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Soil physical properties in variable levels of soil compaction

Propriedades físicas do solo em níveis variáveis de compactação do solo

Propiedades físicas del suelo en distintos niveles de compactación del suelo

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Abstract

Due to the intense transit of agricultural machines and equipment for crop management, soil compaction is causing concern on the part of farmers. The objective of this work was to evaluate the soil physical quality of an Oxisol with different levels of tractor compaction, in Guarapuava, Paraná, PR, Brazil. The experimental design used was randomized blocks, with six repetitions. The treatments were four levels of soil compaction produced by tractor traffic, represented by: control (no last), two pasts, five pasts, and twenty pasts. It was found that soil compaction with tractor traffic greater than two passes, provided an increase in degree of compactness, clay dispersed in water and degree of dispersion, as well as a reduction in the degree of flocculation of the clays. Thus, it emphasizes the importance of considering in agricultural operations that even low levels of tractor traffic are capable of reducing the soil physical quality.

Keywords: Machine traffic; Soil degree of compactness; Clay dispersed in water; Degree of dispersion; Degree of flocculation.

Resumo

Devido o intenso trafego de máquinas e equipamentos agrícolas para o manejo das culturas, a compactação do solo vem causando preocupação por parte de agricultores. O trabalho teve como objetivo avaliar a qualidade física de um Latossolo Bruno com níveis distintos de compactação tratorizada, na região de Guarapuava, Paraná, Brasil. O delineamento experimental utilizado foi o de blocos ao acaso, com seis repetições. Os tratamentos foram quatro níveis de compactação produzidos por tráfico de trator, representados por: testemunha (sem compactação), duas, cinco e vinte passadas. Verificou-se que a compactação do solo com tráfego de trator superiores a duas passadas, proporcionaram aumento das variáveis grau de compactação, argila dispersa em água e grau de dispersão, assim como redução do grau de floculação das argilas. Assim, ressalta a importância de considerar nas operações agrícolas que mesmo níveis baixos de tráfego de trator são capazes de reduzir a qualidade física do solo.

Palavras-chave: Tráfego de máquinas; Grau de compactação do solo; Argila dispera em água; Grau de dispersão; Grau de floculação.

Resumen

Debido al intenso tráfico de maquinaria y equipos agrícolas para el manejo de cultivos, la compactación del suelo preocupa los agricultores. El objetivo de este trabajo fue evaluar la calidad física de un Latossolo Bruno con diferentes niveles de compactación del tractor, en la región de Guarapuava, Paraná, Brasil. El diseño experimental utilizado fue un bloque al azar, con seis repeticiones. Los tratamientos fueron cuatro niveles de compactación producidos por el tráfico de tractores, representados por: testigo (sin compactación), dos, cinco y veinte pasadas. Se encontró que la compactación del suelo con tráfico de tractores mayor a dos pasadas, proporcionó un aumento en el grado de compactación, arcilla dispersa en agua y grado de dispersión, así como una reducción del grado de floculación de las arcillas. Así, enfatiza la importancia de considerar en las operaciones agrícolas que incluso niveles bajos de tráfico de tractores son capaces de reducir la calidad física del suelo.

Palabras clave: Tráfico de maquinaria agrícola; Grado de compactación del suelo; Arcilla dispersa en agua; Grado de dispersión; Grado de floculación.

1. Introduction

The agricultural sector has increasingly sought to increase crop yield, and the study of soil physics has assumed great importance, aiming to maximize crop production and ensure environmental sustainability. One of the major problems is the systematic traffic of machines and implements in agricultural areas that result in changes in soil physical quality. According to Trein et al. (2009), the increase in the size and load of agricultural machinery, associated with the reduced time to carry out agricultural activities, has led farmers to carry out agricultural activities without respecting the ideal soil moisture conditions, resulting in soil compaction.

In mechanized areas, soil compaction is considered the main challenge for obtaining high productivity (Stefanoski et al., 2013), as it increases the resistance to soil penetration and can cause a reduction of root development (Chan et al., 2006; Chen & Weil, 2010). This modification of soil structure caused by soil compaction occurs due to increase in bulk density (BD), as well as by reducing of size of pores and aeration to roots of the plants (Streck et al., 2004). Soil compaction due to inadequate management can result in soil erosion, being considered one of the main causes of environmental degradation (Tretin et al., 2018).

