

Critical values of physical attributes of an Ultisol under uses in South of Brazil

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ABSTRACT: Changes in the soil structural quality have caused alterations in root growth and agricultural yield. With the purpose of finding critical values of physical parameters and alternative, viable and suitable ways of minimize the soil degradation, this study aimed at quantifying aggregate tensile strength (TS), friability (F), bulk density (Bd), total porosity (Tp), macroporosity (Ma), penetration resistance (PR) and total organic carbon (TOC). Relations were established to estimate the structural quality of some parameters of an Ultisol under different uses. The study was carried out on a farm, in the rural area of RS, inserted in the Arroio Moreira waterbasin, Brazil. Disturbed and undisturbed samples were collected from the 0.00 to 0.10 m layer. Regarding TS and soil use, 900 samples were selected, totalling 2700 aggregates. Undisturbed samples (135) were collected for the evaluation of Bd, porosity and PR. The TOC was quantified using 45 aggregates through the dry combustion method. All physical parameters with exception of F are important in monitoring the structural quality. The lowest values of TS, PR and Bd were verified in the soil under fallow, and the highest ones in the soil under pasture. An inverse relation between TS and TOC and between Bd and TOC was verified. Critical values of Bd and TS to crop development might be estimated from the PR.

Key words: organic carbon; soil conservation; soil degradation; soil physics

Limites críticos de atributos físicos de um Argissolo sob usos no Sul do Brasil

RESUMO: Alterações na qualidade estrutural de solos têm modificado o crescimento radicular e a produtividade agrícola. No sentido de estimar valores críticos e viabilizar formas alternativas, viáveis e adequadas que minimizem a degradação do solo, objetivou-se quantificar a resistência tênsil de agregados (RT), a friabilidade (F), a densidade (Ds), a porosidade total (Pt), a macroporosidade (Ma), a resistência à penetração (RP) e o teor de carbono orgânico total (COT). Estabeleceram-se relações para a estimativa da qualidade estrutural de alguns parâmetros de um Argissolo Vermelho Amarelo distrófico sob diferentes usos agrícolas. O estudo foi realizado em áreas agrícolas, na zona rural no RS, inserida na Bacia Hidrográfica do Arroio Moreira, Brasil. Foram coletadas amostras com estrutura deformada e indeformada na camada de 0.00 a 0.10 m. Para a RT e por uso de solo, foram selecionadas 900 amostras, perfazendo um total de 2700 agregados. Amostras com estrutura preservada (135) foram coletadas para a avaliação da Ds, da porosidade e da RP. Pelo método da combustão seca, quantificou-se o COT, utilizando-se 45 agregados. Todos os parâmetros físicos com exceção da F apresentam relevância no monitoramento da qualidade estrutural. Os menores valores de RT, de RP e de Ds foram verificados no solo sob pousio, sendo os maiores em solo sob pastagem. Foi verificada uma relação inversa entre RT e COT e entre Ds e COT. Limites críticos de Ds e de RT ao desenvolvimento de plantas podem ser estimados a partir da RP.

Palavras-chave: carbono orgânico; conservação do solo; degradação do solo; física do solo

Introduction

In Brazil, the intensification of milk production systems occurs mainly in the South, Southeast and Center-West. Pasture covers a total area of around 180 million hectares, which corresponds to over 20% of the Brazilian territory (Dias Filho, 2014). The literature shows evidence that the animals might create from 350 to 400 kPa pressure on the soil (Betteridge et al., 1999). In soils where corn is cropped, Sales et al. (2016) revealed differences from native areas regarding soil quality from the evaluation of soil structure.

Studies about the influence of tillage systems in the soil structure are important to evaluate their impact in the soil quality. One of the great obstacles to obtain high yield has been soil compaction under different soil management. The knowledge of critical values of physical parameters becomes important to monitor soil degradation and crop development.

The bulk density, resistance to penetration, soil porosity (Torres et al., 2015; Silva et al., 2016) and organic carbon (Sales et al., 2016; Rosemary et al., 2017) are some of the indicators of soil degradation under pasture, corn and other managements.

