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Physico-mechanical attributes of a Typic Hapludox in areas with different sugarcane cultivation times

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ABSTRACT: The objective of this study was to evaluate from physical and mechanical parameters the evolution of the compaction of an Oxisol in areas with different sugarcane cultivation times in the city of Salto do Jacuí, RS. The evaluations were conducted in areas with two, four e six years of cultivation and an area of native forest. Soil samples with preserved structure were collected in soil layers from 0.00 to 0.05 m; 0.05 to 0.10 m; and 0.10 to 0.20 m, as to determine soil physical and mechanical attributes. The results have shown that over time conventional sugarcane cultivation provides an increase in soil bulk density and soil penetration resistance values and a decrease in soil porosity, mainly due to the reduce in soil macroporosity. These changes are of such magnitude that they can be considered restrictive to root development. In six years of cultivation, the bulk density was closer to the preconsolidation pressure density value, indicating higher soil degradation.

Key words: bulk density; penetration resistance; soil compaction; soil porosity

Atributos físico-mecânicos de um Latossolo Vermelho em áreas com diferentes tempos de cultivo de cana-de-açúcar

RESUMO: O objetivo deste trabalho foi avaliar, a partir de parâmetros físicos e mecânicos, a evolução da compactação de um Latossolo Vermelho em áreas com diferentes tempos de cultivo de cana-de-açúcar no município de Salto do Jacuí, RS. As avaliações foram realizadas em áreas com dois, quatro e seis anos de cultivo e em uma área de mata nativa. Amostras de solo com estrutura preservada foram coletadas nas camadas de 0,00 a 0,05 m; 0,05 a 0,10 m e 0,10 a 0,20 m para determinação dos atributos físicos e mecânicos do solo. Os resultados mostraram que, ao longo do tempo o cultivo convencional da cana-de-açúcar proporciona um aumento na densidade e nos valores de resistência à penetração do solo e diminuição da porosidade do solo, principalmente pela diminuição da macroporosidade. Essas alterações são de tal magnitude, que podem ser consideradas restritivas ao desenvolvimento radicular. Em áreas com seis anos de cultivo, a densidade esteve mais próxima do valor de densidade na pressão de preconsolidação, indicando uma maior degradação do solo.

Palavras-chave: densidade do solo; resistência do solo à penetração; compactação do solo; porosidade do solo

Introduction

Brazil is the world's leading producer of sugarcane (Brazil, 2013). In the State of Rio Grande do Sul, the cities with the highest production are Roque Gonzales, Salto do Jacuí and Porto Xavier. The city of Salto do Jacuí stands out for reaching an average productivity of 85 t ha^{-1} (CONAB, 2012) and is located in the physiographic region of Plateau where Red Latosols predominate (Embrapa, 2013), which are deep soils in an advanced stage of weathering.

Soil management for the cultivation of sugarcane requires an intensive use of agricultural machinery, from the initial preparation to the harvesting operations (Alakukku et al., 2003; Oliveira, 2008). After preparation for the implantation of the cane field, the soil is usually revolved after the fifth or sixth cut (Carvalho et al., 2011). The impacts caused on the structural physical quality of the soil in these areas can be quantified by means of the density, porosity and resistance to penetration (Machado et al., 2010). Effects such as reduction of total porosity and macroporosity and increase of soil density can be verified in soils under sugarcane cultivation (Souza et al., 2004). Resistance to penetration is a soil quality indicative that may indicate the effects of sugarcane cultivation. Some growing areas may have compaction levels above the critical value in more than half of the sites evaluated (Oliveira Filho et al., 2015), thus showing the impact of sugarcane on the physical properties of the soil.

Additionally, in these areas, indicators related to compressibility have contributed to define management actions to avoid or minimize degradation of the physical quality of soils in areas of sugarcane cultivation. According to a study developed by Silva & Cabeda (2006), areas cultivated with sugarcane had suffered increased pre-consolidation pressure, decreased compression index and, consequently, a higher degree of compaction. This demonstrates that knowledge of load bearing capacity is relevant in the planning of mechanized operations in these areas (Pacheco & Cantalice, 2011).

In general, most studies on sugarcane have been conducted in the Southeast region of the country, since this is the largest producing region. In the South of Brazil there is a lack of studies on this crop, mainly related to the effect of cultivation on the physical attributes of the soil. The various mechanized operations carried out for planting, fertilization, agrochemical applications and sugarcane harvesting alter the soil structure, thus making it necessary to evaluate physical and mechanical properties in order to favor the rational use of natural resources.

