Revista Brasileira de Ciência do Solo

Division - Soil Use and Management | Commission - Soil and Water Management and Conservation

Physical Properties of Soil Structures Identified by the *Profil Cultural* under Two Soil Management Systems

Sônia de Fátima Schilickmann Macedo[(1)], Michel Grimaldi[(2)], Cristiane Conti Medina[(3)], José Edézio da Cunha[(4)], Maria de Fátima Guimarães[(3)] and João Tavares Filho[(3)*]

[(1)] Universidade Estadual de Londrina, Centro de Ciências Agrárias, Departamento de Agronomia, Programa de Pós-graduação em Agronomia, Londrina, Paraná, Brasil.
[(2)] Institut de Recherche pour le Développement, Bondy Cedex, Paris, France.
[(3)] Universidade Estadual de Londrina, Centro de Ciências Agrárias, Departamento de Agronomia, Londrina, Paraná, Brasil.
[(4)] Universidade Estadual do Oeste do Paraná, Centro de Ciências Humanas Educação e Letras - Geografia, Marechal Candido Rondon, Paraná, Brasil.

***Corresponding author:**
E-mail: tavares@uel.br

Received: November 8, 2016
Approved: April 3, 2017

How to cite: Macedo SFS, Grimaldi M, Medina CC, Cunha JE, Guimarães MF, Tavares Filho J. Physical properties of soil structures identified by the *profil cultural* under two soil management systems. Rev Bras Cienc Solo. 2017;41:e0160503.
https://doi.org/10.1590/18069657rbcs20160503

ABSTRACT: Soil structure plays an important role in water retention, infiltration capacity, porosity, and penetration resistance. The aim of this study was to evaluate the unsaturated hydraulic conductivity and physical properties of Oxisol soils (bulk density and macro-, micro-, and total porosity) in the structures identified using the *profil cultural* method in areas under two different management practices (perennial pasture and sugarcane). Three pits were dug in each plot to find out how homogeneous morphological structural units (HMSU) were organized in the soil. Next, unsaturated hydraulic conductivity (Ki) was measured *in situ* inside each HMSU using a triple-ring infiltrometer at multiple suction. Six samples were collected (two samples for each kind of structural organization in each pit) to determine soil bulk density, total porosity, and macro- and microporosity. Each management practice resulted in a distribution of structures in the soil profile. The behavior of morphologically similar clods was the same, regardless of the physical manipulation of the soil. The distribution of structures based on the management practice determines specific hydraulic conductivities in the soil profile.

Keywords: soil use, compaction, soil bulk density, soil porosity.

INTRODUCTION

It is known that soil structure plays an important role in water retention, infiltration capacity, soil porosity and resistance to penetration, gas exchange, nutrient uptake, and crop yields (Bingham et al., 2010; Munkholm et al., 2013; Mentges et al., 2016; Reichert et al., 2016). It is important, therefore, to consider that this role of structure becomes increasingly important when there is fair balance between the processes of order and dissipation. This balance is fundamental to the sustainability of agricultural systems, which, according to Addiscott (1995), are thermodynamically open and tend towards equilibrium and are characterized by minimal entropy production.

In agricultural systems, the structural modification of the soil induced by mechanized agriculture or grazing does not generally affect the volume of the Ap horizon in a homogeneous manner. The cultivated layer is subject to considerable spatial variability, unlike horizons that are not usually affected by tillage (Neves et al., 2003; Fuentes-Llanillo, 2013; Gonçalves et al., 2013; Tavares Filho et al., 2014; Boizard et al., 2016). This variability often allows plants to grow in compacted soils, taking advantage of the flow of water and gas through structural discontinuities (cracks) that also allow root growth (Neves et al., 2003; Reichert et al., 2016). Thus, understanding the dynamics of soil physical properties is improved by using soil properties (such as soil bulk density and porosity) as proposed by Horn and Kutilek (2009). Although the effects of structural changes of the soil on crop yield can be observed, this is not an easy task since the physical properties of the soil change over time and depend on their position in the soil profile (Mueller et al., 2009; Gonçalves et al., 2013; Guimarães et al., 2013; Munkholm et al., 2013).

Soil management changes over time and from one region to another. It is therefore a complex task to evaluate different management systems. This complexity has led to the use of a wide range of quantitative methods of analysis. Furthermore, the spatial variability of physical soil properties makes it difficult to represent the real situation (Tavares Filho et al., 1999; Neves et al., 2003; Llanillo et al., 2006; Fuentes-Llanillo et al., 2013; Silva et al., 2014; Tavares Filho et al., 2014). These difficulties arise because most results are obtained from laboratory evaluations of random samples taken at specific depths, without taking the heterogeneous nature of the soil structure into account.

A method to evaluate and characterize the structural diversity of soils in temperate regions was developed by Gautronneau and Manichon (1987). This method was later adapted for tropical soils by Tavares Filho et al. (1999). It is based on visual examination of alterations in soil structure (degree of compaction, form and size of aggregates, and the presence of cracks within the structural units) brought about by agricultural use.

Studies have shown that this method of soil profile analysis can be helpful in qualitative evaluation of soil management (Coulomb et al., 1993; Roger-Estrade et al., 2000b; Mueller et al., 2009; Mueller et al., 2013; Munkholm et al., 2013; Guimarães et al., 2013; Tavares Filho et al., 2014; Boizard et al., 2016). It enables researchers to establish links between soil structure and other factors, such as root development (Roger-Estrade et al., 2000a; Mentges et al., 2016), the availability and distribution of minerals (Vizier et al., 1995), and hydrodynamic characteristics (Mentges et al., 2016).

