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Physical indicators after mechanical scarification in a Yellow Oxisol under no-tillage

Indicadores físicos após escarificação mecânica em um Latossolo Amarelo sob plantio direto

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Abstract

Scarification improves soil physical conditions, resulting in suitable conditions for root growth in crops and water infiltration. This study evaluates the effects of mechanical scarification on the physical attributes of a Yellow Oxisol cultivated with soybean under no-tillage in the Savanna of Piauí state, Brazil. Three areas under soybean cultivation were chosen, namely: one in the second year of cultivation under no-tillage (CS2); one cultivated for ten years under no-tillage (CS10); one area with soybeans identical to the previous one, but with scarification for a year (ESC); and a native Savana vegetation (CV), used as control. Density, macroporosity, microporosity, total porosity, and soil resistance to penetration at depths between 0-0.20 and 0.20-0.40 m were evaluated. The CS area showed decreased physical indicator values compared to the other management systems. Scarification was efficient in improving soil density, total porosity, and soil resistance to penetration at depths between 0.00 and 0.20 m. CS2 and CV areas showed more favorable physical indicator values. Through multivariate analyses, it was possible to identify which physical variables correlated with each type of soil management and the effects of these managements on the physical characteristics of the soil studied.

Additional keywords: Soil compaction; soy; Cerrado.

Resumo

A escarificação melhora as condições físicas do solo, resultando em condições adequadas ao crescimento radicular das culturas e a infiltração da água. Objetivou-se neste trabalho avaliar os efeitos da escarificação mecânica nos atributos físicos de um Latossolo Amarelo cultivado com soja em plantio direto no Cerrado piauiense. Foram escolhidas três áreas sob cultivo com soja, sendo uma no segundo ano de cultivo sob plantio direto (CS2), uma cultivada há dez anos sob plantio direto (CS10) e uma área com soja idêntica à anterior, mas que sofreu escarificação há um ano (ESC), além de uma mata nativa de cerrado preservada (MN), que foi usada como controle. Avaliaram-se a densidade, macroporosidade, microporosidade e porosidade total, e a resistência do solo à penetração, nas camadas de 0-0,20 e 0,20 – 0,40 m. A área CS mostrou valores de indicadores físicos inferiores em relação aos demais sistemas de manejo. A escarificação foi eficiente em melhorar os valores de densidade do solo, porosidade total e resistência do solo à penetração na camada de 0,00 a 0,20 m. As áreas CS2 e MN apresentaram valores de indicadores físicos mais favoráveis. Por meio das técnicas de análise multivariadas, foi possível identificar quais variáveis físicas estudadas se correlacionaram com cada tipo de manejo do solo adotado e os efeitos desses manejos sob as características físicas do solo estudado.

Palavras-chave adicionais: Compactação do solo; soja; cerrado.

Introduction

The replacement of Savanna vegetation by continuous cultivation of monoculture under conventional management, in general, causes drastic changes in soil physical quality and losses of organic matter content (Vezzani & Mielniczuk, 2011). In turn, the no-tillage system (NT) is characterized as a conservationist management, supporting the maintenance of the soil cover and minimal disturbances that allow increased entry of organic carbon, favoring microbial activity and soil quality (Souza et al., 2019).

However, from the physical point of view, the absence of soil revolving and traffic of agricultural machines in the NT system forms compacted areas in the soil surface layer over time, reducing its physical quality and affecting crop development (Domit et al., 2014). Cortez et al. (2019), who studied the effect of the no-tillage system on soil physical attributes, observed intermediate and critical values of soil resistance to penetration. Nunes et al. (2015) stated that machine traffic and the absence of revolving in a no-tillage system causes serious problems to soil physical properties, inducing compaction.

Soil compaction is a phenomenon that interferes directly with the soil structure, resulting in decreased macropores, increased soil resistance to penetration and, consequently, decreased root development (Cunha et al., 2012; Moura et al., 2019). Thus, scarification has been recommended in several studies to reduce compaction in the soil surface layer in areas under no-tillage. Scarifying equipment is used in this type of management, which acts in a localized way, with less capacity of revolving layers and being less aggressive to the soil structure (Cortez et al., 2011). This mechanical practice minimizes compaction, as it reduces soil density (Nagahama et al., 2016) and soil resistance to penetration (Giacomeli et al., 2016), besides increasing macroporosity and total porosity (Fin et al., 2018).

