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Characterization of soil physical and chemical attributes in different agroecosystems and pedoforms in Areia, Paraíba, Brazil

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ABSTRACT

Knowledge of soil attributes is a basic premise when defining land use systems, as well as in the monitoring of the properties and/or quality indicators of the cropping systems implemented. The objective of this study was to characterize the physical and chemical attributes of Argissolo and Gleissolo in areas under different uses and landforms in the municipality of Areia, PB, Brazil. Areas with different uses were selected, such as banana (*Musa parasidiaca*), pasture (*Brachiaria brizantha*), reforestation with ‘sabiá’ (*Mimosa caesalpiniaefolia*), and open tropical forest, as well as two relief positions (foothill and mid-slope). Samples were taken from the 0.00-0.20 and 0.20-0.40 m layers. The samples were then air-dried, crumbled, and passed through a sieve with a 2 mm mesh to obtain fine air-dried soil. Physical, chemical, and fertility analyses were carried out and cation exchange capacity, sum of bases, and base saturation were calculated. According to the results, in general, the soil physical and chemical attributes were altered by land use and landforms. Soil organic matter levels in the surface layer were higher in the deposition foothills, while in the mid-slope the forest environments (natural or forested) showed higher levels of organic matter.

Keywords: Soil properties, Landforms, Land use systems.

Caracterização dos atributos físicos e químicos do solo em diferentes agroecossistemas e pedoformas em Areia, Paraíba, Brasil.

RESUMO

O conhecimento sobre os atributos dos solos é uma premissa básica tanto na definição dos sistemas de usos, como também no monitoramento das propriedades e/ou indicadores de qualidade dos sistemas de cultivos implantados. Dessa forma, o objetivo deste trabalho foi caracterizar os atributos físicos e químicos de Argissolo e Gleissolo em áreas sob diferentes usos e formas do relevo no município de Areia, PB, Brasil. Foram selecionadas áreas com diferentes usos, tais como bananeira (*Musa parasidiaca*), pastagem (*Brachiaria brizantha*), reflorestamento com sabiá (*Mimosa caesalpiniaefolia*) e floresta tropical aberta, assim como duas posições do relevo (sopé de deposição e meia encosta). Foram coletadas amostras nas camadas 0,00-0,20 e 0,20-0,40 m. Em seguida, as amostras foram secas a ar, destorroadas e passadas em peneira com malha de 2 mm obtendo a terra fina seca ao ar. Foram realizadas análises físicas, químicas e de fertilidade e calculados a capacidade de troca de cátions, soma de bases e saturação por bases. De acordo com os resultados, de maneira geral, os atributos físicos e químicos do solo foram alterados pelos usos do solo e formas do relevo. Os teores da matéria orgânica do solo na camada superficial foram superiores no sopé de deposição enquanto que na meia encosta os ambientes florestais (naturais ou florestados) apresentaram níveis mais elevados de matéria orgânica.

Palavras-chave: Propriedades do solo, Formas do relevo, Sistemas de uso da terra.

1. Introduction

Knowledge of soil attributes (physical, chemical, and biological) is a basic premise when defining land use systems, as well as in the monitoring of the properties and/or quality indicators of the cropping systems implemented, as well as providing an understanding of their multiple functions, so as not to compromise the performance of their functions (provision of ecosystem services or production of consumer goods) (Carneiro et al., 2009). Thus, the assessment of soil quality takes into account a set of soil variables, among which physical indicators include soil density, porosity, aggregate stability and so on (Cunha Neto et al., 2018). When it comes to chemical and fertility indicators, pH in water, nutrient and organic carbon content are fundamental in this assessment (Oliveira et al., 2015). With regard to biological indicators, Sampaio et al. (2008) add that the main indicators for monitoring soil quality are microbial biomass and activity.

In addition to land use systems, landforms also bring variability to the soil system. Shapes play a decisive role in the variation of physical and chemical attributes and ecological influence in the soil of a given region or area (Momoli and Coopoer, 2016). On the other hand, relief is one of the most important factors, as it influences the anisotropic movement of water in the terrain, leading to the loss of soil, water, and nutrients through water erosion and consequently reducing the infiltration and storage of water in the soil (Campos et al., 2008).

In this way, relating the various uses and landforms can be a way of understanding the action of multiple factors on soil attributes. In this sense, some studies highlight this association (uses and landforms), such as Oliveira et al. (2020) in a pedoenvironmental study in the Southwest of the Amazon, Martins et al. (2019) in a study in Southern Brazil, and Santos and Salcedo (2010) in a micro-basin in the Paraibano brejo region.

