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Physical attributes of yellow oxisol under different monocultures in the savanna of Piauí state, Brazil

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ABSTRACT: The objective of this study was to evaluate the physical attributes of an oxisol under soybean monoculture, eucalyptus monoculture, and pasture and native forest conditions at depths of 0–0.20 and 0.20–0.40 m. Disturbed and undisturbed soil samples were collected to perform physical analyses. Specific analyses included texture, soil density, macroporosity, microporosity, total porosity, aggregate stability index, weighted mean diameter, percentage of aggregates with a diameter of >2.00 mm, and soil penetration resistance (PR). The data were analyzed using the Tukey's test for the comparison of mean values and multivariate analysis. Different uses and management of the soil affected its physical attributes, resulting in the deterioration of soil quality in the soybean and pasture areas. Soil management systems in pasture and soybean areas also resulted in higher soil density and lower soil porosity. The eucalyptus monoculture showed soil aggregation equal to that of the native forest. There was a sharp increase in soil PR beyond the 0.15-m deep layer in the pasture and soybean management systems. Multivariate analysis identified variables that correlated with each type of soil management and the effects of changes in soil characteristics.

Key words: bulk density; penetration soil resistance; soil aggregation; soil management

Atributos físicos de um latossolo amarelo sob diferentes monoculturas no cerrado piauiense

RESUMO: O objetivo deste trabalho foi avaliar alterações dos atributos físicos de um LATOSSOLO sob monocultivos de soja, eucalipto, pastagem em relação à mata nativa nas profundidades de 0 - 0,20 e 0,20 - 0,40 m. Foram coletadas amostras de solo com estrutura deformada e indeformada para a realização das análises físicas, a saber: textura, densidade do solo, macroporosidade, microporosidade, porosidade total, índice de estabilidade de agregados, diâmetro médio ponderado, porcentagem de agregados > 2mm, e resistência do solo à penetração. Os dados obtidos foram analisados ao teste de Tukey para a comparação de médias e análise multivariada. Os diferentes usos e manejo do solo afetam os atributos físicos resultando na deterioração da qualidade nas áreas de soja e pastagem. Os sistemas de manejo do solo em áreas com pastagem e soja resultaram na maior densidade e menor porosidade do solo. O monocultivo com eucalipto mostrou uma agregação do solo igual à da mata nativa. Ocorreu um aumento abrupto do valor da resistência do solo à penetração, após a camada de 0,15 m de profundidade para o sistema de manejo pastagem e soja. A análise multivariada permitiu as variáveis que se correlacionaram com cada tipo de manejo do solo e os efeitos na alteração nos atributos físicos do solo.

Palavras-chave: densidade do solo; resistência do solo à penetração; agregação do solo; manejo do solo

Introduction

The state of Piauí has approximately 11.5 million hectares of savanna, of which approximately 70% corresponds to a domain area and approximately 30% to a transition area; thus, the savanna occupies fourth place in the country and first in the northeast region, thereby presenting great potential for exploitation. Oxisol is the most representative unit of soils in this biome and has been intensively incorporated into agricultural processes. It is defined as a mature, deep soil, with excellent drainage due to the flat or slightly undulating reliefs and offers high potential for agricultural exploitation. Over the last three decades, this soil has been used in crop cultivation for the production of grains, mainly soybean (Aguiar & Monteiro, 2005). More recently, pasture and eucalyptus cultivation has also been conducted using oxisol.

The substitution of savanna forests by monoculture systems results in varying degrees of changes in the physical attributes of the soil, depending on the crop and management system adopted. This is because a tropical savanna is composed of several types of vegetation, from grasses to larger trees (Hoffmann & Jackson, 2000), that provide large quantities of vegetal residues in the soil, which favors the soil structuring process and has positive influence on other physical attributes of soil.

Soil preparation is an important component, because it influences the attributes that determine the physical quality of the soil and act on its structure. The agricultural exploitation of these areas with soybean cultivars is based on management systems with intense soil disturbances due to plowing and harrowing, thus modifying the soil's original characteristics (Barbosa et al., 2016). Prolonged conventional management systems leave the latosols exposed and cause the disintegration of macroaggregates, resulting in rapid decomposition of organic matter (Ibiapina et al., 2014). This influences soil density – Sd (Pragana et al., 2012) and penetration resistance – PR (Drescher et al., 2012), which affect the distribution of aggregates into size classes and/or their stability in water (Castro Filho et al., 1998).

