higher levels of Pi_{RTA} (phosphorus readily available for plants) in superficial layers and lower levels in deeper layers (TIECHER *et al.*, 2012a [5]; CARVALHO *et al.*, 2014) [25].

Table 3. Labile Pi and Po contents (Pi_{RTA}, Pi_{BIC} and Po_{BIC}) in two systems, two crop successions and two layers.

System	SPD		PRT	
	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm
		Pi_{RTA} mg·kg^{-1}		
S/F	6.76 Aaα	0.58 Abα	3.01 Aaα	0.0001 Aaβ
M/M + B	5.29 Aaα	0.0001 Bbα	3.13 Aaα	5.56 Aaα
Mean	6.02 Aa	0.29 Ab	3.07 Aa	2.78 Aa
		Pi_{bic} mg·kg^{-1}		
S/F	6.54 Aaα	0.86 Abα	0.0001 Baα	0.0001 Aaα
M/M + B	1.98 Aaβ	0.0001 Aaα	0.0001 Aaα	0.0001 Aaα
Mean	4.26 Aa	0.43 Ab	0.0001 Aa	0.0001 Aa
		Po_{bic} mg·kg^{-1}		
S/F	53.64 Aaα	33.12 Baα	50.19 Abα	85.54 Aaα
M/M + B	41.35 Aaα	34.76 Baα	60.05 Aaα	74.60 Aaα
Mean	47.49 Aa	33.94 Ba	55.12 Ab	80.07 Aa

*Means followed by the same letter do not differ from each other using the Tukey test at 5% probability. Capital letters in the line compare levels between systems in the same layer and succession, lower case letters compare levels in the line between layers within the same succession and same system, Greek letters compare levels in the column between crop successions within the same layer and same system. SPD: direct planting system; PRT: traditional preparation; S/F: Soy/beans; M/M + B: Corn/corn + brachiaria.

Among the crop successions, Pi_{RTA} levels only showed differences when managing the PRT system in the 10 - 20 cm layer. Where the succession (corn/corn + brachiaria) obtained the highest levels of Pi_{RTA}. The lower levels of Pi_{RTA} observed in the succession (soy/beans) may be due to the conversion of inorganic "Pi" applied via fertilizers into organic forms by the microbial biomass of legume plant residues. Since characteristics such as high biomass production, association with mycorrhizal fungi and the low C/N ratio in relation to grasses justify the greater mobilization of phosphorus in organic forms (LEITE *et al.*, 2016) [6].

Pi_{bic} presented low levels in the PRT, with values close to zero (**Table 3**). The "P" extraction process with the resin may also be extracting Pi_{bic} forms, since the resin is prepared with sodium bicarbonate, and both extractors (RTA and Pi_{bic}) extract labile forms of inorganic "Pi". As described by Rheinheimer *et al.*, (2008) [8], RTA promotes the extraction of "P" through its continuous removal from the solution by exchanging it with bicarbonate in the resin, creating a concentration gradient that forces it to leave the surface of the colloids, until an electrochemical balance is reached between the soil and the RTA.

Pi_{bic} showed a difference between systems in the presence of succession (soy/beans) in the 0 - 10 cm layer, where SPD obtained higher Pi_{bic} contents than PRT. Between the layers, there was only a difference in SPD within the succession (soy/beans), with higher levels in the surface layer of the soil. And between the crop successions, there was a difference between the successions in the SPD in the 0 - 10 cm layer of the soil, with higher levels for the succession (soybeans/beans).

The PRT system presented higher Po_{bic} contents than the SPD system in the two successions evaluated for the 10 - 20 cm layer. In the succession (soy/beans) in the PRT, the levels were higher in layer 10 - 20, compared to 0 - 10 cm (**Table 3**). The difference in Po_{bic} levels between systems is seen as a function of the management adopted, where the soil disturbance in the PRT allows crop residues to reach the deeper layers of the soil (CASALI *et al.*, 2016) [26], in addition to contributing to an increase in soil microbial activity, which favors the retention of "P" in organic forms (CARVALHO *et al.*, 2014) [25].