The objective of this study was to evaluate the compaction evolution, from physical and mechanical parameters, of a Red Latosol in areas with different times of sugarcane cultivation (two, four and six years), in Fazenda Grandespe, located in the city of Salto do Jacuí, in Rio Grande do Sul.

Material and Methods

Study area

The present study was carried out at Fazenda Grandespe, in the city of Salto do Jacuí, RS, Brazil. The central point of the experimental area was located at the coordinate reference with Latitude 28° 57' 34.87" S and Longitude 53° 11' 12.30" W. The soil of the study site was classified as a Typic Hapludox (Soil Survey Staff, 2014) and as a Latossolo Vermelho Distrófico típico according to the Brazilian Soil Classification System (Embrapa, 2013), with clayey texture in the superficial layer (0 to 0.20 m) (Table 1). The climate of the region, according to the Köppen climatic classification system, is humid subtropical of type Cfa.

The implantation of sugarcane plantations in the 2, 4 and 6-year areas occurred in the autumn (March to June) of 2010, 2008 and 2006, respectively. The soil preparation system for implantation of cane fields in the three areas was the conventional one, in which the subsoiling operations were performed at 0.50 m depth with a of 5-stem subsoiler and two heavy harrows at a 0.20 m depth with 28-inch diameter cut-off disc harvester grid.

The crop spacing in the experimental areas was 1.40 m. The varieties used in the study were SP821842 and RB835089. During the crop cycle some cultural treatments were carried out, namely: application of herbicide and insecticide products; cover fertilization; and scarification. The sugarcane harvest in the three areas was the semi-mechanized type with previous burning of the cane field, and in the 2, 4 and 6-year areas, 1, 3 and 5 cuts (or harvests) were performed, respectively. In this process, the cane cut was performed manually and the loading and transport operations were performed mechanically.

Table 1. Granulometric fractions (g kg^{-1}) in the layers 0.00 to 0.05 m, 0.05 to 0.10 m and 0.10 to 0.20 m of a Typic Hapludox under native forest and cultivated with different times of implantation of sugarcane in Salto do Jacuí, RS, Brazil.

Treatment[1]	Sand	Silte	Clay
		0.00 a 0.05 m	
C2	318.3	228.4	453.3
C4	239.0	254.6	506.4
C6	356.6	179.0	464.4
NF	285.8	235.9	478.3
		0.05 a 0.10 m	
C2	310.7	228.9	460.4
C4	234.3	271.2	494.5
C6	310.6	216.8	472.6
NF	265.6	267.9	466.5
		0.10 a 0.20 m	
C2	321.9	188.0	490.1
C4	221.6	266.0	512.4
C6	318.0	208.3	473.7
NF	258.8	269.5	471.6

[1]C2 – soil under sugarcane crop with two years of cultivation; C4 - soil under sugarcane crop with four years of cultivation; C6 - soil under sugarcane crop with six years of cultivation and NF - soil under native forest.

Previously to the cultivation of sugarcane, the area covering the second year treatment (C2) was cultivated with soybean (2007 to 2009) and maize (2009 to 2010). In the fourth (C4) and sixth year (C6) areas, soybean cultivation preceded the planting of sugarcane. We used a native forest (NF) area with characteristics similar to the other areas as reference.

Soil sampling and analysis

Soil samples were collected in areas with 2 (C2), 4 (C4) and 6 years (C6) of sugarcane cultivation and in an area of native forest (NF). Soil sampling with preserved structure, using volumetric rings (0.025 m in height and 0.070 m in diameter) was performed in January 2012.

In each area, 18 collection points were randomly assigned to the cultivation lines and the sampling was performed in the layers 0.00 to 0.05 m, 0.05 to 0.10 m and 0.10 to 0.20 m, in a total of 216 samples.

After equilibration (ψ) of -10 kPa in Richards pressure chambers (Klute, 1986), the samples were weighed and evaluated for penetration resistance (PR). Determinations were performed at three equidistant points from the center of each sample with readings every 0.015 m. We used a digital bench penetrometer with a 0.003 m diameter stem, at a penetration rate of 10 mm min^{-1}.

