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CHANGES IN PHYSICAL QUALITY OF OXISOLS UNDER DIFFERENT MANAGEMENT SYSTEMS IN THE BRAZILIAN CERRADO

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KEYWORDS

S index, land cover change, physical properties, infiltration, soil compaction.

ABSTRACT

Soil compaction in agricultural areas has greatly increased in recent decades due to intensive farming practices, including short-cycle crops and machinery intensification. This study aimed to evaluate the impacts of management systems on the physical quality of a dystrophic Yellow Oxisol, in the Cerrado region of Brazil. Treatments consisted of five soil management systems, with five replications (native forest [control], slash-and-burn agriculture, pasture, no-tillage, and conventional tillage). Data analysis was performed using a completely randomized experimental design. All systems were analyzed for soil density, macroporosity, microporosity, total porosity, hydraulic conductivity, infiltration, water retention curve, penetration resistance, and soil quality index (S index). The systems had significant effects on soil structure, and the evaluated properties responded well to changes promoted by them. No-tillage implementation raised soil resistance in the area previously damaged by intensive farming. Moreover, soils under pasture and slash-and-burn systems presented higher water retention in field capacity and higher S indexes, thus having a better structural quality.

INTRODUCTION

To achieve food security and meet world demand for food and energy, Brazil has expanded its agricultural boundaries with intensive use of machinery, inputs, and improved crop varieties. However, soils in these areas, which until the 1970s were considered non-agricultural, mainly in the Cerrado biome, have low fertility and high acidity (Fischer et al., 2018).

In the Brazilian Cerrado, Oxisols have shown some problems related to improper management practices, as these soils are highly susceptible to compaction under natural conditions, mainly by machinery traffic during rainy season (Severiano et al., 2011). The effects of heavy traffic compaction may persist for more than a decade and are especially unfavorable in highly moist soils (Guaman et al., 2016, Holthusen et al., 2018).

Agricultural exploration with unsustainable soil management practices is common in many developing countries. In this sense, concerns have been raised about impacts on soil physical properties, resulting in soil compaction (Medina et al., 2017; Caviglione, 2018). Among the physical properties related to compaction, soil resistance to penetration stands out for its high relationship with crop yields. The compaction promotes a mechanical impediment to root growth, which can be simulated fast and economically, besides generating a number of observations that allow analyze resolution spatial structural of the soil (Parahyba et al., 2019).

Currently, few studies on soil management in the Brazilian Cerrado and other dry areas have investigated how to reduce soil mechanical resistance to improve water storage. Our hypothesis is that areas under intensive use of machinery tend to undergo changes in their soil structure, causing aggregation fragmentation and soil compaction, hence reducing soil quality. Therefore, our study aimed to evaluate the impacts of different management systems on the physical quality of a dystrophic Yellow Oxisol in the Brazilian Cerrado.

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MATERIAL AND METHODS

Field characteristics

This study was carried out in Chapadinha, Maranhão, Brazil (03° 44' 27" S, 43° 18' 44" W, 110-m altitude) from February to May 2015 (Figure 1). To add to our dataset, we also used the findings of Farias et al. (2017) on the soil physical properties on the same areas and under different management systems, from 2013 to 2014. Therefore, our findings add substantial new information and do not repeat the results already presented by this previous study.