$Pi_{Hid\ 0.1}$ showed a difference only when comparing the layers within each system (**Table 4**). Their levels were higher in the 0 - 10 cm layer, compared to the 10 - 20 cm layer in both systems evaluated (SPD and PRT). The lower levels of $Pi_{Hid\ 0.1}$ in the SPD layer are due to the concentration of phosphate fertilizer in the surface layer and the low mobility of "P" in the soil (NOVAIS *et al.*, 2007)

Table 4. Pi and moderately labile Po contents ($Pi_{Hid0.1}$, $Po_{Hid0.1}$ and Pi_{HCl}) in two systems, two crop successions and two layers.

System	SPD		PRT	
	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm
		$Pi_{hid\ 0.1}$ mg·kg^{-1}		
S/F	18.78 Aa*α*	4.87 Aa*α*	28.31 Aa*α*	4.87 Ab*α*
M/M + B	23.37 Aa*α*	4.30 Ab*α*	29.39 Aa*α*	0.0001 Ab*α*
Mean	21.08 Aa	4.59 Ab	28.85 Aa	2.44 Ab
		$Po_{hid\ 0.1}$ mg·kg^{-1}		
S/F	62.07 Aa*α*	76.69 Aa*α*	51.05 Aa*α*	73.85 Aa*α*
M/M + B	51.29 Aa*α*	73.24 Aa*α*	80.25 Aa*α*	77.07 Aa*α*
Mean	56.68 Aa	74.96 Aa	65.65 Aa	75.46 Aa
		Pi_{HCl} mg·kg^{-1}		
S/F	1.87Aa*α*	0.80 Aa*α*	1.38 Aa*α*	1.87 Aa*α*
M/M + B	1.51 Aa*α*	0.40 Aa*α*	0.98 Aa*α*	1.64 Aa*α*
Mean	1.69 Aa	0.60 Bb	1.18 Aa	1.76 Aa

*Averages followed by the same letter do not differ from each other using the Tukey test at 5% probability. Capital letters in the line compare levels between systems in the same layer and succession, lower case letters compare levels in the line between layers within the same succession and same system, Greek letters compare levels in the column between crop successions within the same layer and same system. SPD: direct planting system; PRT: traditional preparation; S/F: Soy/beans; M/M + B: Corn/corn + brachiaria.

[27], which together promote an increase in "P" levels in the surface layer. For the PRT system, they may be related to the greater exposure of clay minerals, such as iron and aluminum oxyhydroxide, in addition to silicate minerals, due to the disturbance and increased adsorption of "P" by the soil, and over time, favors the increase in the binding energy of these forms of adsorbed "P", turning them into non-labile forms (SANTOS *et al.*, 2008) [28].

In the PRT system with succession (corn/corn + brachiaria), the $Pi_{hid0.1}$ content was close to zero. Possibly, the process of soil disturbance, associated with grass residues, contributes to the increase in carbon in microbial biomass, which is retaining higher levels of "P" in organic form. The increase in microbial biomass carbon is a compartment regulated by several factors, including the availability of organic substrate and type of cultivation system (VENZKE FILHO *et al.*, 2008) [29]. Thus, the succession (corn/corn + brachiaria) favors higher carbon contents of microbial biomass due to its greater capacity for deposition of organic residues in relation to the succession with legumes.

$Po_{Hid0.1}$ showed no difference between the systems (SPD and PRT), in the successions and layers evaluated, demonstrating the stability of this form of phosphorus in both systems (**Table 4**). The return of plant residues to the soil, favored by the succession of crops, combined with phosphate fertilizers carried out throughout the growing season, allows the accumulation of higher levels of $Po_{Hid\ 0.1}$. The increase in the levels of this fraction is very important in the dynamics of "P", and, through mineralization/immobilization processes, $Po_{Hid0.1}$ can behave as a reservoir, buffering the more labile forms of "P" (NOVAIS *et al.*, 2007) [27].

