

Physical properties of Oxisol under conventional corn cultivation and no-till management systems

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Abstract

Searches for soil management systems that aim at maintaining soil quality are fundamental, along with sustainable agricultural and farming management. Thus, the aim of the present research was to assess soil parameters such as porous system, soil resistance to penetration, aggregate stability, relative soil density and the S index of an Oxisol under the conventional and no-till sowing management systems of corn production. They soils of the experimental areas were classified as a typical Oxisol with medium texture (LVd1) and typical Oxisol of clayey texture (LVd2). The experimental design was completely randomized split plot, with six replications. The plots (60 m²) consisted of six soil management systems (1 - SD¹_{LVd1} = after one year no-till sowing; 2 - SD⁸_{LVd1} = after 8 years no-till sowing; 3 - SD¹⁰_{LVd1} = after 10 years no-till sowing; 4 - CC_{LVd1} = conventional sowing; 5 - SD¹²_{LVd2} = after 12 years no-till sowing; 6 - CC_{LVd2} = conventional sowing) and the subplots consisted of three soil layers (0-0.10, 0.10-0.20 and 0.20-0.30 m deep). The results showed that in three analyzed layers, the no-till sowing on medium texture Oxisol had higher densities. Treatments of medium texture Oxisol showed higher values of maximum soil density. This occurred because the clay content influenced a larger quantity of surface charges and specific surface area which decreased the susceptibility to soil compacting. The 12-year-old no-till sowing yielded the lowest corn productivity (5.9 Mg ha⁻¹), probably due to the formation of compact layers, mainly near the soil surface.

Keywords: S index, aggregation, water retention, conventional sowing, no-tilling sowing.

Abbreviations: CC_conventional sowing; SD_{no-till sowing}; LVd1_typical Oxisol medium texture; LVd2_typical Oxisol clayey texture; DMP_mean weighted diameter; Ug_water content; Ds_soil density; Dsmax_the maximum density; Dsr_the relative soil density

Introduction

The preparation system influences the physical attributes of the soil, modifying the air and water dynamic, by which management system controls and reduces degradation, maintaining the agronomic and economic sustainability of the soils. The soil may be compacted by human action, after which it does not allow growth of plant root system. The soil compaction also reduces infiltration, nutrient absorption, crop productivity and increases the surface water run-off.

However, no-till sowing can maintain the agricultural system more productive due to the reduction in machine traffic and soil turnover, allowing its preservation and even the recovery of its structure. This system maintains the soil organic carbon at proper levels and gives better sustainability and production capacity to agricultural soils (Vezzani and Mielniczuk, 2009). However, in some situations, no-till sowing can increase soil compacting (Almeida et al., 2008), and increase soil resistance to penetration and

reduce macroporosity (Gozubuyuk et al., 2014). Constant machine traffic and the implementation used in conventional sowing of the soil can aggravate the physical attributes of the soil (Oliveira et al., 2015). This can cause increase in density, decrease in macroporosity, total porosity, organic matter accumulation and consequently the crop yield.

Among the soil physical attributes used to assess its structure, the most outstanding is soil density, macroporosity, soil resistance to penetration, aggregate stability, S index and maximum soil density. These attributes are used in the study of management systems and their impact on the soil physical quality.

According to Reichert et al. (2009), porosity controls several physical properties of the soil, and macroporosity is an important indicator to assess the soil structure, because

reduced macroporosity to values below $0.10 \text{ m}^3 \text{ m}^{-3}$ may restrict crop yield (Beutler and Centurion, 2004).

Another physical attribute of the soil that can be used to assess the effect of management systems on the root environment is soil resistance to penetration that influences root growth (Tavares Filho and Ribon, 2008). Soil management practices and their intrinsic characteristics (mineralogy and texture) directly interfere with soil aggregation formation because of their influence on microorganism activity (Vargas and Scholles, 2000), organic matter dynamic (Zanatta et al., 2007) and plant root development (Li et al., 2006). In clayey soils, with increase of organic matter contents, the maximum soil density is decreased and the optimal moisture of compacting is enhanced (Marcolin and Klein, 2011).

Dexter (2004) proposed a method to identify degradation of the physical quality of soil, called the S index, that is based on the inflection point of the water retention curve model. However, factors related to the texture, structure and organic matter influence pore size and distribution that reflect the physical quality of the soil. Thus, structural conditions that indicate adequate physical functioning of the soil are related to a steeper curve slope and higher S index values ($S > 0.035$). The better size distribution of the pore and S index values less than 0.035 are found in areas with restrictive root growth. The values less than 0.020 for this index indicate strong restriction to plant root growth, that is, the physical conditions of degraded soils (Dexter, 2004).

Thus the objective of the present research was to assess the physical attributes of an Oxisol (clayey and medium texture) under the no-till and conventional sowing management systems and to assess the corn crop production.

Results and Discussion

Soil porosity

The conventional sowing on 0-0.10 m and 0.10-0.20 m layers of clayey texture soil (CC_{LVd2}) affected the macroporosity compared to other treatments that showed higher values (Table 1). Rós et al. (2012) reported similar results but in the 0-0.15 m layer, where the macroporosity was higher in the conventional compared to the no-till sowing. This is mainly due to the effects of soil mobilization that destroyed the aggregates and also affected the pore development. In 0.20-0.30 m layer, the treatments of one year no-till sowing ($SD1_{LVd1}$), 8 years no-till sowing ($SD8_{LVd1}$), 12 years no-till sowing ($SD12_{LVd2}$) and conventional sowing (CC_{LVd2}) in medium texture soil clayey texture did not differ but $SD1_{LVd1}$ was similar to 10 years no-till sowing ($SD10_{LVd1}$) and conventional sowing (CC_{LVd1}) in medium texture soil. According to Calonego et al. (2012), there is a natural process of particle accommodation in the subsurface, which does not show difference between the treatments, permitting similarity of soil with and without turnover. Macroporosity values below $0.10 \text{ m}^3 \text{ m}^{-3}$ can alter crop development and productivity, according to Lanza et al. (2007). Thus, the results of all the treatments show that in all the layers, the macroporosity values are not considered impediments.