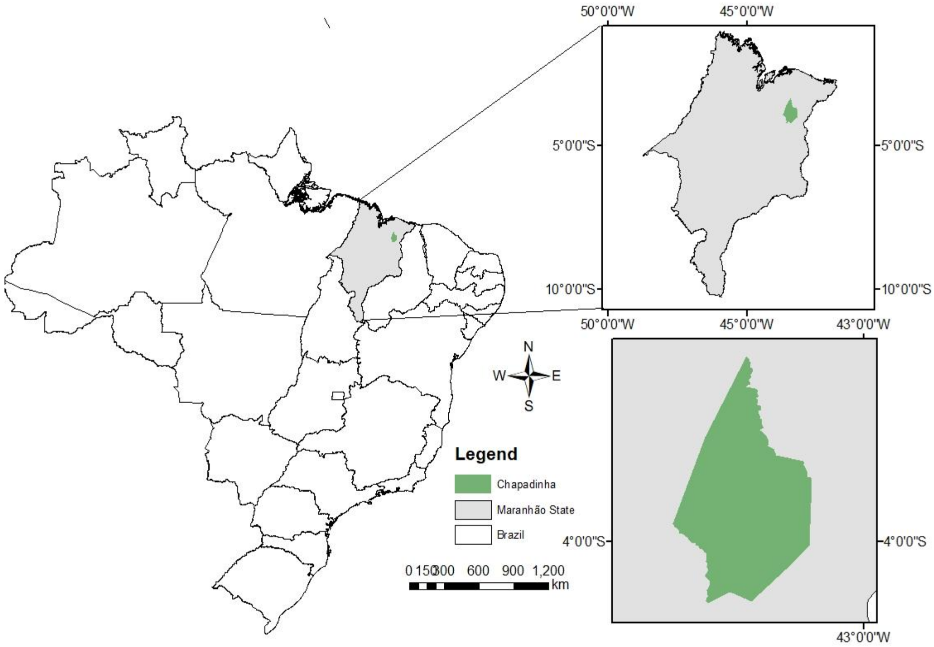

FIGURE 1. Study site location.

According to Thornthwaite & Mather (1957), the local climate is defined as sub-humid megathermic, with great water deficiency in summer (C2s2A 'a'). Average annual rainfall is 1613 mm, concentrated between January and May, with shortage from June to December. Average annual temperature is 28 °C (Passos et al., 2016). The local soils are classified as dystrophic Yellow Oxisols (Santos, 2013; IUSS Working Group WRB, 2015) and are predominantly covered by Cerrado vegetation, with diverse floristic composition (Bandeira, 2013). Table 1 shows the chemical and physical characteristics of the soils under study.

TABLE. 1. Chemical and physical properties of soil under different management systems at the depth range of 0.0 - 0.10 m.

Soil Management	pH	OM g dm^{-3}	Sand	Silt g kg $^{-1}$	Clay
Native forest	4.1	21	810	70	120
Conventional tillage	4.8	19	800	80	120
No-tillage	4.7	20	860	20	120
Slash-and-burn	4	25	610	210	280
Grassland	4	38	600	160	240

Legend: pH - hydrogenionic potential; OM - organic matter.

Physical and physical-hydric soil parameters

The experimental design was completely randomized, with five treatments and five replications. Each treatment consisted of a management system: conventional tillage (area grown with soybeans [*Glycine max*]), pasture (area under elephant grass pasture [*Pennisetum purpureum*]), slash-and-burn agriculture (area deforested and burned before planting, then grown with manioc [*Manihot esculenta*]), no-tillage (soybeans cultivation over millet straw [*Pennisetum glaucum*]), and native forest (Cerrado). The study was carried out *in situ* by estimating the following parameters: resistance to penetration, moisture, bulk density, infiltration, and hydraulic conductivity of soils.

Deformed soil samples were collected from the depth range of 0.0 - 0.10 m, using a probe-type auger. Retention curves were established by saturating the soil samples with water for 24 hours and determined using Richards chambers (Embrapa, 1997). Soil moistures were estimated at 6, 10, 30, 100, 300, 500, and 1500 kPa. The sampled points used for retention curve were fitted using the equation proposed by Van Genuchten (1980). Infiltration speed was determined based on basic infiltration rate, using samples collected *in situ* and a constant flow permeameter (Guelph Permeameter – model 2800). The infiltration rate is normally established as the volume of water passing the soil surface per unit of time (mm h^{-1}). The soil samples used for hydraulic conductivity were collected randomly from five 5-cm-diameter holes, opened at 15 cm depth. The sampling was performed as homogeneously as possible so that data were not altered. Then, hydraulic loads were calibrated using a beaker to confirm the fit of hydraulic load by the Guelph permeameter. Lastly, the hydraulic conductivity was measured using the method of Elrick et al. (1989).

Soil microporosity was determined by the method of Richards and Embrapa (1997), whereas macroporosity was obtained by the difference between total porosity and microporosity. Resistance to penetration was tested using a Stolf impact penetrometer. The tests were performed in the five management systems up to a maximum depth of 0.40 m, subdivided into three different layers (0.10, 0.20, and 0.40 m depths). To be used as soil resistance to penetration data, the number of impacts required to trespass the layers (0.00 - 0.10, 0.10 -0.20, and 0.20 - 0.40 m) were converted to mPa, as described by Stolf (1991). During penetration resistance tests, soil samples were taken from the depth ranges of 0.0-10 m and 0.10-0.20 m. The samples were placed in closed capsules, conditioned in a thermal box, and taken to the laboratory for moisture content determination by the gravimetric method.