Pi_{HCL} levels were low (always lower than 2 $mg \cdot kg^{-1}$), this can be attributed to the fact that tropical soils are more weathered and have low calcium phosphate contents (**Table 4**). Since HCl extracts the "P" forms of calcium phosphates, the levels in this form are low (RAIJ, 1991) [30]. Oxisols normally have only traces of Pi_{HCL}, since all the "P" associated with apatite (the mineral that is found in P) would have already been transformed into other forms of "P", due to the acidity and high degree of weathering of these soils. Thus, in tropical conditions, this fraction would be more indicative of the degree of weathering of these soils than relevant to the supply of "P" to plants, representing on average 3% of all "P" present in soils (YANG & POST, 2011) [31].

$Pi_{Hid0.5}$ showed a difference between the systems in the two successions in the 0-10 cm layer. $Pi_{Hid0.5}$ levels were higher in the SPD system compared to the PRT system (**Table 5**). This higher concentration in the form of non-labile "P" in the SPD 0-10 cm does not indicate that this system provides greater adsorption than the PRT system, but as soon as there is saturation of the active adsorption sites by "P", and that It is possibly contributing to higher levels of the non-labile "P" fraction in the surface layer of the soil (RODRIGUES *et al.*, 2015 [32]; PAVINATO *et al.*, 2008 [33]).

In the assessment between layers, the SPD system showed higher levels in the surface layer of the soil, in both successions. The maintenance of the fertilized

Table 5. Pi and non-labile Po contents ($Pi_{Hid0.5}$, $Po_{Hid0.5}$ and $P_{Residual}$) in two systems, two crop successions and two layers.

System	SPD		PRT	
	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm
		$Pi_{hid0.5}$ mg·kg^{-1}		
S/F	20.82 Aaα	2.31 Abα	4.49 Baα	0.0001 Aaα
M/M + B	16.46 Aaα	0.0001 Abα	3.54 Baα	0.0001 Aaα
Mean	18.64 Aa	1.16 Ab	4.01 Ba	0.0001 Aa
		$Po_{hid0.5}$ mg·kg^{-1}		
S/F	48.05 Aaα	42.78 Aaα	61.92 Aaα	26.67 Abα
M/M + B	56.87 Aaα	52.83 Aaα	51.81 Aaα	28.18 Bbα
Mean	52.46 Aa	47.81 Aa	56.87 Aa	27.42 Bb
		$P_{residual}$ mg·kg^{-1}		
S/F	171.67 Aaα	196.33 Aaα	203.33 Aaα	266.00 Aaα
M/M + B	137.67 Baα	181.67 Aaα	228.00 Aaα	186.67 Aaα
Mean	154.67 Aa	189.00 Aa	215.67 Aa	226.33 Aa

*Averages followed by the same letter do not differ from each other using the Tukey test at 5% probability. Capital letters in the line compare levels between systems in the same layer and succession, lower case letters compare levels in the line between layers within the same succession and same system, Greek letters compare levels in the column between crop successions within the same layer and same system. SPD: direct planting system; PRT: traditional preparation; S/F: Soy/beans; M/M + B: Corn/corn + brachiaria.

layer and the cycling of "P" by crops over the years, through the decomposition of plant residues deposited on the soil surface and the "P" absorbed by the roots that concentrate in this layer, allow for greater accumulation of Pi in the surface layer of the SPD system. For the PRT system, the disturbance of the soil in a layer of up to 20 cm promotes a distribution of "P" and reduces its accumulation in specific layers (COSTA *et al.*, 2010) [34]. Over time, there is a favoring conversion of this "P" from fertilizers or mineralization to more strongly retained forms, such as $Pi_{hid\ 0.5}$ (SANTOS *et al.*, 2008) [28].