Microporosity values show that in 0-0.10 m layer, $SD1_{LVd1}$ was similar to CC_{LVd1} and $SD12_{LVd2}$ in the clayey texture and there was similarity between $SD8_{LVd1}$ and $SD10_{LVd1}$, because

the soil management did not directly influence the microporosity (Giarola et al., 2007). For the 0.10-0.20 m layer, $SD12_{LVd2}$ showed a bigger value that did not differ from $SD1_{LVd1}$ which in turn did not differ from CC_{LVd1} . The CC_{LVd1} and CC_{LVd2} were similar in 0.20-0.30 m layer.

Regarding total porosity, the CC_{LVd2} , showed higher values in all three analyzed layers and differed from the other treatments. The increase in the macroporosity and total porosity in the CC_{LVd2} surface layers was coherent with the reduction in density in this treatment. Similar results were found by Mendonça et al. (2012), where the soil was sown with grasses and legumes. The mixture of grasses and legumes had different root systems and lengths, causing bigger macroporosity and less density to the soil after the decomposition of the plant root matter.

Bulk density

Higher bulk density values were observed in the 0-0.10 m and 0.10-0.20 m layers in the soil under $SD8_{LVd1}$ and $SD10_{LVd1}$ treatments. In the 0-0.10 m layer, $SD10_{LVd1}$ was similar to $SD1_{LVd1}$ that; however, did not differ from CC_{LVd1} . In the 0.20-0.30 m layer, the $SD1_{LVd1}$, $SD8_{LVd1}$ and $SD10_{LVd1}$ had statistically similar higher values. The $SD1_{LVd1}$ also did not differ from the CC_{LVd1} . Therefore, in the three analyzed layers, the no-till sowing, in the medium texture soil, presented higher densities than CC_{LVd2} . In some cases, compaction of surface soil can be considered as normal under the no-till sowing system, in which it does not damage crop production, as demonstrated by Tavares Filho et al. (2006). These authors reported that in Oxisol, the highest soil density values were observed in the treatment under the no-till sowing system for more than 20 years, compared to treatments with scarification. Beutler et al. (2012), worked with a Litolite Neosol and also reported lower soil density in the 0-0.05 m layer under conventional sowing compared to the no-till sowing system due to soil turnover. Similar results were reported by Rós et al. (2012), who observed that the D_s was smaller in the conventional compared to no-till sowing in the 0-0.15 m layer of an red – yellow Argisol. However, it was consequence of using a disc plough, leveling grade and construction swath, that decreased the D_s in the mobilized layer.

Soil resistance to penetration

For soil resistance to penetration, the $SD12_{LVd2}$ presented a value higher than that of the other treatments in the 0-0.10 m layer. Similar results were reported by Sales et al. (2016), where the biggest RP was observed in the SD for all the rotations (sorghum, sunflower and corn) at the depth of 0.00-0.05 m. In the 0.10-0.20 m layer, $SD12_{LVd2}$ and $SD8_{LVd1}$ presented higher values, but the last treatment did not differ from the others. In the 0.20-0.30 m layer, $SD12_{LVd2}$ differed from $SD1_{LVd1}$, $SD10_{LVd1}$ and CC_{LVd1} .

These data corroborate with findings of Bono et al. (2013), who observed increase of soil resistance to penetration in the no-till system. Rós et al. (2012) also observed that in conventional sowing, as far as the 0.25 m layer, the RP was less than that in no-till sowing. At the depth of 0.30 m, the two sowing systems presented similar RP values that were bigger than in the other layers, corroborating with the results of the present study.

Table 1. Physical attributes of the Oxisol under management systems.

Layers (m)	Management Systems					
	SD1 _{Lvd1}	SD8 _{Lvd1}	SD10 _{Lvd1}	CC _{Lvd1}	SD12 _{Lvd2}	CC _{Lvd2}
Macroporosity (m ³ m ⁻³)						
0-0.10	0.13 DEa	0.12 Ea	0.15 CDa	0.16 BCa	0.19 Ba	0.31 Aa
0.10-0.20	0.13 Ba	0.13 Ba	0.13 Bb	0.15 Ba	0.13 Bb	0.26 Ab
0.20-0.30	0.13 ABa	0.13 ABa	0.11 Bc	0.11 Bb	0.14 Ab	0.15 Ac
CV (%) Plot = 10.43	CV(%) Split-plot = 9.42					
Microporosity (m ³ m ⁻³)						
0-0.10	0.30 Aa	0.27 Ba	0.26 Ba	0.30 Aa	0.28 Aba	0.22 Cb
0.10-0.20	0.28 ABb	0.23 Db	0.21 Db	0.26 BCb	0.29 Aa	0.24 CDb
0.20-0.30	0.28 Bb	0.25 Cab	0.25 Ca	0.30 Aba	0.29 Ba	0.32 Aa
CV (%) Plot = 6.58	CV(%) Split-plot = 6.39					
Total Porosity (m ³ m ⁻³)						
0-0.10	0.46 Ba	0.38 Ca	0.41 Ca	0.46 Ba	0.47 Ba	0.53 Aa
0.10-0.20	0.41 Bb	0.36 Ca	0.34 Cb	0.41 Bb	0.42 Bb	0.50 Ab
0.20-0.30	0.39 CDb	0.38 CDa	0.36 Db	0.41 BCb	0.43 Bb	0.47 Ac
CV (%) Plot = 3.85	CV(%) Split-plot = 4.51					
Bulk Density (kg dm ⁻³)						
0-0.10	1.46 BCa	1.60 Aa	1.53 ABb	1.41 CDb	1.35 Db	1.18 Ec
0.10-0.20	1.50 Ba	1.62 Aa	1.64 Aa	1.53 Ba	1.46 Ba	1.26 Cb
0.20-0.30	1.54 ABa	1.57 Ab	1.62 Aa	1.50 Ba	1.37 Cb	1.36 Ca
CV (%) Plot = 2.58	CV(%) Split-plot = 3.69					
Soil Resistance to Penetration (MPa)						
0-0.10	0.33 Cb	0.75 Ba	0.27 Cb	0.82 Ba	1.21 Aa	0.18 Cb
0.10-0.20	0.57 Bab	0.89 ABa	0.61 Ba	0.67 Ba	1.15 Aa	0.68 Ba
0.20-0.30	0.79 BCa	0.98 ABa	0.55 Ca	0.68 BCa	1.12 Aa	0.84 ABCa
CV (%) Plot = 18.59	CV(%) Split-plot = 22.57					