Soil profile analysis also allows visualization of soil compaction and can help in collection of samples for laboratory analysis (Neves et al., 2003; Portella et al., 2012; Guimarães et al., 2013; Silva et al., 2014; Tavares Filho et al., 2014; Boizard et al., 2016). This method is an important diagnostic tool for field use, especially when studying soil compaction problems (Neves et al., 2003). However, because this method is primarily qualitative, it can be difficult to analyze and compare the results obtained in different experiments (Tavares Filho et al., 1999). It is therefore necessary to consider the concept of soil intensity properties in which the properties and process of dynamics produce variations in time and space (Horn and Kutilek, 2009; Mentges et al., 2016; Reichert et al., 2016).

Hydraulic conductivity is a soil property that depends on other soil properties, such as pore size distribution, texture, drainable porosity, and soil bulk density. Therefore, it can be used to identify structural differences between the soil layers and diagnose and quantify the changes imposed by environmental and anthropogenic factors on the internal structure of the soil and its functional properties or processes (Reichert et al., 2016).

Our hypothesis is that a profile with a given sequence of structures under a given management system, classified by the *profil cultural* method (Tavares Filho et al., 1999; Boizard et al., 2016), may have different physical hydraulic behaviors. Thus, the aim of this study was to evaluate hydraulic conductivity and soil physical properties (soil bulk density, and macro-, micro- and total porosity) in the structures identified by the profil cultural method in Oxisol soils under two contrasting management systems (perennial pasture and sugarcane).

MATERIALS AND METHODS

Characteristics of the soil and study area

The two land management systems studied (perennial pasture and sugarcane) were located in the northwest of the Brazilian state of Parana (23° 06′ 46″ S, 51° 31′ 55″ W, elevation 370 m). The climate in this region is predominantly subtropical, with warm summers (Köppen classification system - Cfa) and mean temperatures below 18 °C (mesothermal) during the coldest month and above 22 °C during the warmest month. Parana is also subject to warm summers and infrequent frosts. Rainfall tends to be a summer phenomenon, and there is no clearly defined dry season (Caviglione et al., 2000).

The soil in the areas studied was classified as an Oxisol (Brazilian classification: *Latossolo Vermelho-Amarelo distrófico típico*); particle size analysis is shown in table 1. The material of origin consisted of weathered residues from the Caiuá Sandstone Formation within the São Bento Group from the Cretaceous period (Viana et al., 2011). The slope was approximately 4 %. Both areas (perennial pasture and sugarcane) were located in the upper third of the slope and were separated by a road (width of 0.20-0.25 m).

Plot characteristics

Two adjacent 20 ha plots were selected based on how well they represented the region under study, their proximity within the same micro-watershed, and their common soil classification. The first plot had been under pasture (*Brachiaria brizantha* Hochst Stapf) for 30 years, with a stocking rate of 1.4 head of cattle per hectare under continuous grazing and annual burning of plant residue to stimulate pasture regrowth. The second plot had been under sugarcane for 10 years, preceded by 20 years under pasture (*Brachiaria brizantha* Hochst Stapf), with a stocking rate of 1.2 head of cattle per hectare under continuous grazing and annual burning of plant residue to stimulate pasture regrowth. The conventional method of plowing and disking was used to prepare the soil for planting sugarcane. Vinasse was applied annually in the planting furrow (120 m^3 ha^{-1}) in November. The sugarcane was manually harvested after burning plant residues.

Table 1. Particle size analysis, particle density (PD), and organic matter (OM) in four layers of an Oxisol under two systems of soil use

Depth	Perennial pasture					Sugarcane				
	Clay	Sand	Silt	PD	OM	Clay	Sand	Silt	PD	OM
m		g kg^{-1}		Mg m^{-3}	g kg^{-1}		g kg^{-1}		Mg m^{-3}	g kg^{-1}
0.0-0.2	120	842	38	2.66	9.98	128	839	33	2.65	11.05
0.2-0.4	120	845	35	2.65	10.02	131	839	30	2.65	12.02
0.4-0.6	131	842	27	2.66	11.21	148	839	13	2.63	13.89
0.6-0.8	130	850	20	2.64	12.97	148	838	14	2.63	15.75

Clay, sand, silt: pipette method (Claessen, 1997), PD: ethyl alcohol method (Claessen, 1997), OM: Walkley-Black method.

Soil profile analysis

Three pits (1.00 m deep, 0.80 m wide, and 1.20 m long) were dug in each plot. In each pit, the structures resulting from management were determined using the profil cultural method (Gautronneau and Manichon, 1987) adapted by Tavares Filho et al. (1999) (Figure 1).

Soil physical analysis

The profil cultural was studied to discover the organization of the homogeneous morphological structural units (Figure 1), and then unsaturated hydraulic conductivity (Ki) was measured *in situ* using a triple-ring infiltrometer at multiple suctions (Ankeny et al., 1991; Mathieu and Pieltain, 1998). Three soil water potentials were applied (0.03, 0.6, and 1.0 kPa) to each structural volume of soil described (Figure 1a) by the profil cultural method to check whether there were differences in infiltration and which pore classes were affected by the management system (Mathieu and Pieltain, 1998).

Unsaturated hydraulic conductivity (Ki) was calculated using Wooding's equation (1968):

$$q_0 = k + \frac{4Ø_o}{\pi r} \qquad \text{Eq. 1}$$

where: q_0 is the steady state flow based on the trace as a function of the cumulative infiltration flow time; $Ø_0$ is the potential matrix flow (mm); k (mm s^{-1}) is the hydraulic conductivity at a pressure of h_0 (mm); and r (mm) is the radius of the disk used.