In the 10-20 cm layer of the PRT system in both successions and in the SPD system (corn/corn+ Brachiaria), the $Pi_{hid0.5}$ levels were close to zero. In this case, "Pi" may be retained in more recalcitrant forms ($P_{residual}$), or in organic forms ($Po_{hid0.5}$).

The time taken to adopt the SPD system allowed the stabilization of organic compounds in non-labile forms, justifying the higher average levels of $Po_{Hid0.5}$ for the SPD system compared to the PRT system. Between the layers, there was a difference in PRT in the two successions, with the highest levels of $Po_{Hid0.5}$ observed in the surface layer of the soil (Table 5). Due to the lower accumulation of organic matter in the layer (PARTELLI *et al.*, 2009 [15]; TIECHER *et al.*, 2012a [5]), and the soil disturbance in this system, which favors the exposure of clay minerals capable of adsorbing "P" in inorganic forms (CARVALHO *et al.*, 2014) [25], are factors that contribute to the lower availability of $Po_{Hid0.5}$ in deeper layers.

The $P_{residual}$ only showed a difference between the systems in the succession (corn/corn + Brachiaria) in the 0 - 10 cm layer, with the levels being higher in the PRT system (**Table 5**). The high levels of $P_{residual}$ in the two systems evaluated may be due to the fact that these cultivated soils are always receiving phosphate fertilizers, and with the saturation of the adsorption sites, the transformation of the phosphate fertilizer may occur in the long term, into less available forms of "P", such as those linked to Fe and Al oxides, as found by Silva *et al.*, (2003) [35]. Mainly in Oxisols that have high levels of clay and Fe and Al oxides (LOSS, 2011) [36], therefore, with a high capacity for adsorption of "P", making it less available to plants and microorganisms.

When analyzing the total and labile "Pi" and "Po" contents in the systems, there were differences between the SPD and PRT systems for the total "Pi", labile "Pi" and labile "Po" contents. The SPD system obtained the highest levels of total "Pi" and labile "Pi" in the 0 - 10 cm layer. The PRT system presented the highest levels of labile "Po" in the 10 - 20 cm layer. Between layers, SPD obtained higher levels of total "Pi" and labile "Pi" in the 0 - 10 cm layer. And the PRT system obtained higher levels of total "Pi" in the 0 - 10 cm layer, and labile "Po" in the 10 - 20 cm layer, as shown in **Table 6**.

Systems in which there is constant addition of plant residues, with no soil disturbance, combined with the addition of phosphate fertilizers to the soil surface, intensify the cycling of "P" in the surface layer of the soil, contributing to an increase in Pi levels (OLIVEIRA *et al.*, 2014) [37]. Furthermore, in the surface layer of the soil, the adsorption of "P" is lower, due to the saturation of adsorption sites and the decrease in the binding energy of phosphate with soil colloids, leading to an increase in "P" in more labile forms (BEZERRA *et al.*, 2015) [38].

The highest levels of labile "Po" observed in the PRT system in the 10 - 20 cm layer must be due to the soil disturbance, which favors greater microbial activity in this layer and, therefore, a temporary retention of "P" in organic

Table 6. Total and labile P contents in inorganic (Pi) and organic (Po) forms under direct planting and traditional planting systems.