Against this backdrop, there is a need for studies comparing different land uses in different landforms. Thus, the central hypothesis of the research was that land use and landforms interfere with the physical and chemical attributes of the soil. The aim of this study was to characterize the physical and chemical attributes of Argissolos and Gleissolos in areas under different uses and landforms in the municipality of Areia, PB, Brazil.

2. Material and Methods

The study was carried out in an area of the Engenho Varzea Coaty, on the banks of the PB 87 highway, between the municipalities of Pilões and Areia, in the state of Paraíba, Brazil, under the geographical coordinates 6º 98’ 35.63” S and 35° 73’ 17.57” W (Figure 1). The region has specific soil and climate conditions due to its geographical distribution, with the coast and the Borborema Plateau (Agreste) being considered the highest points in the state of Paraíba.

The highest rainfall rates are due to altitudinal variations (orographic rain) reaching up to 1,500 mm and the average temperature in this part of the state is around 26 ºC. The relief is characterized as undulating to strongly undulating (8-45%) over almost its entire length, with a predominance of gently undulating terrain with an altimetric range of 400 m, contrasting with some areas of small unevenness, hills and/or hillsides with gentle slopes ranging from 0 to 8%.

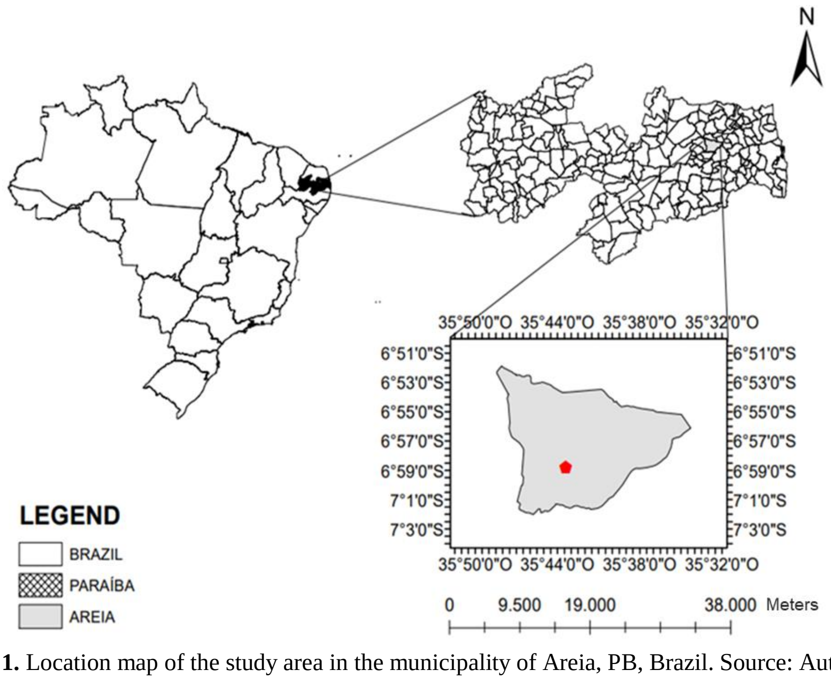

Figure 1. Location map of the study area in the municipality of Areia, PB, Brazil. Source: Author (2023).

In this way, rainfall levels and the climate end up influencing the vegetation, which is marked by the Caatinga biome, made up of deciduous vegetation, with species such as cacti, bromeliads, and some legumes being found in abundance in this mesoregion. Areas with different uses were selected (Figure 2 and Table 1). In historical terms, these areas initially received the following cultural cycles, with sugar cane (*Saccharum officinarum*), coffee (*Coffea arabica*), and agave (*Agave attenuata*).

The geological material in the study area is included under the São Caetano complex which, in turn, contains rocks that outcrop in contact with millonitized syenites, in which this unit is mainly made up of fine- to medium-grained biotite gneisses, foliation and well-marked stretching lineation, and mineralogically made up of quartz (40-50%), feldspars (10-20%), biotite (20-30%), muscovite, and opaque minerals (Freitas et al., 2018). The soils in the study area were classified as Argissolo Vermelho Amarelo Distrófico and Gleissolo Melânico (Santos et al., 2018).

The region climate is classified as type “As” according to Köppen-Geiger and as B1Ra ‘a’ according to Thornthwaite, characterizing it as tropical with winter rains and little moisture deficiency, average rainfall varying approximately between 1,300 and 1,600 mm year^{-1} and temperature varying between 22 and 30 °C (Alvares et al., 2013). The hypsometry of this area varies from 164 to 635 m within the domain of the Vaca Brava sub-basin, with a biogeographic predominance of the Atlantic Forest and associated ecosystems (Marques et al., 2014).