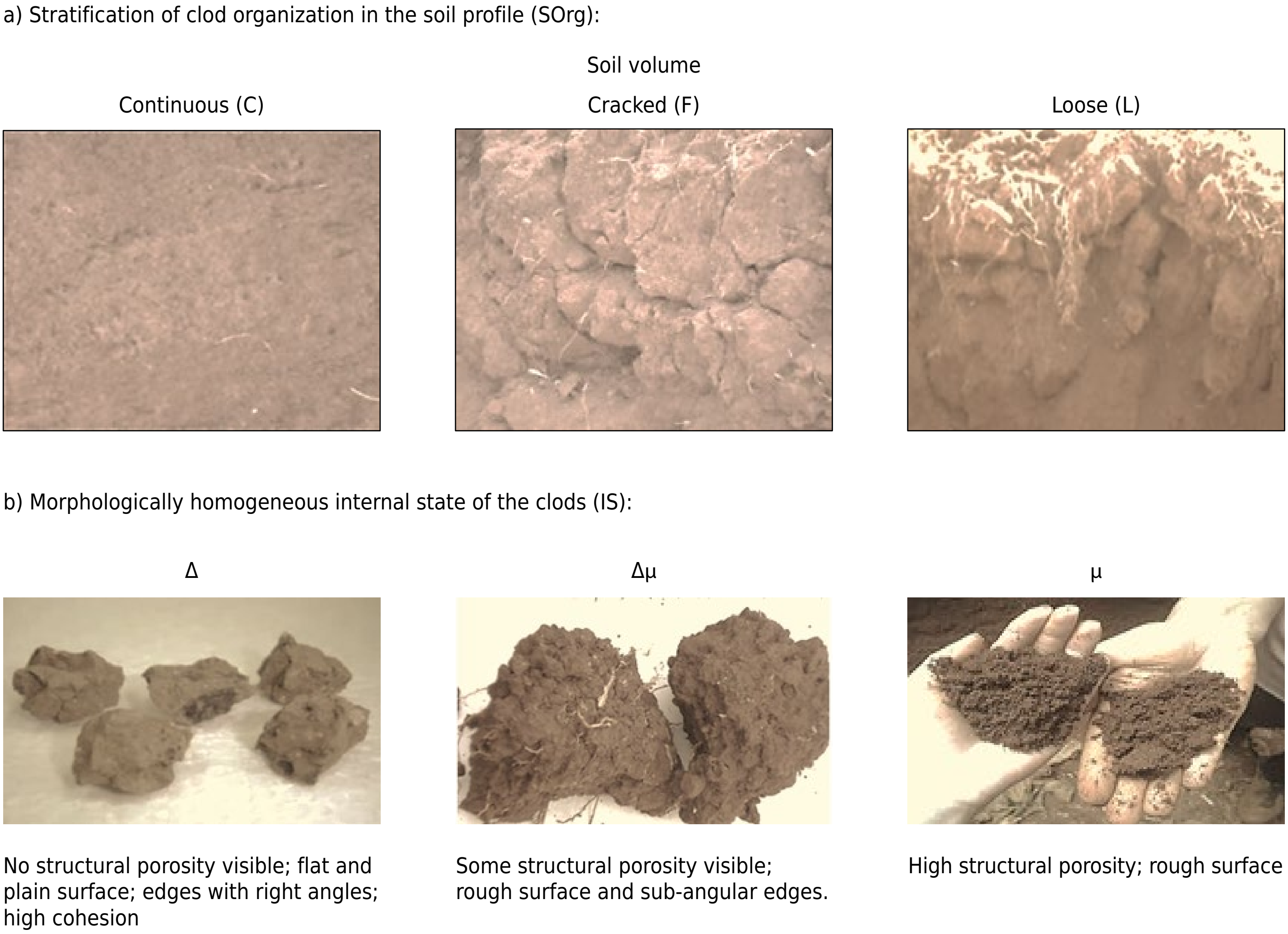

Figure 1. Soil profile methodology used for study of the structural evolution of soils in the different management systems. Adapted from Gautronneau and Manichon (1987) by Tavares Filho et al. (1999).

Using two disks of different radii (r_1 and r_2) (Mathieu and Pieltain, 1998), we can determine the values of the steady state flows q_{01} and q_{02} under the same initial hydraulic conditions (Θ_n) and at the same pressures (h_0) applied to the surface, giving:

$$k = \frac{q_{01} \cdot r_1 - q_{02} \cdot r_2}{r_1 - r_2} \quad \text{Eq. 2}$$

Six samples were collected (two samples for each structural volume of soil described [Figure 1a] in each pit) with an internal volume of 98.17 cm^3 (0.05 m diameter × 0.05 m height) to determine soil bulk density (BD), total porosity, microporosity (pores 0.05 mm or less in diameter [Richards, 1965]) according to the tension table method (Claessen, 1997), and macroporosity (pores 0.05 mm or more in diameter [Richards, 1965]) according to the difference between total porosity and microporosity.

Data analysis

Data analysis was conducted for each plot (perennial pasture and sugarcane). Data were grouped for each volume of soil described (Figure 1a), the standard error was calculated, and after verifying data normality, the F-test (analysis of variance) and the Tukey test (comparison of means) were run at 5 % probability on the results for unsaturated hydraulic conductivity, soil bulk density, and porosity of the structures identified by the profil cultural method.

RESULTS

Soil profile

Figure 2a (continuous grazing for 30 years) shows three stratifications described in terms of how the clods are organized. There were two volumes of soil affected by human activity: one denoted CΔ — a continuous volume (C) from 0.00 to 0.15 m deep, with internal state (Δ), with no visible structural porosity, and with flat, regular surfaces and high cohesion, and one denoted Fma/gtΔμ — a cracked soil volume (F) from 0.15 to 0.30 m deep, with clods (Δμ) of different sizes (ma: medium-sized [0.06-0.10 m in diameter] and gt: large clods [>0.10 m]), and with some visible structural porosity, rough surfaces, and sub-angular edges separated by cracks. In addition, there was a volume of soil unaffected by human activity denoted Cμ — a continuous volume (C) over 0.30 m deep, with internal state (μ), lack of compaction, high structural porosity, and rough surfaces, corresponding to the Bw horizon of the Oxisol.