Management systems	Total				Labile			
	Pi		Po		Pi		Po	
	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm
	$mg \cdot kg^{-1}$							
SPD	51.69 Aa	7.06 Ab	156.63 Aa	156.70 Aa	10.29 Aa	0.72 Ab	47.49 Aa	33.94 Ba
PRT	37.11 Ba	6.97 Ab	177.64 Aa	182.95 Aa	3.07 Ba	2.78 Aa	55.12 Ab	80.07 Aa

*Averages followed by the same letter do not differ from each other using the Tukey test at 5% probability. Capital letters in the column compare levels between systems in the same layer, lower case letters compare levels in the line between layers within the same system and same form of P. SPD: direct planting system; PRT: traditional preparation.

form, due to the increase of microbial biomass carbon (MBC). Fiorelli-Pereira (2017) [39], evaluating COS and CBM contents in this same area, observed higher COS levels for the SPD system in the two layers evaluated, however, higher CBM levels for the PRT, as a result of soil disturbance that promotes greater contact between plant residues and soil, stimulating the microbial population, and increases in decomposition rates. Since higher carbon contents in biomass imply a higher rate of temporary immobilization of "P" (MERCANTE *et al.*, 2004) [40], increasing the content of "P" stored in microbial biomass, which is responsible for the production of "P" organic from inorganic (TIECHER *et al.*, 2012b) [41].

Although there is a 10-year effect of the PRT system, the way this system is managed with only one soil preparation per year and with successions of crops with large residue production, did not allow the presence of problems commonly observed in Brazilian commercial crops, such as erosion, and the consequent loss of soil and nutrients. Thus, in this experiment, the amplitude of the effects of the SPD and PRT treatments on phosphorus availability were minimal, and greater differences could be expected between the effects of these systems on the labile forms of "P" in the soil in commercial crops.

4. Conclusions

The chemical element phosphorus is one of the main plant nutrients and is commonly present in soils in insufficient quantities for plant nutrition, due to its dynamics and relationship with soil colloids.

The SPD and PRT systems have lower forms of inorganic phosphorus than the forms of organic phosphorus.

Among the fractions that make up the organic and inorganic forms of phosphorus, labile phosphorus is influenced in layers in the SPD system, obtaining higher levels in the surface layer of the soil. The PRT system promotes the homogenization of this fraction in the arable layer.

The moderately labile and non-labile phosphorus fractions were not influenced by the systems. However, the fractions of non-labile phosphorus in both SPD and PRT systems were higher in relation to labile and moderately labile phosphorus.

Acknowledgements

The authors would like to thank the Federal University of Rondônia, the postgraduate program in regional development and environment and the Department of Chemistry for their support and critical suggestions during the development of the research and preparation of the manuscript for providing valuable comments and contributions.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Lopes, A.S. (1998) Manual Internacional De Fertilidade Do Solo. 2nd Edition, Potafos, Piracibaca, 177.

[2] Faquim, V. and Andrade, A.T. (2004) Nutrição Mineral E Diagnose Do Estado Nutricional Das Hortaliças. UFLA/FAEPE, Lavras, 88.

[3] Silva, I.R. and Mendonça, E.S. (2007) Matéria Orgânica Do Solo. In: Novais, R.F., Alvarez, V.V.H., Fernandes, N., Fontes, R.L., Cantarutti, R.B. and Neves, J.C.L., Eds., *Fertilidade Do Solo*, Sociedade Brasileira De CiÊNcia Do Solo, Viçosa, 275-374.

[4] Gatiboni, L.C., Kaminski, J., Rheinheimer, D.S. and Flores, J.P.C. (2007) Biodisponibilidade De Formas De Fósforo Acumulados Em Solo Sob Sistema Plantio Direto. *Revista Brasileira De Ciência Do Solo*, *Viçosa*, **31**, 691-699. https://doi.org/10.1590/S0100-06832007000400010

[5] Tiecher, T., Rheinheimer, D.S., Kaminski, J. and Calegari, A. (2012) Forms of Inorganic Phosphorus in Soil under Different Long Term Soil Tillage Systems and Winter Crops. *Revista Brasileira De Ciência Do Solo*, **36**, 271-281. https://doi.org/10.1590/S0100-06832012000100028

[6] Leite, J.N.F., Cruz, M.C.P., Ferreira, M.E., Andrioli, I. and Braos, L.B. (2016) Frações Orgânicas E Inorgânicas Do FÓSforo No Solo Influenciadas Por Plantas De Cobertura E Adubação Nitrogenada. *Pesquisa Agropecuária Brasileira*, **51**, 1880-1889. https://doi.org/10.1590/s0100-204x2016001100010

[7] Gatiboni, L.C., Brunetto, G., Rheinheimer, D.S. and Kaminski, J. (2013) Fracionamento Químico Das Formas De Fósforo Do Solo: Usos E Limitações. *Tópicos em Ciência do Solo*, *Viços*a, **8**, 141-187.