Fifteen single samples were collected from the different land uses (banana, pasture, reforestation, and natural forest) and two relief positions (deposition foothills and mid-slope) to make up a composite sample, collected from the 0.00-0.20 and 0.20-0.40 m layers. The samples were then air-dried, then crushed and passed through a sieve with a 2 mm mesh to obtain fine air-dried soil (FADS). In the laboratory, physical, chemical, and fertility analyses were carried out according to the methodology proposed by Teixeira et al. (2017).

Texture analysis was carried out using the pipette method, using a 0.1 mol L^{-1} NaOH solution as a chemical dispersant and mechanical stirring in a high-speed apparatus for 15 minutes. The clay fraction was separated by sedimentation, the sand by sieving and the silt was calculated by difference (Teixeira et al., 2017). From the total and dispersed clay data, it will be possible to calculate the soil degree of flocculation, according to Equation 1:

$$DF(g\ kg^{-1}) = \left(\frac{ArgT - ArgH_2O}{ArgT}\right) \times 1000 \qquad \text{Eq. (1)}$$

where: DF - degree of flocculation (g kg^{-1}); ArgT - fraction of clay dispersed in sodium hydroxide - NaOH (g kg^{-1}); and, $ArgH_2O$ - fraction of clay dispersed in water (g kg^{-1}).

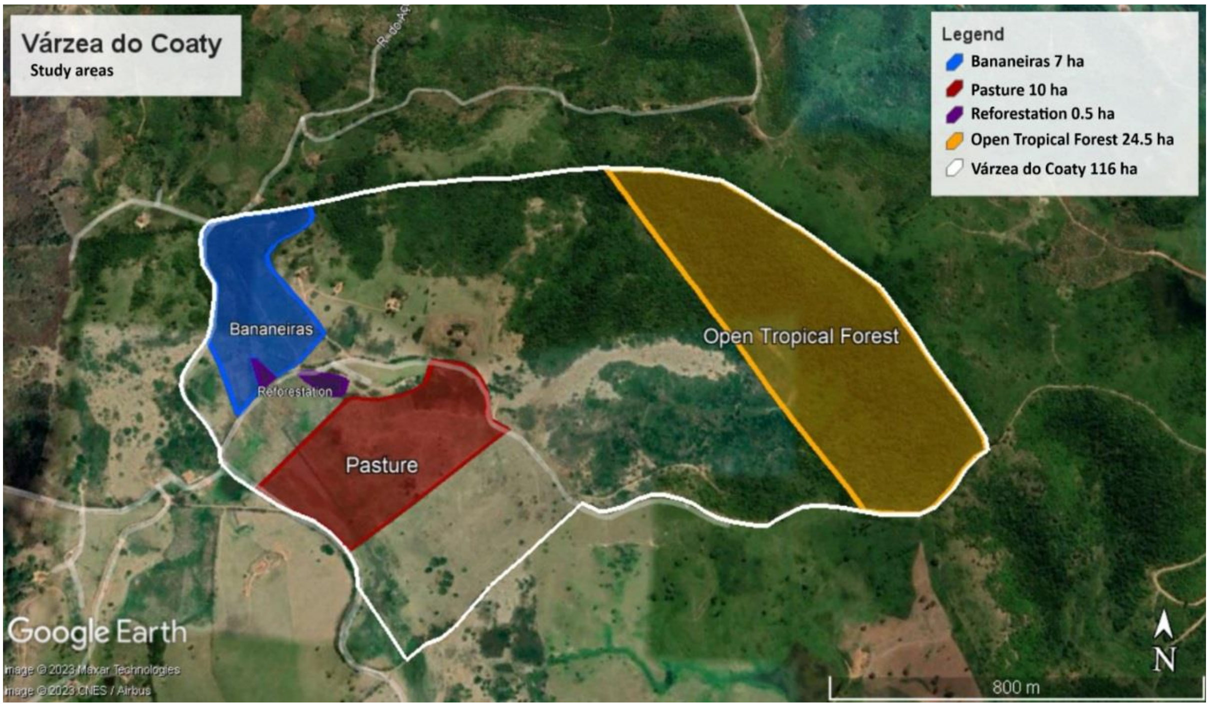

Figure 2. Delimitation of the Engenho Varzea Coaty area with the boundaries of uses. Areia, PB, Brazil. Source: Author (2023).

Table 1. Description of use and history of areas under different agroecosystems and forest. Areia, PB, Brazil.

