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Phosphorus Concentrations and Stocks in Different Soil Classes, Uses and Coverages in Agreste Pernambucano, Brazil

Concentraciones y existencias de fósforo en diferentes clases de suelo, usos y coberturas en Agreste Pernambucano, Brasil

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Abstract. Changes in land use cause a mosaic of areas in the landscape with different uses and coverage. This condition compromises soil nutrient stocks, especially phosphorus (P). In this sense, this study aimed to determine the concentrations of extractable and total phosphorus in 04 soil classes (Yellow Argisol, Litholic Neosol, Entisol and Planosol), 04 uses and covers (Open Native Caatinga, Dense Native Caatinga, Agriculture and Pasture) of the soil, in 04 depths (0-10, 10-20, 20-30 and 30-40 cm). To determine the extractable P, the Mehlich 1 and colorimetric reading were used. Total phosphorus was determined by sulfur digestion and colorimetry. The results of extractable and total P concentrations were higher for the Argisol and Planosol classes. It was observed that there were reductions in extractable P concentrations between the soil layers as the soil profile deepened. Depths between 0-20 cm generally showed higher concentrations of extractable and total phosphorus in agriculture. Among the four soil classes studied, the highest average values of extractable and total P stocks occurred in Litholic Neosols and Planosols, mainly due to agricultural use. P deficiency has been a limiting factor to agricultural productivity and, especially in the Agreste region of Pernambuco, where the main soil classes under natural cover have low levels of available and total P.

Keywords: management systems, availability, tropical region.

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Resumen. Los cambios en el uso del suelo provocan un mosaico de áreas en el paisaje con diferentes usos y coberturas. Esta condición compromete las reservas de nutrientes del suelo, especialmente el fósforo (P). En ese sentido, este estudio tuvo como objetivo determinar las concentraciones de fósforo extraíble y total en 04 clases de suelo (Argisol Amarillo, Neosol Litólico, Entisol y Planosol), 04 usos y coberturas del suelo (Caatinga Nativa Abierta, Caatinga Nativa Densa, Agricultura y Pastos), en 04 profundidades (0-10, 10-20, 20-30 y 30-40 cm). Para determinar el P extraíble se utilizó el Mehlich 1 y la lectura colorimétrica. El fósforo total se determinó por digestión de azufre y colorimetría. Los resultados de las concentraciones de P extraíble y total fueron mayores para las clases Argisol y Planosol. Se observó que hubo reducciones en las concentraciones de P extraíble entre las capas del suelo a medida que se profundizaba el perfil del suelo. Las profundidades entre 0 y 20 cm generalmente mostraron concentraciones más altas de fósforo extraíble y total en la agricultura. Entre las cuatro clases de suelo estudiadas, los valores promedio más altos de existencias de P extraíble y total se presentaron en los Neosoles y Planosoles Litólicos, principalmente debido al uso agrícola. La deficiencia de P ha sido un factor limitante para la productividad agrícola y, especialmente en la región de Agreste de Pernambuco, donde las principales clases de suelo con cobertura natural tienen niveles bajos de P disponible y total.

Palabras clave: sistemas de gestión, región tropical, tipos de suelos, cambio de uso del suelo, nutrientes.

INTRODUCTION

The replacement of natural ecosystems by agricultural activities can cause nutrient losses that are necessary and essential for plant development (Valera 2016). Natural forests and conservation areas, when replaced by pasture and other intensive crops, alter the physical, chemical and biological properties of the soil and this causes changes in the quality and capacity of the soil to produce sustainably (Matson, 1997; Jangid et al., 2011; Gregory et al., 2015). In addition, the natural environment can be negatively impacted by decreasing plant species biodiversity, biological complexity and nutrient cycling (Higginbottom, 2014; Berhe et al., 2018).

