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Aggregate stability and penetration resistance after mobilization of a dystrocohesive Ultisol

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Key words:
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harrowing
soil resistance

ABSTRACT

Evaluation of mobilized soil profiles can provide important information on soil compaction reduction processes. In this context, the objective of this study was to evaluate alterations in soil penetration resistance and the impact on the aggregate stability of a cohesive Ultisol cultivated with sugarcane. The experiment was carried out at the Carpina Sugarcane Experimental Station (EECAC/UFRPE), located in the city of Carpina, PE. Penetration resistance, mobilized area and depth, and percentage of soil aggregates were evaluated before and after soil tillage. Soil mobilization improved soil aggregate uniformity and decreased penetration resistance in the 0-0.20 m layer. Coarse soil fraction, moisture and organic carbon positively contributed to the increase in soil mobilization.

Palavras-chave:
sulcagem
gradagem
resistência do solo

Estabilidade de agregados e resistência à penetração após mobilização de um Argissolo Amarelo distrocoeso

RESUMO

A avaliação dos perfis mobilizados do solo pode fornecer informações sobre os processos de redução da compactação do solo. Neste contexto, o objetivo do presente estudo foi avaliar alterações na resistência à penetração e o impacto sobre a estabilidade de agregados de um Argissolo Amarelo cultivado com cana-de-açúcar. O experimento foi realizado na Estação Experimental de Cana-de-açúcar do Carpina (EECAC/UFRPE), no Município de Carpina, PE. Medidas da resistência à penetração, área e profundidade mobilizada, e percentual de agregados do solo foram realizadas antes e após o preparo do solo. O sistema de preparo permitiu maior uniformidade nas classes de agregados e reduziu a resistência à penetração na camada 0-0,20 m. A fração grossa do solo, a umidade e o carbono orgânico contribuíram positivamente para maior área mobilizada e profundidade do perfil.

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Introduction

Brazil is the largest sugarcane producer in the world, which has placed the country also as the largest sugar producer and exporter (FAO, 2016) and second largest ethanol producer (Marin & Nassif, 2013). In order to meet the demand for inputs, the agricultural production system has intensified soil tillage and mechanized harvest, aiming to provide a favorable environment to crop growth, increment in yield and reduction of costs (Hasan, 2012; Souza, 2012; Vischi Filho et al., 2015). Kumar et al. (2012) observed improvement in sugarcane yield with subsoiling of two soils in India and found that tillage was beneficial to reduce compaction and have lower costs, compared with other practices.

However, studies indicate that, in cases of excessive intensity, frequency and/or duration in the use of vehicles and implements, there may be destruction of the natural structure of the soil and its aggregates, reduction in total porosity and processes of compaction (Martins et al., 2013; Botta et al., 2016). When the soil is compacted, its porosity and aeration decrease and its resistance to root penetration increases (Ramos et al., 2013).

Hasan (2012) found increment in penetration resistance, due to traffic, of 100, 51 and 15% at depths of 10, 20 and 30 cm, respectively, and indicated moldboard plow as the most efficient implement to reduce penetration resistance in the studied soil. This author also associated the passing of tractor to the increment in resistance to penetration and reduction in plant growth and yield.

Studies have demonstrated higher levels of aggregate stability in soil under no-tillage system compared with conventional tillage (Hickmann et al., 2011) and significant relationship with soil properties, such as texture, moisture, dispersed clay, porosity and organic carbon (Vicente et al., 2012). Based on these properties, soil aggregates are pointed as good indicators of soil quality (Tormena et al., 2008).

The objective of the present study was to evaluate alterations in penetration resistance and aggregate stability due to tillage system in a dystrocohesive Ultisol cultivated with sugarcane.

Material and Methods

The study was carried out at the Carpina Sugarcane Experimental Station (EECAC/UFRPE), situated in the municipality of Carpina-PE, Brazil (7º 51' S; 35º 14' W; 178 m). The climate of the region, according to Köppen's classification, is As, tropical rainy with dry summer.

According to the average values (Table 1), the soil was classified as sandy loam (Lemos & Santos, 1996). The experimental area has a rectangular shape of approximately 0.88 ha, divided into a grid of 16 experimental plots of 26.00 × 16.00 m, spaced by 2.00 m, and is located in a dystrocohesive Ultisol, according to EMBRAPA (2013).