Research by Nunes et al. (2015), who studied the effect of soil scarification on root structure and growth in a clayey soil under no-tillage, found that mechanical scarification contributed to improve soil physical attributes (resistance to penetration, macroporosity, and apparent density) and root development (root density). Seki et al. (2015), who studied the effect of soil decompaction in a no-tillage system, also reported benefits from scarification and subsoiling on soil physical attributes, with effect on crop development and yield.

Thus, this study evaluates the effects of mechanical scarification on the physical attributes of a Yellow Oxisol cultivated with soybean in the agricultural frontier of the Savanna of Piauí state, Brazil.

Material and methods

The study was carried out at Chapada Grande farm, located in the municipality of Regeneração, Piauí (06°14′16″ S latitude and 42°41′18″ W longitude). This region has an average annual temperature of 32 ºC and average annual rainfall of 1,350 mm, with rainfall distributed from January to May (Equatorial Continental Regime, with annual isohyets between 800 and 1,400 mm). The climate, according to the Köppen climate classification, is of the type Aw’. The soil is classified as Yellow Latosol (Barbosa et al., 2016).

Four areas were selected. Three areas were cultivated with soybeans and one area was a preserved native vegetation, which was used as control (Table 1). In each area, four 200-m^2 plots were demarcated, where four soil samples were collected at depths of 0.00-0.20 and 0.20-0.40 m in January 2017 for physical analysis.

Table1 - History and description of the management systems studied.

Management system and soil use	Description
Area with two years of cultivation (CS2)	Area in the second year of cultivation, where rice was cultivated in the first year and soy was cultivated in the following year. Fertilization and liming were applied based on the recommendation of soil analysis for soybean culture.
Area with ten years of cultivation (CS10)	Area in the tenth year of cultivation, where rice was cultivated in the first year and soybean was cultivated from the second to the sixth year under conventional management using plow and harrow. From the seventh year on, only soybeans were cultivated, without off-season. Fertilization and liming identical to the aforementioned was carried out based on the recommendation for soybean crop.
Area with ten years of scarified cultivation (ESC)	Area with ten years of use. Management was identical to CS10 until the ninth year. However, scarification was carried out at a depth of 0.18 cm with a scarifier with five rods spaced 0.30 m apart and a ripper roller, in the previous year, with the soil characterized by friable consistency.
Native vegetation area (NV)	Native Forest of the Savanna Biome, with predominance of the following species: *Genipa americana, Hymenaea stigonocarpa, Caryocar brasiliense.*

Granulometric analysis (Table 2) was performed by the pipette method. Total soil porosity (TP), macroporosity (Map), and microporosity (Micro) were determined with undisturbed samples by suction table. Soil density (Sd) was determined by volumetric ring and aggregate stability was performed in a vertical shaker with sets of sieves with meshes of 2.0; 1.0; 0.5; 0.25, and 0.105 mm apertures (EMBRAPA, 2017). Organic carbon (CO) was analyzed by wet method, according to Yeomans & Bremner (1988).

Table 2 - Soil granulometric composition in the management systems studied.

Soil system management	Granulometry (g kg^{-1})			Texture class
	Sand	Silt	Clay	
		Depth (0.00 - 0.20 m)		
CS2	370	203	427	Clayey
CS10	343	220	438	Clayey
ESC	335	215	440	Clayey
NV	367	205	428	Clayey
		Depth (0.20 - 0.40 m)		
CS2	360	170	470	Clayey
CS10	337	216	447	Clayey
ESC	342	208	450	Clayey
NV	385	185	430	Clayey

CS2 = two-year-old soybean cultivation area; CS10 = ten-year-old soybean cultivation area; ESC = ten-year-old soy cultivation area that underwent scarification a year ago; NV = area under native Savanna vegetation.

Soil resistance to penetration (SRP) was determined with gravimetric moisture, ranging from 20 to 24% up to the 0.40-m layer (Table 3) using an impact penetrometer (model IAA / Planalsucar-Stolf) (Stolf, 1991).

Table 3 - Gravimetric soil moisture in the studied management systems.

Depth	CS2	CS10	ESC	NV	Average
(m)			(%)		
0.00-0.20	24.45	24.10	24.25	24.80	24.4
0.20-0.40	22.15	20.20	21.15	22.90	21.6

CS2 = two-year-old soybean cultivation area; CS10 = ten-year-old soybean cultivation area; ESC = ten-year-old soy cultivation area that underwent scarification a year ago; NV = area under native Savanna vegetation.