Means followed by the same uppercase letter on the line and the same lowercase letter in the column do not differ by the Turkey test ($p < 0.05$). SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVd1 and LVd2 = Oxisol from the experimental area, medium clayey texture, respectively.

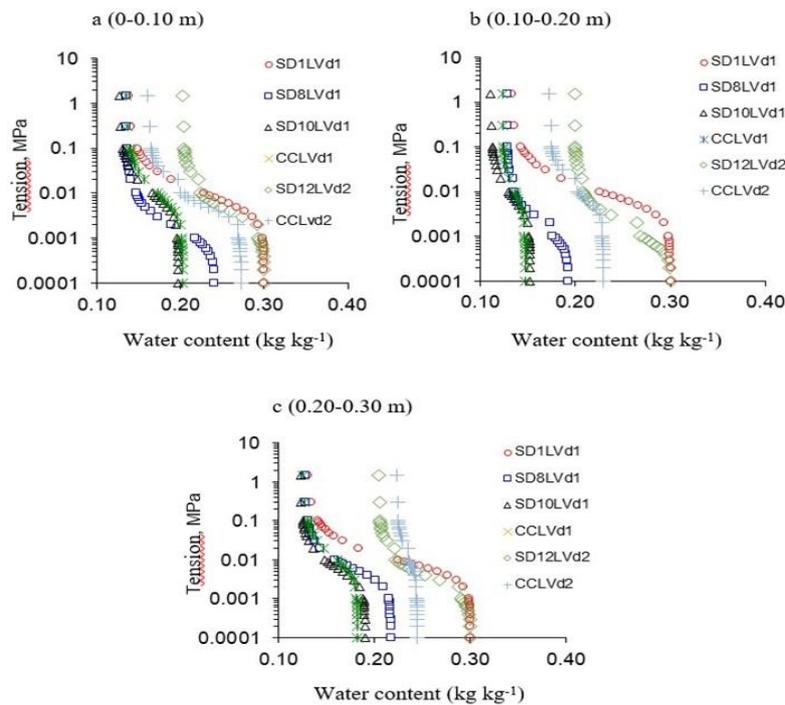


Fig 1. Water retention curves in the different soil use and management systems, in different layers. SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVd1 and LVd2 = Oxisol from the experimental area, medium clayey texture, respectively.

Table 2. S index values for the Oxisol management systems.

Tratamentos	S
SD1 _{Lvd1} ⁽²⁾	0.055 b ⁽¹⁾
SD8 _{Lvd1}	0.035 d
SD10 _{Lvd1}	0.035 d
CC _{Lvd1}	0.053 b
SD12 _{Lvd2}	0.043 c
CC _{Lvd2}	0.081 a
DMS	0.005
CV(%)	11,49
F	162,42**

⁽¹⁾Means followed by the same letter in the column do not differ by the Turkey test ($p < 0.05$). ** significant at 1% probability. SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVD1 and LVD2 = Oxisol from the experimental area, medium clayey texture, respectively.