Study area	Description of the area
Banana (*Musa parasidiaca*)	An area of 7.6 ha with 4 × 4 spacing, liming (1.8 tons of dolomitic limestone/hectare) and fertilization (NPK formula 20-10-20 with 50 g per plant) are carried out annually, cleaning between the lines and weed control.
Pasture (*Brachiaria brizantha*)	An area of approximately 10 ha under the cultivation of *Brachiaria brizantha* cv. Piatã; previously barred and limestoned (1.5 tons of dolomitic limestone/hectare) annually and used for beef cattle on a rotational basis.
Reforestation with 'sabiá' (*Mimosa caesalpiniaefolia*)	About 0.5 ha, with planting of sage *Mimosa caesalpiniaefolia* with spacing of 2 × 2 m, lateral and branch pruning is carried out, to correct growth, as well as the removal of cuttings for maintenance of property fences.
Open Tropical Forest	Evergreen vegetation made up of dense, multi-layered trees between 20 and 50 m high.

Source: Author (2023).

The chemical and fertility analyses were carried out according to the methodology proposed by Teixeira et al. (2017), where the pH in water, potential acidity (H^+ + Al^{3+}), exchangeable aluminum (Al^{3+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), phosphorus (P), potassium (K), and organic carbon (OC) were analyzed. The pH in water was determined potentiometrically using a pH meter with a soil:water ratio of 1:2.5. Exchangeable aluminum (Al^{3+}) was extracted using a 1 mol L^{-1} KCl solution, with levels determined by titration using 0.025 mol L^{-1} NaOH and bromothymol blue as a colorimetric indicator.

Potential acidity (H + Al) was extracted with calcium acetate at pH 7.00 and determined by tilulometry using 0.025 mol L^{-1} NaOH and phenolphthalein as an indicator. Phosphorus (P), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) were extracted using the ion exchange resin method. Based on the determinations of exchangeable cations and potential acidity, the following were calculated: cation exchange capacity (CEC), sum of bases (SB), and base saturation (V). Total organic carbon was determined using the Walkley-Black method modified by Yeomans and Bremner (1988), while organic matter was estimated based on organic carbon.

3. Results and Discussion

The results of the textural attributes studied in the two layers and landforms are shown in Tables 2 and 3. In general, the soils fall into the sandy loam class. The contents of the sand fraction were higher both at the foot of deposition and in the middle of the slope, regardless of the layers, varying between 513 and 759 g kg^{-1}, followed by the clay fraction between 138 and 338 g kg^{-1}. These results are similar to those found by Silva et al. (2022) in which the sand fraction dominated, showing the influence of the gneissic material interfering in this behavior.

It was also observed that the landforms (depositional foothills and mid-slopes) and uses (banana plantations, pasture, reforestation, and forest) did not interfere with the distribution of the textural fractions. According to Campos et al. (2022) it is possible that landscape positions and uses are not capable of altering the skeletal composition of the soil.

With regard to water-dispersed clay and degree of flocculation (Table 2 and 3), it was found that in the mid-slope environment, in both layers studied in the banana and pasture agro-ecosystems, there was a lower degree of flocculation and higher water-dispersed clay. At the foothill of deposition in both layers, the banana and reforestation agroecosystems showed a lower degree of flocculation and higher water-dispersed clay. This indicates that the areas of pasture in the depositional foothills, reforestation in the mid-slopes and banana plantations in the two relief forms (mid-slopes and depositional foothills) are vulnerable to the disaggregation of microaggregates (the base of the hierarchical chain that forms aggregates), which are basically made up of flocculated clay stabilized by cementing agents such as organic matter, Fe, and Al oxides (Hillel, 2003) and predisposed to erosion.

Environments that have higher amounts of water-dispersed clay are predisposed to soil compaction, while environments that have soils with higher aggregation tend to have a higher flocculation index, which suggests a more advanced process of structure maintenance, since flocculation is the first condition for the formation of aggregates (Barreto et al., 2019). The chemical and fertility attributes of the soil are shown in Tables 4 and 5. It was found that in the mid-slope in both layers, the lowest pH values in water were found in the reforestation and forest areas, as opposed to the highest contents in the banana and pasture areas. The same trend was seen in the deposition foothills, where the banana and reforestation areas had the lowest pH in the 0.00-0.20 m layer and the reforestation and forest areas had the lowest pH in the 0.20-0.40 m layer, indicating greater acidity. In studies carried out by Oliveira et al. (2015), it was observed that soils under native forest and agroforestry systems tend to show a strong correlation with soil acidity.