Agricultural soils have a wide range of bulk density due to their mineralogical characteristics, texture and organic matter content (Marcolin & Klein, 2011). This bulk density variation due to the soil intrinsic properties, makes it difficult to make a decision if the soil is compacted (Brady & Weil, 2008). Through the normal Proctor test it is possible to obtain mathematically the maximum soil density (BD_{max}), as well as, the optimum humidity for soil compaction with a given applied energy (Marcolin & Klein, 2011).

Due to the difficulty of soil density not providing sufficient information about the soil compaction, depending on the texture and other soil properties, the concept degree of compactness (DC) has been used (Torres & Saraiva, 1999; Hakansson & Lipiec, 2000; Krzic et al., 2003; Santos et al., 2005; Beutler et al., 2005; Klein, 2014), which is the relationship between BD and BD_{max}, obtained by the normal Proctor test.

According to Klein (2014), the determination of the amount of clay dispersed in water (CDW) is important to determine the stability of soil aggregates. The higher the CDW levels, the greater the soil's susceptibility to erosion. Agreement with Mota et al. (2015) high levels of CDW cause problems in soil physical quality, such as clogged pores and, consequently, reduced soil water and air permeability. Despite these reports of pore clogging by CDW, there are few studies that indicate that soil compaction can negatively influence soil aggregation.

In this context, this study aimed to evaluate soil physical properties of an Oxisol with different levels of tractor compaction, in the region of Guarapuava, Paraná, Brazil.

2. Metodology

The study was carried out in the experimental area of the Department of Agronomy at UNICENTRO, located at the Cedeteg Campus, in Guarapuava, Paraná, Brazil. The soil in the experimental area is classified as Oxisol (Latossolo Bruno) with very clayed texture (EMBRAPA, 2013). The region's climate is classified as humid mesothermal subtropical Cfb (Köppen, 1948), characterized by cool summers, winters with severe and frequent frosts, with no dry season. The maximum annual average temperature is 23.5ºC and the minimum annual average temperature is 12.7ºC (IAPAR, 2015).

The experimental design was a randomized block with four treatments and six repetitions. The treatments were defined by tractor traffic: control (no last), two pasts, five pasts, and twenty pasts. The agricultural tractor used to generate the compaction levels was the John Deere 6515 model, with 110 hp power, weighted with ¾ of the tire volume with water, plus six front ballasts of 50 Kg each and four rear ballasts of 75 Kg each, generating a total load of 6 Mg.

The experimental units were represented by 16 x 5 m (80 m^2) plots, wherein the compaction treatments with agricultural tractor wheels occupied the total area of the plots. After tractor compaction, soil physical analyzes were carried out, consisting of: degree of compactness (DC, %), at depths of 7 to 12 cm and 17 to 22 cm; clay dispersed in water (CDW, g kg^{-1}), degree of flocculation (DF, %) and degree of dispersion (DD, %).

Undisturbed soil samples were collected to determination of the soil bulk density (BD) using steel rings with an internal volume of 100 cm^3 (EMBRAPA, 2017), which were dried at 105 °C for 48 hours.

To determine the maximum bulk density (BD_{max}), the normal Proctor test was used. Approximately 30 Kg of soil was collected at three random points in the experimental area. After collection, the soil was dried, disaggregated and passed through a 4 mm mesh sieve. After this procedure, the samples were subjected to the normal Proctor test, which consists of using the impact resulting from a fixed load on soil samples subjected to different humidity, resulting in a curve which represents the bulk density achieved as a function of humidity. To simulate the impact load, a 2.5 kg socket, a 10 cm diameter cylindrical mold with a height of 12.73 cm and a complementary metal ring were used as basic equipment, allowing the compaction of the third layer of material inside the cylinder.