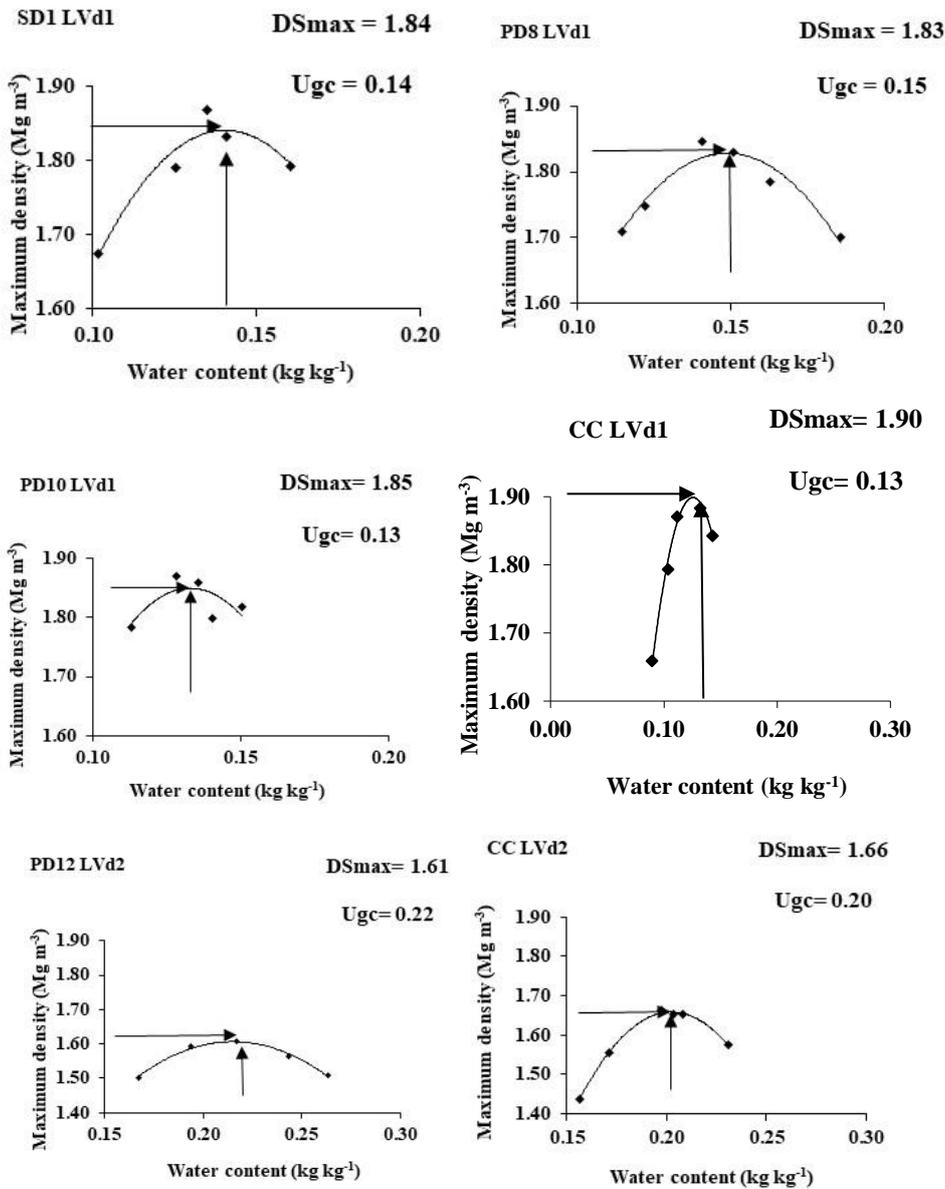


Fig 2. Maximum density (DSmax) and critical particle moisture Critical gravimetric moisture (Ugc) determined by the Proctor test in the 0-0.10 m layer. SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVD1 and LVD2 = Oxisol from the experimental area, medium clayey texture, respectively.

Table 3. Mean weighted diameter of the Oxisol submitted to management systems and layers and to native Forest.

Layers (m)	Treatments							
	MN _{Lvd1}	SD1 _{Lvd1}	SD8 _{Lvd1}	SD10 _{Lvd1}	CC _{Lvd1}	MN _{Lvd2}	SD12 _{Lvd2}	CC _{Lvd2}
DMP (mm)								
0-0.10	5.78 Aa	3.12 Ca	3.81 Ba	3.90 Ba	2.50 Da	5.84 Aa	4.10 Ba	2.41 Da
0.10-0.20	5.36 Ab	2.64 BCb	1.57 Db	2.22 Cb	2.84 Ba	5.89 Aa	2.19 Cb	2.49 BCa
0.20-0.30	5.22 Bb	1.16 Dc	0.99 Dc	1.08 Dc	2.60 Ca	5.78 Aa	1.24 Dc	2.56 Ca
CV (%) Plot = 7.62	CV (%) Split-plot = 7.54							

Means followed by the same uppercase letter on the line and the same lowercase letter in the column do not differ by the Turkey test ($p < 0.05$). MN = native forest. SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVd1 and LVd2 = Oxisol from the experimental area, medium clayey texture, respectively. DMP = weighted mean diameter.

Table 4. Maximum density (Dsm_{ax}), soil density (Ds) and relative density (Dsr) of Oxisol under the management systems.

	SD1 _{Lvd1} ⁽¹⁾	SD8 _{Lvd1}	SD10 _{Lvd1}	CC _{Lvd1}	SD12 _{Lvd2}	CC _{Lvd2}
Ds _{m_{ax}} (kg dm ⁻³)	1.84	1.83	1.85	1.90	1.61	1.66
Ds (kg dm ⁻³)	1.50	1.40	1.48	1.39	1.34	1.11
Dsr	0.82	0.77	0.80	0.73	0.83	0.67

⁽¹⁾ SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVd1 and LVd2 = Oxisol from the experimental area, medium clayey texture, respectively.

Table 5. Plant height (Alt), height of insertion of the first year (Ins), stem diameter (Col) and yield (Prod) of corn plants in Oxisol, under no-till sowing and conventional sowing.

Treatamentos	Alt (m)	Ins (m) ^{ns}	Col (mm)	Prod (Mg ha ⁻¹)
SD1 _{Lvd1}	2.77 ab	1.41	23.46 abc	7.5 ab
SD8 _{Lvd1}	2.66 bc	1.40	23.45 abc	6.2 ab
SD10 _{Lvd1}	2.73 ab	1.38	22.00 c	7.0 ab
CC _{Lvd1}	2.59 c	1.32	22.68 bc	8.0 a
SD12 _{Lvd2}	2.78 a	1.32	24.97 a	5.9 b
CC _{Lvd2}	2.78 a	1.39	24.32 ab	7.8 ab
CV (%)	2.47	5.95	5.04	15.07

Means followed by the same letter in the column do not differ by the Turkey test t 5% ns = n on significant. SD1 = after one year of no-till; SD8 = after eight years of no-till; SD10 = after ten years no-till sowing; SD12 = after twelve years no-till sowing and CC = conventional sowing; LVd1 and LVd2 = Oxisol from the experimental area, medium clayey texture, respectively.