Table 2. Soil physical attributes in a mid-slope area under different uses. Areia, Paraíba, Brazil.

Land use	Sand	Silt	Clay	Clay dispersed in water	Degree of flocculation
	(g kg^{-1})				
0.00-0.20 m					
Banana	627	133	240	53	779
Pasture	605	136	259	27	896
Reforestation	759	67	174	0	1,000
Forest	604	119	277	13	953
0.20-0.40 m					
Banana	618	140	242	66	727
Pasture	589	141	270	66	756
Reforestation	700	88	212	26	877
Forest	513	149	338	54	840

Source: Author (2023).

Table 3. Soil physical attributes in a deposition foothill area under different uses. Areia, Paraíba, Brazil.

Land use	Sand	Silt	Clay	Clay dispersed in water	Degree of
	(g kg^{-1})				
0.00-0.20 m					
Banana	623	148	229	27	882
Pasture	694	120	186	13	930
Reforestation	663	98	239	27	887
Forest	712	78	210	0	1,000
0.20-0.40 m					
Banana	638	155	207	65	686
Pasture	761	101	138	26	812
Reforestation	593	136	271	54	801
Forest	648	94	257	13	949

Source: Author (2023).

The mid-slope of the landscape showed the highest levels of Ca^{2+} in the banana area in the two layers studied when compared to the other uses (Table 4). In the foothill deposition environment, the environments under banana cultivation, pasture, and reforestation performed better in both layers than the use under native forest (Table 5). With regard to Mg^{2+} content, similar values were observed in all the use systems on the mid-slope. On the other hand, in the deposition foothills, the area under banana plantations had the lowest values. The K^{+} and Na^{+} contents were low and similar in all use systems (banana, pasture, reforestation, and forest), landforms (mid-slope and depositional foothills) and layers (0.00-0.20 and 0.20-0.40 m) (Table 4 and 5).

In terms of exchangeable aluminum, the values were similar in all uses, layers and landforms, except in the 0.20-0.40 m layer of the banana plantation in the foothill environment, which had a higher Al^{3+} value (Table 4 and 5). Potential acidity (H + Al) behaved similarly in all the use systems and layers in the mid-slope environment. In the deposition foothills, there were higher potential acidity values in the 0.00-0.20 m layer in the area under banana cultivation and in the 0.20-0.40 layer in the area under native forest (Table 4 and 5). This corroborates the results obtained by Novak et al. (2021) who studied the chemical composition of the soil under different environmental conditions in the Cerrado.

The cation exchange capacity (CEC) did not vary in the mid-slope environment regardless of the position of the landscape, uses and layers, while for the foothills, only the lowest CEC value stands out in the banana area, in the 0.00-0.20 m layer (Table 4 and 5). In the mid-slope position, it was observed that the available P levels were lower in the banana area than in the other uses (Table 4). In the deposition foothills, the uses under pasture and reforestation had the highest values when compared to the uses under banana and forest (Table 5).

The organic matter (OM) content in the mid-slope, 0.00-0.20 m layer was higher in the reforestation and forest environments, reversing in the 0.20-0.40 m layer, with the areas under banana and pasture showing the highest content (Table 4), indicating that these species have a greater capacity to store organic carbon, even when compared to forest environments, probably due to their greater capacity to provide carbon at depth. At the foothill of deposition, the highest organic matter contents were found in the reforestation and forest areas, regardless of the layers studied like in Table 5.

Table 4. Soil chemical and fertility attributes in a mid-slope area under different uses. Areia, PB, Brazil.

Land use	pH in water	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H + Al	CEC	P	OM	V
		($cmol_c$ kg^{-1})							(mg kg^{-1})	(g kg^{-1})	(%)
					0.00-0.20 m						
Banana	5.4	2.57	1.45	0.08	0.02	0.15	4.87	8.99	1.77	28.8	45.94
Pasture	5.3	1.75	1.70	0.13	0.02	0.25	4.97	8.58	2.55	30.5	42.07
Reforestation	4.7	1.04	1.42	0.14	0.01	0.60	5.20	7.81	4.83	30.7	33.42
Forest	5.2	1.77	1.60	0.15	0.02	0.15	4.97	8.50	3.33	39.1	41.65
					0.20-0.40 m						
Banana	5.1	1.79	1.18	0.06	0.02	0.25	4.47	7.52	1.64	23.7	40.56
Pasture	5.2	1.31	1.22	0.07	0.04	0.60	5.74	8.38	1.96	24.9	31.50
Reforestation	4.8	0.53	1.27	0.11	0.01	0.50	4.52	6.44	2.94	17.3	29.81
Forest	5.1	1.02	1.03	0.19	0.02	0.40	4.22	6.49	1.83	17.8	34.98

Ca^{2+} - Calcium; Mg^{2+} - Magnesium; K^{+} - Potassium; Na^{+} - Sodium; Al^{3+} - Aluminum; H+AL – Potential acidity; CEC - Cation exchange capacity; P – Phosphor; OM - Organic matter; V - Base saturation. Source: Author (2023)

Table 5. Soil chemical and fertility attributes in a foothill deposition area under different uses. Areia, PB, Brazil.