Resistance values were calculated from a depth of 0.05 m. From the values obtained, layers were discriminated with respect to their degree of compaction, according to the USDA protocol (USDA, 1993), with a limit of 2 MPa considered as a strong restriction to root growth. The weighted mean diameter (WMD) and aggregate stability index (ASI) were obtained according to Castro Filho et al. (1998).

The data were submitted to analysis of variance by F test and analyzed in a completely randomized experimental design. Mean comparison was performed using the Tukey test at 5%. In addition, Principal Component Analysis (PCA) was used to reduce data dimensions and, consequently, facilitate the interpretation of soil patterns in relation to the data obtained. PCA was processed with the correlation matrix of the original variables, which built the eigenvectors, processed in the R program (R Core Team, 2016).

Results and discussion

Soil density (Sd) in the studied areas ranged between 0.90 and 1.16 Mg m^{-3} for the 0.00-0.20 m layer and between 0.96 and 1.27 Mg m^{-3} for the 0.20-0.40 m layer (Table 4). The CS10 surface layer had the highest Sd value, while ESC had an intermediate value. On the other hand, in the 0.20-0.40 m layer, CS10 and ESC treatments did not differ, with values close to the upper limit of Sd, which is 1.30 Mg m^{-3} for clayey soils (Reynolds et al., 2007), after which there will be restrictions for root growth and plant development. This shows that the effect of the scarifier occurred only in the surface layer, where compression is more intense in no-tillage, demonstrating the effectiveness of this mechanical practice to minimize this limiting factor for crop yield, as also observed by Klein & Klein (2015).

Macroporosity reduced in the surface layer (0.20 m) in tCS10 and ESC management systems. The observed result is probably linked to the history of these areas, worked on conventional management for six years. As of 2013, that is, four years before the study, soil management was changed to no-tillage. Thus, it is likely that there was not enough time for improvements in this variable. In the 0.20-0.40 m layer, no statistical differences were observed in the Map values between areas under management and native vegetation.

A study by Moraes et al. (2016) found that the conventional planting system for 20 years in a clayey Red Latosol increased soil density and reduced macroporosity in the 0.20 m layer to values below critical for crop development in relation to no-tillage. According to the authors, soil physical quality improves over time after adopting no-tillage. For Dal Ferro et al. (2014), conventional planting contributes to soil pulverization, leading to less macroporosity in the surface layer in relation to no-tillage. Map values are important for the quick flow of water and air in the soil and for diagnosing soil compaction, since the main reduction in soil pore volume occurs in this fraction of total porosity (Schjonning & Lamande, 2010).

Table 4 – Soil density (SD), total porosity (TP), macroporosity (Map), microporosity (Mip), weighted average diameter (WAD), aggregate stability index (ASI), and total organic carbon (TOC) at two depths of the soil in the management systems studied.

Treatment	SD ($Mg\ m^{-3}$)	Map	Mip ------------ ($m^3\ m^{-3}$) ------------	TP	WAD (mm)	ASI (%)	TOC ($dag\ kg^{-1}$)
				0.00-0.20 m			
CS2	0.90 c	0.25 b	0.39 a	0.63 a	1.00 b	0.67 b	2.42 a
CS10	1.16 a	0.16 c	0.35 a	0.51 c	0.72 b	0.49 b	2.00 b
ESC	1.04 b	0.19 c	0.39 a	0.58 b	1.02 b	0.64 b	2.18 ab
NV	0.91 c	0.34 a	0.30 b	0.63 a	1.56 a	1.04 a	2.52 a
				0.20-0.40 m			
CS2	0.96 c	0.30 a	0.31 a	0.61 a	1.05 ab	0.71 b	1.50 b
CS10	1.27 a	0.25 a	0.23 b	0.48 c	0.79 b	0.51 b	1.48 b
ESC	1.23 a	0.32 a	0.18 b	0.50 c	1.22 a	0.81 b	1.44 b
NV	1.06 b	0.33 a	0.24 b	0.57 b	1.31 a	0.85 a	1.90 a

CS2 = two-year-old soybean cultivation area; CS10 = ten-year-old soybean cultivation area; ESC = ten-year-old soy cultivation area that underwent scarification a year ago; NV = area under native Savanna vegetation. Averages followed by the same letter in the column do not differ by Tukey test ($p > 0.05$).