Water retention curves

Fig (1a, b, c) shows the water retention curves in the Oxisol, under the sowing systems studied in the 0-0.10 m, 0.10-0.20 m and 0.20-0.30 m layers. Each soil presented a specific water retention curve, due to factors such as the clay fraction content and mineralogy (Ferreira et al., 1999), organic matter content, soil structure and density (Beutler et al., 2001).

In our three analyzed layers, the SD10_{Lvd1} and CC_{Lvd1} treatments had similar water retention at 0.01 MPa tension, corresponding to the field capacity. SD1_{Lvd1} and SD12_{Lvd2} presented bigger water retention, which probably occurred due to the alteration in the pore size distribution, where these treatments presented larger microporosity (Table 1) in the 0-0.10 m and 0.10-0.20 m layers, followed by the CC_{Lvd2} and SD8_{Lvd1} treatments. However, although these treatments presented lower values, the bigger water retention was occurred because no-till sowing presented larger organic matter content and CC_{Lvd2} also contained high iron oxide levels.

S index

The S index values were calculated from the parameters established by the water retention curves, Fig 1. Table 2 refers to the S index, where CC_{Lvd2} presented the biggest value, differing from the other treatments. SD1_{Lvd1} and CC_{Lvd1} were similar, and neither SD8_{Lvd1} nor SD10_{Lvd1} did differ, showing the lowest values of 0.035. This value was

found by Dexter (2004) to be limiting for the soils that have degraded structure. But S index values lower than 0.020 were not observed, which considered as an impediment to plant root development. Similar results were reported by Almeida et al. (2014).

Mean weighted diameter

MN_{Lvd2} showed higher values for DMP in the three analyzed layers (Table 3). Analysis of the 0-0.10 m layer showed that the soils under native forest differed from the other sowing systems for the DMP. Similar results were reported by Cunha et al. (2011), where the soil under MN presented bigger DMP compared to different cover plants and in experiments with beans and corn.

In this index, the oldest no-till sowing presented bigger values than the conventional sowing in the 0-0.10 m layer in both soils. The best conditions of structure, in this specific case, were not shown by the highest aggregate percentages, because the highest Ds values (SD8_{Lvd1} and SD10_{Lvd1}) and RP values (SD12_{Lvd1}) were observed in this layer. This confirm the results by Soares et al. (2016) who observed higher percentage of aggregation with bigger diameters, and the highest Ds and RP values and the lowest macroporosity and total porosity values in the pasture area. This smaller aggregation under conventional sowing was related to the small accumulation of organic matter and soil turnover, as reported by Vezzani and Mielniczuk (2011). Similar performance was observed by Calegari et al. (2006), who observed that eight years of no-till sowing, with the annual

addition of residues on the surface, benefited soil aggregation.

There was no difference among layers in the treatments under conventional sowing in both the soil textures (medium and clayey) and in the soil under forest with clayey texture. This was probably due to soil turnover (conventional sowing). The oxide mineralogy of the soil under forest conferred high natural aggregation to this soil, resulting in more developed porous structure with more stable aggregates (Góes et al., 2005).

In the 0.20-0.30 m layer, the conventional sowing presented higher DMP than the no-till sowing systems. As reported by Cunha et al. (2011), the bigger aggregation in this layer was due to compression forces, contrary to the biological action of microorganisms and roots.

Maximum density

In order to establish reference values, the amplitude of the maximum density in different soils and textures reflects the importance of this study. Higher soil density values ($D_{s_{max}}$) were found in the treatments under LVd1 (medium texture), with 1.90 kg dm^{-3} , compared to LVd2 (clayey texture) with 1.61 kg dm^{-3} (Fig 2). These differences are related to the texture of the soils, because clayey soil interacts better with water, decreasing the susceptibility of the soil to compacting. In addition, there are other attributes that interfere in the performance of the soil compacting curve, such as the soil organic matter content and composition.

It was observed that the clay variable significantly influenced the $D_{s_{max}}$, because the lowest $D_{s_{max}}$ of 1.61 kg dm^{-3} was found in the SD12_{LVd2} treatment. Klein (2008) reported $D_{s_{max}}$ of 1.55 kg dm^{-3} for a clayey soil (660 g kg^{-1} clay), while in a medium texture soil (320 g kg^{-1} clay), the $D_{s_{max}}$ was 1.77 kg dm^{-3} , proving the effect of texture on the $D_{s_{max}}$. Comparison of these data with the characteristics of each soil showed that there was an inverse relationship of the $D_{s_{max}}$ with the organic matter and clay contents, corroborating the results obtained by Brady and Weil (2008), whereas the bigger the organic matter content, the lower is the $D_{s_{max}}$. Meurer et al. (2000) reported that this occurs because of the fact that the clay influences a larger quantity of surface charges and specific surface area. Reichert et al. (2009) also attributed bigger water retention to clayey soils due to bigger capillarity, compared to soils with larger silt and/or sand content. Clay soils are also related to clay particle aggregation, that present intra-aggregated porosity that increases the porous space volume, mainly those pores with reduced diameter (Brady and Weil, 2008).

The $D_{s_{max}}$ values were occurred when the water content was between 0.13 kg kg^{-1} and 0.22 kg kg^{-1} (Fig 2). Nogueira (1998) reported that under conditions of less water content in the soil, there is a smaller degree of compacting, because the particles are agglutinated by cohesion forces, forming more resistant microaggregates that prevent the displacement of the particles and their rearrangement and consequent increase in density. The $D_{s_{max}}$ values have increased with the intensity of the adopted management, and under more conservationist management systems, such as no-till sowing, the resistance of the soil to compaction is increased (Blanco-Canqui et al., 2009).