Pasture monoculture involves extensive breeding of cattle that often leads to compaction due to trampling. However, it also involves the contribution of organic residues to the decomposing subsystem, resulting from constant renewal due to the death of grass roots (Wendling et al., 2005). In eucalyptus cultivation, soil preparation is limited to one subsoiling with plowing and harrowing at the time of planting. This provides litter with an increased C/N ratio (>25) and high levels of lignin and polyphenols as well as high C/P and C/S ratios, which contribute to the slow decomposition of the vegetal residue (Pulrolnik et al., 2009).

Studies focused on the monitoring of soil quality through physical attributes are important for the evaluation and maintenance of sustainable agricultural systems and for signaling adequate management of the environment by focusing on conservation and productivity. Based on this information, the objective of this study was to evaluate the changes in the physical attributes of soils of different monocultures in yellow oxisol in the savanna of Piauí state.

Materials and Methods

The study was carried out at the Chapada Grande farm, located in the municipality of Regeneração/PI at an altitude of 400 m (geographic coordinates: 06°14′16′′ S latitude and 42°41′18′′ W longitude). This region has an average annual temperature of 32ºC and average annual rainfall of 1350 mm, with rainfall distributed from January to May (Equatorial Continental Regime, with annual isohyets between 800 and 1,400 mm; Figure 1). The climate according to the Köppen climate classification is of the type Aw′.

The soil, according to the exploratory survey/soil recognition of the state of Piauí, was classified as yellow oxisol with clayey texture (Table 1).

Four areas were selected based on the proximity to the desired crops and presence of the same soil type. Cultivated areas were established in 2008 (Figure 2) as follows: (1) Area was cultivated with rice in the first year and soybean in the subsequent years. Initial soil preparation consisted of plowing, furrowing, root collection, and incorporation of 4

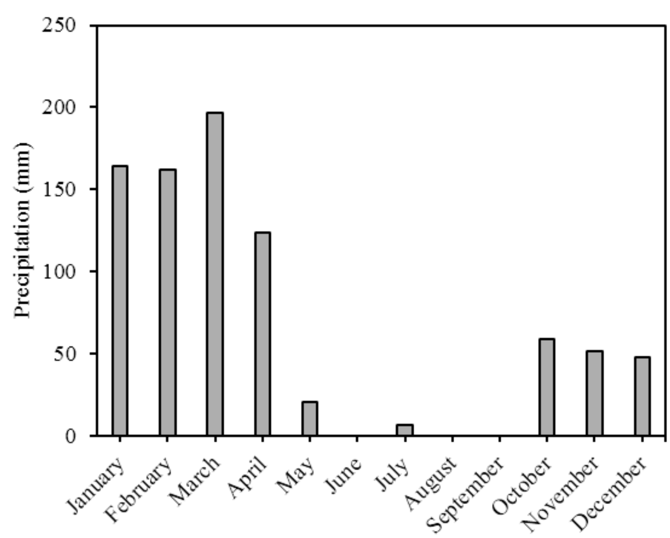

Figure 1. Monthly precipitation in the year 2015 at Chapada Grande Farm.

Table 1. Granulometric composition of soils in the management systems studied.

System	Granulometry (g kg^{-1})			Textural class
	Sand	Silt	Clay	
	Depth (0.00 – 0.20 m)			
Soybean	367	192	441	Clayey
Eucalyptus	224	373	403	Clayey
Pasture	273	219	508	Clayey
Native Forest	288	280	432	Clayey
	Depth (0.20 – 0.40 m)			
Soybean	342	208	450	Clayey
Eucalyptus	284	292	424	Clayey
Pasture	293	273	434	Clayey
Native Forest	268	290	442	Clayey

t ha^{-1} of limestone and fertilization of 250 kg ha^{-1} of NPK. Conventional management was performed with the use of plow and harrow until the year 2013. In 2014, a no-tillage system was used. (2) Eucalyptus was planted (Ma, 2000) after clearing of the savanna forest with windrowing and burning of branches and leaves. Initial soil preparation consisted of harrowing and furrowing for planting and incorporation of 4 t ha^{-1} of limestone and 400 kg ha^{-1} of triple superphosphate. Eucalyptus was planted in 2008 using a spacing of 3.5 × 2.5 m. Cover fertilization was carried out with NPK (20-00-20) using 150 kg/plant. The following operations were performed: subsoiling at the time of soil preparation, manual weeding in the area 2 months after planting, and harrowing between rows 3 months after planting. In August 2015, 1 month before the second soil collection, there was an accidental burn. (3) The pasture area had a prevalence of the grass *Brachiaria brizantha* and was managed under intensive grazing with 3 AU per hectare for 8 months. Prior to pasture management practices, this area was cultivated with soybean until 2011. (4) The native forest soil area under savanna consisted of natural vegetation and was without anthropic interference for use as reference.