Initially, the studied area had been for 5 years under sugarcane cultivation and successive traffic of vehicles. Soil samples were collected at two times: T1 - before soil mobilization and T2 - after soil mobilization.

Soil mobilization in T2 corresponded to the application of two soil tillage systems: P1 - harrowing + furrowing; and P2 - furrowing. Two sugarcane varieties were selected and randomly cultivated in each tillage system: RB86 7515 and RB92 579. At two established periods, T1 and T2, and in the central point of each experimental plot, soil samples were collected to determine physical and chemical attributes.

Organic carbon contents (OC), plasticity limit (PL), liquidity limit (LL) and plasticity index (PI), and soil texture, density (Ds) and moisture (w) were determined according to the methodology of EMBRAPA (2011). In the comparison with soil mobilization, the following variables were quantified: organic carbon contents (OC), plasticity limit (PL), moisture during soil tillage (w_{ST}) and coarse sand content.

Penetration resistance (PR) test was conducted at times T1 and T2, in the central point of the plot, using a reduced impact penetrometer (model IAA/Planalsucar-Stolf) with cone angle of 30°. The device's rod penetration in the soil (cm per impact) was transformed into penetration resistance, in MPa, according to Stolf, using Eq. 1:

$$PR = \frac{Mg + mg + \left(\frac{M}{M+m}\right)}{A} \quad (1)$$

where:

PR - soil penetration resistance, kgf cm^{-2} (kgf cm^{-2}× 0.098 = MPa);

M - hammer mass, 1.6 kg (Mg - 1.6 kgf);

m - mass of the device without hammer, 1.47 kg (Mg - 1.47 kgf);

h - hammer fall height, 26 cm;

x - device's rod penetration, cm per impact; and,

A - cone area, 1.35 cm².

Mobilized area (MA) and furrow depth were determined using a profilometer, according to Carvalho Filho et al. (2008); digital photographs recorded the distribution of the profilometer's stylus along the soil profile before and after mobilization. The vertical distance between furrow bottom and soil surface corresponded to its maximum depth.

Aggregate stability was analyzed by wet sieving in Yoder apparatus. The results, expressed in the classes > 2, 2-1, 1-0.5, 0.5-0.25, < 0.25 mm, were used to calculate mean weight diameter (MWD), fineness modulus (FM) and percentage of aggregates, at 2.00 mm (AGRI), according to Freire & Piedade

Table 1. Chemical and physical characterization of dystrocohesive Ultisol cultivated with sugarcane

	Clay	Fine sand	Coarse sand	Silt	Ds	W_{ST}	θfc	K	Na	Ca	Mg	pH
	g kg^{-1}				g cm^{-3}	%		cmol$_c$ dm^{-3}				
0-0.20 m	130.41	214.47	511.06	140.85	1.41	13.74	9	0.13	0.06	2.1	1.3	5.1
0.20-0.40 m	137.79	212.86	517.71	130.38	1.59	13.74	10	0.07	0.03	1.8	0.8	4.8

Ds - Soil bulk density; W_{ST} - Moisture during soil tillage; θfc - Moisture at field capacity; Na - Sodium; K - Potassium; Ca - Calcium; Mg - Magnesium

Júnior (1979), Kemper & Rosenau (1986), and Wendling et al. (2005), respectively.

Soil mobilization times (before and after soil tillage) were evaluated based on covariance analysis using the SAS statistical software. The data obtained after soil tillage were subjected to analysis of variance in randomized block design in split-plot scheme, and treatment means were compared by Tukey test at 0.05 probability. Plots corresponded to soil tillage systems (P1 - harrowing + furrowing; P2 - furrowing) and subplots to two sugarcane varieties (V1 - RB86 7515; V2 - RB92 579), totalizing 4 treatments (P1V1, P1V2, P2V1, P2V2), with four replicates.

Results and Discussion

The results for Ds, w, OC, PR, MWD and FM are presented in Table 2. Since the T1 condition (before mobilization) has no treatment, only the overall mean and its standard error are presented.