In these samples equilibrated in the potential of - 10 kPa, successive pressures of 25, 50, 100, 200, 400, 800 and 1,600 kPa were applied, according to Silva et al. (2007), to obtain the uniaxial compression curves of the soil. From the curves, the pre-consolidation pressure (σ_p) values (Dias Junior & Pierce, 1995) and the compression index (CI) were determined, according to the methodology proposed by Larson et al. (1980).

The degree of compaction (DC) was obtained by the ratio between the initial density (Dsi) and the reference density (Dsref), which was determined in the pre-consolidation pressures (Dsσp) of 200 kPa (DC200) (Hakänsson, 1990) and 1,600 kPa (DC1,600), according to Suzuki (2005).

For the determination of soil density, total porosity and macro and microporosity, we used the methodology described in Donnagema et al. (2011).

Statistical analysis

When the data set fulfilled the assumptions of the parametric analysis, the analysis of the variance was performed by the F test at the significance level of 5% and the comparison between the means was performed by the Tukey test at the significance level of 5%. When one or both assumptions of the parametric analysis were not met, the analysis of the variance was performed by the Kruskal-Wallis non-parametric test at a significance level of 5% and the comparison between the areas by the Dunn test was performed at the significance level of 5 %. Pearson's correlation was used to analyze the relationship between the variables. All analyzes were performed using the Sigmaplot 9.01 software.

Results and Discussion

Density, porosity and penetration resistance

In the 0.00 to 0.05 m layer there was no significant difference of the Ds between the cultivated areas. However, considering the absolute values of these areas, the lowest soil Ds occurred in C2 (Figure 1a). In the other layers, C2 presented significantly lower values of Ds than those of areas C4 and C6 (Figures 2a and 3a), which can be explained by the soil preparation effect, since in the area with 2 years

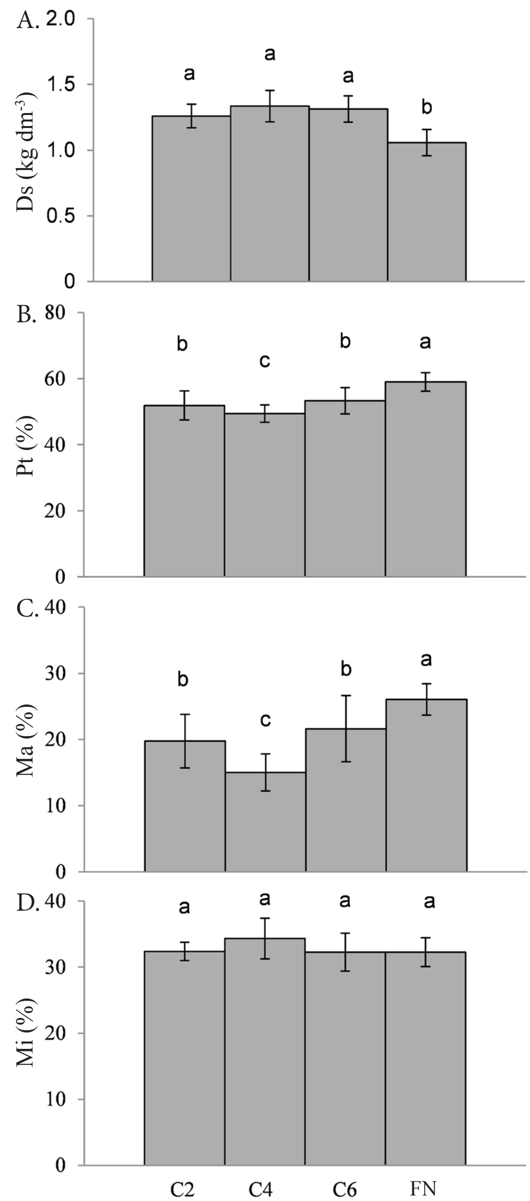

Figure 1. Density (Ds) (a); total porosity (Pt) (b); macroporosity (Ma) (c) and microporosity (Mi) (d) of a Red Latosol with two (C2), four (C4) and six (C6) years of cultivation and under native forest area in 0.00 to 0.05 m layer. For the variables Mi, Pt and Ds, values followed by the same letter do not differ by Tukey test at 5% of significance. For the variable Ma, values followed by the same letter do not differ among themselves by the Dunn test at 5% of significance. Vertical bars indicate the standard deviation of the mean of each evaluation

of cultivation the soil rotation is more recent than in other areas, so the lower soil density in C2 is a consequence of soil disruption by scarification, weeding and furrowing. In areas C4 and C6 where three and five crops have already occurred, respectively, the increase in soil density may have been driven by the traffic of machines and trucks to transport the cut cane from the crop to the plant. These results corroborate with Centurion et al. (2007), where the authors verified that the cultivation time can provide increased density in areas cultivated with sugarcane.