The degree of compactness (DC) was determined by the following equation:

$$DC\ (\%) = \frac{BD\ (g\ cm^{-3})}{BD_{max}(g\ cm^{-3})}\ .100$$

Clay dispersed in water (CDW, g kg^{-1}) was estimated from air-dried fine earth, using slow mechanical stirring and distilled water, without the addition of chemical dispersant, the reading being determined from densimeter method (EMBRAPA, 2017).

The degree of clay flocculation (GF) and the degree of clay dispersion (DD) were calculated respectively by the equations:

$$DF\ (\%) = \frac{total\ clay\ (g\ Kg^{-1}) - \text{CDW}(g\ Kg^{-1})}{total\ clay\ (g\ Kg^{-1})}\ .100$$

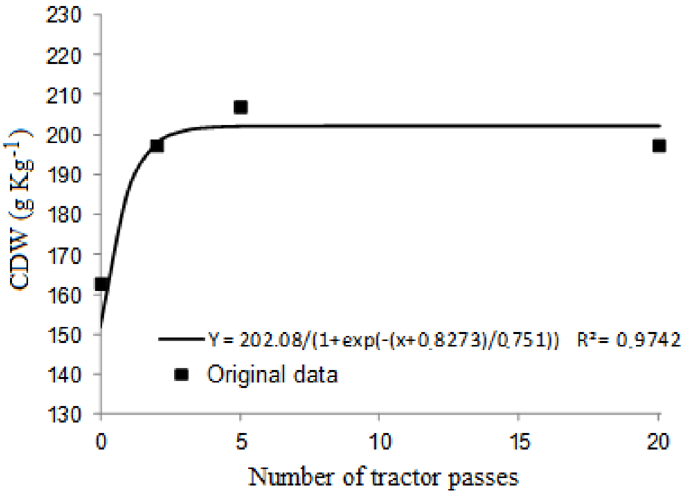
$$DD\ (\%) = 100 - DF$$

The data were subjected to analysis of variance and, through their means, regression curves were established, choosing the mathematical equations that best fit the original data, using the statistical software SigmaPlot 10.0.

3. Results and Discussion

For the clay dispersed in water (CDW) variable, the logistic regression model provided data adjustment with high precision (R^2 = 0.97) (Figure 1). The lowest amount of CDW (151 g Kg^{-1}) occurred with the control treatment, which was not subjected to compaction with a tractor, unlike treatments consisting of 2, 5 and 20 passes of the tractor, which reached the highest levels of CDW.

Figure 1. Clay dispersed in water (CDW) due to the soil compaction caused by tractor traffic.

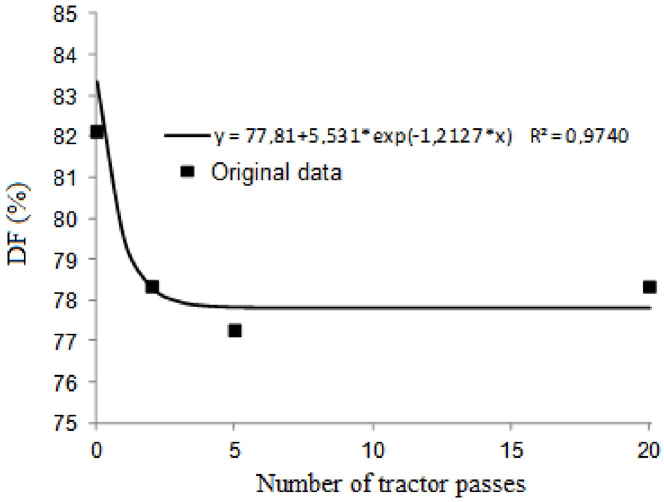


Source: Authors.

Thus, it is possible to affirm that only two tractor passes were enough to increase CDW close to the maximum limit obtained, not changing with the increase in the number of passes. According to Klein (2014), higher levels of soil erodibility occur due to compaction causing a reduction in soil porosity, since high levels of CDW cause the pores to clog, affecting its physical-water properties, with water saturation of the surface layer, reducing water infiltration and, consequently, favoring soil erosion. In this way, a poorly permeable soil or with a low water infiltration capacity and without vegetation, can be conducive to increased runoff (Figueiredo et al., 2010).