More recently, aggregate tensile strength and friability have been pointed out as indicators of structural quality (Reis et al., 2014; Tang et al., 2015). The tensile strength is defined as the stress or strength per unit of area required to break aggregates when submitted to pressure being the most useful measure of individual resistance of soil aggregates consisting of an indicator sensitive to the structural soil condition that reflects the effects of natural factors, as well as land use and management. The friability is the tendency of a soil mass to dismantle into smaller aggregate sizes under the application of some stress or load. As a result of its heterogeneous nature, TS responds to the weakness planes or fault zones between aggregates in this way the soil friability can be estimated by the coefficient of variation of TS (Dexter & Watts, 2000).

The impacts of soil use on the aggregate tensile strength and soil friability and its relation with other soil parameters and the estimation of critical values of soil physical parameters in the Brazilian sub-tropical have not been widely studied yet. With the purpose of proposing alternative and viable ways to monitor and favour the structural quality in areas of agricultural production, this study aimed at evaluating the aggregate tensile strength, soil friability, bulk density, soil porosity, resistance to penetration and organic carbon and indicated critical values for crop development of an Ultisol under agricultural systems.

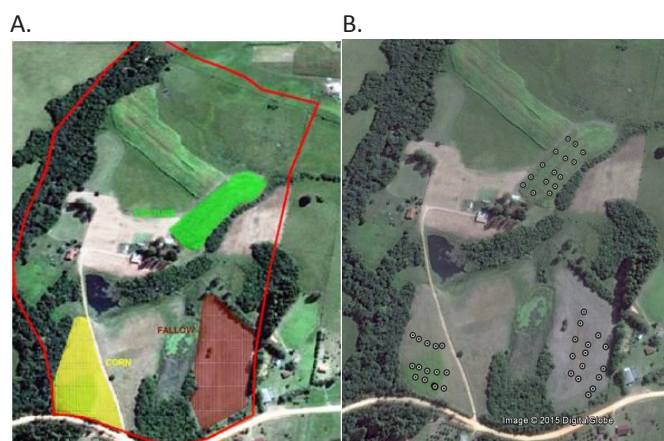
Material and Methods

The study was developed on a farm of 24.2 ha, whose main activity is the production of milk, located in the rural area in RS, and inserted in the Arroio Moreira washbasin (Brazil), which is the urban source of water supply. The place

presents the coordinates 31°40'58.38" latitude South and 52°31'38.39" longitude West and 55 m altitude above the sea level. The climate in the region, according to Köppen, is Cfa, subtropical humid, with 17 °C annual average temperature and 1400 mm rainfall. The site is composed of sedimentary rocks with outcrops of homogeneous migmatites and the relief is undulated with an average slope of 7%. The soil is classified as Ultisol (NRCS, 2010), with sandy loam texture and average contents 173, 178 and 648 g kg⁻¹ of clay, silt and sand, respectively in the superficial layer (0.00 to 0.10 m). In order to identify soil quality, some chemical analyzes were also carried out, such as pH in water, phosphorus (P) and potassium (K), extracted by Mehlich-1 method. The soil presented a mean value of pH in water equal to 5.48, P content of 4.61 mg dm⁻³ and K equal to 51.67 mg dm⁻³. Most of the rural property presents an oat/ryegrass pasture in rotation system that has been developed over the last 10 years. In the initial eight years biannual sub-soiling was performed aiming at reducing compaction while annual mowing and the application of fertilizers have been used for two years.

Sampling was carried out in July 2014, in three areas: Ultisol under: i) fallow; ii) corn in no-till system and; iii) oat and ryegrass pasture rotation (Figure 1A). The fallow area presents spontaneous vegetation, without agricultural activity for at least twenty-five years, with previous rice conventional system. The area with corn crops had been covered with pasture four years ago. Soil management is the no-tillage system aimed at reducing the use of machinery that prevents soil degradation.

The correct number of replications of soil sampling in each management system was established according to the Cline (1944). After the undisturbed and disturbed samples in georeferenced points in the 0.00 to 0.10 m layer, were collected randomly considering different relief topographical positions (upper, middle and lower) (Figure 1B) to reduce the variability of the soil attributes in each management system.



Source: Google Earth (2016).