Land use	pH in water	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H+Al	CEC	P	OM	V
		($cmol_c$ kg^{-1})							(mg kg^{-1})	(g kg^{-1})	(%)
					0.00-0.20 m						
Banana	5.1	2.26	0.70	0.06	0.10	0.35	7.19	3.12	4.70	31.2	30.2
Pasture	5.8	2.23	1.57	0.19	0.10	0.10	3.81	7.91	18.00	30.8	51.7
Reforestation	5.0	1.64	1.31	0.11	0.05	0.25	4.69	7.80	8.50	36.3	39.9
Forest	5.5	1.53	1.25	0.30	0.06	0.15	4.04	7.19	3.30	46.9	43.8
					0.20-0.40 m						
Banana	5.7	1.76	0.77	0.05	0.17	5.05	0.35	7.79	3.72	16.8	35.3
Pasture	6.1	1.84	0.91	0.11	0.12	0.05	3.05	6.04	11.00	17.1	49.5
Reforestation	5.2	1.99	1.87	0.09	0.21	0.20	4.32	8.48	11.50	26.9	49.1
Forest	5.0	0.74	1.29	0.08	0.06	0.75	6.47	8.65	3.50	25.3	25.2

Ca^{2+} - Calcium; Mg^{2+} - Magnesium; K^{+} - Potassium; Na^{+} - Sodium; Al^{3+} - Aluminum; H+AL – Potential acidity; CEC - Cation exchange capacity; P – Phosphor; OM - Organic matter; V - Base saturation. Source: Author (2023)

Fontana et al. (2011), studying organic matter levels in an Atlantic Forest area, found that total organic carbon (TOC) levels were similar between the banana area (agroforestry system) and the forest area, while the cassava and capoeira areas provided the lowest TOC levels, regardless of depth and season. With regard to base saturation (V%), the values were very similar between the landforms, uses and layers, all of which were classified as dystrophic (Table 4 and 5). Portugal et al. (2010), studying the physical and chemical properties of soil in areas with productive systems and forest in the Zona da Mata region of Minas Gerais, Brazil, some soil attributes are more vulnerable or susceptible to changes in use and management, including cation exchange capacity (CEC), available P, and base saturation (V%).

Isolating the levels of available phosphorus and organic matter according to the landforms, it can be seen that in the 0.00-0.20 m layer, the levels of available phosphorus (Figure 3A) and organic matter (Figure 3B) were more expressive in the foothill pedoform when compared to the mid-slope, regardless of use. These results are probably due to the accumulation of particles, water and nutrients in these places, as well as the morphological characteristics and erosion features of the mid-slope. Santos and Salcedo (2010) in studies carried out in the Vaca Brava basin, in Areia, PB, Brazil, show that physical and chemical attributes are influenced by land use, with an increase in levels in the direction of forest agriculture.

In relation to the 0.20-0.40 m layer (Figure 4), it was found that the levels of available P (Figure 4a) behaved similarly to the surface layer, with the highest levels remaining at the foothill compared to the mid-slope, a fact possibly associated with its low mobility in the soil. Similar results were found by Martins et al. (2019) in studies of the physical and chemical attributes of the soil on a gradient of slope under high-montane Mixed Ombrophilous Forest.