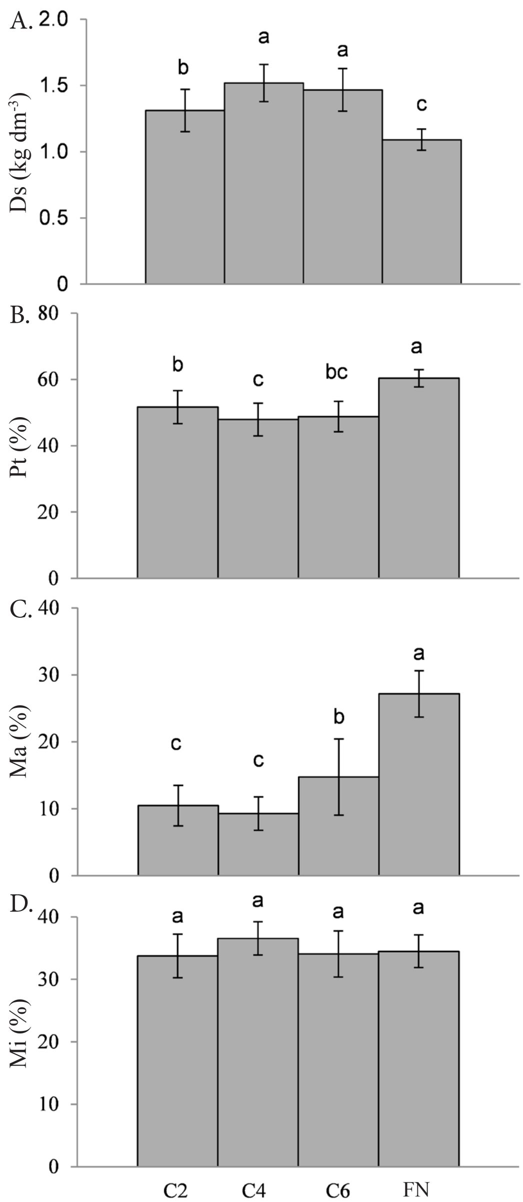

Figure 2. Density (Ds) (a); total porosity (Pt) (b); macroporosity (Ma) (c) and microporosity (Mi) (d) of a Red Latosol with two (C2), four (C4) and six (C6) years of cultivation and under native forest area in 0.05 to 0.10 m layer. For the variables Ma, Mi and Ds, values followed by the same letter do not differ by Dunn test at 5% of significance. For the variable Pt, values followed by the same letter do not differ among themselves by the Tukey test at 5% of significance. Vertical bars indicate the standard deviation of the mean of each evaluation

In the layers 0.00 to 0.05 m (Figure 1d) and 0.05 to 0.10 m (Figure 2d) there was no significant difference for microporosity between the studied areas. In the soil layer 0.10 to 0.20 m there were differences only between areas C2 and NF (Figure 3d). The fact that the cultivation did not significantly influence the microporosity of this soil may have occurred due to the predominance of iron and aluminum oxides. According to Brady & Weil (2002), micropores are generally found inside structural units and many weathered soils tend to have a more stable aggregation due to the effect of iron and aluminum sesquioxides.

In the cultivated areas, the Ds was significantly higher than the native forest and, consequently, the Pt and Ma values