Statistical analyses

Means of each soil depth were compared by the Tukey's test (p<0.05). Statistical analyses were carried out through Info Stat software (Di Rienzo et al. 2011). A multivariate hierarchical clustering was used to gather treatments into groups by Ward's method, comparing their similarities by Euclidean distance (Sneath & Sokal, 1973). A first-order linear principal component analysis (PCA), using an orthogonal linear transformation, was performed to separate the correlated and uncorrelated variables, using a vector matrix to reduce dimensionality (Cruz et al., 2011) and facilitate dataset interpretation (Bořůvka et al. 2005). The PCA is a type of indirect gradient analysis that evaluates data total variability (Ter Braak & Smilauer, 2002). The biplot rule was used for the vector analysis (Kroonenberg, 1995).

RESULTS AND DISCUSSION

Soil resistance to penetration, retention curve, physical and physical-hydric parameters

Although grain size was predominantly sandy, penetration resistance values were above 2 mPa in all tested soils and depths. Under pasture and native forest, resistance to penetration was relatively lower (Figure 2). This suggests that organic matter increases from vegetation and animal presences and plant density reduction from grass planting decrease soil resistance to penetration, corroborating the findings of Cherubin et al. (2016).

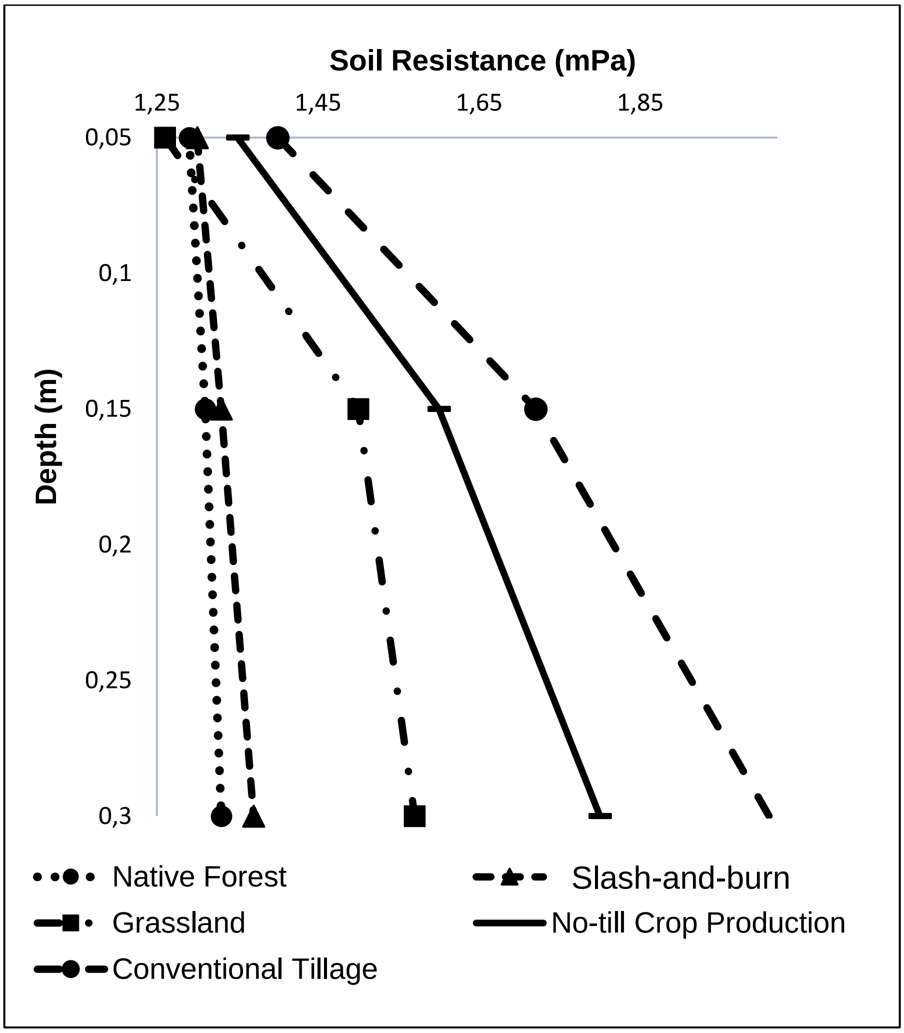

FIGURE 2. Soil resistance to penetration at three soil depths five management systems.