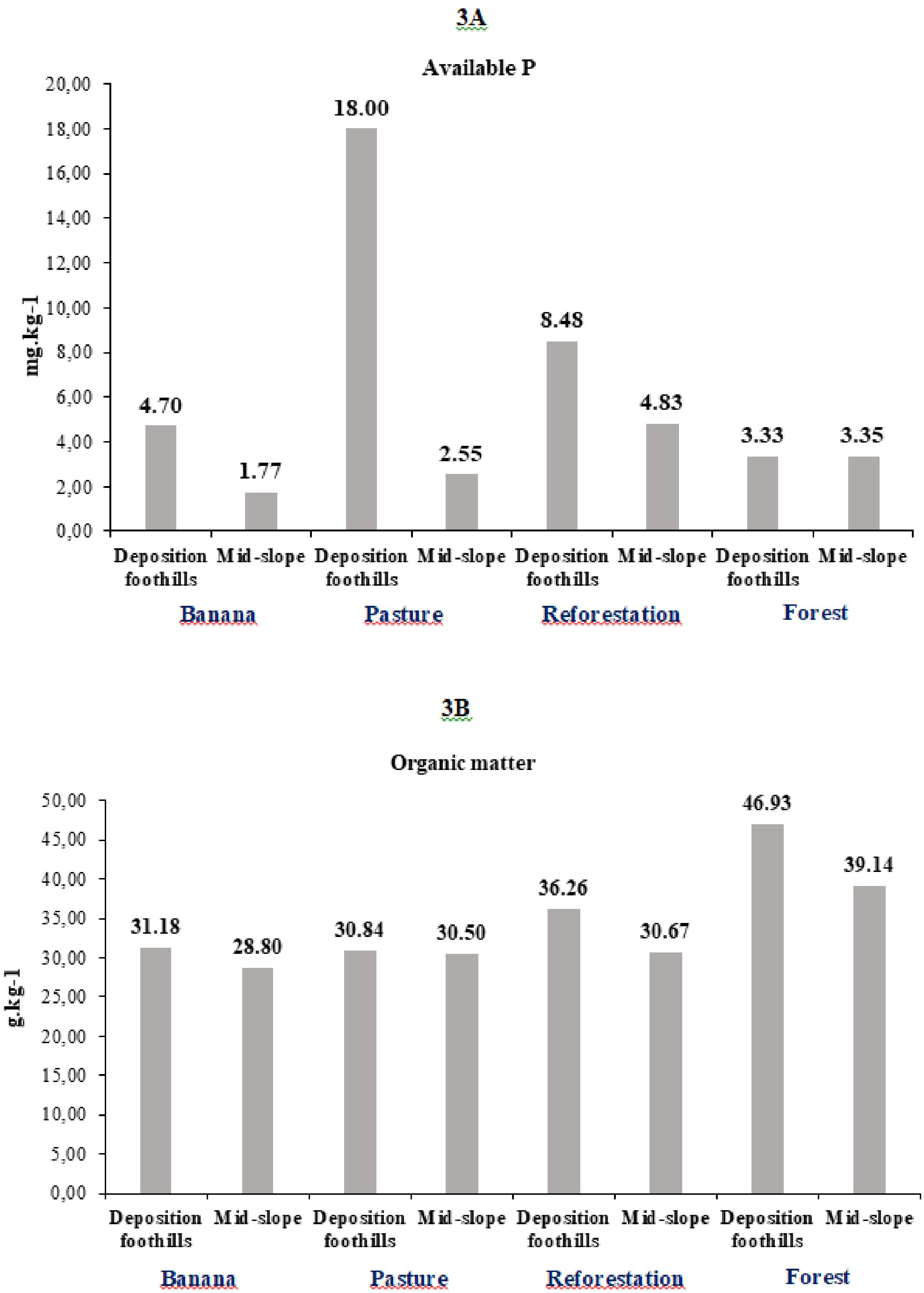

Figure 3. Comparison of available of 3A (P available) and 3B (soil organic matter) as a function of landforms (foothills and mid-slopes under different uses in the 0.00-0.20 m layer). Areia, PB, Brazil. Source: Author (2023).

On the other hand, the organic matter content in the 0.020-0.40 m layer (Figure 4b) showed higher values at the foothill of deposition of the uses under forest and reforestation when compared to the mid-slope. However, these results were reversed for the uses under banana and pasture, with higher levels of organic matter in the mid-slope compared to the foothill (Figure 4). These results point in two directions, the first being that in the agroecosystems (banana and pasture) on the mid-slope there is probably constant removal of organic matter from the A horizon, with the more stable organic matter remaining in the subsurface, which explains this result. In forest environments (natural or forested), the presence of leaf litter aids in the maintenance of carbon levels and stocks, providing high levels of organic matter in the foothills compared to the mid-slopes. According to Artur et al. (2014) the chemical attributes of the soil varied spatially, so the micro-relief influences the direction of water flow and induces spatial variability in the chemical attributes of the soil.