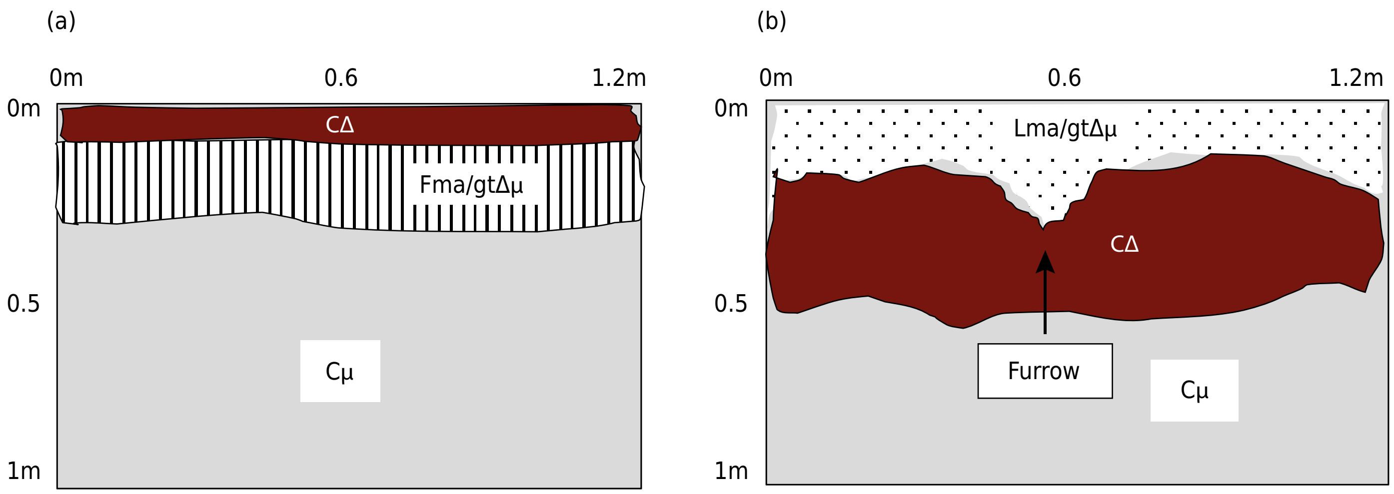

Figure 2. Design, means of three pits for each management practice (a) - perennial pasture and (b) - sugarcane of the stratification of clod organization in the soil profile. Stratification of clod organization: C (Continuous), F (Cracked), and L (Loose), and morphologically homogeneous internal state of the clods: Δ (No structural porosity visible), Δμ (Some structural porosity visible), and μ (High structural porosity). ma and gt: means medium (0.06-0.10 m) and large (>0.10 m) diameter size of clods, respectively.

Figure 2b (soil profile during the 10 years of sugarcane cultivation) shows three different stratifications in clod organization. There were two volumes of soil affected by human activity: one denoted Lma/gtΔμ —a loose volume (L) from 0.00 to 0.22 m deep, with non-adhering clods (Δμ) of different diameters (ma, medium-sized [0.06-0.10 m in diameter] and gt, large clods [>0.10 m in diameter]), some visible structural porosity, rough surfaces, and sub-angular edges; and the other denoted CΔ— a continuous volume (C) from 0.22 to 0.55 m deep, with internal state (Δ), no visible structural porosity, flat, regular surfaces, and high cohesion. One volume was unaffected by human activity, denoted Cμ — a continuous volume (C) at a depth of over 0.55 m, with internal state (μ), lack of compaction, high structural porosity, and rough surfaces (same as the previous).

Soil bulk density (BD), porosity (TP, Ma, and Mi), and unsaturated hydraulic conductivity (Ki) of the structures identified in the soil profile.

The BD and porosity (TP, Ma, and Mi) of each structure described in the soil profiles of the two management systems examined are shown in table 2. Examining each structure separately (CΔ, Fma/gtΔμ, and Cμ in the pasture profile and Lma/gtΔμ, CΔ, and Cμ for the soil profiles under sugarcane), differences in BD and porosity (TP, Ma, and Mi) values were observed at 5 % probability in two profiles. The general trend in BD for the structures under perennial pasture and sugarcane was CΔ>F and Lma/gtΔμ>Cμ; the trend for porosity (TP and Ma) was Cμ>F and Lma/gtΔμ>CΔ, and the trend for Mi was CΔ>F and Lma/gtΔμ>Cμ. The average Bd, TP, Ma, and Mi for both profiles studied (Table 2) were the same at 5 % probability.

Examining each structure separately (CΔ, Fma/gtΔμ, and Cμ in the pasture profile and Lma/gtΔμ, CΔ, and Cμ for the soil profiles under sugarcane) (Table 3), Ki results were

Table 2. Bulk density (BD), total porosity (TP), macro (Ma), and microporosity (Mi) of the structures described in the three soil profiles under perennial pasture and sugarcane in an Oxisol

Soil use	Structure	BD	TP	Ma	Mi
		$Mg\ m^{-3}$		$m^3\ m^{-3}$	
Perennial pasture	CΔ(1)	1.66±0.01 a[**]	0.38±0.01 c	0.12±0.01 c	0.26±0.00 a
	Fma/gtΔμ	1.55±0.03 b	0.42±0.03 b	0.19±0.03 b	0.23±0.01 b
	Cμ	1.37±0.01 c	0.48±0.02 a	0.32±0.01 a	0.16±0.00 c
	Mean	1.53 A	0.41 A	0.21 A	0.22 A
Sugarcane	Lma/gtΔμ	1.51±0.04 b	0.43±0.03 b	0.21±0.03 b	0.22±0.01 a
	CΔ	1.63±0.01 a	0.38±0.01 c	0.15±0.01 c	0.23±0.00 a
	Cμ	1.39±0.01 c	0.47±0.02 a	0.33±0.01 a	0.14±0.00 b
	Mean	1.51 A	0.43 A	0.23 A	0.20 A