As for chemical conditions, changes in land use and occupation can impact nutrient stocks, especially phosphorus (P), which is considered the chemical element of great importance for plant development (Gil-Sotres et al., 2005; Elser, 2012) and limiting nutrient in agricultural crop yields in most tropical regions (Spohn et al., 2013). In these regions, which generally have acidic and weathered soils, the presence of oxides adsorb phosphorus and chemically fix it, making it unavailable to plants (Bucher et al., 2001). In addition, in moderately weathered soils, such as Chernosols, Vertisols and Neosols, phosphorus is present in primary minerals, but most of this element is found in organic form (Po) or in mineral form (Pi), adsorbed weakly to secondary minerals (Novais and Smith, 1999). On the other hand, in acidic soils, which are generally quite weathered, such as Oxisols, inorganic forms linked to the mineral fraction with high energy and physical and chemically stabilized organic forms prevail (Rheinheimer et al., 2008). In this context, it is clear that P is a nutrient with limited availability in the soil. This limitation depends on some circumstances such as the type of soil, presence of Fe and Al oxides that transform large proportions of total P in the soil into unavailable forms (Solomon, 2002).

In addition to having considerable effects on its availability and distribution, actions resulting from inappropriate use of the soil can also lead to losses of this nutrient, due to the excessive external input of chemical fertilizers, which can be transferred to aquatic reservoirs, causing phenomena such as eutrophication, generating negative impacts on the environment (Ulén et al., 2007; Withers and Jarvie, 2008; Csathó et al., 2011; Maranguit, 2017).

Some studies have already analyzed P indices in land use change, its distribution along soil depth, plant availability and stability in different management systems (Motavalli, 2002; Zamuner, 2008; Maranguit, 2017). These studies highlight that P status and distribution depend on land use and management practices. Changes in land use cause a mosaic of areas with different uses and landscape coverage (Maharjan, 2018). However, knowledge of the dynamics of phosphorus (P) is still limited, especially in the Northeast region of Brazil, in the depths of the soil profile and in the different uses and coverage. Thus, it was sought to know which use and class of soil in the Agreste region of Pernambuco that presented the highest stocks of phosphorus in the soil. Therefore, the objective was to determine the phosphorus concentrations and stocks along the soil profile (0-40 cm), in the main soil classes (Yellow Argisol, Litholic Neosol, Entisol and Planosol) under native vegetation areas (dense and open native caatinga), agriculture and pasture, from the physiographic region of the Agreste in the Agreste region of Pernambuco).

MATERIAL AND METHODS

The surveys of P concentrations and stocks were carried out with soil samples from the Agreste region of the state of Pernambuco, Brazil. These samples came from the soil bank of the group of researchers from the Department of Nuclear Energy at the Federal University of Pernambuco (DEN-UFPE), collected from 2011 to 2015. The Agreste region of Pernambuco is a transition area between Zona da Mata and Sertão, with an extension of 24,396 km^2 (IBGE, 2014). It presents approximately 42% of the area occupied with some type of native vegetation. The dense caatinga is the most predominant vegetation, being more than twice the area of open caatinga, due to the soils associated with the moved relief (Accioly, 2017). With regard to anthropized areas, emphasis is given to areas with altered vegetation for the introduction of agriculture and pasture (CONDEPE/FIDEM, 2006). The areas with agriculture and pasture occupy respectively about 21% and 33% of the entire Agreste region (Accioly, 2017). Below, in table 2, the main types of land use and cover are presented with their respective characteristics.

Samples of four types of land use and cover were used: native vegetation (dense and open native caatinga), agriculture and pasture, in the four main soil classes (Yellow Argisol, Litholic Neosol, Entisol and Planosol) at four depths (0-10, 10-20, 20-30, 30-40 cm). For each combination of cover, soil class and depth, three sampling points were chosen, taken as repetitions (04 soil classes x 04 types of uses and covers x 04 depths x 03 repetitions) totaling 192 samples.

In possession of the soil sampling bank previously informed and practically processed in the Soil Fertility laboratory at UFPE, laboratory procedures for the determination of two forms of P, extractable and total, were started. Extractable P concentrations were determined by Mehlich 1 solution and colorimetry according to Murphy and Ryley (1962). While for total P concentrations they were determined by the concentrated sulfuric acid solution according to the methodology of Thomas et al., 1976 and colorimetry according to Murphy and Ryley (1962).

The total P stocks for each of the soil depths of the studied areas were calculated according to the following equation (Veldkamp, 1994):

$$Stocks = \frac{(T)(Ds)\,(e)}{10}$$

Where:

Stock = bulk of C, N, O ou P per unit of equivalent depth area (Mg ha^{-1}).

T = content of C, N ou P total and extractable at sampled depth (g kg^{-1});

Ds = depth soil density (kg dm^{-3});

e = considered depth thickness (cm).