For the degrees of flocculation (DF) and degree of dispersion (DD) of clay, the exponential regression model was the one that, in both cases, confirmed adequate precision and adjustment, presenting correlation coefficients (R^2) of 0.9740 and 0.9740, respectively (Figures 2 and 3). It was observed that the DF presented an opposite behavior to that of CDW, a result already expected due to the flocculated clay particles not being dispersed under the conditions of greater compaction (Figure 2).

Figure 2. Degree of clay flocculation (DF) as a function of soil compaction caused by tractor traffic.



Source: Authors.

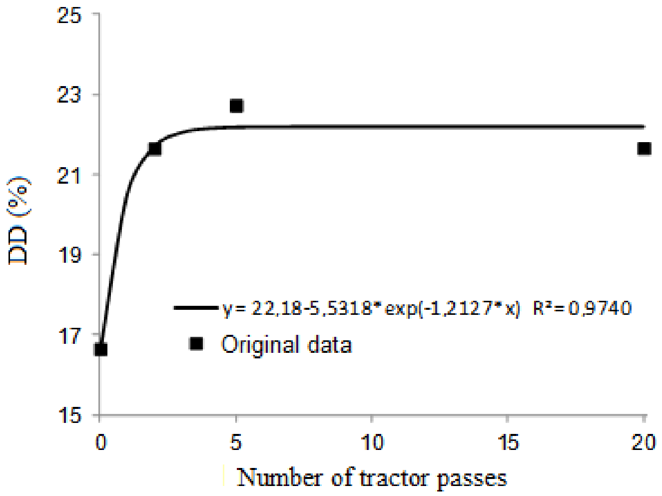
The highest degree of flocculation occurred in the treatment without tractor compaction (control) (83%), again demonstrating the importance for soil with a lower degree of compactness, as a condition for the soil physical quality, providing conditions for adequate soil structuring (Dexter, 2004).

According to Almeida et al. (2009), firstly the development of the soil structure is, under the action of dispersion-flocculation, which is linked to the balance of electrical charges present in the soil, that is, organic matter has a great influence on dispersion-flocculation and the aggregate stability. Therefore, structural porosity can be altered by soil management and compaction, mainly by decreasing total porosity and macroporosity (Richard et al., 2001; Tarawally et al., 2004). This decrease in soil pores due to compaction causes fragmentation of soil aggregates, destroying the inter-aggregated spaces that are larger in diameter (Horn et al., 1995), thus affecting the retention and redistribution of water in the soil profile.

The compressive effect caused by inadequate handling with intensive machine traffic tends to disrupt the soil with a consequent increase in CDW, due to the change in the interaction of mineral particles, thus decreasing the flocculation index (Oliveira et al., 2003). Almeida et al. (2009) reported a higher CDW content in soil under mechanized sugarcane harvesting compared to manual harvesting, due to the great pressure exerted by the implements used in this type of soil management.

The DD of clay had the opposite results to that of flocculated clay (Figure 3). These results demonstrated a lower degree of clay dispersion (16%) without tractor compaction (control), while treatments with 2, 5 and 20 passes showed levels around 21%, 22% and 21%, respectively. The absence of tractor compaction again provided better soil physical quality, as well as indicating stability in relation to the DD values, regardless of the degree of compaction increase. These results corroborate those described by Silva and Mielniczuk (1998), who also reported that the DD affected the aggregation of Latosol Roxo and Podzólico Vermelho, both with a very clay texture.

Figure 3. Degree of dispersion (DD) of clay as a function of compaction caused by tractor traffic.