Figure 1. Farm boundaries (red line) and different soil uses: fallow, corn crop and pasture, respectively represented in brown, yellow and green (A) and soil sampling georeferenced points (black circles) (B).

The samples undisturbed were collected using volumetric rings of 5 cm height and 5 cm diameter, totalling 135 samples (5 sampling points x 3 topographic positions x 3 use systems x 3 replications) (Figure 1B). These samples were saturated with water through capillarity, for a minimum period of 48 hours, weighed, placed on tension table and, submitted to the 6 kPa potential to determine soil macroporosity. Next, they were submitted to 10 kPa potential in Richards chambers (Klute, 1986) to quantify the penetration resistance (PR) and dried in oven at 105°C for 24 hours to determine the bulk density (Bd) (Blake & Hartge, 1986).

In the same places (Figure 1A) disturbed samples (5 sampling points x 3 topographic positions x 3 use systems x 3 replications) (Figure 1B) were collected totalling 135 samples. The 900 soil aggregates per soil use were selected to evaluate TS, totalling 2700 evaluations. Before applying the force, each aggregate was weighed and assessed to obtain height, width and length for the determination of the average diameter and then accommodated in the most stable position to receive the load. A linear electronic actuator with 4 mm s⁻¹ (MA 933) constant speed was used. The load applied to the aggregate tensile rupture was recorded in a data acquisition electronic system, and the TS was calculated, according to Dexter & Kroesbergen (1985):

$$TS = 0.576 \left(\frac{P}{D^2} \right)$$

where: 0.576 is the proportionality coefficient; P, is the load applied (N) and D, is the effective diameter (mm). The effective diameter (D) was calculated according to Watts & Dexter (1998), considering:

$$D = Dm \left(\frac{M}{M_0} \right)^{\frac{1}{3}}$$

where: Dm, is the aggregate mean diameter (mm); M is the individual aggregate mass; and Mo is the mean mass of the population aggregates (g). The aggregate individual gravimetric water content was evaluated, and the values obtained for the soil under fallow, corn crop and pasture were: 8.9; 10.0 and 13.3 g kg⁻¹ respectively.

The total organic carbon (TOC) quantification was performed in each point sampled (Figure 1B), resulting in 45 additional aggregates, which were manually ground in agate mortar, placed in a 2 ml eppendorf tube and determined with an elemental analyzer Perkin Elmer through the dry combustion method.

The results were submitted to the variance analysis and, when the normality of data was determined (Shapiro-Wilk test), the average values for each variable and management system (45) were compared using Duncan test (p = 5%). Linear correlation analyses were carried out for some soil attributes (TS, Bd, PR and OC). The statistics software Assisat 7.7 was used (Silva & Azevedo, 2016).

Results and Discussion

Overall evaluation as a referential for variability, the proposal presented by Pimentel Gomes (2000) is usually used. This author classifies variability as low when the coefficient of variation (CV) is below 10%, average when it is between 10 and 20%, high between 20 and 30% and very high when it is over 30%. The TS presented average variability for the soil under fallow and corn crop (Table 1), with values below those described by Imhoff et al. (2002) and similar to those found by Bavoso et al. (2010). The F variation coefficient ranged between 7.68 and 10.66% (Table 1) being lower than that described by Imhoff et al. (2002), Guimarães et al. (2009) and Bavoso et al. (2010) but similar to that presented by Tormena et al. (2008) in Oxisols. The TS and friability differences are associated with soil use and management system, soil type and the aggregates shape. The aggregates fracture occurs in the planes of weakness derived from the cracks that form zones of less soil strength. The number of total pores and the bulk density usually present low variability in different surveys, similar to that obtained by Castagnara et al. (2012), Chieza et al. (2013) and Torres et al. (2015). On the other hand, the PR presented high variability, except for the area under pasture (Table 1). The variability of the RP is influenced by soil management and water content. However, intense trampling of animals may also have influenced the greater homogeneity of PR.