PR showed value of 2 MPa, considered as high by Soil Survey Staff (1993), in both layers. The observed MWD is higher than that found by Vicente et al. (2012) in both layers, but similar to that found by Hickmann et al. (2011) in areas with lower soil mobilization. The higher the proportion of larger aggregates, the higher the MWD. Hickmann et al. (2011) showed that the adoption of practices with lower soil mobilization, such as no-tillage, promoted 30% increase in MWD in soils worked with disc plow + heavy harrow, for two decades. Such positive increment in MWD due to the lower soil disturbance can be observed in the present study after soil mobilization with different implements (Table 3).

After soil mobilization with the application of soil tillage treatments and sugarcane varieties, there was no interaction between both factors and the isolated effects of soil tillage and sugarcane varieties were not significant on the variables Ds, w, OC, PR, MWD and FM, in both layers, except for the interaction on FM and MWD in the 0.20-0.40 m layer and for soil tillage on w and PR in the 0-0.20 m layer (Table 3).

The non-significant effect on FM and MWD in the 0-0.20 m layer in this study corroborates other studies (Vicente et al., 2012; Oliveira et al., 2010), especially FM in areas cultivated with sugarcane and without vinasse application (Vicente et al., 2012). FM and MWD were not good indicators to differentiate the conditions of native forest and soil fertigated with vinasse in the layers of 0-0.20 m and 0.20-0.40 m (Oliveira et al., 2010), confirming the better applicability of FM to evaluate dry aggregate stability.

Covariance analysis showed significant difference between T1 and T2 for PR, MWD and FM in surface (mean values of

Table 2. Soil density (Ds), moisture (W), organic carbon (OC), penetration resistance (PR), mean weight diameter (MWD), fineness modulus (FM), for the time T1 (before soil tillage)

	Ds g cm^{-3}	W %	OC dag kg^{-1}	PR MPa	MWD mm	FM
			0-0.20 m			
Mean	1.43	11.99	1.68	2.73	2.77	3.27
Standard error	0.03	0.29	0.09	0.27	0.24	0.12
			0.20-0.40 m			
Mean	1.61	13.33	1.48	2.89	1.61	2.69
Standard error	0.02	0.33	0.07	0.17	0.10	0.06

Table 3. Soil density (Ds), moisture (W) organic carbon (OC) penetration resistance (PR), mean weight diameter (MWD) and fineness modulus (FM) for the interaction Soil tillage x sugarcane varieties and their isolated effects after soil mobilization at time T2

	Ds g cm^{-3}	W %	OC dag kg^{-1}	PR MPa	MWD mm	FM
			0-0.20 m			
P1V1	1.34 a	9.97 a	1.57 a	1.50 a	2.59 a	3.22 a
P1V2	1.39 a	9.43 a	1.55 a	1.47 a	2.46 a	3.19 a
P2V1	1.37 a	11.23 a	1.64 a	2.25 a	2.68 a	3.24 a
P2V2	1.34 a	12.35 a	1.65 a	2.40 a	2.92 a	3.37 a
Mean	1.36	10.75	1.6	1.91*	2.66*	3.26*
V1	1.44 a	10.59 a	1.6 a	1.87 a	2.63 a	3.23 a
V2	1.44 a	10.89 a	1.6 a	1.93 a	2.69 a	3.28 a
P1	1.44 a	9.69 b	1.56 a	1.48 b	2.52 a	3.2 a
P2	1.44 a	11.79 a	1.65 a	2.32 a	2.8 a	3.3 a
			0.20-0.40 m			
P1V1	1.58 a	12.83 a	1.35 a	2.48 a	1.87 ab	2.85 ab
P1V2	1.53 a	12.40 a	1.29 a	2.22 a	1.31 b	2.54 b
P2V1	1.60 a	12.48 a	1.26 a	2.46 a	1.62 ab	2.71 ab
P2V2	1.56 a	12.35 a	1.35 a	2.63 a	2.52 a	3.20 a
Mean	1.57	12.52	1.31	2.45	1.83	2.83
V1	1.63 a	12.41 a	1.29 a	2.4 a	1.75 a	2.78 a
V2	1.57 a	12.38 a	1.32 a	2.42 a	1.92 a	2.87 a
P1	1.63 a	12.38 a	1.3 a	2.28 a	1.59 a	2.7 a
P2	1.58 a	12.41 a	1.31 a	2.56 a	2.07 a	2.95 a