The values of extractable and total P concentrations and stocks were subjected to analysis of variance to assess the difference in uses at each depth and depth within each use of the different classes of soils. Comparisons of avareges were performed using the Tukey test at 5% ($P < 0.05$) of significance. Data analyzes and transformations were performed using the SISVAR statistical program (Ferreira, 2011).

RESULTS AND DISCUSSION

The results demonstrate significant differences for extractable P at depths in all soil classes under study (Table 1). Higher concentrations of this form of P were observed at depths of 0-10 and 10-20 cm in all uses. The use of agriculture "AG" and depth "0-10 cm" stood out statistically over the others.

Concentrations of extractable P from 0-10 cm depth, of the Yellow Argisol class, had higher values in agriculture (AG) and lower values in dense native caatinga (ONC), with concentrations

Table 1. Mean values of extractable P concentrations (mg dm-³) at depths of 0-10, 10-20, 20.30 and 30-40 cm in four uses and four different soil classes.

Soils/Depths	Land uses			
	P extractable (mg dm-³)			
Yellow Argisol	DNC	ONC	AG	PA
0-10	4.55bA	3.56cA	10.88aA	5.49bA
10-20	4.23aA	4.44aA	3.83aB	4.79aA
20-30	0.98aB	0.97aB	0.93aC	1.70aB
30-40	1.27aB	1.61aB	1.24aC	1.49aB
Litholic Neosol	DNC	ONC	AG	PA
0-10	13.46aA	6.25cA	13.79aB	9.86bA
10-20	3.61bB	5.07bA	5.26bC	7.78aB
20-30	1.90aB	1.29aB	1.97aD	3.45aC
30-40	2.39bB	2.97bB	18.94aA	2.05bC
Entisol	DNC	ONC	AG	PA
0-10	19.12aA	6.29cA	2.47dB	16.23bA
10-20	9.90aB	5.90bA	4.92bA	5.68bB
20-30	1.55aD	2.56aB	1.31aB	1.49aC
30-40	3.52aC	3.20aB	2.01bB	1.63bC
Planosol	DNC	ONC	AG	PA
0-10	15.94aA	5.16bC	18.64aA	13.06aA
10-20	6.11cB	33.87aA	24.03bA	6.46cB
20-30	1.67bB	11.90aB	8.24aB	3.17bB
30-40	2.24bB	1.54bC	11.82aB	2.68bB

Averages followed by lowercase letters in the rows compare land uses at each depth and uppercase letters in the column compare depths within each land use. Equal letters do not differ statistically by Tukey's test at 5% probability. DNC= dense native caatinga, ONC= open native caatinga, AG=agriculture e PA=pasture.

Source: Authors.

of 10.88 e 3.56 mg dm^{-3}, respectively. The highest value found in AG is probably associated with the excessive use of chemical fertilizers in order to meet the needs of the soil as a "source" and of the crop as a "drain", thus characterizing the surface depth with greater amounts of available P in relation to DNC. This is due to the Argisols for presenting a Bt horizon with clay accumulation which, in this case, is mainly composed of kaolinite and iron and aluminum oxides which have specific P adsorption sites, making it less available for the culture (Núñez *et al.*, 1999).

Concentrations of extractable P from a depth of 30-40 cm in Neosol Litólico and Planosol in AG were higher compared to the other uses. Although they are classes of soils that naturally present low concentrations of P, explain the values in the uses of DNC and ONC, the high values are certainly explained by the fact that these are soils that are widely used in agriculture, in which correction managements are carried out and phosphate fertilizers, making them richer in extractable phosphorus. Overall, across all classes, reductions in extractable P concentrations were seen as profound depths were analyzed for each land use. This is justified by the fact that P is considered a nutrient with low mobility in the soil, a behavior attributed to its "fixation" by clay minerals, present in tropical soils that have higher acidity, high concentrations of iron and aluminum oxides, with which the P has great affinity (Pereira, 2009). Under these conditions, the surfaces of these oxides are positively charged, attracting anions, such as phosphate. Thus, P, which is a determinant element in plant growth, becomes scarcely available (Meurer, 2007). In semiarid soils, Corrêa et al. (2004) also attribute the availability of P to the source material of these soils. The availability of this element, according to Queiroz (2013), is greater on the soil surface and this is due to its low mobility and the greater amount of organic matter contained in this horizon.