The Ma variation coefficient was seen to be the highest of all, ranging from 22.48 to 24.75 % (Table 1), which is above

Table 1. Statistical moments of tensile strength (TS, kPa), friability (F), bulk density (Bd, Mg m⁻³), total porosity (Tp, m³ m⁻³), macroporosity (Ma, m³ m⁻³), penetration resistance (PR, kPa) and total organic carbon content (TOC, g kg⁻¹) of an Ultisol under different uses.

Uses	Atributtes	Minimum	Maximum	SD ¹	CV (%) ²
Fallow	TS	57.50	96.49	11.75	15.72
	F	0.35	0.47	0.03	7.68
	Bd	1.45	1.64	0.05	3.15
	Tp	0.34	0.43	2.26	5.75
	Ma	0.05	0.13	2.09	23.27
	PR	1066	2640	2.64	21.02
	TOC	11.41	16.80	0.14	9.81
Corn	TS	56.65	114.61	15.52	18.52
	F	0.34	0.45	0.04	10.24
	Bd	1.44	1.70	0.07	4.42
	Tp	0.32	0.43	3.01	8.19
	Ma	0.05	0.12	1.96	22.48
	PR	870	3403	3.40	20.43
Pasture	TOC	11.60	14.0	0.12	9.00
	TS	57.75	146.90	20.18	22.76
	F	0.33	0.44	0.04	10.66
	Bd	1.59	1.72	0.04	2.40
	Tp	0.30	0.37	1.94	5.71
	Ma	0.03	0.10	1.74	24.75
	PR	1932	3856	3.86	13.43
TOC	11.13	17.88	0.17	13.98	

¹SD: Standard deviation; ²CV: Coefficient of variation (%).

those described by Castagnara et al. (2012) while similar to the ones obtained by Costa et al. (2015). Regarding the results obtained (Table 1), Guimarães et al. (2016) reported lower Bd (1.08 to 1.49 Mg m⁻³), higher porosity (0.41 to 0.59 m³m⁻³) and Ma (0.00 to 0.22 m³ m⁻³) for an Ultisol under pasture. Low to average variability was ascribed to the total organic carbon (TOC), which is similar to the results obtained by Castagnara et al. (2012) in Oxisol under pasture.

The effect of use and management on the TS was observed, with average values: 74.73; 83.81 and 88.66 kPa in the soil under fallow, corn crop and pasture, respectively (Figure 2A). These values are above those found by Bavoso et al. (2010), but similar to the ones reported by Tormena et al. (2008) in different areas of agricultural production.

The TS in the soil under fallow was significantly lower than that in the soil under pasture, which did not differ from the area under corn crop (Figure 2A). The highest TS in the soil under pasture was associated to the effect of technified practices, different from that obtained by Bavoso et al. (2010) in Oxisol under pasture. With the purpose of evaluating structural quality, Tormena et al. (2008) confirmed and agreed with lower TS in the area under fallow when compared to the area under management.

Based on F values (Figure 2B) and Utomo and Dexter classification (1981), the soils are classified as very friable, since they are in the 0.25 to 0.40 band. These categories

are based on the F estimates, as the slope of a straight line which related the TS logarithm to the aggregated size logarithm. However, when the coefficient of variation method is employed (Watts & Dexter, 1998), the results present lower values. Based on this assumption, Imhoff et al. (2002) multiplied the F value by 2, to evaluate the structural quality of Oxisols. This classification, the most used in Brazil, is presented as: non friable (< 0.10), slightly friable (0.10 to 0.20), friable (0.20 to 0.50), very friable (0.50 to 0.80) and mechanically unstable (> 0.80). Thus, under this classification, the soil under different uses is seen as friable (Figure 2B), a condition that requires reduced management intensity and presents suitable structure to the germination and establishment of plants. Unlike TS, F was not sensitive to indicate the management effects (Figure 2B), which is in agreement with Bavoso et al. (2010), Reis et al. (2014) and Tang et al. (2015). Tormena et al. (2008) found differences between the soil under native forest in relation to that under fallow and crop, presenting high F in the forest in comparison to the other conditions. On the other hand, higher F values in soil under pasture were found by Watts and Dexter (1998). According to Utomo & Dexter (1981), high F values indicate that the soil has a tendency to disaggregate when minimum load is applied, becoming, therefore, unsuitable for mechanized agricultural systems due to the high environmental vulnerability. Intermediary F values indicate that larger aggregates show lower TS than the small ones, and can be more easily broken into smaller fragments. Reduced F values indicate the soil tendency to break into random sizes (either very large or very small), when submitted to management procedures, becoming unsuitable to plant germination and growth. Although these two indicators (TS and F) have been widely evaluated in soils of temperate climate regions, information about soils developed under the influence of tropical and sub-tropical climate with different uses and managements is still scarce (Imhoff et al., 2002; Tormena et al., 2008).