[8] Rheinheimer, D.S., Gatiboni, L.C. and Kaminski, J. (2008) Fatores Que Afetam a Disponibilidade Do P E O Manejo Da Adubação Fosfatada Em Solos Sob Sistema Plantio Direto. *Ciência Rural*, **38**, 576-586. https://doi.org/10.1590/S0103-84782008000200049

[9] Brady, N.C. and Weil, R.R. (1996) The Nature and Properties of Soils. 11th Edition, Prentice Hall, Upper Saddle River.

[10] Chen, X., *et al.* (2002) Phosphatesolubilizing Microbes in Rhizosphere Soils of 19 Weeds in Southeastern China. *Journal of Zhejiang University Science*, **3**, 355-361. https://doi.org/10.1631/jzus.2002.0355

[11] Son, H.J., Park, G.T., Cha, M.S. and Heo, M.S. (2006) Solubilization of Insoluble Inorganic Phosphates by a Novel Salt and PH-Tolerant Pantoea Agglomerans R-42 Isolated from Soybean Rhizosphere. *Bioresource Technology*, **97**, 204-210. https://doi.org/10.1016/j.biortech.2005.02.021

[12] Illmer, P., Barbato, A. and Schinner, F. (1995) Solubilization of Hardly-Soluble $AlPO_4$ with P-Solubilizing Microorganisms. *Soil Biology and Biochemistry*, **27**, 265-270. https://doi.org/10.1016/0038-0717(94)00205-F

[13] Barroso, C.B. and Nahas, E. (2005) The Status of Soil Phosphate Fractions and the Ability of Fungi to Dissolve Hardly Soluble Phosphates. *Applied Soil Ecology*, **29**, 73-83. https://doi.org/10.1016/j.apsoil.2004.09.005

[14] Richardson, A.E. (1994) Soil Microrganisms and Phosphorus Availability. In: Pankhurst, C.E., Doube, B.M., Gupta, V.S.R. and Grace, P.R., Eds., *Soil Biota Management in Sustainable Farming Systems*, CSIRO, Melbourne, 50-62.

[15] Partelli, F.L., Busato, J.G., Vieira, H.D., Viana, A.P. and Canellas, L.P. (2009) Qualidade Da Matéria Orgânica E Distribuição Do Fósforo No Solo De Lavouras

Orgânicas De café Conilon. *Revista Ciência Rural*, **39**, 2065-2072. https://doi.org/10.1590/S0103-84782009000700017

[16] Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.A., Lumbreras, J.F., Coelho, M.R., Almeida, J.A., Cunha, T.J.F. and Oliveira, J.B. (2013) Sistema Brasileiro De Classificação De Solos. 3rd Edition, Embrapa, Brasília, 353.

[17] Hedley, M.J., Stewart, J.W.B. and Chauhan, B.S. (1982) Changes in Inorganic and Organic Soil Phosphorus Fractions Induced by Cultivation Practices and by Laboratory Incubations. *Soil Science Society of American Journal*, **46**, 970-976. https://doi.org/10.2136/sssaj1982.03615995004600050017x

[18] Condron, L.M., Goh, K.M. and Newman, R.H. (1985) Nature and Distribution of Soil Phosphorus as Revealed by a Sequential Extraction Method Followed by 31P Nuclear Magnetic Resonance Analysis. *Journal of Soil Science*, **36**, 199-207. https://doi.org/10.1111/j.1365-2389.1985.tb00324.x

[19] Gatiboni, L.C. (2003) Disponibilidade De Formas De Fósforo Do Solo às Plantas. Tese (Doutorado Em Biodinâmica Dos Solos), Universidade Federal De Santa Maria, Santa Maria, 231 p.