Differently from that, values in the Planosol class showed depth increases from 0-10 to 10-20 cm in the ONC and AG uses. In the Litholic Neosol class in AG, there was an increase in depth from 0-10 to 30-40 cm. These results can be attributed to more sustainable forms of management, using techniques such as: incorporation of M.O, which bring benefits to physical, chemical and biological conditions, thus providing a better distribution of extractable P in all soil depths. In this sense Silveira et al. (2006) observed that 33% of the phosphorus in a soil poor in this nutrient is linked to organic matter, reinforcing that this is an important source of P. In a work developed by Menezes and Silva (2008) with the annual application of manure, combined or not with sunn hemp, the authors verified the increase in total phosphorus contents up to 40 cm deep. Therefore, agricultural practices that favor the increase or maintenance of soil organic matter are indicated for tropical soils with the purpose of soil structuring, moisture retention and increasing the soil cation exchange capacity (Silva et al., 2005).

On the other hand, we can observe that in DNC, all classes presented high values of extractable P only in the first 10 cm of depth. Similar result, observed by Tokura (2012) where in soils never cultivated, the highest values of P were found at a depth of 5-10 cm. Silva et al., (1997) justifies that this probably occurs because of the decrease in organic matter content and the consequent increase in P fixation at this depth.

The use of pasture in the entisol class presented a high value of extractable P at a depth of 0-10 cm, evidencing the fact that the use of phosphate fertilization is essential, regardless of the production system, whether extensive or intensive, so that this element does not limiting the response of the forage plant.

The results showed high variability in total P concentrations in the classes presented (Table 2). Significant differences were observed for this variable in the class of Yellow Argisol, Litholic Neosol and Planosol, comparing the uses in each studied depth.

It is noteworthy that in the Yellow Argisol class at a depth of 0-10 cm, AG presented the lowest concentration of total P compared to other uses. This can be explained due to topographic ground reasons. Soils with high topography can cause P losses due to soil erosion, being carried from

Table 2. Mean values of total P concentrations (mg dm-³) at depths of 0-10, 10-20, 20-30 and 30-40 cm in four classes under four land use and cover, in the Agreste region of Pernambuco.

Soils/Depths	Land uses			
	P total (mg dm-³)			
Yellow Argisol	DNC	ONC	AG	PA
0-10	360.42aA	394.26aA	55.31bC	322.82aA
0-20	415.15aA	421.19aA	498.12aA	201.96bA
20-30	234.10bB	405.59aA	411.04aA	329.76aA
30-40	388.23aA	376.44aA	226.15bB	244.48bA

Table 2. Continue.

Soils/Depths	Land uses			
	P total (mg dm-^{3})			
Litholic Neosol	DNC	ONC	AG	PA
0-10	545.28aA	60.36dC	364.18bB	151.74cD
10-20	483.28bA	457.90bA	538.35aA	576.05aA
20-30	559.23aA	122.09cC	436.32bB	481.41bB
30-40	186.42cB	363.00aB	422.00aB	298.05bC
Entisol	DNC	ONC	AG	PA
0-10	350.39aA	386.11aA	349.77aA	310.34aA
10-20	410.63aA	374.43aA	384.99aA	360.85aA
20-30	370.40aA	371.39aA	343.63aA	374.20aA
30-40	357.90aA	408.09aA	280.97bB	352.47aA
Planosol	DNC	ONC	AG	PA
0-10	327.83bB	110.09cC	597.29aA	366.06bB
10-20	365.88bB	497.11aA	499.63aB	455.38aA
20-30	434.33aA	334.51bB	238.56cD	309.43bB
30-40	403.45aA	455.36aA	419.81aC	345.38bB

Averages followed by lowercase letters in the rows compare land uses at each depth and uppercase letters in the column compare depths within each land use. Equal letters do not differ statistically by Tukey's test at 5% probability. DNC= dense native caatinga, ONC= open native caatinga, AG=agriculture e PA=pasture.

Source: Authors.

higher to lower locations (Tarkalson 2009; Rolim Neto 2004; Novais and Smyte 1999), with this, also justifying the high the planosol class at 0-10 cm depth in the AG presented a higher value than the other uses, basically due to the fact since the amounts added with fertilizers were higher than those exported by the grains (Rheinheimer, 2001).