Ordóñez et al. (2018) concluded that planting of grasses is the factor that most reduced soil compaction and maintained its physical quality. In our study, the soil under slash-and-burn agriculture showed the highest resistance to penetration. This is because the use of fire to clean fields reduces soil humidity and increases its cohesion, hence increasing resistance to penetration. Under low humidity, soil resistance to penetration varies widely and can lead to soil-metal friction by soil cohesion and adhesion increases after moisture loss (Silva et al., 2016). Conventional and no-tillage areas showed penetration resistance increases at all depths and humidity reductions compared to the others. This might have been caused by intense machinery traffic. These findings corroborate those of Farias et al. (2017), who verified resistance to penetration increases due to changes in soil structure at surface and subterranean layers. In other words, this can be related to aggregation changes in the soil, which is mechanically fragmented by its excessive use, thus resulting in soil densification and compaction.

The slash-and-burn area had lower apparent soil density, whereas conventional tillage showed the highest value. It may have been due to a porous space reduction by management system, with consequences on the other parameters (Table 2). When compared to the conventional system, no-till had soil densities relatively lower. This difference can be attributed to the OM accumulation in no-till areas, resulting in longer reductions in soil compaction and increases in soil aggregation (Guaman et al., 2016).

TABLE 2. Averages of soil bulk density (Ds, in kg dm^{-3}), infiltration rate (IR, in cm min^{-1}), hydraulic conductivity (K, cm h^{-1}), total porosity (%), macroporosity (%), and microporosity (%) of soils under different management systems, Chapadinha, Maranhão state, Brazil, 2015.

Management System	Ds	IR	K	Macroporosity	Microporosity	Total Porosity
	(g cm^{-3})	(cm min^{-1})	(cm h^{-1})	------------------------ (%) ---------------------		
Native Forest	1.27 c	0.29 bc	0.00633 a	42;5 bc	5.5 a	52 a
Conventional no-tillage	1.53 bc	0.04 a	0.002039 a	35 c	7.3 a	42.0 ab
No-tillage	1.39 b	0.10 ab	0.002682 a	42;7 ab	4.8 a	47.5 a
Slash-and-burn	1.13 a	0.15 abc	0.006974 a	48 a	8.6 a	49.8 a
Grassland	1.17 bc	0.31 c	0.005901 a	49.2 a	6.6 a	55.8 a
CV (%)	10.5	70.19	19	12.81	14.80	12.34

Means followed by the same letter in the treatment and between them do not differ statistically from each other by the Tukey's test at 5% probability ($p<0.05$).

The highest infiltration speed was observed in soil under pasture followed by native forest and slash-and-burn areas. These areas, in turn, were significantly different from conventional and no-tillage systems. Therefore, OM input and vegetation root system improve aggregate stability and aeration in soils (macroporosity), increasing water infiltration and hydraulic conductivity. Zhipeng et al. (2018) obtained similar results and concluded that higher OM and moisture levels enhance soil infiltration and hydraulic conductivity, thus allowing water storage and a more effective infiltration.

It is worth noting that when intensive agricultural practices are conducted in an Oxisol, macropores are severely affected by the first passages of agricultural machinery. This occurs because Oxisols are highly susceptible to compaction (Carducci et al., 2011), and thus have their infiltration and hydraulic conductivity reduced. Nevertheless, installation of a no-till system increases soil resilience against anthropogenic effects.

Each management system provided unique differences in soil water retention curves (Figure 3). Therefore, soil properties were affected and water contents in samples of the different applied potentials reduced. By contrast, Farias et al. (2017) found that soil horizons with the same textural class do not always present similar curves. Thus, soil textural class influence should also be considered. Moreover, other factors such as rainfall, soil sampling techniques, wildlife, and machinery traffic can affect the shapes of the water retention curves.