Undisturbed samples with volumetric rings were collected to determine Sd at four different points within the depths of 0–0.20 and 0.20–0.40 m. Particle density (Pd) was determined by the volumetric flask method. Total porosity (TP) was calculated using the following equation:

$$TP = \left(\frac{1-Sd}{Pd}\right)\times 100 \quad (1)$$

where:

Sd - soil density, mg m^{-3};

Pd - particle density, mg m^{-3}.

Aggregate stability was determined by sieving the soil in water using sets of sieves with meshes of 2.0, 1.0, 0.5, 0.25, and 0.105 mm apertures, and then the aggregates were subjected to vertical shaking. Subsequently, the contents of each sieve were heated in an oven at 105°C until their mass remained constant.

The aggregate stability index (ASI), weighted mean diameter (WMD), and aggregation, related to the sum of the percentages of aggregates with a diameter of >2.00 mm, were determined according to the following formulas:

$$ASI = \left(\frac{WMD_w}{WMD_d}\right)\times 100 \quad (2)$$

$$WMD = \sum_{i=1}^{n}\left(xi \cdot wi\right) \quad (3)$$

$$Aggregation = \left(W_w > 2\right)100 \quad (4)$$

where:

WMD_w - WMD - wet pathway, mm;

WMD_d - WMD - dry pathway, mm;

wi - proportion of each class in relation to the total;

xi - mean diameter of classes, mm;

W_w - proportion of aggregates > 2.00 mm stable in water.

The soil PR was determined using an impact penetrometer (IAA/Planalsucar–Stolf) calculating the impact of a free falling weight from a height of 40 cm. Gravimetric moisture ranged from 22% to 24% up to the 0.4-m layer (Table 2).

The resistance values were calculated from a depth of 0.05 m. From the obtained values, the layers were discriminated with respect to their degree of compaction according to the USDA protocol (USDA, 1993), with a limit of 2 MPa considered as a strong restriction to root growth.

The data were analyzed in a completely randomized design (CRD) using the analysis of variance (ANOVA) and Tukey's test at 5% probability. For the confirmation or rejection of the statistical hypothesis, the statistical package R was used. Multivariate techniques of principal component analysis (PCA) were also used to understand how the variables interacted simultaneously. The attributes considered included sand, silt, clay, soil density, microporosity (MiP), macroporosity (MaP), TP, WMD, percentage of stable aggregates, ASI, organic matter content, and PR.

Table 2. Gravimetric moisture of soils in the management systems studied.

Layer (m)	Soybean	Pasture	Eucalyptus	Na ve Forest
	kg kg^{-1}			
0 – 0.20	22.07	22.90	23.80	23.35
0 – 0.40	23.49	23.89	24.50	24.75
Mean	22.78	23.40	24.15	24.05

Results and Discussion

Sd ranged between 0.89 and 1.19 g cm^{-3} for the 0–0.20-m layer and between 0.99 and 1.27 g cm^{-3} for the 0.20–0.40-m layer (Table 2). Reynolds et al. (2007) suggested that the upper limit of Sd for adequate aeration of the root zone in fine-textured soils varies from 1.25 to 1.30 g cm^{-3} and that root elongation is severely restricted with densities ranging from 1.4 to 1.6 g cm^{-3}. Thus, Sd of the soybean cultivation area was at the upper limit in the 0.20–0.40-m layer for clayey soils.

In the surface layer, all the systems exhibited >50 m m^{-3} porosity, with pastures showing the lowest value (Table 3). The soil under soybean cultivation presented TP of <50 m m^{-3} in the 0.20–0.40-m layer. For the pasture, TP was approximately 50 m m^{-3} with a predominance of micropores, whereas for the forest and eucalyptus soils, these values were 57 and 59%, respectively.

The increase in Sd and reduction in TP in the soybean system, particularly in the 0.20–0.40-m layer, may be

Table 3. Soil physical attributes in the management systems studied.