Relative density

The highest Dsr values shown in Table 4 were detected in the treatments under the no-till sowing system, compared to the treatments under conventional sowing. Thus, it was observed that the Dsr is a soil quality indicator and it is independent from its texture class, as reported by Luciano et al. (2012). Reduction in Ds, with the increase in organic matter content in the soil results from the positive effect of the soil structural stability. It is associated to the fact that the density presented by the organic material is less than the density from other mineral solids in the soil (Braida et al., 2006).

Plant height

For plant height in Table 5, SD12_{LVd2} and CC_{LVd2} presented the highest values, but did not differ from SD1_{LVd1} and SD10_{LVd1}. These two systems did not differ from SD8_{LVd1}. The CC_{LVd1} presented the lowest value but did not differ from SD8_{LVd1}. There were differences between the treatments assessed for first ear insertion height. The stem diameter in SD12_{LVd2} presented the highest value, but was similar to SD1_{LVd1}, SD8_{LVd1} and CC_{LVd2}. The treatments that differed in yield were CC_{LVd1} and SD12_{LVd2}, whereas SD12_{LVd2} had the lowest yield. However, both of treatments were similar to the others. Almeida et al. (2014) also worked with corn and obtained bigger production in SD_{LVd1} compared to CC_{LVd1}, in medium texture. However, between the SD_{LVd2} and CC_{LVd2} treatments in clayey texture, there was no difference regarding the corn yield.

No-till sowing with the longest implementation time probably produced less yield because of the formation of compacted layers, especially close to the soil surface, because there was bigger soil resistance to penetration in this treatment in the 0-0.10 m layer (Table 1). Carvalho et al. (2004) obtained similar results when worked with a clayey type Oxisol, where corn yield in conventional sowing was bigger than that in no-till sowing.

Materials and Methods

Site description and soil classification

The experiment was carried out on two soils on the Teaching and Research Farm of the College of Agrarian and Veterinarian Sciences (Fazenda de Ensino e Pesquisa da Faculdade de Ciências Agrárias e Veterinárias da UNESP), Campus de Jaboticabal-SP, Brazil. The climate of the region is the Cwa type according to the Köppen climatic classification, with a warm summer and dry winter, 1,428 mm total annual mean precipitation and 21°C average temperature.

The soils in the two areas were classified according to the criteria of Embrapa (2006), as a typical Oxisol with clayey texture and a moderate caulinitic hypoferric (LVd). The experimental area on the medium texture soil (LVd1) resided in geographic coordinates 21°15'11"S and 48°15'58"W at 619 m altitude, cropped with corn under no-till sowing for 1, 8 and 10 consecutive years, and the experimental area on the clayey texture soil (LVd2) had geographic coordinates of 21°15'33"S and 48°16'17"W at 607 m altitude, under no-till for 12 consecutive years and under conventional sowing.

Experimental design and treatments

The experimental design was completely randomized in split plots with six replications. The plots (60 m²) consisted of six soil management systems (1 - SD1_{Lvd1} = after one year no-till sowing; 2 - SD8_{Lvd1} = after 8 years no-till sowing; 3 - SD10_{Lvd1} = after 10 years no-till sowing; 4 - CC_{Lvd1} = conventional sowing; 5 - SD12_{Lvd2} = after 12 years no-till sowing; 6 - CC_{Lvd2} = conventional sowing) and the subplots consisted of three soil layers (0-0.10, 0.10-0.20 and 0.20-0.30 m deep).

Experimental procedure and plant material

Six contiguous areas were marked for sampling purposes of each treatment, sampled in the layers 0-0.10, 0.10-0.20 and 0.20-0.30 m deep. Two adjacent areas of native forest (medium texture and clayey) were used as a reference, because it is a balanced system, without anthropic action.

Chemical analysis was made for the soils (0-0.20 m) and granulometric analysis by the pipette method following methodologies described by Embrapa (1997). Before setting up the experiment with the implantation of the no-till sowing system, the soil was cropped in the conventional preparation system with an annual rotation of corn and soybean in the summer and corn in the winter harvest.

The soil was prepared for conventional sowing (CC_{Lvd1} and CC_{Lvd2}) by scarifying to 0.30 m depth, followed by heavy and light grading. Two 2 t ha⁻¹ lime and atrazine (2.5 L ha⁻¹) were applied before sowing and nicosulfuron (1 L ha⁻¹) was applied in post emergence.

The corn (*Zea mays*) hybrid Impacto Viper from Syngenta was sown at 0.03 m depth, 0.90 m between the rows and a population of 60.000 plants per hectare in all plots. Fertilization at sowing was 350 kg ha⁻¹ of the 08-28-16 formula with zinc and the cover fertilization was made with 400 kg ha⁻¹ of the 20-00-20 formula and 200 kg ha⁻¹ urea. The herbicides used on the crop were Soberan (200 mL ha⁻¹) and Atrazine (2.0 L ha⁻¹). The plot consisted of two 6m long rows of the crops, and the useful area was considered to be the three central rows, discarding 1.5 m from each end.

Characteristics evaluated

Undisturbed soil samples were collected between the crop rows after sowing, using stainless steel cylinders with height of 0.03 m and diameter of 0.048 (53.16. cm³), that were saturated and submitted to water column heights of 0.001, 0.003, 0.006, 0.01, 0.033, 0.06, 0.1 and 0.3 MPa, in a Richards pressure chamber. The following were determined in these samples: soil density, micro-porosity by drying (0.006 MPa matrix potential), total porosity and the macroporosity was obtained from the difference between the total porosity and the microporosity (Embrapa, 1997).