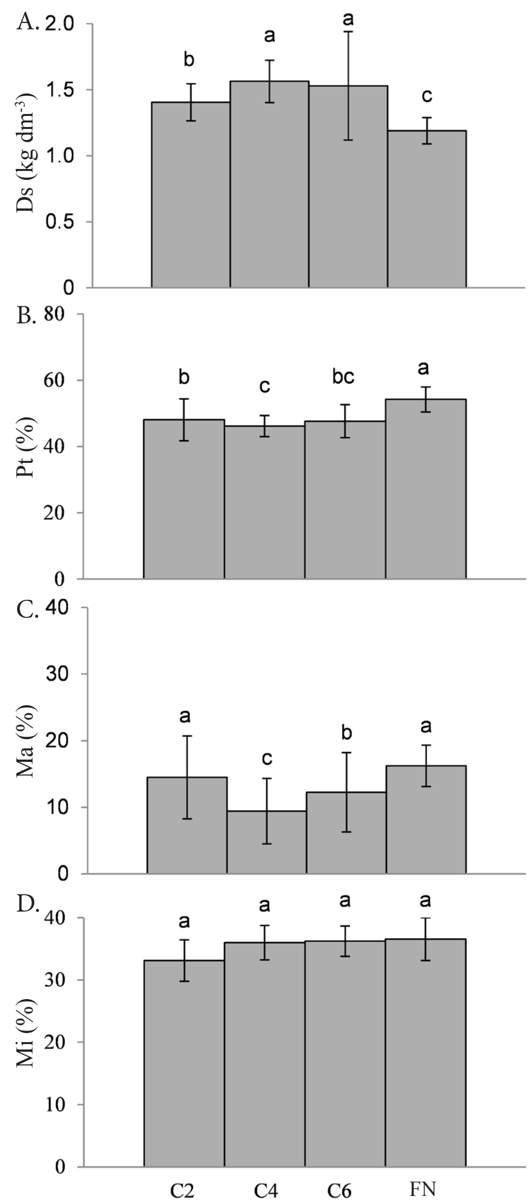

Figure 3. Density (Ds) (a); total porosity (Pt) (b); macroporosity (Ma) (c) and microporosity (Mi) (d) of a Red Latosol with two (C2), four (C4) and six (C6) years of cultivation and native forest area in 0.10 to 0.20 m layer. Values followed by the same letter do not differ by Dunn test at 5% significance. Vertical bars indicate the standard deviation of the mean of each evaluation

were lower (Figures 1, 2 and 3). Similar results were found by Machado et al. (2010), in which the authors observed higher values of Ds in soil with sugarcane when compared to native forest, attributing this to the effect of traffic of heavy machinery during the planting and harvesting of sugarcane.

In the 0.10 to 0.20 m layer there was no difference between the volume of macropores of area C2 and NF (Figure 3c). As observed for the values of soil density, the higher percentage of macropores in C2 can be justified by the effect of the soil rotation operations before planting the cane. Changes in the mass/volume ratios of cultivated soils occur mainly due to the effect of the use of machines for soil preparation and crop harvesting. The macropores can be considered the least stable and thus undergo changes when subjected to the stresses applied by the preparation and traffic systems, becoming easily unstable and affecting the total porosity (Tormena et al.,1998).

In the three layers evaluated, the lowest values of penetration resistance were obtained in NF (Figure 4). There was a variation of the PR values of the 0.00 to 0.05 m layer. The C2 presented the lowest PR (1.49 MPa) while the areas C4 and C6 presented higher values (3.16 MPa and 3.69 MPa, respectively).

The highest values of PR found in areas C4 and C6 can be attributed to the longer exposure time to the pressures exerted by agricultural machinery during crop cycles, such as fertilization and application of insecticide and herbicide products. The values of PR found in the areas C4 and C6 are above the value of 3 MPa, which can be considered restrictive to the growth of the roots for agricultural production and conventional preparation systems o (Beutler et al., 2001; Silva Júnior et al., 2013).

In the 0.05 to 0.10 m layer, the lowest PR value was obtained in area C2 and no difference was observed between C4 and C6. In the 0.10 to 0.20 m layer there was no significant difference of PR in C2, C4 and C6, and these values were higher than in NF, corroborating with Tavares Filho et al. (2001) and Baquero et al. (2012).