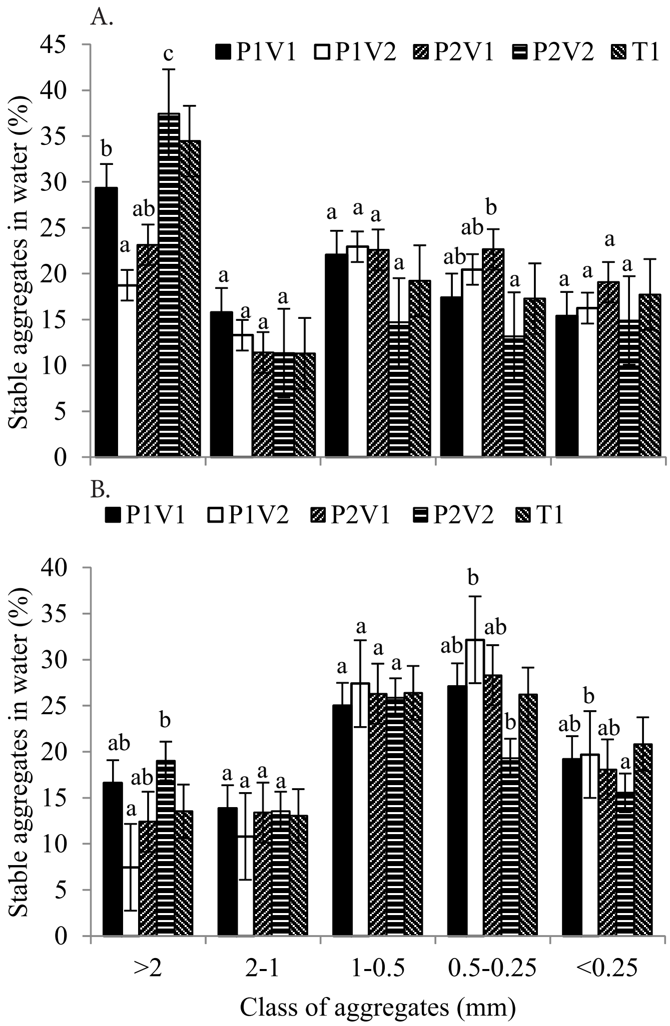
Same lowercase letters in the column for each P × V combination, V and P do not differ by Tukey test at 0.05 probability level; *Significant by the covariance analysis of the mean of T1 (Table 2) for T2; T1 - Before soil tillage; T2 - After soil tillage; P1 - Harrowing + Furrowing; P2 - Furrowing; V1 - RB86 7515; V2 - RB92 579

Tables 2 and 3), in which soil mobilization with harrow and furrower led to reduction in PR, MWD and FM, and reduced the percentage of the aggregate classes. Thus, considering the results found by Vicente et al. (2012) and Oliveira et al. (2010), it can be inferred for the present study that FM and MWD can be good indicators of aggregate stability when the soil has been recently mobilized and compared with its previous condition of mobilization, regardless of organic carbon contents.

According to Medvedev (2009), PR was a more sensitive soil attribute to characterize soil tillage than Ds. The interaction between both treatments did not lead to statistical difference in soil physical or chemical attributes, most likely because of the implements used and the reduced cultivation time (one cycle) of both sugarcane varieties (Table 3). In a similar study, Vizzotto (2014) found that shank-type furrowers reduced Ds, increased total porosity in the crop row and caused larger surface and volume of mobilized soil.

There was statistical difference for the aggregates (Figure 1). Aggregates with larger diameter (> 2 mm) are found in surface, and differences between treatments were more evident in this layer. Reduction in this class of aggregates, as soil depth increases, may be related to the reduction in the organic matter content along soil depth, as observed by Oliveira et al. (2010).