[20] Brookes, P.C. and Powlson, D.C. (1982) Preventing Phosphorus Losses during Perchloric Acid Digestion of Sodium Bicarbonate Soil Extracts. *Journal of the Food and Agriculture*, **32**, 671-674. https://doi.org/10.1002/jsfa.2740320707

[21] Dick, W.A. and Tabatabai, M.A. (1977) Determination of Orthophosphate in Aqueous Solutions Containing Labile Organic and Inorganic Phosphorus Compounds. *Journal of Environmental Quality*, **6**, 82-85. https://doi.org/10.2134/jeq1977.00472425000600010018x

[22] USEPA (1971) Methods of Chemical Analysis for Water and Water. United States Environmental Protection Agency, Cincinnati (EUA).

[23] Murphy, J. and Riley, J.P. (1962) A Modified Single Solution Method for the Determination of Phosphate in Natural Waters. *Analytica Chemica Acta*, **27**, 31-36. https://doi.org/10.1016/S0003-2670(00)88444-5

[24] Ferreira, D.F. (2011) Sisvar: A Computer Statistical Analysis System. *Ciência e Agrotecnologia*, **35**, 1039-1042. https://doi.org/10.1590/S1413-70542011000600001

[25] Carvalho, J.L.N., Raucci, G.S., Frazão, L.A., Cerri, C.E.P., Bernoux, M. and Cerri, C.C. (2014) Crop-Pasture Rotation: A Strategy to Reduce Soil Greenhouse Gas Emissions in the Brazilian Cerrado. *Agriculture*, *Ecosystems and Environment*, **183**, 167-175. https://doi.org/10.1016/j.agee.2013.11.014

[26] Casali, C.A., Tiecher, T., Kaminski, J., Santos, D.R., Calegari, A. and Piccin, R. (2016) Benefícios do uso de plantas de cobertura de solo na ciclagem de fósforo. Manejo e conservação do solo e da água em pequenas propriedades rurais no sul do brasil: Práticas alternativas de manejo visando a conservação do solo e da água [Recurso Eletrônico]. Cap. 2, 23-33.

[27] Novais, R.F., Smyth, T.J. and Nunes, F.N. (2007) Fósforo. In: Novais, R.F., Alvarezv, V.H., Barros, N.F., Fontes, R.L.F., Cantarutti, R.B. and Neves, J.C.L., Eds., *Fertilidade Do Solo*, Sociedade Brasileira de Ciência do Solo, Viçosa, 471-537.

[28] Santos, J.Z.L., Furtini Neto, A.E., Resende, A.V., Curi, N., Carneiro, L.F. and Costa, S. (2008) Frações de fósforo em solo adubado com fosfatos em diferentes modos de aplicação e cultivado com milho. *Revista Brasileira de Ciência do Solo*, **32**, 705-714. https://doi.org/10.1590/S0100-06832008000200025

[29] Venzke Filho, S.P., Feigl, B.J., Poccolo, M.C., Siqueira Neto, M. and Cerri, C.C. (2008) Biomassa Microbiana Do Solo Em Sistema De Plantio Direto Na Região De Campos Gerais—Tibagi, PR. *Revista Brasileira de Ciência do Solo*, **35**, 599-610.

https://doi.org/10.1590/S0100-06832008000200015

[30] Raij, B. (1991) Fertilidade Do Solo E Adubação. Agronômica Ceres, São Paulo, 343.