	Soybean	Pasture	Eucalyptus	Forest
		0 – 0.20 m		
Bulk density (kg dm^{-3})	1.04 b	1.19 a	0.97 bc	0.89 c
Total Porosity (m^3 m^{-3})	0.56 b	0.51 c	0.60 ab	0.61 a
Macroporosity (m^3 m^{-3})	0.22 b	0.27 b	0.35 a	0.39 a
Microporosity (m^3 m^{-3})	0.34 a	0.24 b	0.25 b	0.22 b
Agreggate Stab.	54.63 c	65.27 b	83.51 a	89.72 a
WMD (cmol kg^{-1})	0.70 b	1.00 a	1.02 a	1.28 a
Aggreg. > 0.2mm	21.91 c	45.14 b	48.07 b	52.89 a
		0.20 – 0.40m		
Bulk Density (mg kg^{-1})	1.27 a	1.22 a	1.05 b	0.99 b
Total Porosity (%)	0.45 c	0.50 c	0.56 a	0.57 a
Macroporosity	0.27 b	0.30 b	0.38 a	0.30 a
Microporosity	0.20 a	0.20 a	0.21 a	0.19 a
Agreggate Stab. Index	55.17 b	58.94 b	82.90 a	86.42 a
WMD cmol kg^{-1})	0.77 b	0.77 b	0.97 ab	1.21 a
Aggregates > 0.2mm	23.5 b	24.12 b	42.80 ab	42.90 a

WAD - Weighted mean diameter; Means followed by the same letter do not differ statistically by Tukey's test at 1% probability.

associated with machine traffic for an extended period of time (5 years). A report by Bono et al. (2013) demonstrated that intense traffic from agricultural machines and tools used in conventional management systems can lead to soil compaction over time by increasing Sd and decreasing TP in deeper layers due to the formation of a compacted subsurface layer, usually up to 20 cm.

A study by Moraes et al. (2016) found that a 20-year conventional plantation system in a clayey red oxisol increased Sd and decreased MaP in the layer below 0.20 m to values below the critical level for crop development compared with the no-tillage system. In this report, the soil physical quality was improved over time after the adoption of no-tillage management. Conventional planting contributes to soil pulverization and can lead to greater MaP in the surface layer in relation to soils that undergoes no-tillage practices (Dal Ferro et al., 2014).

The higher density observed in the surface layer in the pasture system in this study may be due to the intense trampling caused by overgrazing. Permanent grazing deteriorates the soil's physical quality due to an increase in Sd and decrease in TP of the surface layer (Jakelaitis et al., 2008). In addition, taking into account the history of the area under pasture management, it was observed that in the 3 years prior to the implementation of this system, the soil was subjected to soybean cultivation under conventional management, which may have contributed to the higher density in the subsurface layer in the pasture soil.

On the other hand, the native forest and eucalyptus systems exhibited higher TP, ranging from 0.58 to 0.61 m^3 m^{-3} in the two layers (Table 3), probably due to the higher deposition of organic residues in these areas. In addition, the clayey texture of these soils may have favored higher TP. A study by Wendling et al. (2012) on very clayey oxisol showed that Sd ranged from 0.55 to 0.65 m^3 m^{-3} up to a depth of 0.2 m in the native savanna and pine forest areas.

In this study, MaP was reduced in soils under management systems compared with those under native forest conditions, with the exception of eucalyptus. MaP was higher in the native forest (0.39 m^3 m^{-3}) and lower in the pasture system (0.20 m^3 m^{-3}). The MaP values are important for the rapid flow of water and air in the soil and for the diagnosis of soil compaction, as the main reduction of soil pore volume occurs in this fraction of TP (Schjonning & Lamande, 2010). MiP ranged from 0.19 to 0.34 m^3 m^{-3}, and the soil under native forest had the lowest MiP (Table 3). MiP did not statistically differ in the surface layers of the pasture and eucalyptus soils, demonstrating that soils collected from these areas had MiP values similar to those of samples obtained from natural soil conditions. No significant differences were observed in MiP for the second layers in these systems. Therefore, MiP does not provide evidence that pores are predominantly dependent on soil texture, particularly the clay and/or silt contents (Table 1), which were similar in the evaluated layers (Lima et al., 2014).

Regarding WMD and ASI, an interaction between the type of use and depth was observed (Table 3). Native forest soils often demonstrate higher amounts of organic matter and increased aggregate stability (Secco et al., 2005; Albuquerque et al., 2005) as a result of the prevalence of plant material and lack of interference from cultivation. However, in cases of managed systems that experience high degrees of soil disturbance for several years, soil aggregates are destroyed, thus reducing aggregate stability (Sousa Neto et al., 2008).