In table 4 also shows that soybean cultivation did not interfere with microporosity (Mi) in the 0.0-0.20 m layer. The observed result is probably due to the pores related to soil texture, especially clay and silt levels, that were similar between the areas evaluated, as also evaluated by Lima et al. (2014). In the subsurface layer, Mi was significantly higher in the CS2 area, possibly due to higher clay content in this layer.

The highest values of total porosity (TP) in the depths studied were observed in the NV and CS2 areas. Barbosa et al. (2016), who studied the chronosequence of conventional management in soybean crops, also found higher TP in newly explored areas under native vegetation, compared to areas with longer management time. In relation to areas with a longer history of management, the result observed for ESC in the superficial layer indicates that scarification can be an alternative to improve the porosity of a soil that has been managed for a certain time in a conventional manner. Giacomeli et al. (2016) found an increase of 18% in total porosity and 58% in macroporosity after scarification of a compacted soil.

Regarding weighted mean diameter (WMD) and aggregate stability index (ASI), the area with NV was superior to the other areas at 0–0.20 and 0.20–0.40 m depths (Table 4). Generally, native forest soils have more organic matter and greater aggregate stability (Secco et al., 2005) due to increased input and diversity of organic residues without interference from any cultivation form. In this study, higher values of organic carbon, (indicators of organic matter) were observed in the area of native forest and in CS2 (Table 4). In management systems with intense soil moving for several years, as occurred for six years in the CS10 and ESC areas, aggregates are destroyed, reducing ASI (Sousa Neto et al., 2008).

Research carried out in areas of the Savana of Piauí showed that intense soil revolving with the combination of plowing and harrowing, as to create favorable physical conditions to the development of soybean roots, compromised the stability of aggregates and reduced WMD (Ibiapina et al., 2014; Araújo et al., 2010).

In figure 1 shows that the CS10 area expressed higher soil resistance to penetration (3.81 MPa) up to a depth of 0.20 m, which is generally more affected by different soil managements, compared to other treatments. Marasca et al. (2011), who analyzed the SRP of a Dystrophic Red Oxisol cultivated under no-tillage for 13 years, found mean SRP values ranging between 2.9 MPa and 4.2 MPa, with moisture contents between 0.13 and 0.25 kg kg^{-1} in the 0.0-0.20 m layer. This can be explained by machine traffic over the years during agricultural operations, causing damage to the soil physical structure, consequently reducing porous space and resulting in soil compaction.

On the other hand, in the ESC system, the soil showed values of less than 2.00 MPa in the layer close to 10 cm, which fits in the moderate class according to USDA (1993). This shows the positive effect of the 18-cm rod scarifier in this 0-20 cm layer, even twelve months after this practice. Research by Girardello et al. (2014) and Drescher et al. (2016) in a clayey Red Latosol under long-term no-tillage observed that scarification significantly reduced soil resistance to penetration, creating more favorable conditions for plant root development. On the other hand, NV and CS2 systems, more preserved, had the lowest SRP values, ranging between 0.75 and 2.08 MPa in all depths studied, which fits them in the low and moderate resistance range.