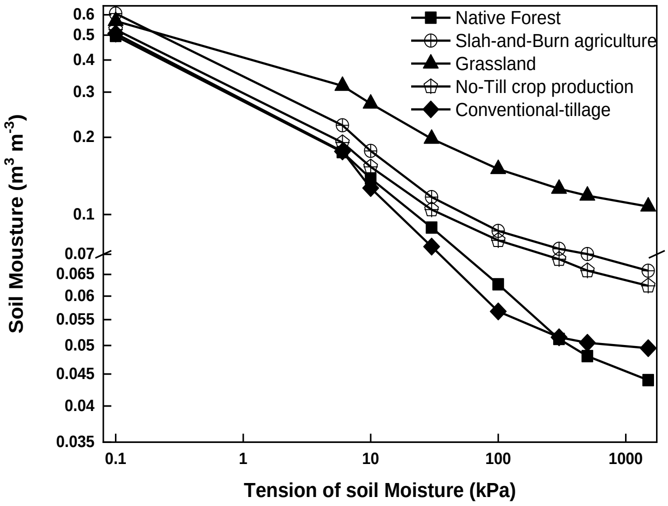

FIGURE 3. Water retention curves for different soil management systems.

At saturation point, the soil under slash-and-burn system reached the highest moisture level, followed by pasture, other management systems, and finally native forest area. Regarding the water retention curve performance of the other applied potentials, we observed that soil under pasture maintained a higher water content than the other systems. What can be associated with a greater number of micropores, whose size and shape help retain water by capillarity. Microporosity is mainly related to the clay content in a given textural class, which, due to the colloidal sizes, predispose formation of such micropores (Silva et al., 2018).

The soil under no-tillage system showed greater water retention. This may be due to its higher OM contents at surface layers, what is typical of such management, allowing greater soil aggregation and hence resistance (Rezanezhad et al., 2016). The conventional tillage area tended to have low water retention along points, which remained until the so-called permanent wilting point. This may be derived from soil structure destruction by intensive use of agricultural machinery.

Second Carducci et al., (2011), macropores are affected by intense machine traffic and soil disturbance increasing susceptibility soil to compaction (Carducci et al., 2011). Especially Amazon soils undergo changes in their physical and structural quality and become automatically susceptible to degradation when submitted to agricultural machinery management and trafficability of tractors and implements. Soil compaction in conventional tillage increased soil matrix influence on water movement, that is, soil matrix potential increased due to transformation of macropores into micropores and, thus, increasing water retention (Gomes et al., 2019).

S index and multivariate analysis

The values of S indexes obtained in the soil management systems (Table 3) are clearly related to soil porosity and bulk densities (Caviglione, 2018).

TABLE 3. Averages of S index for each soil management systems.

System	Textural Class	S Index
Native forest	Loamy sand	-0.11
Conventional Tillage	Loamy sand	-0.08
No-tillage	Loamy sand	-0.10
Pasture	Clay loam	-0.15
Slash-and-burn	Clay loam	-0.14

The highest S index was obtained in pasture followed by slash-and-burn, native forest, no-till, and conventional tillage. In this sense, the introduction of fire was very recent. Providing to a lesser extent, degradation soil physical properties, still preserving its structure. Xu et al. (2017) observed a close relationship between S index and soil organic matter, therefore, such factor is fundamental for preservation, remediation, and formation of aggregates, and hence improvements in soil physical properties that directly influence S index values.

Both conventional and no-tillage areas had lower S indexes compared to the others. We noted that these areas also showed higher soil densities and reductions in macroporosity and total porosity. This can be seen by a steepest slope in the soil water retention curve, resulting in a quality index reduction. It occurs because of frequent changes in soil structure, that is, improper use of soil favoring degradation of its structural quality (Valipour, 2014; Naderi-Boldaji & Keller, 2016).

Despite the intensive management, the studied areas showed good physical conditions for plant growth, given their S indexes above 0.056. These S indexes presented in porous systems are within the limits for arable soils, indicating soils with preserved structure, even that under conventional tillage (Farias et al., 2017).

Figure 4 shows the hierarchical cluster analysis dendrogram for the soil managements. Conventional and no-tillage systems were grouped in the same cluster since they had the smallest Euclidean distances, thus similar in terms of soil properties. This occurred because the no-tillage system has been just recently implemented in the area. Conversely, the soil properties of this cluster were quite different from those of the native forest area. The second cluster comprised the native forest, slash-and-burn, and pasture areas, which had the largest Euclidean distances compared to those of the first group, i.e., they had similar soil properties.