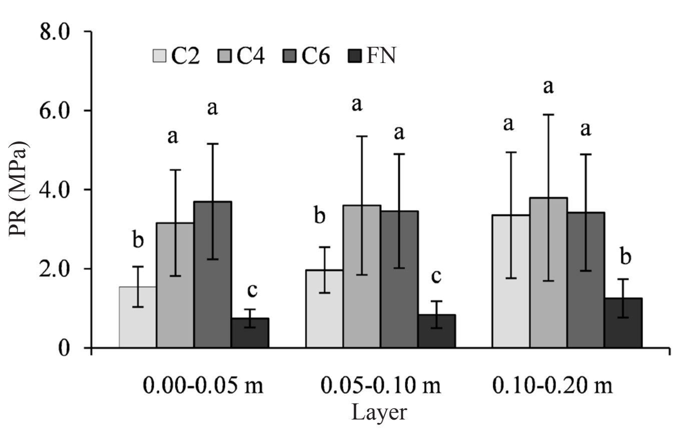

Figure 4. Penetration resistance (PR, kPa) of a Red Latosol with two (C2), four (C4) and six (C6) years of cultivation and native forest (NF) area in the layers 0.00 to 0.05 m, 0.05 to 0.10 m and 0.10 to 0.20 m. Values followed by the same letter in each layer do not differ by Dunn test at 5% significance. Vertical bars indicate the standard deviation of the mean of each evaluation.

Soil compressibility

The uniaxial compression curves reveal that in all the layers the curves of the soil under NF presented the greatest deformations in comparison to the curves in the soils cultivated with cane, which can be verified by the higher values of displacement of the curves. The higher deformation may be associated with lower initial compaction, indicated by lower density (Figures 5a, 5b and 5c). According to Silva et al. (2002), in systems with lower density there is greater susceptibility to compaction due to the larger void space and fewer points of contact between solid particles.

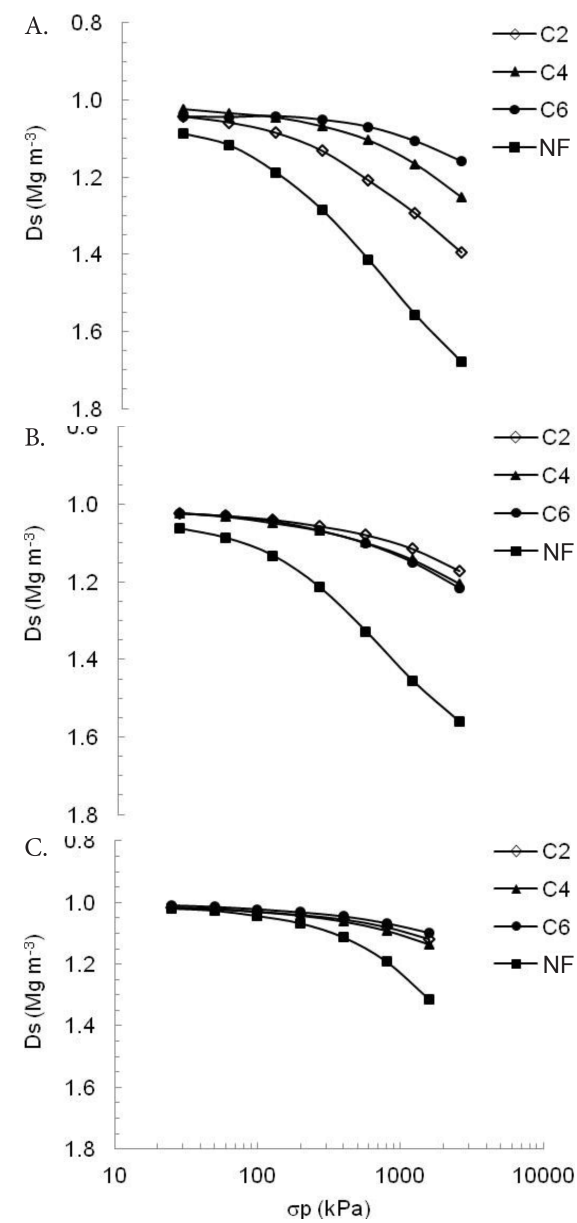

Figure 5. Normalized uniaxial compression curves of layers 0.00 to 0.05 m (a), 0.05 to 0.10 m (b) and 0.10 to 0.20 m (c) of a Red Latosol with two (C2), four (C4) and six (C6) cultivation years of sugarcane and in the native forest area (NF) in Salto do Jacuí, RS, Brazil.

In the layers 0.00 to 0.05 m and 0.05 to 0.10 m, σp was significantly higher in areas cultivated with sugarcane when compared to NF (Table 2). According to Silva & Cabeda (2006), the soil under native forest presents the lowest values of pre-consolidation pressures due to the fact that it did not suffer the pressures of agricultural machinery of a cultivated soil, but only the pressures of a soil exposed to the environment developed during the wetting and drying cycles (Vasconcelos et al., 2012).