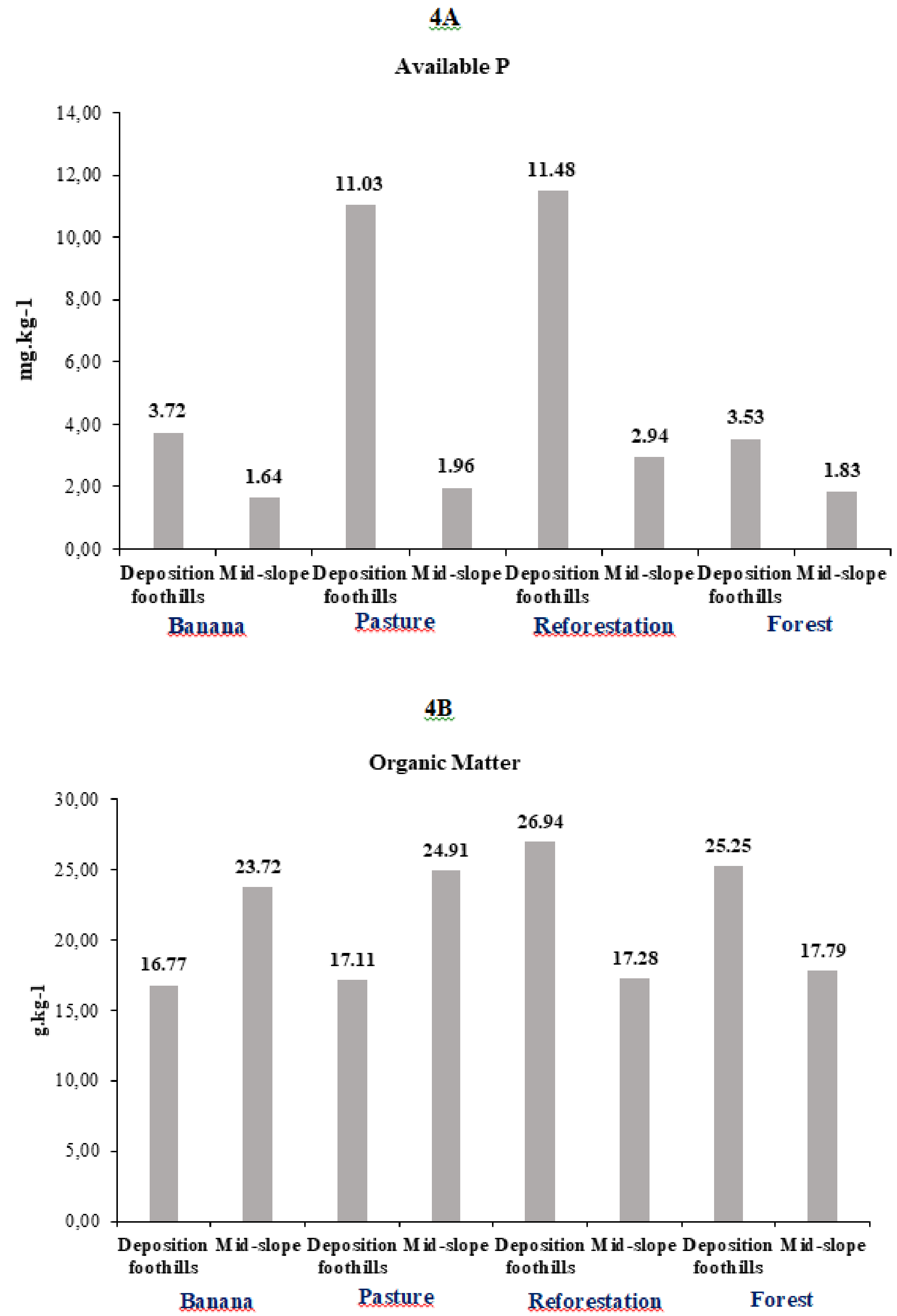

Figure 4. Comparison of available of 4A (P available) and 4B (Soil organic matter) as a function of landforms (foothills and mid-slopes under different uses in the 0.20-0.40 m layer). Areia, PB, Brazil. Source: Author (2023).

4. Conclusions

In general, the physical and chemical attributes of Argissolos and Gleissolos were altered by land use and landforms. In addition, soil organic matter levels in the surface layer were higher in the deposition foothills, while in the mid-slope the forest environments (natural or forested) showed higher levels of organic matter.

Authors' Contribution

Diego Melo dos Santos, Roseilton Fernandes dos Santos and Rossana Lucena de Medeiros carried out the conception and design of the study. Diego Melo dos Santos, Roseilton Fernandes dos Santos and Rossana Lucena de Medeiros carried out the acquisition, analysis or interpretation of the data. Milton César Costa Campos and Diego Melo dos Santos contributed to the writing of the manuscript. Renato Abreu Lima, Robson Vinício dos Santos and Flávio Pereira de Oliveira contributed to the critical review of the intellectual contente.

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