(1) Stratification of clods in the soil profile: C (Continuous), F (Cracked), and L (Loose), and Homogeneous morphological internal state of the clods: Δ (No structural porosity visible), Δμ (Some structural porosity visible), and μ (High structural porosity). ma and gt: means for medium (0.06-0.10 m diameter) and large (>0.10 m diameter) clods. [**] Uppercase letters differentiate structure for soil use and the general mean for soil uses; lowercase letters differentiate the soil water potential within each structure for each soil use (Tukey, $p<0.05$).

Table 3. Average hydraulic conductivity (Ki) in three Oxisol soil profiles under perennial pasture and sugarcane (± standard error)

Soil use	Structure	Ki			Mean
		0.03 kPa	0.3 kPa	1.0 kPa	
					$mm\ h^{-1}$
Perennial pasture	CΔ(1)	20±8 Ca[**]	30±5 Ca	30±5 Ca	
	Fma/gtΔμ	250±28 Ba	230±21 Ba	220±30 Ba	256 A
	Cμ	510±16 Aa	520±24 Aa	490±20 Aa	
Sugarcane	Lma/gtΔμ	470±28 Ba	470±61 Ba	430±60 Ba	
	CΔ	30±8 Ca	40±5 Ca	30±7 Ca	344 A
	Cμ	560±33 Aa	550±16 Aa	520±12 Aa	

(1) Stratification of clods in the soil profile: C (Continuous), F (Cracked), and L (Loose), and Homogeneous morphological internal state of the clods: Δ (No structural porosity visible), Δμ (Some structural porosity visible), and μ (High structural porosity). ma and gt: means for medium (0.06-0.10 m diameter) and large (>0.10 m diameter) clods. [**] Uppercase letters differentiate structure for soil use and the general mean for soil uses; lowercase letters differentiate the soil water potential within each structure for each soil use (Tukey, $p<0.05$).

the same at 5 % probability for the three soil water potentials studied. However, upon comparing the structures at each soil water potential individually (0.03, 0.3, and 1.0 kPa), differences in Ki values were observed. The CΔ structure exhibited the lowest Ki and the Cμ structure the highest Ki in two profiles (pasture and sugarcane), and the trend for Ki was Cμ>F and L ma/gtΔμ>CΔ. The average Ki for both profiles studied (Table 3) were the same at 5 % probability.

DISCUSSION

Soil profile

We know that in agricultural systems, structural changes in soil induced by mechanized farming or grazing generally do not affect the volume of the Ap horizon homogeneously. However, using the profil cultural method, we were able to evaluate the soil profile of the surface up to a 1.00 m depth and determine the structures under tillage (sugarcane) and grazing (Figure 2). The results show that different management systems in Oxisols have resulted in a specific distribution of structures, with different structural characteristics in the soil profile, as has also been shown by Giarola et al. (2010) and Guimarães et al. (2013).

The structural trend in the area used for continuous grazing for 30 years (Figure 2a) was CΔ (0.00-0.15 m) → Fma/gtΔμ (0.15-0.30 m) → Cμ (>0.30 m). In our study, structural modification of the soil was not induced by mechanized agriculture but by grazing, and the occurrence of clods with a homogeneous morphological internal state Δ (more compact, with no structural porosity visible - see figure 1b) on the soil surface (maximum depth of 0.15 m) was most likely the result of animal trampling over the 30 years period. This result is consistent with the results of Cecagno et al. (2016), who have worked with integrated crop-livestock systems and have shown that intensive grazing results in compaction of the soil surface but not deeper layers.

After compaction, the occurrence of clods in state Dμ (in the process of compaction, with some structural porosity visible; see figure 1b) at depths from 0.15 to 0.30 m was most likely caused by the presence of grass roots (*Brachiaria decumbens* in this case) over the 30-years period. Correchel et al. (1999) found that the formation of a less compact structure occurred when the grass roots (*Brachiaria-decumbens*) occurred because there was a tendency for the aggregates to be less angular and rough. Grass root may increase the amount of soil organic matter and biological activity, and that may improve the quality of the soil structure (Horn and Peth, 2009; Mentges et al., 2016; Reichert et al., 2016). However, Tavares Filho et al. (1999), Portella et al. (2012), Fuentes-Llanillo et al. (2013), and Silva et al. (2014) reported that the presence of these Dμ internal states indicates a non-critical drop in macroporosity (caused by the onset of compaction). Furthermore, these authors state that the Dμ internal state would continue to evolve into D units if this kind of soil usage continued. However, our results show that this is probably not the case in our soils because 30 years of continuous use in the same way should create a fair balance among the processes that characterized minimal entropy production. Reichert et al. (2016), studying a no-till area, considered that the soil became “quasi-stable” after 14 years, which may indicate that the soil in our study is also in “a state of minimal entropy” (“a quasi-stable situation”).