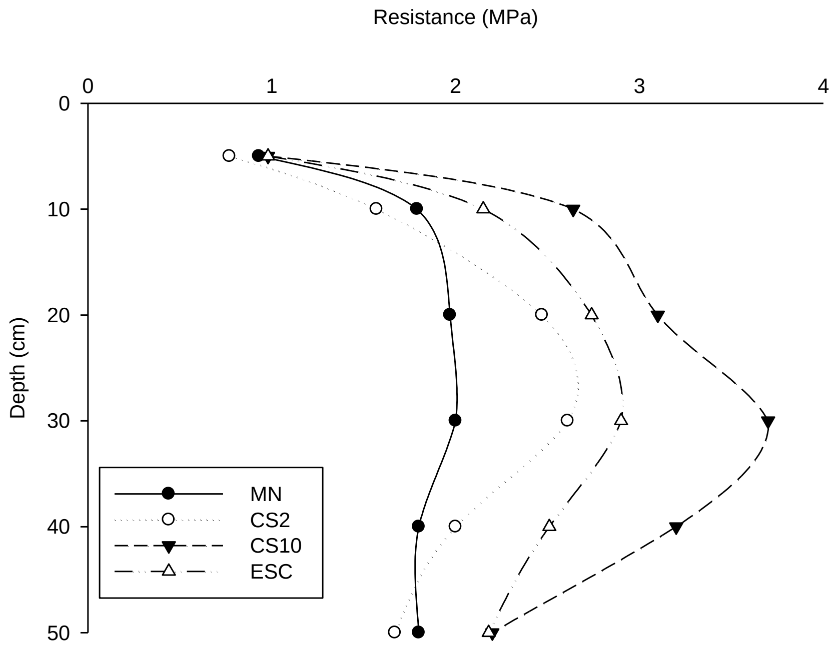

Figure 1 - Soil resistance to vertical soil penetration in the studied management systems.

CS2 = two-year-old soybean cultivation area; CS10 = ten-year-old soybean cultivation area; ESC = ten-year-old soy cultivation area that underwent scarification a year ago; NV = area under native Savanna vegetation.

Soil density (SD), total porosity (TP), macroporosity (Map), microporosity (Mip), weighted average diameter (WAD), aggregate stability index (ASI), and total organic carbon (TOC) at two depths of the soil in the management systems studied.

Principal component analysis (PCA) was performed on the data matrix consisting of seven variables (Figure 2). Regarding the percentage of variance explained by the principal component analysis, it appears that the first two principal components account for 88% of the original variability, with CP1 and CP2 retaining 52.2% and 35.8%, respectively. According to the multivariate analysis, variation in the efficiency of treatments at both depths was observed, and it was possible to identify which variables correlated more with each management type and the effects on changes in soil characteristics.

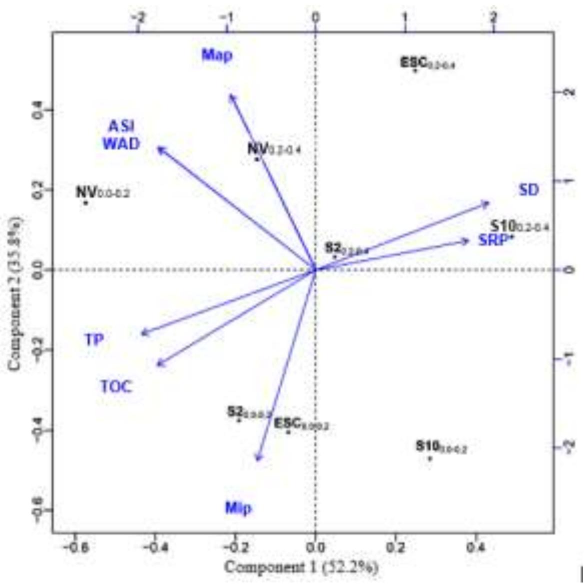

Figure 2 - Main components (1 and 2) based on the soil variables of the different areas studied at two depths (0.0-0.20 m and 0.20-0.40 m).

CS2 = two-year-old soybean cultivation area; CS10 = ten-year-old soybean cultivation area; ESC = ten-year-old soy cultivation area that underwent scarification a year ago; NV = area under native Savanna vegetation.

It is observed that NV, in the two depths studied (0.0-0.20 and 0.20-0.40 m), formed an isolated group, positioned in the upper left quadrant. This group was better correlated with ASI, WMD, and Map variables. This occurs due to higher CO content (Table 4) from organic residue in these systems, which contributes to a better soil structure, favoring the values of these variables.

The CS10 area at a 0.20-0.40 m depth was positioned in the upper right quadrant and was more associated with Sd and SRP variables, since this area was managed for a long time in conventional planting followed by no-tillage, whose mobilization absence and machine traffic causes compaction in the subsurface layer (Moraes et al., 2020), providing higher values of Sd and RP variables. The CS2 and ESC areas, at a depth of 0.20-0.40 m, are also included in the same quadrant. However, they did not correlate with any variable.

In turn, CS2 and ESC areas at 0.00-0.20 m depth showed similarity and were positioned in the lower left quadrant, being more correlated to the micro variable in relation to the other areas studied.

Conclusions

The no-tillage system for ten years showed values of physical indicators that indicate soil compaction.

Scarification was efficient to improve the values of soil physical quality indicators in the layer between 0.00 and 0.20 m.

The multivariate analyses identified which physical variables correlated with each soil management type and the effects of these managements on the physical characteristics of the soil studied.

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