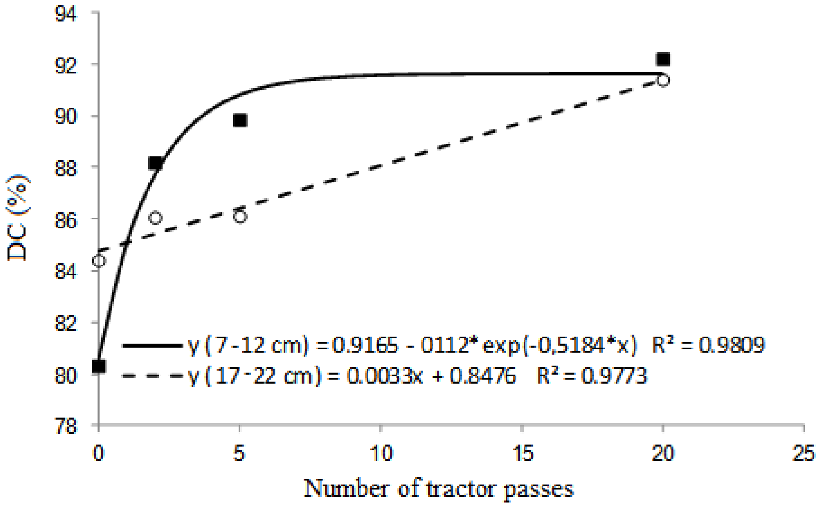


Source: Authors.

There is information in the literature that mentions the possibility that in soils with dispersed microaggregates, the percolation water promotes the eluviation of the dispersed clay particles and the rearrangement of these particles changes the solid soil matrix (Torres & Saraiva, 1999; Kochhann et al., 2000). Thus, the natural soil porosity becomes obstructed by the lightened clay particles, increasing the soil bulk density (Spera et al., 2008). Consequently leading to the formation of a dispersed surface layer and with compact structure of simple grains. Concomitantly, heavy machinery traffic allows the microaggregates to approach, increasing the bulk density.

For the soil DC, a different behavior was observed for the two depths studied (Figure 4). In both cases there was an increase in DC with the increase in tractor compaction, the exponential and linear regression models were the ones that best adjusted to the results with high precision, for depths of 7 - 12 and 17 - 22 cm, with correlation coefficients (R^2) of 0.98 and 0.98, respectively (Figure 4). The superficial layer of the soil (7 - 12 cm) suffered more intensely the impacts of the tractor compaction, presenting an expressive effect even with smaller numbers of passes, when compared to the deeper profile of the soil (17 - 22 cm). However, it is important to emphasize that the degree of compactness with a few passes of the tractor will also depend on the type of tractor and/or agricultural implement used.

Figure 4. Degree of compactness (DC) as a function of compaction exerted by tractor traffic at depths of 7-12 and 17-22 cm.



Source: Authors.

Research results obtained by Beutler et al. (2005) in laboratory conditions consider that the ideal DC for plant development is 84% and 75% for soils with.570 and 270 g Kg^{-1} of clay, respectively. Spliethoff et al. (2020) also verified ideal DC of 85% to *Ilex paraguariensis*. At field level, the ideal DC value was considered by Klein (2014) to be 80% for soils with 570 g Kg^{-1} of clay.

Ferreras et al. (2000), comparing no-till system with a chisel in Argentina (silty soil), found DC values of 82% and 69% in the superficial layer (0-6cm) and in the layer of 10-16 cm values of 87% and 85%, respectively. Under these conditions, the authors reported a reduction in productivity in soybean under no-tillage in relation to the scarified system. Thus, the DC values found in the present work are above the ideal value for good vegetation development.

The knowledge of changes in soil physical conditions in the soil layers after different levels of traffic with machines makes it possible to indicate appropriate management right afterwards, to avoid problems with plant development. For this, soil compaction detected in the surface layer indicates the need for cutting discs in precision seeders or double discs with higher pressure in the springs to act on this layer. On the other hand, only for traffic with more of five passes it is necessary to use shanks in precision seeders to act in the subsurface layer, because, in other traffic, soil compaction was more prominent in the superficial layer.

4. Conclusion

The soil compaction caused by tractor traffic reduced the soil physical quality, and highlighted the high fragility of the soil due to improper handling, that is, the greater the number of times that the machinery passes through the area, the more prone the soil compaction will be. This demonstrates that the proper handling with the rational use of the machines and respecting the conditions of soil moisture can favor the soil physical quality, consequently contributing to increase crop yield.

All treatments that provided soil compaction, regardless of the number of passes over the soil, showed an increase in degree of compactness, clay dispersed in water and degree of dispersion, as well as a reduction in the degree of flocculation of clays.

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