The water retention curves were fitted by the model proposed by Van Genuchten (1980), from which was obtained the slope of the curve at the inflection point and, consequently the S index, as follows:

$$S = n(\theta_{sat} - \theta_{res}) + \frac{1}{m} \quad (1)$$

Where, n and m are parameters that govern the shape of the curve; θ_{sat} and θ_{res} are the saturation and residual moisture, respectively.

To determine the soil resistance to penetration, the samples were saturated by gradual increase of a water sheet in a tray and then submitted to 0.01 Mpa matrix potential in a Richards pressure chamber (Embrapa, 1997). This was measured using a laboratory static electronic penetrometer, with 0.01 m min⁻¹ constant penetration speed, reading recorded per second, cone with a 30° semi-angle and 3,14.10⁻⁶ m² area, equipped with a linear atuator and 20 kgf charge cell.

To analyze the aggregate stability in water, the samples were sieved through an 8mm mesh sieve and for each 50g sample, aggregate class distribution (8.0-4.0; 4.0-2.0; 2.0-1.0; 1.0-0.5; 0.5-0.25; < 0.25 mm) was determined, analyzed by wet sieving and slow shaking for 15 minutes. The portions retained in each sieve were transferred to aluminum tins and dried in a chamber at 105 °C, for 24 h. The mean weighted diameter (DMP) was calculated, following the method described by (Embrapa, 1997).

The maximum soil density was determined in disturbed samples, collected in the 0-0.20 m layer and sieved through 0.004 m mesh. For this, the normal Proctor test was used, with material re-use (Nogueira, 1998) To obtain the compacting curve. The soil was compacted by addition of amounts of water with 0.025 kg kg⁻¹ intervals. After each compacting, two samples were removed from the specimen (top and bottom) to determine the soil water content (Ug). Thus, for each sample, Ug values and soil density (Ds) values were obtained. The maximum density (Dsmax) was obtained from the equation of Ds with the Proctor test values. The relative soil density (Dsr) was obtained by dividing the soil density by the maximum soil density obtained in the Proctor test.

When the corn flowered, the plant height, first ear insertion height and stem diameter were determined. The crop yield was quantified at physiological maturation (corrected to 13% moisture).

Statistical analysis

The results of the soil attributes and the agronomic parameters of the corn crop were submitted to analysis of variance and the means were compared by the Tukey's test at 0.05 probability level.

Conclusion

No-till sowing medium textured soil, showed higher density values compared to conventional sowing, in the soil under clayey texture in all three studied layers. However, surface compaction of the soil in this planting system does not always damage yield. The treatments under medium texture soil showed the biggest soil maximum density values, that is the granulometric composition interfered in susceptibility to compacting. The 12 year no-till sowing system probably produced less because of the formation of compacted layers, especially close to the soil surface.