Aggregates with smaller diameter prevailed in subsurface (Figures 1A and B). At T2, significant difference occurred for aggregates > 2 mm and in the interval 0.5-0.25 mm, in both layers, and aggregates < 0.25 mm in the 0.20-0.40 m layer. However, the class of 2-1 mm aggregates did not present variation between treatments, collection times or soil layers. On the other hand, in the 0.20-0.40 m layer, aggregates < 0.25 mm showed higher occurrence. This result may be related to the organic carbon (OC), which contributed to soil aggregation



Same lowercase letters do not differ by Tukey test at 0.05 probability level for the applied treatments. T1 - Before soil tillage; P1 - Harrowing + Furrowing; P2 – Furrowing; V1 – variety RB 867515; V2 – variety V2 RB 92579

Figure 1. Aggregate distribution before and after soil mobilization in the layers of 0-0.20 (A) and 0.20-0.40 m (B)

in surface after mobilization, due to the higher clay content in subsurface, promoting cementing effect on the aggregates.

Soil tillage with harrow and furrower (P1) led to reductions in PR of 45% in the 0-0.20 m layer and 20% in the 0.20-0.40 m layer. In soil tillage with only furrower (P2), reductions were equal to 17 and 12% in the layers of 0-0.20 and 0.20-0.40 m, respectively (Table 4).

Considering only soil tillage treatment, the use of harrow + furrower caused statistical difference in PR. Soil tillage using harrow + furrower was more efficient in the reduction of PR, statistically differing from the initial conditions and from the treatment with furrower until the depth of 20 cm.

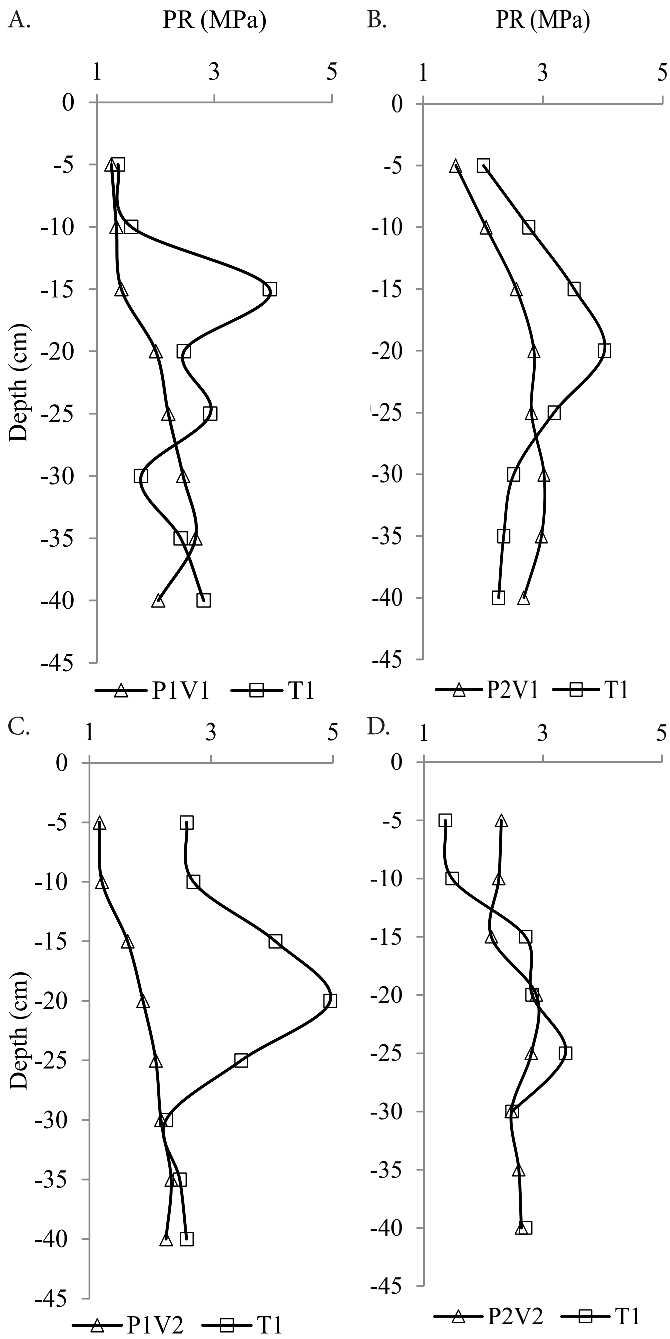
Table 4. Penetration resistance (kPa) before (T1) and after (T2) soil compaction, and mobilized area (m²) and profile depth (m) after soil mobilization