The Bd variation was possibly related to the soil use and associated to the TS (Table 1, Figure 3A and Figure 5). According to Blanco-Canqui et al. (2005), compaction might generate aggregates coalescence, increasing Bd and individual resistance, reducing the intra-aggregate porous space. Lower Bd (Figure 3A) and higher Tp in the soil under fallow (Figure 3C) favour the soil fracturing with less energy use and lower TS (Figure 2A).

The soil under pasture presented higher Bd (Figure 3A), due to the intense animal trampling. Dörner et al. (2016) revealed negative alterations in the physical parameters of soil under pasture when compared to native areas. Different from the results found by Chieza et al. (2013), the soil under corn crop presented intermediary results when compared to the remaining ones.

The soil under pasture presented lower macroporosity values (Ma) (Figure 3B), also reported by Castagnara et al. (2012). Schiavo & Colodro (2012) and Costa et al. (2015) when evaluating integrated systems of crop and livestock in no-till.

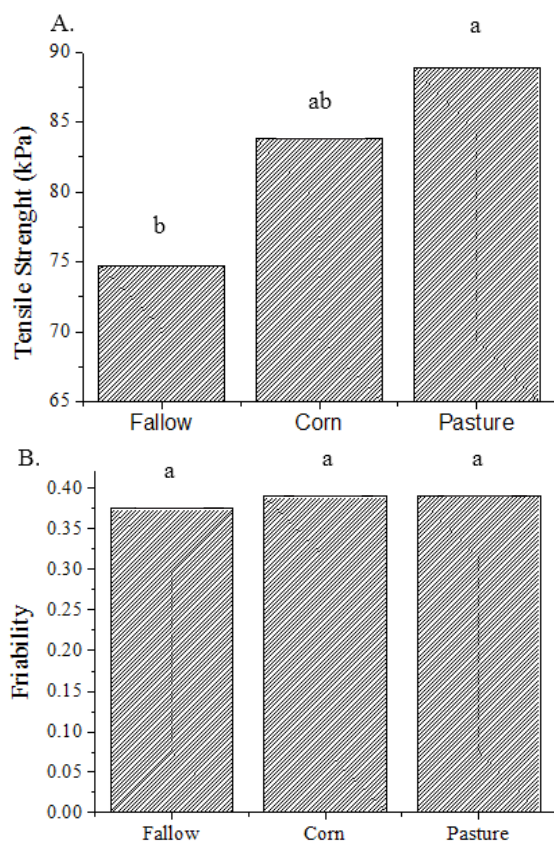


Figure 2. Tensile strength (A) and soil friability (B) of an Ultisol under fallow, corn crop and pasture. Averages followed by the same letter did not differ significantly in the Duncan test ($p \geq 0.05$).