Here, the soybean system showed the lowest values for both WMD and ASI in the evaluated soil layers. Previous studies in the savanna areas of Piauí state showed that WMD and ASI were lower in all the conventional cropping system soils than in native forest soils; this was due to intense soil disturbance and heavy plowing and harrowing carried out for creating favorable conditions for soybean monocultures (Fontenele et al., 2009; Ibiapina et al., 2014). Castro Filho et al. (1998) studied aggregate stability and confirmed that the continuous disturbance of soil through the use of plows promotes the rupture of aggregates, thereby impairing aggregate stability and decreasing WMD in the subsequent crops adopting this system.

For this variable, the pasture and eucalyptus systems showed values similar to those of the surface layer in the original savanna. Grasses, such as *Brachiaria*, have an aggregating effect on the root system, which favors the formation of more stable aggregates (Kasper et al., 2009). Moreover, grasses lead to an increase in microbial activity by providing a large fasciculate root system that is constantly renewed in the surface layer, because grazing causes the death of absorbent roots of the plants. This results in greater carbon intake via the rhizosphere and necromass and can favor the activation of soil microbiota and soil aggregation (Tisdall & Oades, 1982). After 2 years, a eucalyptus crop incorporates the more tender plant tissues, such as leaves and thin branches, to the soil, and after 3–4 years, a material richer in lignin, such as the bark, begins to fall and may lead to a yield of up to 5.20 tons of litter per hectare. The addition of this carbon promotes the development of the root system and microbial activity, besides contributing to a more favorable environment for aggregation (Cortez et al., 2014).

WMD values in the soil under pasture conditions tended to decrease from the 0.20-m depth, with the lowest value (0.77 mm) being observed in the 0.20–0.40-m layer. This result may have occurred due to lower occurrence of roots and a lower content of humic substances (e.g., fulvic acids, humic acids, and humins) at this depth in the pasture soil compared with native forest and eucalyptus soils.

The highest percentages of aggregates of the class >2 mm were observed in forest, surface layer, and forest and eucalyptus soils in the 0.00–0.20-m layer, indicating a positive effect of the accumulation of vegetal residues on the soil surface. Soils under forest areas generally exhibit a larger structure connected to a greater content of organic material due to the contribution of vegetal residues incorporated in the soil, with greater quantity and quality, in addition to climatic conditions that favor greater aggregation (Wendling et al., 2012).

The pasture management system showed intermediate values for aggregates of the class >2.00 mm in the surface layer, whereas the soybean area had the lowest values. The occurrence of *Brachiaria* provides a good vegetative cover to the soil and can prevent or reduce the direct action of raindrops on the aggregates (Loss et al., 2011). Dantas et al. (2012) reported that an annual crop results in greater physical degradation of the soil compared to a perennial crop due to reduction in the soil hydraulic conductivity and stability of aggregates larger than 2.00 mm.

There was a sharp increase in soil PR beyond the 0.15-m deep layer in pasture and soybean management systems (Figure 2). Beyond this depth, PR values were higher than the limit of 2.00 MPa according to USDA (1993) as restrictive to root development. In a study with clayey oxisol, Silva et al. (2000) found that the maximum yield of soybean was

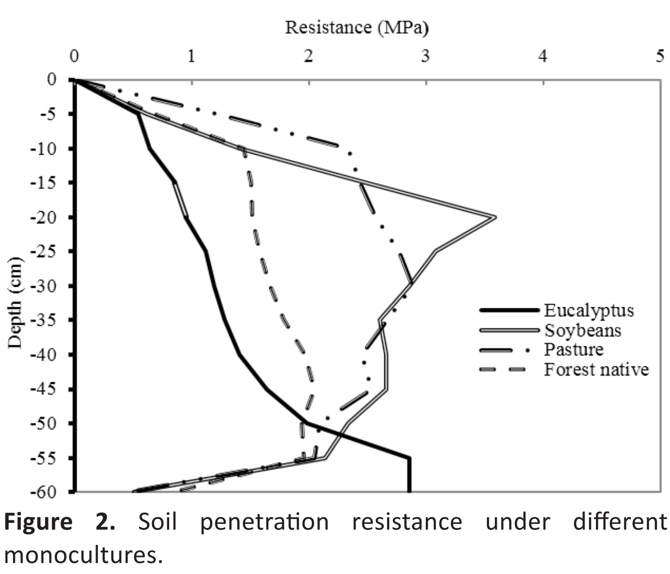

Figure 2. Soil penetration resistance under different monocultures.

associated with a PR of 1.80 MPa, which is well below the value for soybean soil in this study. This may be attributed to the conventional management system, because operation of heavy agricultural machines carried out continuously for annual crops can lead to soil compaction, in addition to the action of the plow that typically affects depths up to 0.20 m (Beutler et al., 2001).