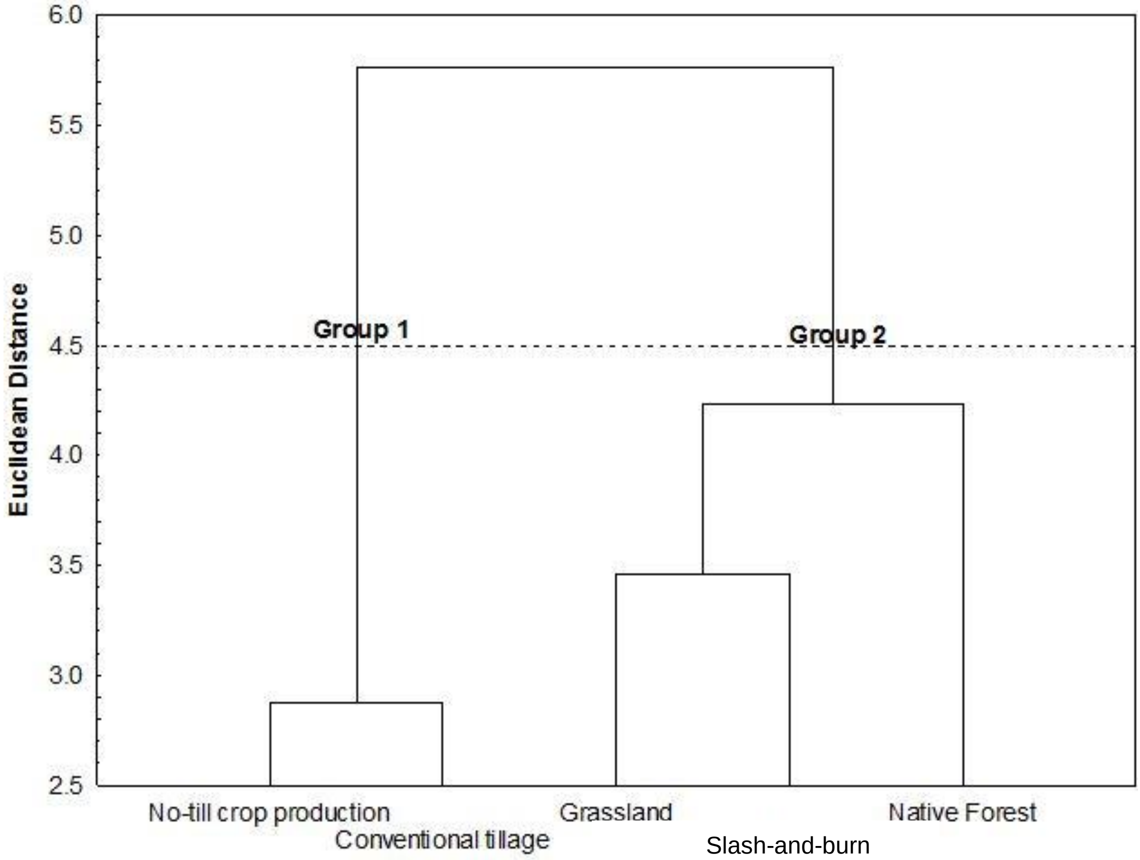

FIGURE 4. Dendrogram showing the hierarchy of clusters for soil management systems as a function of soil physical properties.

The management systems explained 84.61% of the variability in soil physical properties, as already reported in the literature (Ji et al., 2013). In the principal component 1 (CP1), the management systems remained explaining the largest part of the variation in soil physical properties (Figure 5).