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References

- Almeida VP, Alves MC, Silva EC, Oliveira AS (2008) Crop rotation and physical and chemical properties of a red latosol in the cerrado under conventional tillage and recent no-tillage. *R Bras Ci Solo*. 32: 1227-1237.
- Almeida CX, Jorge RF, Centurion JF, Borges EN, Rossetti KV, Pereira FC (2014) Physical quality of an oxisol under no-tillage and conventional tillage. *Biosc J*. 30(5): 1395-1411.
- Beutler AN, Silva MLN, Curi N, Ferreira MM, Cruz JC, Pereira Filho IA (2001) Resistance to penetration and permeability of a typic dystrophic red latosol under management systems in the cerrado region. *R Bras Ci Solo*. 25: 167-177.
- Beutler AN, Centurion JF (2004) Effect of soil compaction in root development and in soybean yield. *Pesq Agropec Bras*. 39: 581-588.
- Beutler AN, Munareto JD, Ramão CJ, Galon L, Dias NP, Pozzebon BC, Rodrigues LAT, Munareto GS, Giacomeli R, Ramos PV (2012) Soil physical properties and rice straw levels in management systems: effect on irrigated rice yield. *R Bras Ci Solo*. 36: 1601-1607.
- Blanco-Canqui H, Stone LR, Schlegel AJ, Lyon DJ, Vigil MF, Mikha MM, Stahlman PW, Rice CW (2009) No-till induced increase in organic carbon reduces maximum bulk density of soils. *Soil Sci Soc Am J*. 73: 1871-1879.
- Bono JAM, Macedo MCM, Tormena CA (2013) Soil physical quality of an oxisol in the southwestern cerrado region under different use and management systems. *R Bras Ci Solo*. 37: 743-753.
- Brady NC, Weil RR (2008) The nature and properties of soils. 14.ed. New Jersey, Pearson Prentice Hall, 975p.
- Braida JA, Reichert JM, Veiga M, Reinert DJ (2006) Mulch and soil organic carbon content and their relationship with the maximum soil density obtained in the proctor test. *R Bras Ci Solo*. 30: 605-614.
- Calegari A, Castro Filho C, Tavares Filho J, Ralisch R, Guimarães MF (2006) Soil particle aggregation improvement through no-tillage system. *Semina Ciênc Agrár*. 27: 147-158.
- Calonego JC, Santos CH, Tiritan CS, Cunha Júnior JR (2012) Carbon stock and soil physical properties submitted to different management system. *R C*. 25:128-135.
- Carvalho MAC, Soratto RP, Athayde MLF, Arf O, Sá ME (2004) Yield of corn grown after green manures under no-tillage and conventional management system. *Pesq Agropec Bras*. 39: 47-53.
- Cunha EQ, Stone LF, Moreira JAA, Ferreira EPB, Didonet AD, Leandro WM (2011) Soil tillage systems and cover crops in organic production of common bean and corn. I - soil physical properties. *R Bras Ci Solo*. 35: 589-602.
- Dexter AR (2004) Soil physical quality: Part I. Theory. Effects of soil texture, density, and organic matter, and effects on root growth. *Geod*. 120: 201-214.
- Embrapa - Empresa Brasileira de Pesquisa Agropecuária, Centro Nacional de Pesquisa de Solos (1997) Manual de métodos de análise de solos. 2.ed. Rio de Janeiro, 212p.
- Embrapa - Empresa Brasileira de Pesquisa Agropecuária, Centro Nacional de Pesquisa de Solo (2006) Sistema brasileiro de classificação de solos. Brasília, Embrapa Produção de Informação, Rio de Janeiro, Embrapa Solos, 306p.
- Ferreira MM, Fernandes B, Curi N (1999) Mineralogy of clay fraction and structure of latosols (oxisols) from southeastern Brazil. *R Bras Ci Solo*. 23: 507-514.
- Giarola NFB, Tormena CA, Dutra AC (2007) Physical degradation of a red latosol used for intensive forage production. *R Bras Ci Solo*. 31(4): 863-873.
- Góes GB, Greggio TC, Centurion JF, Beutler AN, Andrioli I (2005) Efeito do cultivo da cana-de-açúcar na estabilidade de agregados e na condutividade hidráulica do solo. *Irrig*. 10: 116-122.
- Gozubuyuk Z, Sahin U, Ozturk I, Celic A, Adiguzel MC, (2014) Tillage effects on certain physical and hydraulic properties of a loamy soil under a crop rotation in a semiarid region with a cool climate. *Catena*. 118: 195-205.
- Klein VA (2008) Física do solo. Passo Fundo, EDIUPF, 212 p.
- Lanzanova ME, Nicoloso RS, Lovato T, Eltz FLF, Amado TJC, Reinert DJ (2007) Soil physical attributes in integrated cattle raising-crop production system under no-tillage. *R Bras Ci Solo*. 31: 1131-1140.
- Li L, Sun J, Zhang F, Guo T, Bao X, Smith A, Smith S (2006) Root distribution and interactions between intercropped species. *Oecol*. 147: 280-290.
- Luciano RV, Albuquerque JA, COSTA A, Batistella B, Warmling MT (2012) Physical attributes related to soil compaction under native vegetation of Southern Brazil. *R Bras Ci Solo*. 36: 1733-1744.
- Marcolin CD, Klein VA (2011) Determination of relative soil density through a pedotransfer function of maximum bulk density. *Acta Sci Agron*. 33: 349-354.
- Mendonça VZ, Mello LMM, Andreotti M, Pereira FCBL, Lima RC, Valério Filho WV, Yano EH (2012) Evaluation of soil physical properties in a forage-corn intercropping in succession with soybean in the cerrado region. *R Bras Ci Solo*. 37: 251-259.
- Meurer EJ, Rhenheimer D, Bissani C (2000) Fenômenos de superfície. In: Meurer E.J., ed. Fundamentos de química do solo. Porto Alegre, Genesis, 174p.
- Nogueira JB (1998) Mecânica dos solos: ensaios de laboratório. São Carlos, EESC-USP, 248 p.
- Oliveira IA, Campos MCC, Freitas L, Soares MDR (2015) Characterization of soils under different land uses in the southern region of the Amazonas. *Acta Amaz*. 45(1): 1-12.
- Reichert JM, Suzuki LEAS, Reinert DJ, Horn R, Kansson IH (2009) Reference bulk density and critical degree-of-compactness for no-till crop, production in subtropical highly weathered soils. *Soil Till Res*. 102: 242-254.
- Rós AB, Tavares Filho J, Barbosa GMC (2012) Soil physical properties and growth of sweet potato under different soil managements. *R Bras Ci Solo*. 37: 242-250.
- Sales RP, Portugal AF, Moreira JAA, Kondo MK, Pegoraro RF (2016) Physical quality of a Latosol under no-tillage and conventional tillage in the semi-arid region. *R Ciênc Agron*. 47: 429-438.
- Soares MDR, Campos MCC, Oliveira IA, Cunha JM, Santos LAC, Fonseca JS, Souza ZM (2016) Soil physical properties in areas under different land uses systems in the Manicoré region, Amazonas State, Brazil. *R Ciênc Agrar*. 59: 9-15.
- Tavares Filho J, Fonseca ICB, Ribon AA, Barbosa GMC (2006) The soil scarification effects in hydraulic conductivity of the Red Latosol (Oxisol) under No-tillage system. *Ci Rural*. 36: 996-999.

- Tavares Filho J, Ribon AA (2008) Variation in soil penetration resistance in response to sample number and sampling type. *R Bras Ci Solo.* 32: 487-494.
- Van Genuchten MTA (1980) A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci Soc Am J.* 44: 892-897.
- Vargas LK, Scholles D (2000) Microbial biomass and C-CO₂ and mineral nitrogen production in paleudult soil cultivated under different management systems. *R Bras Ci Solo.* 24: 35-42.
- Vezzani FM, Mielniczuk J (2009) An overview of soil quality. *R Bras Ci Solo.* 33: 743-755.
- Vezzani FM, Mielniczuk J (2011) Soil aggregation and carbon stock of a paleudult under different agricultural managements. *R Bras Ci Solo.* 35: 213-223.
- Zanatta JA, Bayer C, Dieckow J, Vieira FCB, Mielniczuk J (2007) Soil organic carbon accumulation and carbon costs related to tillage, sowing systems and nitrogen fertilization in a subtropical Acrisol. *Soil Till Res.* 94: 510-519.