In the sugarcane area, the structural changes in the soil in the 10 years of cultivation with plowing and disking, plant residue burning, and manual harvesting resulted in the following structures: Lma/gtΔμ (0.00-0.22 m) → CΔ (0.22-0.55 m) → Cμ (>0.55 m). These results are in line with those reported by Viana et al. (2011), working with an Oxisol (*Latossolo Vermelho*) under different management systems, and Baquero et al. (2012), working with an Oxisol under sugarcane. The occurrence of the LΔμ structure (loose and some structural porosity visible, see figure 1) at depths of 0.00-0.22 m and the CΔ structure (continuous and no structural porosity visible, see figure 1) at depths of 0.22-0.55 m was most likely due to the use of heavy machinery during cultivation (formation of the LΔµ structure) and harvest (transportation) (formation of the CΔ structure) over 10 years. Vehicles used to carry the harvest weigh from 12 to 14 metric tons when loaded (Viana et al., 2011), and heavy machinery is used intensively during the harvest season (Baquero et al., 2012).

Unlike soil management with grazing and also unlike the proposal of Reichert et al. (2016) that considered the soil "quasi stable" after 14 years, it can be considered that this soil with 10 years under sugarcane does not have the right balance between the processes that characterize a minimum production of entropy. However, the internal states of the clods (with decreased macroporosity, caused by compaction) may continue to evolve into "Δ" units if this type of land use continues, as indicated by Tavares Filho et al. (1999), Portella et al. (2012), Fuentes-Llanillo et al. (2013), and Silva et al. (2014).

Unsaturated hydraulic conductivity (Ki), soil bulk density (BD) and porosity (TP, Ma, and Mi) of the structures identified in the soil profile.

Hydraulic conductivity was used to characterize the structural differences between soil layers determined by the profil cultural and thus to diagnose and quantify the changes imposed by environmental and anthropogenic factors on the internal structure of the soil and its functional properties or processes (Reichert et al., 2016). As hydraulic conductivity (intensity property) is a property that depends on bulk density and soil porosity (capacity properties), these properties have been determined and have shown that the Fma/gtΔµ (perennial pasture) and Lma/gtΔµ (sugarcane) structures differ from the CΔ and Cµ structures, both for density and for porosity (TP, Ma, and Mi) under the two land uses, which is in agreement with Tavares Filho et al. (1999), Silva et al. (2000), Folegatti et al. (2001), Neves et al. (2003), Llanillo et al. (2006), Portella et al. (2012), and Fuentes-Llanillo et al. (2013). This indicates that field description prior to sampling to determine the capability properties (soil density and porosity) is very important for interpreting the data when we want to assess the physical state to diagnose and quantify the changes imposed by environmental and anthropogenic factors on the internal structure of the soil and on its functional properties or processes (Reichert et al., 2016) with respect to plant development (Fuentes-Llanillo et al., 2013).

The structures in Fma/gtΔµ (perennial pasture) and Lma/gtΔµ (sugarcane) exhibited BD values (which in turn affect soil porosity) of 1.55 (pasture) and 1.51 Mg m^{-3} (sugarcane), values higher than those of the Cµ soil (1.37 [perennial pasture] and 1.39 [sugarcane] Mg m^{-3}). This is reflected in the lower porosity of the Cµ soil, indicating that we determined values that correspond to the internal state of the Δµ clods (Figures 1 and 2). This was because the volume of the rings used to evaluate BD was 98.17 cm^3 and was therefore probably insufficient to encompass the volume of cracks which occurred in the organization of clods in soil profiles L and F (Figures 1 and 2) when the sample was taken for laboratory analysis.

The comparison between the averages of the BD, TP, Ma, and Mi for the two profiles studied (Table 2), without considering the structures, clearly showed that there were no differences between the data. However, it has already been said that the profile under 30 years of continuous pasture use is in a "state of minimal entropy" (Reichert et al., 2016). In contrast, it seems that this is not the case for the 10-years profile of sugarcane. Considering that this profile was used for grazing for 20 years before being used for sugarcane, considering that the rings used to evaluate BD had only 98.17 cm^3, and considering that the soil aggregates are the forming units (and thus reflect the behavior of the estructure), we are probably still determining the aggregate values that were formed under the 20 years of grazing and the 10 years of management with sugarcane were not sufficient to promote changes in the values of BD and porosity.

Perhaps the time of use of the soil with sugarcane after grazing, combined with temporal and spatial variability of the soil, was not sufficient to induce a change in the aggregates.

Thus, we can consider that there is some difficulty in considering soil density as an indicator of the physical quality of these soils under sugarcane (Tormena et al., 2007; Cecagno et al., 2016)

The results for the BD and porosity of the structures identified in the soil profile confirmed the Ki results (Table 3), but the Ki for the entire profile, whether under pasture (256 mm h^{-1}) or sugarcane (344 mm h^{-1}), is not significantly different at 5 % probability.

Under pasture, the Ki differed from the results obtained by Cardoso et al. (2011) (Ks = 194 mm h^{-1}) who worked with natural pastureland in the Brazilian state of Mato Grosso. However, considering the stratification in the organization of clods found in the soil profile (Figure 1a), the low infiltration may be due to surface runoff. Furthermore, evapotranspiration is more likely to occur because the way the clods are organized facilitates water loss on hot days, which means that plants will be affected by poor rainfall distribution. Under sugarcane, the Ki differed from the results reported by Lyra et al. (2003) (Ks ~207 mm h^{-1}), who studied a soil toposequence fertigated with vinasse in order to understand the contribution made by groundwater to water quality. If we consider the stratification of the clods found in the soil profile (Figure 1b), the surface profile under the sugarcane did not seem to be blocked, because there were larger discontinuity pores in volume L (Figure 1) so that water could seep in. However, it accumulated at this point, and there was practically no runoff. Furthermore, it did not boost evapotranspiration, because there was no pore continuity. The plant is therefore less affected by the problem of poor rainfall distribution.