Among the cultivated areas, in the superficial layer, the σp in C2 was lower than the values of C4 and C6, which can be justified by the fact that after two years there may still exist the effect of soil tillage operations (plowing, weeding) for the implantation of sugarcane. The σp in the 0.05 to 0.10 m layer did not differ between cultivated areas and in the 0.10 to 0.20 m layer there was no difference between the treatments (Table 2).

In the 0.00 to 0.05 m layer, the value of the CI in NF was significantly higher when compared to C4 and C6, but this difference was not observed between NF and C2. In the other layers evaluated, the CIs of the cultivated areas did not differ and were significantly lower than those of NF. In a study by Scariot et al. (2009), the authors found higher CI in native forest when compared to cultivated soil, and they concluded that the greater compressibility under native forest is probably due to the higher porosity and lower soil density.

In the three layers evaluated, the $Ds_{σp}$ did not differ between the areas C2, C4 and C6, being the values higher than the NF. By analyzing the mean values of Ds (Figures 1a, 2a and 3a), we verified that all areas presented values lower than the maximum allowed by $Ds_{σp}$. However, the values of Ds and $Ds_{σp}$ are close, which indicates that the permanence of the adopted management may in the future cause degradation of the soil structure.

Correlations between density, porosity, penetration resistance and soil compressibility

There was a negative correlation between PR and Pt and positive correlation of PR with Ds in the three layers analyzed (Table 3). The increased PR is a consequence of the decreased porous space and increased density, corroborated by Melo et al. (2008). In the 0.00 to 0.05 m and 0.05 to 0.10 m layers, there was a positive correlation between the PR and the p, confirming that higher values of σp are related to the increase in penetration resistance (Lima et al., 2006; Suzuki et al., 2008).

There was a negative correlation between σp and Ma in the layers 0.00 to 0.05 m and 0.05 to 0.10 m. With the compacting process there is a reduction of the porous space, especially the macroporosity. According to Boone & Venn (1994), during soil compression the larger pores, responsible for soil aeration, decrease and this decrease in aeration porosity may be 1.5 to 2 times greater than the decrease in total porosity.

In general, areas with more than two years of sugarcane cultivation had higher values of Ds, of pre-consolidation pressure and, consequently, of degree of compaction. Therefore, it is relevant to evaluate the ability of a soil to be used properly, considering different agricultural managements in order to avoid degradation.

Table 2. Pre-consolidation pressure (σp), compression index (CI), pre-consolidation pressure density (**$Ds_{σp}$**), degree of compaction in pre-consolidation pressure (DCσp), at 200kPa (DC_{200}kPa) and at 1,600kPa ($DC_{1.600}$kPa) in the areas and layers of a Red Latosol.