[31] Yang, X. and Post, W.M. (2011) Phosphorus Transformations as a Function of Pedogenesis: A Synthesis of Soil Phosphorus Data Using Hedley Fractionation Method. *Biogeosciences*, **8**, 2907-2916. https://doi.org/10.5194/bg-8-2907-2011

[32] Rodrigues, M., Pavinato, P.S., Withers, P.J.A., Teles, A.P.B. and Herrera, W.F.B. (2015) Legacy Phosphorus and No Tillage Agriculture in Tropical Oxisols of the Brazilian Savanna. *Science of the Total Environment*, **542**, 1050-1061. https://doi.org/10.1016/j.scitotenv.2015.08.118

[33] Pavinato, P.S. and Rosolem, C.A. (2008) Disponibilidade de nutrientes no solo-decomposição e liberação de compostos orgânicos de resíduos vegetais. *Revista Brasileira de Ciência do Solo*, **32**, 911-920. https://doi.org/10.1590/S0100-06832008000300001

[34] Costa, S.E.V.G.A., Souza, E.D., Anghinoni, I., Flores, J.P.C., Vieira, F.C.B., Martins, A.P. and Ferreira, E.V.O. (2010) Patterns in Phosphorus and Corn Root Distribution and Yield in Long-Term Tillage Systems with Fertilizer Application. *Soil and Tillage Research*, **109**, 41-49. https://doi.org/10.1016/j.still.2010.04.003

[35] Silva, M.A., Nóbrega, J.C.A., Curi, N., Siqueira, J.O., Sá, J.J.G., Marques, M. and Motta, P.E.F. (2003) Frações de Fósforo em Latossolos. *Pesquisa Agropecuária Brasileira*, *Brasília*, **38**, 1197-1207. https://doi.org/10.1590/S0100-204X2003001000009

[36] Loss, A. (2011) Dinâmica Da Matéria Orgânica, Fertilidade E Agregação Do Solo Em Áreas Sob Diferentes Sistemas De Uso No Cerrado Goiano. Tese (Doutorado Em Agronomia—Ciência Do Solo), Universidade Federal Rural Do Rio De Janeiro, Seropédica, 122 p.

[37] Oliveira, L.B., Tiecher, T., Quadros, F.L.F., Trindade, J.P.P., Gatibone, L.C., Bruneto, G. and Santos, D.R. (2014) Formas De Fósforo No Solo Sob Pastagens Naturais Submetidas à Adição De Fosfatos. *Revista Brasileira de Ciência do Solo*, **38**, 867-878. https://doi.org/10.1590/S0100-06832014000300018

[38] Bezerra, R.P.M., Foss, A., Pereira, M.G. and Perin, A. (2015) Frações de Fósforo e Correlação Com Atributos Edáficos Sob Sistemas de Plantio Direto E Integração Lavoura-Pecuária No Cerrado Goiano. *Ciências Agrárias*, **36**, 1287-1306. https://doi.org/10.5433/1679-0359.2015v36n3p1287

[39] Fiorelli-Pereira, E.C. (2017) Indicadores De Qualidade Em Um Latossolo Sob Diferentes Usos E Manejos Em Rondônia. Tese (Doutorado Em Desenvolvimento Regional E Meio Ambiente), Fundação Universidade Federal De Rondônia, Porto Velho, 131.

[40] Mercante, F.M., Fabricio, A.C, Machado, L.A.Z. and Silva, W.M. (2004) Parâmetros Microbiológicos Como Indicadores De Qualidade Do Solo Sob Sistema Integrados De Produção Agropecuária. Embrapa Agropecuária Oeste, Dourados, 27 p. (Embrapa Agropecuária Oeste. Boletim De Pesquisa E Desenvolvimento, 20)

[41] Tiecher, T., Rheinheimer, D.S. and Calegari, A. (2012) Soil Organic Phosphorus Forms under Different Soil Management Systems and Winter Crops, in a Long Term Experiment. *Soil Tillage Research*, **124**, 57-67. https://doi.org/10.1016/j.still.2012.05.001