The general trend for Ki values in soils under continuous grazing and sugarcane was found to be Cμ>Fma/gtΔμ - Lma/gtΔμ>CΔ at the three water potentials. As infiltration was determined at three different potentials, the results indicate lower macroporosity in CΔ than in Fma/gtΔμ - Lma/gtΔμ, with the highest macroporosity in Cμ (Table 3). These findings are in line with those of Neves et al. (2003), Baquero et al. (2012), Portella et al. (2012), and Fuentes-Llanillo et al. (2013) and confirmed our field observations (Figures 1 and 2).

CONCLUSIONS

Each soil management type resulted in a specific distribution of structures in the soil profile.

The hydraulic conductivity of the soil under pasture and sugarcane did not differ, but the distribution of structures under a given management system does result in specific hydraulic conductivity in the soil profile.

Morphologically similar clods behave the same way, regardless of physical manipulation.

The determinations made from the 98.17 cm^3 rings showed the density and porosity of the soil and, consequently, the hydraulic conductivity. This corresponds to the internal state of the clods, without including the volume of cracks (inter-aggregate porosity), observed in analysis of clod organization in the profil cultural of the soil.

ACKNOWLEDGMENTS

Our thanks to CAPES for granting a graduate studies scholarship to the first author, and CNPQ for grating a rechearch scholarship to the last two authors.

REFERENCES

Addiscott TM. Entropy and sustainability. Eur J Soil Sci. 1995;46:161-8. https://doi.org/10.1111/j.1365-2389.1995.tb01823.x

Ankeny MD, Ahmed M, Kaspar TC, Horton R. Simple field method for determining unsaturated hydraulic conductivity. Soil Sci Soc Am J. 1991;55:467-70. https://doi.org/10.2136/sssaj1991.03615995005500020028x

Baquero JE, Ralisch R, Medina CC, Tavares Filho J, Guimarães MF. Soil physical properties and sugarcane root growth in a red oxisol. Rev Bras Cienc Solo. 2012;36:63-70. https://doi.org/10.1590/S0100-06832012000100007

Bingham IJ, Bengough AG, Rees RM. Soil compaction-N interactions in barley: root growth and tissue composition. Soil Till Res. 2010;106:241-6. https://doi.org/10.1016/j.still.2009.10.008

Boizard H, Peigné J, Sasal MC, Guimarães MF, Piron D, Tomis V, Vian JF, Cadoux S, Ralisch R, Tavares Filho J, Heddadj D, Battista J, Duparque A, Franchini JC, Estrade JR. Developments in the "profil cultural" method for an improved assessment of soil structure under no-till. Soil Till Res. 2016. In press. https://doi.org/10.1016/j.still.2016.07.007

Cardoso EL, Silva MLN, Curi N, Ferreira MM, Freitas DAF. Qualidade química e física do solo sob vegetação arbórea nativa e pastagens no pantanal sul-mato-grossense. Rev Bras Cienc Solo. 2011;35:613-22. https://doi.org/10.1590/S0100-06832011000200030

Caviglione JH, Kiihl LRB, Caramori PH, Oliveira D. Cartas climáticas do Paraná. Londrina: IAPAR; 2000.

Cecagno D, Costa SEVGA, Anghinoni I, Kunrath TR, Martins AP, Reichert JM, Gubiani PI, Balerini F, Fink JR, Carvalho PCF. Least limiting water range and soybean yield in a long-term, no-till, integrated crop-livestock system under different grazing intensities. Soil Till Res. 2016;156:54-62. https://doi.org/10.1016/j.still.2015.10.005

Claessen MEC, organizador. Manual de métodos de análise de solo. 2a ed. Rio de Janeiro: Centro Nacional de Pesquisa de Solos; 1997.

Correchel V, Silva AP, Tormena CA. Influência da posição relativa à linha de cultivo sobre a densidade do solo em dois sistemas de manejo do solo. Rev Bras Cienc Solo. 1999;23:165-73. https://doi.org/10.1590/S0100-06831999000100020

Coulomb I, Caneill J, Manichon H, Tremblay M. Comportement du sol au labour: évolution de l'état structural au cours du labour. Agronomie. 1993;13:457-65.

Folegatti MV, Brasil RPC, Blanco FF. Sampling equipment for soil bulk density determination tested in a Kandiudalfic Eutrudox and a Typic Hapludox. Sci Agric. 2001;58:833-8. https://doi.org/10.1590/S0103-90162001000400027

Fuentes-Llanillo R, Guimarães MF, Tavares Filho J. Morfologia e propriedades físicas de solo segundo sistemas de manejo em culturas anuais. Rev Bras Eng Agric Amb. 2013;17:524-30. https://doi.org/10.1590/S1415-43662013000500009

Gautronneau Y, Manichon H. Guide méthodique du profil cultural. Lyon: Ceref-Geara; 1987.

Giarola NFB, Silva AP, Tormena CA, Ball B, Rosa JA. Visual soil structure quality assessment on Oxisols under no-tillage system. Sci Agric. 2010;67:479-82. https://doi.org/10.1590/S0103-90162010000400016

Gonçalves MA, Telles TS, Caviglione JH, Urbano A, Tavares Filho J. Diferenciação dos solos em duas topossequências sobre rochas basálticas no norte-central paranaense. Semina: Cienc Agrár. 2013;34:2777-92. https://doi.org/10.5433/1679-0359.2013v34n6p2777

Guimarães RML, Ball BC, Tormena CA, Giarola NFB, Silva AP. Relating visual evaluation of soil structure to other physical properties in soils of contrasting texture and management. Soil Till Res. 2013;127:92-9. https://doi.org/10.1016/j.still.2012.01.020

Horn R, Kutilek M. The intensity-capacity concept-How far is it possible to predict intensity values with capacity parameters. Soil Till Res. 2009;103:1-3. https://doi.org/10.1016/j.still.2008.10.007

Horn R, Peth S. Soil structure formation and management effects on gas emission. Biologia. 2009;64:449-53. https://doi.org/10.2478/s11756-009-0089-4

Llanillo RF, Richart A, Tavares Filho J, Guimarães MF, Ferreira RRM. Evolução de propriedades físicas do solo em função dos sistemas de manejo em culturas anuais. Semina: Cienc Agrár. 2006;27:205-20. https://doi.org/10.5433/1679-0359.2006v27n2p205

Lyra MRCC, Rolim MM, Silva JAA. Topossequência de solos fertigados com vinhaça: contribuição para a qualidade das águas do lençol freático. Rev Bras Eng Agric Amb. 2003;7:525-32. https://doi.org/10.1590/S1415-43662003000300020

Mathieu C, Pieltain F. Analyse physique des sols: méthodes choisies. Paris: Tec & Doc Lavoisier; 1998.