Variables	C2	C4	C6	NF
		0.00 - 0.05 m		
[1]σp (kPa)	196.4 (±40.72) c	323.9 (±31.05) a	282.1(±41.26) b	78.0 (±27.27) d
[2]CI	0.43 (±0.05) ab	0.33 (±0.09) b	0.38 (±0.10) b	0.44 (±0.05) a
[1]$Ds_{σp}$ (kg dm^{-3})	1.40 (±0.09) a	1.44(±0.12) a	1.44 (±0.12) a	1.23 (±0.11) b
[1]$DC_{σp}$ (%)	90.2(±0.02) b	92.9 (±0.02) a	91.7 (±0.01) ab	86.2 (±0.03) c
[1]DC_{200} kPa (%)	87.7 (±0.03) b	92.1(±0.02) a	90.0 (±0.02) ab	77.6 (±0.04) c
[1]$DC_{1,600}$ kPa (%)	70.4 (±0.04) b	79.6 (±0.05) a	77.3 (±0.04) a	58.5 (±0.04) c
		0.05 - 0.10 m		
[2]σp (kPa)	334 (±56.93) a	312 (±46.32) a	306 (±89.74) a	101 (±35.01) b
[2]CI	0.26 (±0.05) b	0.25 (±0.09) b	0.31 (±0.10) b	0.42 (±0.05) a
[2]$Ds_{σp}$ (kg dm^{-3})	1.57 (±0.09) a	1.62 (±0.14) a	1.56 (±0.16) a	1.24 (±0.08) b
[2]$DC_{σp}$ (%)	93.7 (±0.01) a	93.2 (±0.01) a	93.6 (±0.01) a	88.5 (±0.02) b
[2]DC_{200} kPa (%)	93.0 (±0.01) a	92.5 (±0.02) a	92.0 (±0.02) a	79.7 (±0.04) b
[1]$DC_{1,600}$ kPa (%)	83.7 (±0.04) a	81.7 (±0.04) a	80.6 (±0.06) a	62.7 (±0.05) b
		0.10 - 0.20 m		
[2]σp (kPa)	359 (±40.14) a	347 (±34.36) a	318 (±38.87) a	389 (±82.04) a
[2]CI	0.16 (±0.07) b	0.23 (±0.10) b	0.17 (±0.11) b	0.49 (±0.12) a
[2]$Ds_{σp}$ (kg dm^{-3})	1.53 (±0.15) a	1.65 (±0.15) a	1.57 (±0.30) a	1.28 (±0.09) b
[2]$DC_{σp}$ (%)	94.7 (±0.01) a	94.1 (±0.01) a	95.8 (±0.14) a	93.5 (±0.01) a
[2]DC_{200} kPa (%)	94.1 (±0.01) a	93.7 (±0.01) a	94.9 (±0.01) a	92.2 (±0.03) b
[2]$DC_{1,600}$ kPa (%)	88.9 (±0.04) a	86.7 (±0.04) a	92.0 (±0.03) a	76.9 (±0.07) b

C2 - soil under sugarcane with two years of cultivation; C4 - soil under sugarcane with four years of cultivation; C6 - soil under sugarcane with six years of cultivation; NF - soil under native forest area. [1]Variable analyzed by the F test; values followed by the same letter in the row do not differ from each other by the Tukey test at 5% significance; [2]Variable analyzed by the Kruskal-Wallis test; values followed by the same letter in the row do not differ by Dunn test at 5% significance.

Table 3. Pearson correlation of the soil physical parameters for the soil layers analyzed in the areas cultivated with sugarcane (C2, C4 and C6) and in the native forest (NF) area.

	Ds	Ma	Mi	Pt	PR
			0.00 a 0.05 m		
PR	0.59***	-0.71***	0.238*	-0.56***	
CI	-0.385**	0.483***	-0.101^{ns}	0.374***	-0.518***
σp	0.668***	-0.702***	0.249*	-0.597***	0.745***
$DC_{\sigma p}$	0.524***	-0.614***	0.215**	-0.522***	0.637***
			0.05 a 0.10 m		
PR	0.495***	-0.476***	0.109^{ns}	-0.49***	
CI	-0.386***	0.221^{ns}	-0.104^{ns}	0.386***	-0.366***
σp	0.42***	-0.668***	0.1^{ns}	-0.45***	0.55***
$DC_{\sigma p}$	0.44***	-0.606***	0.0793 ns	-0.478***	0.469***
			0.10 a 0.20 m		
PR	0.261*	-0.182^{ns}	-0.148^{ns}	-0.319**	
CI	-0.323**	0.137^{ns}	0.114^{ns}	0.142^{ns}	-0.478***
σp	-0.151^{ns}	0.213^{ns}	0.0674^{ns}	0.232^{ns}	-0.16^{ns}
$DC_{\sigma p}$	-0.0958^{ns}	0.0674^{ns}	-0.112^{ns}	0.0637^{ns}	-0.0281^{ns}

C2 - sugarcane with two years of cultivation; C4 - sugarcane with four years of cultivation; C6 - sugarcane with six years of cultivation; NF - native forest area. Ds - soil density (kg dm^{-3}); Ma – macroporosity (%); Mi - microporosity (%); Pt - total porosity (%); PR - penetration resistance (MPa); CI - compression index; σp – pre-consolidation pressure (kPa) and DC - degree of compaction. (%). * significant at 5%; ** significant at 1% and *** significant at 0.1%.

Conclusions

Over time, conventional sugarcane cultivation provides an increase in soil density, soil penetration resistance and soil porosity, mainly due to the reduction of macroporosity. These changes are of such magnitude that they can be considered restrictive to root development.

In the area with six years of cultivation, in which the values of the soil density are, on average, closer to the values of density in the pre-consolidation pressure, there was a greater soil degradation.

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