Total phosphorus concentrations in the use of DNC and lower in the use of ONC, with concentrations of 545.28 and 60.36 mg dm-3 at depth 0-10 cm and 483.28 and 457.90 mg dm-3 at depth 10-20 cm, respectively. This is probably due to the greater amount of plant material that was deposited in the soil, with this, there was an increase in the amount of organic matter and nutrient release in the mineralization process. Rodrigues (2010) studying the comparison between the average levels of phosphorus (mg dm-3) in the native forest and in the capoeira at a depth of 20 cm, he observed higher levels in the native forest due to the greater amount of plant material that was deposited in the soil increase in the amount of organic matter and nutrient release in the mineralization process. Fernandes (2005) also states that in the native forest area, there is greater litter deposition, with this the production of organic acids presumably becomes higher than in the capoeira area, which favors the availability of P in the native forest. Soils of the Yellow Argisol, Lithic Neosol and Planosol had the highest stocks of extractable P in AG, except in the entisol class, where the opposite occurred and had the smallest stock for that use (Table 3).

According to Azevedo (2018), soils with lower P sorption capacity generally present problems with loss of nutrients, as they have higher levels of soluble P, which allows the free movement of the nutrient in the soil solution, being susceptible to loss by leaching. Thus justifying the low extractable

Table 3. Stocks of extractable P (Mg ha-1) in four classes under four uses and soil cover, along the 0-40 cm profile, in the Agreste region of Pernambuco.

Soil Classes	Land uses			
	P extractable (Mg ha^{-1})			
	DNC	ONC	AG	PA
Yellow argisol	0.014	0.016	0.025	0.021
Litholic Neosol	0.030	0.022	0.057	0.029
Entisol	0.049	0.028	0.016	0.040
Planosol	0.035	0.075	0.095	0.040

DNC= dense native caatinga, ONC= open native caatinga, AG=agriculture e PA=pasture.

Source: Authors.

P stock in the Neosol Regolithic class, as it is a class that presents characteristics such as: low organic matter content, high permeability, low CTC and low moisture retention capacity. Therefore, even with the introduction of agricultural crops together with managements with pH corrections and phosphate fertilizers, they will not be enough to ensure considerable levels of this stock in the soil.

Highlight also for the Planossolo class used for AG, in which the extractable P stock value was the highest among all other classes and uses. The Yellow Argisol class, on the other hand, had the lowest stock in the use of DNC. According to Duarte (1992), lower phosphorus contents in native forest are associated with lower pH values.

The soils of the Neosol Litholic and Planosol classes presented the highest total P stocks in AG (Table 4). On the contrary, the Yellow Argisol class used for AG had the smallest total P stock, which is also justified by reasons mentioned earlier in the other tables.

The Planosolo class used in AG had 2.64 Mg ha-1, indicating a higher value for this variable in relation to all other classes and land uses. The reason for this is in order to obtain high concentrations of P to compensate for this supposedly low efficiency of phosphate fertilization, which is why many farmers resort to high and frequent applications of soluble sources, which have generated an increase in the total P stock in the soil.

Table 4. Stocks of total P (Mg ha-1) in four classes under four uses and land cover, along the 0-40 cm profile, in the Agreste region of Pernambuco.

Soil Classes	Land uses			
	P total (Mg ha^{-1})			
	DNC	ONC	AG	PA
Yellow Argisol	1.83	2.34	1.79	1.68
Litholic Neosol	2.53	1.45	2.51	1.63
Entisol	2.19	2.37	2.06	2.22
Planosol	2.20	2.02	2.64	2.38

DNC= dense native caatinga, ONC= open native caatinga, AG=agriculture e PA=pasture.

Source: Authors.

For Oliveira (2018), whenever this accumulation occurs, this shows that the amount of nutrient exported in the harvested products is smaller than that added through fertilizers, as long as there are no erosion losses.

CONCLUSIONS

The depths of 0-20 cm, the most superficial of the soil, presented the highest concentrations of extractable and total P, mainly in agriculture.

There were reductions in total and extractable P concentrations as deeper layers were analyzed.

The main soil classes in DNC and ONC uses presented, in general, the lowest extractable and total P values among the studied layers.

Extractable and total P stocks from Agreste Pernambucano soils were more eminent in Litholic and Planosols Neosols, mainly in AG.

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