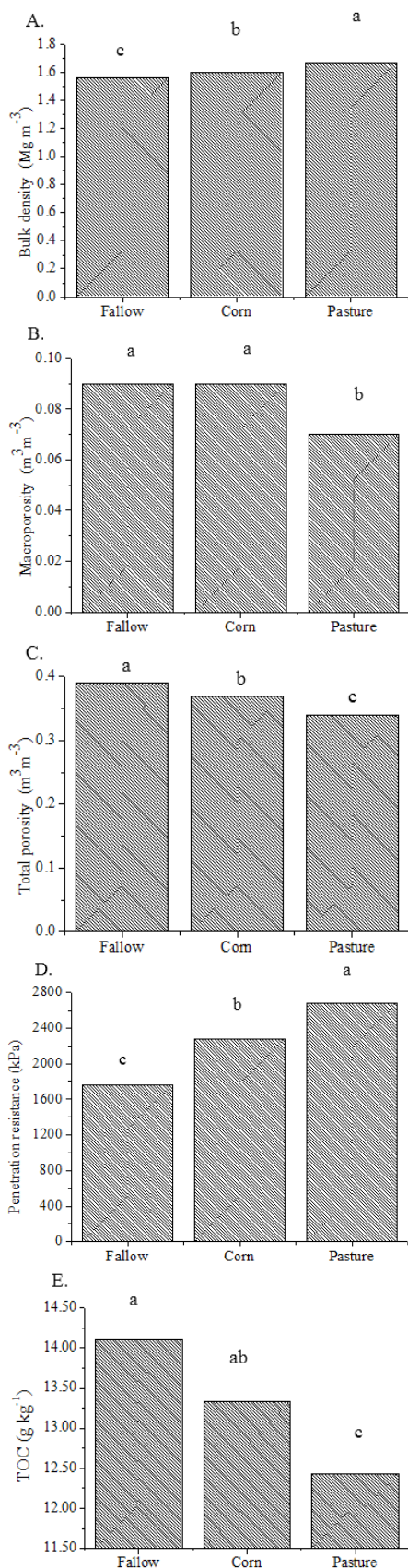


Figure 3. Bulk density (A), macroporosity (B), total porosity (C), penetration resistance (D) and total organic carbon (E) of an Ultisol under fallow, corn crop and pasture. Averages followed by the same letter did not differ significantly in the Duncan test ($p \geq 0.05$).

Structure represents one of the main soil physical attributes indicators and the soil porous system is directly linked to the soil structure (Pires et al., 2017). Porosity can be seen as a suitable indicator of soil use and management, since it is related to the granulometric composition and organic carbon, influencing the development of the root system and the aeration. Grable & Siemer (1968) defined a minimum aeration porosity of 10%, so that the oxygen diffusion can meet the root system requirements. All the systems evaluated were below this value (Figure 3B), which confirms the need for technological adjustments in the management system to improve the conditions of development for the plants and other organisms in the soil. The Ma reduction might increase resistance to root growth, in conditions of low soil water content and reduce oxygenation, making the plant more susceptible to water deficit and limit nutrient absorption. When there is reduction in the soil aeration porosity, limiting the development of crops, it becomes necessary to adopt mitigating measures such as the intercropping of grass and leguminous species which promote the increase in Ma.

Penetration resistance (RP) in the different systems (Figure 3D) is in agreement with the Bd (Figure 3A) and Tp (Figure 3C) values, since the PR integrates the effects of Bd and Pt. The Tp, PR and Bd demonstrate that the soil use under pasture might present problems since it is above critical values usually indicated in the literature, for example, presenting 2680 kPa average PR, 52% higher than that in the soil under fallow (1760 kPa). In the soil under corn crop, the PR average values around 2300 kPa, were 30% higher than that under fallow.

Lima et al. (2012) and Lima et al. (2016), using values established by Taylor et al. (1966), considered in general that the resistance to penetration above 2000 kPa hampers growth and functioning of the root system. Therefore, only the fallow was seen to present value below the estimates (Figure 3D), which might indicate, also by adopting 2500 kPa as the critical limit to pasture establishment (Leão et al., 2004), hampering crops development. Ortigara et al. (2014) evaluated the soil physical properties in perennial pasture in rotation and found out that animal trampling result in alterations in the soil structure, causing increase in the Bd and the PR with Ma reduction.

The highest Bd and lowest Tp in soil under pasture (Figures 3A and 3C) are due to higher pressure resulting from animal trampling. Castagnara et al. (2012) found the same relation in a soil under fallow when compared to the grass cultivation under pasture. Lower Bd values and higher Tp values in soil under fallow (Figures 3A and 3C) are due to the absence of animal trampling or technified anthropic interventions.

Total organic carbon content differs between soil use systems, following the sequence: fallow > corn crop > pasture (Figure 3E). Tormena et al. (2008) also found TOC higher values in the soil under fallow. However, confirming the results obtained, Schiavo & Colodro (2012) did not find differences between pasture and corn crop. Sales et al. (2016) reported TOC values obtained in fallow close to those obtained in the superficial layer of soils under corn crop in

the no-till. Another relevant evidence is the inverse tendency of TOC in relation to TS (Figure 4A), confirmed by Ferreira et al. (2011) and Reis et al. (2014).