Conventional management systems have extremely high PR values, particularly after long periods of land use. Ramos et al. (2011) studied a native savanna area with soybean plantation under conventional management practices of disk plowing for 7 consecutive years. They measured PR values in the upper range from the 0.20-m layer and attributed these values to the high traffic of machines and action of disk plows that always occurred in the same layer.

In contrast, eucalyptus and native forest areas had lower PR values (<2.00 MPa throughout the soil profile). As a result, roots did not experience growth restrictions, due to homogeneity of the soil attributes in these areas, probably in virtue of the greater quantity and quality of organic material incorporated in the soil that may have preserved the soil structure. In addition, the scarification carried out in the eucalyptus system at the time of planting certainly contributed to PR values being lower than those observed in the native forest. A study by Prevedello et al. (2013) showed that scarification at 0.30-m depth in a eucalyptus plantation resulted in PR values in the lower range throughout the soil profile and that this favored greater root depth and density.

PCA of the physical attributes and of the soil layers analyzed are presented in Figure 2. According to the multivariate analysis of the data obtained, a variation in terms of the efficiency of the treatments in both the soil depths was observed. The first two principal components were responsible for 82.87% of the original variability, and PC1 and PC2 accounted for 68.30% and 14.57% of original variability, respectively.

The formation of three groups is shown in Figure 3. The first group represents only pasture area 1, positioned in the upper left quadrant. This group correlated with the variables clay and Sd, which may be due to greater soil compaction as a result of the overgrazing in the area that led to soil compaction.

The second group is formed by the areas of soybean 1 and 2 and pasture 2 and is positioned in the lower left quadrant. This group was associated with the variable sand. It is observed that MiP is in the opposite quadrant and exhibits a negative correlation with sand, indicating that the increase of one may lead to the decrease of the other. It is also observed that soybean 2 area is associated with PR given that this layer had high Sd and low TP, implying soil compaction.

The third group consists of the native forest and eucalyptus systems and is positioned in the upper and lower right quadrants. This group is associated with most of the soil attributes related to soil aggregation and porosity. This is likely the result of the greater prevalence of organic residues

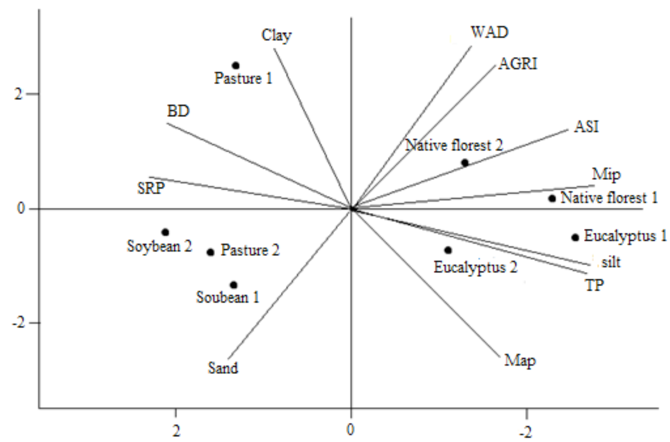

Figure 3. Principal component analysis (PCA) based on the soil physical attributes. Sd = soil density; TP = total porosity; Mip= micoporosity; Map= macroporosity; WMD = weighted mean diameter; ASI= aggregate stability index; Aggr. = percentage of stable aggregates of the class (>2mm); SPR = soil penetration resistance. Soybean 1, Pasture 1, Eucalyptus 1 and Forest 1 correspond to the 0-0.20 m layer; and Soybean 2, Pasture 2, Eucalyptus 2 and Forest 2 correspond to the 0.20-0.40 m layer.

in these systems that can lead to increased biological activity and consequently better soil structure. It can be observed that Sd and TP, located in opposite quadrants, exhibited negative correlation.

Conclusions

Annual monoculture crops result in greater physical degradation of the soil compared with perennial monocultures.

Soils under soybean and pasture management systems exhibited PR above the critical limit from the depth of 0.10 m.

Multivariate analysis identified variables that correlated with each type of soil management and the effects of changes in the soil attributes.

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