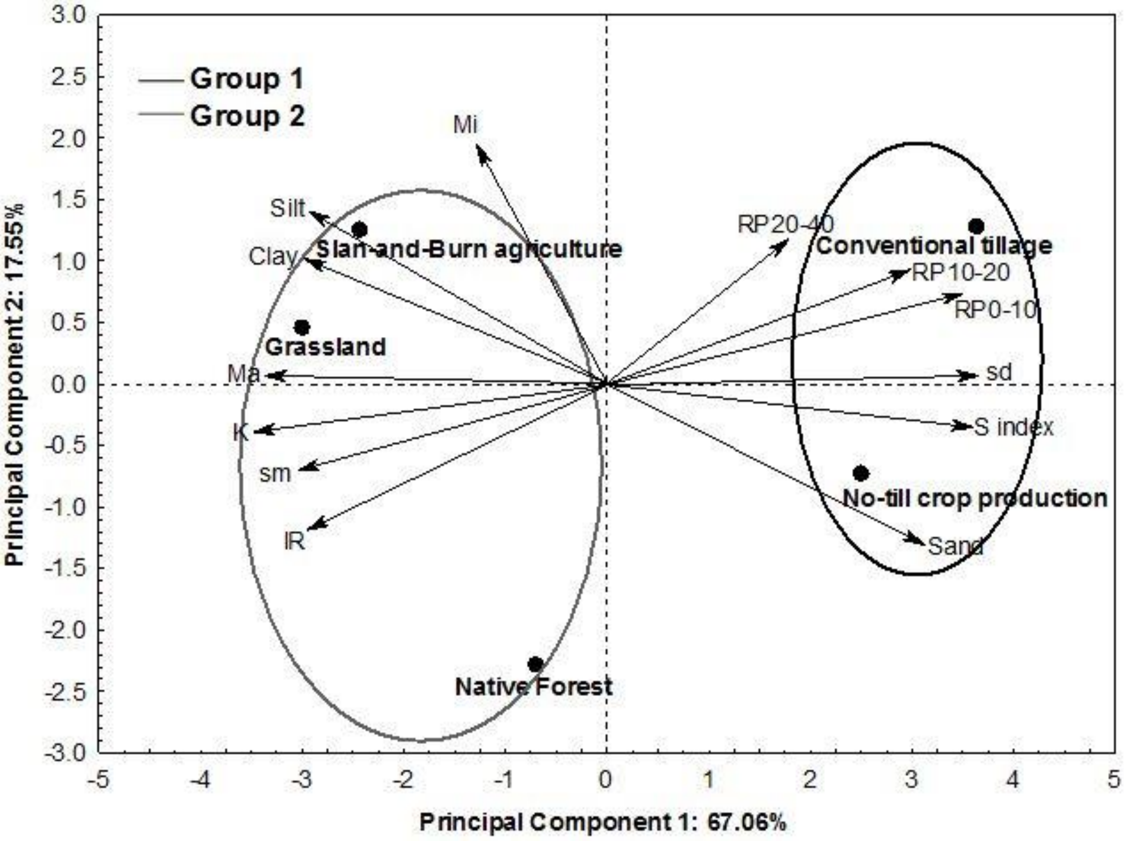

FIGURE 5. Biplot of the principal component analysis for soil properties and management systems.

A relationship of direct dependence was observed among the following physical properties: resistance to penetration (RP) 20-40, RP 10-20, RP 0-10, soil bulk density, S-index, and sand. All of them were designed in the same direction of the conventional and no-tillage systems. On the other hand, a relationship of indirect dependence was registered between the same properties with microporosity, silt, clay, macroporosity, K, US, and VI, but now in the opposite direction, and on the side of the slash-and-burn, pasture, and native forest systems.

The above-mentioned relationships indicate that conventional tillage areas had greater resistance to penetration. This is because these areas are mostly compacted by machinery traffic, compressing soil air by fragmentation of aggregates, thus reducing soil quality. Conventional tillage was also greatly influenced by the properties S index and sand content. Such finding proves that a proper soil management can improve soil quality, especially for sandy soils. The pasture and slash-and-burn systems had a relationship with microporosity, clay, and silt, once clayey soils have smaller amounts of macropores and larger amounts of micropores, which makes infiltration slower than in sandy soils that have larger pores (Parahyba et al., 2019). The native forest area was mostly influenced by hydraulic conductivity, soil moisture, and infiltration speed, which might have been due to accumulation of organic materials on the soil, thus increasing infiltration.

Regarding the complexity of soil variables, multivariate analysis proved to be suitable for understanding the system structure jointly, identifying variables that most contribute to changes in soil physical properties. As discriminative as univariate analysis procedures are, it was clear that they were unable to establish relationships between the studied variables.

CONCLUSIONS

Soil management systems have significant effects on the structure of Oxisol, and the studied properties responded well to changes promoted by them. A no-tillage system improves parameters that increase soil resistance, after damaged by previous intensive agriculture use. The soils under pasture and slash-and-burn systems showed higher water retention in field capacity and high S indexes, indicating these soils have a better structural quality.

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