The reduction in TOC content in soils under crop is associated to the changes in the physical structure. According to Zhang (1994), not only can the amount of organic matter in the soil affect TS, but also its humification degree. The more humified the organic matter is, the lower the TS reduction is. On the other hand, less humified organic matter leads to the dilution effect, which implies in reduction in the aggregate density or increase in porosity and, consequently, reduction in TS (Ferreira et al., 2011).

Tensile strength and Bd under different soil uses are correlated in a linear, significant and inverse with organic carbon content (Figures 4A and 4B). Calonego et al. (2012) pointed out the same behavior in an Ultisol under conventional management, no-till and native forest. Studies explain this relation as a result of the low specific weight of the organic matter and its humification degree (Braidá et al., 2017). Kato et al. (2010), evaluating the effect of different soil uses also observed a negative linear correlation between organic carbon and Bd, similarly to Castagnara et al. (2012), in soil under fallow compared to grass cover under pasture.

The highest TS, Bd and PR and lowest Tp values were observed in the soil under pasture. The presence of animals

on the soil under pasture favoured the coalescence of soil particles, increasing the bond between them. Bertol et al. (2000), when studying an Inceptisol, found out that the stocking rate control as a function of forage production promoted improvements to the structural quality. High water content, associated to low vegetable cover are maximized in pasture conditions, which shows the need for keeping vegetable cover, in order to mitigate the negative effects of animal trampling on the physical quality.

The TS was significantly and linearly influenced by PR (Figure 5A) and Bd (Figure 5B). Higher Bd values observed in the soil under pasture indicated higher TS values (Table 1). Similar association was also confirmed by Tormena et al. (2008) in soils under different tillages. Aiming at establishing critical values of TS (TSc) from the PR for plant development, a correlation was established between these two parameters (Figure 5A).

Leão et al. (2004) used 2500 kPa as a limit to the development of pastures, agreeing with Miola et al. (2015) for soils under different management and, thus, suggesting TSc values of 88.67 kPa (Figure 5A). The PR critical limits correspond to 3000 and 3500 kPa, as pointed out by Moraes et al. (2014), might be established for the conditions of this study, as signals of degradation, TSc values over 98.67 and 108.67 kPa (Figure 5A), respectively. On the other hand, considering the limit value of 2000 kPa, usually reported in

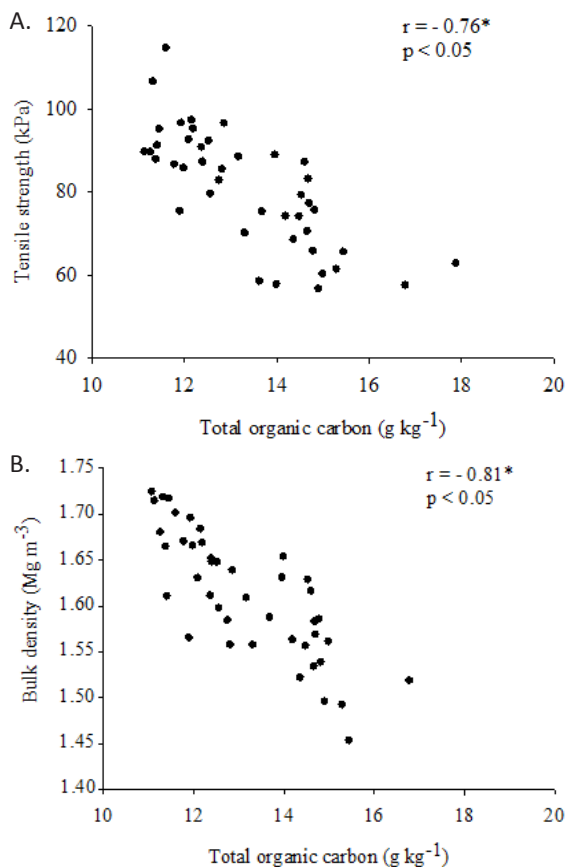


Figure 4. Correlation between tensile strength and total organic carbon (A) and bulk density and total organic carbon (B) of an Ultisol under different uses: fallow, corn crop and pasture.