	T1	T2	
		P1	P2
0-0.20 m	2.73 a	1.48 bA	2.28 bB
0.20-0.40 m	2.89 a	2.32 aA	2.56 aA
Mobilized area	-	0.08 A	0.09 A
Profile depth	-	0.31 A	0.31 A

Same uppercase letters in the row do not differ between treatments by Tukey test at 0.05 probability level. Equal lowercase letters do not differ between times by Tukey test at 0.05 probability level. P1 - Harrowing + Furrowing; P2 - Furrowing

In the layer 0.20-0.40 m, there was no difference in PR between treatments, probably due to the disc plow, which reaches only the first 10 cm of the soil layer. Likewise, mobilized area and profile depth did not differ statistically (Table 4). Vizzotto (2014) observed that furrower shank reduces soil compaction along the crop row until the depth of 16 cm. Carvalho Filho et al. (2008) observed larger mobilized area of the soil layer using moldboard plow, followed by scarifier and disc plow.

Considering the interaction Soil tillage x Sugarcane variety, the efficiency in the reduction of PR followed the order P1V2 > P1V1 > P2V1 > P2V2, respectively with 54.5, 26.3, 23.5 and 19.1% of PR reduction for each treatment compared with the initial condition, until the depth of 25 cm (Figure 2). According to Portz et al. (2009), the ideal moisture for the measurement of penetration resistance is the moisture content at field



T1 - Before tillage; P1 - Harrow + furrower and cultivated; P2 - Furrower; V1 - Soil cultivated with the variety RB 867515; V2 - Soil cultivated with the variety V2 RB 92579

Figure 2. Penetration resistance grouped per treatment

capacity, because this condition provides good correlation with plant root growth. The gravimetric moisture at field capacity estimated in the studied Ultisol was 9% for 0-0.20 m and 10% for 0.20-0.40 m (Table 1).

Moisture contents at the moment of PR measurement differed from the moisture at field capacity in the studied Ultisol, and high PR values were found at moisture contents lower than 10%. Another factor that influenced the result of PR was the mobilized area; according to the profilometry, the mobilization depth caused soil mobilization until the maximum depth of 29-32 cm.

There was no statistical difference between the soil tillage systems for the variables mobilized area (0.85 m^2) and furrow depth (0.31 m) (Table 4), probably due to the work of the disc plow, which mobilized the soil until the depth of 10 cm, which suggests studies using other implements in the evaluated Ultisol. In studies with other types of soil, such as acriferric Red Latosol, larger area was mobilized using moldboard plow, followed by scarifier and disc plow (Carvalho Filho et al., 2008). In addition, the use of the same implement applied at different depths or under different covers (Debiasi et al., 2010), or the use of different implements, but whose action is of lower impact on the soil, such as harrow and furrower, may not cause significant differences in the soil.

Significant correlation was found between furrow depth and fine sand content (R^2 = -60%), which suggests decrease of mobilization in subsurface with the increment in fine sand content. Other correlations with furrow depth were observed with w (R^2 = 45%), coarse sand (R^2 = 42%) and OC (R^2 = 33%); and the best correlations with MA were observed with w (R^2 = 46%), CO (R^2 = 32%) and fine sand (R^2= -31%), suggesting that organic carbon and soil moisture during tillage positively contributed to greater soil mobilization, while clay and fine sand contributed negatively, possibly because their contents are lower than those of coarse sand, favoring the reduction of water availability in the profile.

Conclusions

1. Tillage system reduced soil penetration resistance in the 0-0.20 m layer.

2. Coarse soil fraction, moisture and organic carbon positively contributed to greater mobilized area and profile depth.

3. Soil tillage systems and sugarcane varieties allowed higher uniformity in the classes of aggregates.

4. Penetration resistance characterized the soil tillage system better, compared with soil bulk density.

5. The soil mobilization promoted a 0.31 m furrow depth.

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