Mentges MI, Reichert JM, Rodrigues MF, Awe GO, Mentges LR. Capacity and intensity soil aeration properties affected by granulometry, moisture, and structure in no-tillage soils. Geoderma. 2016;263:47-59. https://doi.org/10.1016/j.geoderma.2015.08.042

Mueller L, Kay BD, Hu C, Li Y, Schindler U, Behrendt A, Shepherd TG, Ball BC. Visual assessment of soil structure: evaluation of methodologies on sites in Canada, China and Germany. Part I: Comparing visual methods and linking them with soil physical data and grain yield of cereals. Soil Till Res. 2009;103:178-87. https://doi.org/10.1016/j.still.2008.12.015

Mueller L, Shepherd G, Schindler U, Ball BC, Munkholm LJ, Hennings V, Smolentseva E, Rukhovic O, Lukin S, Hu C. Evaluation of soil structure in the framework of an overall soil quality rating. Soil Till Res. 2013,127:74-84. https://doi.org/10.1016/j.still.2012.03.002

Munkholm LJ, Heck RJ, Deen B. Long-term rotation and tillage effects on soil structure and crop yield. Soil Till Res. 2013;127:85-91. https://doi.org/10.1016/j.still.2012.02.007

Neves CSVJ, Feller C, Guimarães MF, Medina CC, Tavares Filho J, Fortier M. Soil bulk density and porosity of homogeneous morphological units identified by the cropping profile method in clayey Oxisols in Brazil. Soil Till Res. 2003;71:109-19. https://doi.org/10.1016/S0167-1987(03)00023-0

Portella CMR, Guimarães MF, Feller C, Fonseca ICB, Tavares Filho J. Soil aggregation under different management systems. Rev Bras Cienc Solo. 2012;36:1868-77. https://doi.org/10.1590/S0100-06832012000600021

Reichert JM, Rosa VT, Vogelmann ES, Rosa DP, Horn R, Reinert DJ, Sattler A, Denardin JE. Conceptual framework for capacity and intensity physical soil properties affected by short and long-term (14 years) continuous no-tillage and controlled traffic. Soil Till Res. 2016,158:123-36. https://doi.org/10.1016/j.still.2015.11.010

Richards LA. Physical conditions of water in soil. In: Black CA, Evans DD, White JL, Ensminger LE, Clarck FE, editors. Methods of soil analysis. Physical and mineralogical methods. Madison: Soil Science Society of America; 1965. Pt. 1. p.128-52.

Roger-Estrade J, Richard G, Boizard H, Boiffin J, Caneill J, Manichon H. Modeling structural changes in tilled topsoil over time as a function of cropping systems. Eur J Soil Sci. 2000a;51:455-74. https://doi.org/10.1046/j.1365-2389.2000.00323.x

Roger-Estrade J, Richard G, Manichon H. A compartmental model to simulate temporal changes in soil structure under two cropping systems with annual moldboard ploughing in a silt loam. Soil Till Res. 2000b;54:41-53. https://doi.org/10.1016/S0167-1987(99)00111-7

Silva AP, Babujia LC, Franchini JC, Ralisch R, Hungria M, Guimarães MF. Soil structure and its influence on microbial biomass in different soil and crop management systems. Soil Till Res. 2014;142:42-53. https://doi.org/10.1016/j.still.2014.04.006

Silva VR, Reinert DJ, Reichert JM. Comparação entre os métodos do cilindro e do torrão na determinação da porosidade e da densidade do solo. Cienc Rural. 2000;30:1065-8. https://doi.org/10.1590/S0103-84782000000600025

Tavares Filho J, Melo TR, Machado W, Maciel BV. Structural changes and degradation of Red Latosol under different management systems for 20 years. Rev Bras Cienc Solo. 2014;38:1293-303. https://doi.org/10.1590/S0100-06832014000400025

Tavares Filho J, Ralisch R, Guimarães MF, Medina CC, Balbino LC, Neves CSVJ. Método do perfil cultural para avaliação do estado físico de solos em condições tropicais. Rev Bras Cienc Solo. 1999;23:393-9. https://doi.org/10.1590/S0100-06831999000200022

Tormena CA, Araujo MA, Fidalski J, Costa JM. Variação temporal do intervalo hídrico ótimo de um Latossolo Vermelho distroférrico sob sistemas de plantio direto. Rev Bras Cienc Solo. 2007;31:211-19. https://doi.org/10.1590/S0100-0683200700020000

Viana ET, Batista MA, Tormena CA, Costa ACS, Inoue TT. Atributos físicos e carbono orgânico em Latossolo Vermelho sob diferentes sistemas de uso e manejo. Rev Bras Cienc Solo. 2011;35:2105-14. https://doi.org/10.1590/S0100-06832011000600025

Vizier JF, Tamia A, Fardoux J. Apport de l'électrodialyse à l'étude de l'influence de l'organisation du sol sur la disponibilité des éléments minéraux dans les sols tropicaux. Comptes Rendus Acad Scienc. 1995;321:1163-9.