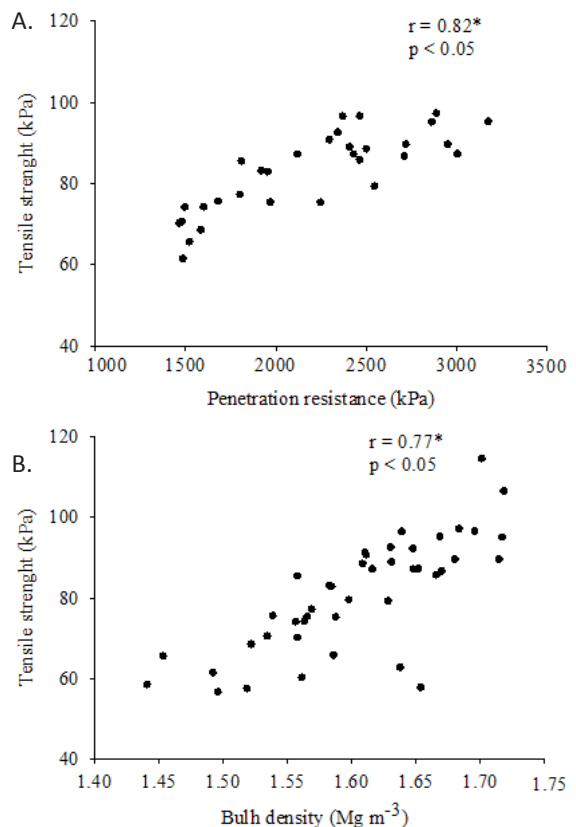


Figure 5. Correlation between tensile strength (TS), resistance to penetration (A) and TS and bulk density (Bd) (B) of an Ultisol under different uses: fallow, corn crop and pasture.

the literature (Moraes et al., 2014; Lima et al., 2016), the TSc obtained is 78.67 kPa (Figure 5A) and, in such case, all the systems of soil use proposed presented higher TS, which hampers crop development. Considering the TSc of 78.67 kPa for PR = 2000 kPa (Figure 5B), 1.59 Mg m⁻³ critical bulk density (Bdc) is obtained, which is restrictive to crop development. Therefore, by analysing the soil management, there is evidence of degradation, mainly more critical in the soils under corn crop and pasture (Bd = 1.60 and 1.67 Mg m⁻³, respectively) (Figure 3A) for presenting Bd > Bdc, in relation to the fallow area (Bd = 1.56 Mg m⁻³).

The TS, Bd, Tp, Ma, PR and TOC parameters were efficient to evaluate the structural quality. However, additional studies are needed so that the critical values of sustainability indicators can be suitably defined for different types of soil, mainly in areas of technified activity. Mitigation of adverse impact in agriculture should support the decision making in the future in order to establish new indicative paradigms for the management of mitigating measures aiming at soil quality. The monitoring of physical attributes and mainly soil water content at the moment of adoption of agricultural practices is important in the planning of agricultural practices and increase of crop productivity. Another suggestion, in agreement with Gould et al. (2016), as a viable alternative, is the implementation of systems that favour the combination and diversity of vegetable species for the improvement and recovery of the soil physical quality in the proximity of water basins.

Conclusions

All attributes evaluated, except for the soil friability, were shown sensitive in monitoring the soil structural quality under different soil uses.

The tensile strength of aggregates and bulk density presented a tendency contrary to that of the organic carbon content values.

The tensile strength can be suitably obtained from the resistance to penetration and bulk density.

To obtain the tensile strength and, considering the values of resistance to penetration 2000, 3000 and 3500 kPa critical to the development of crops, the relations obtained were around 1: (24 - 30).

Considering a resistance to penetration of 2000 kPa, the approximate values of critical tensile strength and bulk density indicated are 79 kPa and 1.60 Mg m⁻³, respectively.

The soil under pasture and fallow presented attributes which reflect decrease and increase of the soil structural quality respectively.

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