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Soil physical quality after the fifth and sixth harvest of sugarcane in Brazilian Cerrado

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Abstract

On most cultivated areas with sugarcane the crop cycle allows between five to seven ratoon crops. The longevity of the plantation is determined by physical changes in soil during this period. This study evaluated the changes to soil physical properties after the fifth and sixth harvest of sugarcane using physical quality indicators. The experimental design was completely randomized blocks with two treatments, each with four replications: treatment 1 - sugarcane after the fifth ratoon crop; treatment 2 - sugarcane after the sixth ratoon crop. The physical attributes of soil: soil penetration resistance (PR), soil density (Sd) volumetric water content (VWC), macroporosity (Ma), microporosity (Mi) and total porosity (TP) were evaluated at six depths; while stability of aggregates (AS), mean weight diameter (MWD) and geometric mean diameter (GMD) were evaluated at four depths. Degradation of soil physical properties after the fifth and sixth ratoon crop was detected in this study. The area had a compacted layer between 0.10 and 0.30 m of depth. The correlations between soil density and the other parameters prove their importance as indicators of soil quality, and the need to evaluate soil moisture prior to tillage or harvest of the crop.

Keywords: Soil conservation, penetration resistance, soil density, macroporosity, microporosity, aggregate stability.

Abbreviations: SOM_Soil Organic Matter; SC_Soil Conservation; PR_Penetration Resistance; Sd_Soil Density; Ma_Macroporosity; Mi_Microporosity; TP_Total Porosity; AS_Aggregate Stability; VWC_Volumetric water content; MWD_Mean Weight Diameter; GMD_Geometric mean diameter; EA_ Stability of aggregates; ASI_Aggregate Stability Index; AGRI_Diameter greater than 2.0 mm; Si_Sensitivity index.

Introduction

Current tillage techniques of sugarcane are based on plowing during soil preparation and planting, which add traffic of machines and vehicles, causing changes both to physicochemical attributes and levels of soil organic matter (SOM). Some physical attributes have been frequently used to measure changes in soil quality to evaluate the impacts of tillage systems. Compaction, soil density, macroporosity, microporosity, total porosity, water holding capacity and aggregate stability are the most frequent ones (Torres et al., 2015). However, compaction has been identified as the primary cause of soil degradation because it negatively influences all other physical attributes (Materechera et al., 2009; Gorucu et al., 2006). This phenomenon creates a less favorable environment for the development of the root system of sugarcane (Otto et al., 2011; Kingwell et al., 2011).
In sugarcane it is mainly caused during the harvest, either manual or mechanical (Oliveira Filho et al., 2015). Harvesters and transporters with total weight of 20-30 tones are used during this process. Their traffic, under varying humidity conditions, is repeated during the crop cycles, which vary between six to seven harvests. It causes soil structural degradation at different depths restricting root growth (Souza et al., 2012). The cane root system develops at greater depths then in other crops. The system consists of rhizomes and fasciculated roots, 85% of which are in the 0.0-0.50 m layer, and 60% in the 0.20-0.30 m layer. (Oliveira Filho et al., 2015). Souza et al. (2014) emphasize that the physical changes in soil structure caused by compaction occur mainly in the top 0.0-0.40 m layer. Without chemical or physical obstructions these roots can reach depths greater than 2.00 m. According to Alameda et al. (2012) the plant responds to soil compaction with changes in the development and operation of the roots. Those changes can affect productivity and product quality. Souza et al. (2014) observed that soil scarification allows a better development of the roots, helping the plant remain stable during dry periods. Evaluating areas with two cropping systems of sugarcane after the second and the third harvest, Campos et al. (2015) observed that those areas did not need soil ripping. The compaction level of the cane interrow still did not restrict the growth of the roots. However, Paulino et al. (2004) point out that the same did not happen after the fifth and the sixth harvest where scarification was required to reduce soil density and mechanical resistance for root penetration and increased soil permeability.

Given this context, this study evaluated the changes in physical attributes of soil after the fifth and sixth harvest of sugarcane using physical quality indicators.

Results and Discussion

The indicators of soil compaction

Penetration resistance (PR), soil density (Sd) and volumetric water content (VWC)

Analyzing the values of PR and Sd, a compacted layer at depths from 0.10 to 0.30 m was observed (Table 1) The values were higher ($p \leq 0.05$) at depths between 0.10 and 0.20 m after the fifth harvest (4.32 MPa and 1.73 kg dm^{-3}), and the sixth harvest (5.78 MPa and 1.75 kg dm^{-3}). They were followed by values at depths between 0.20 and 0.30 m after the fifth (3.63 MPa and 1.69 kg dm^{-3}) and the sixth (4.56 MPa and 1.70 kg dm^{-3}) harvest (Table 1), while VWC was constant throughout the profile. In general, soil penetration resistance values around 2.5 MPa are considered low, while values around 3.5 to 6.5 MPa are considered harmful for root development of legumes and grasses (Torres and Saraiva, 1999).

Table 1. shows PR limiting values in the layers of 0.10-0.20 and 0.20-0.30 m, after the fifth and the sixth harvest, which may possibly have caused decreased productivity of sugarcane.

Regarding Sd, Reinert et al. (2001) propose the following critical values for a compacted soil as 1.55 kg dm^{-3} and 200 - 550 g kg^{-1} of clay. We observed that all evaluated layers reached critical values, with the highest intensity and greatest limitation to the growth of roots in the layers 0.10-0.20 and 0.20-0.30 m after both harvests.

Evaluating soil management in sugarcane, Oliveira Filho et al. (2015) observed no differences in soil water content between plots and between layers up to 0.40 m of depth. PR values were not influenced by this variable, effectively indicating the compacted soil layers. Their data can be used without correcting them for humidity. Their results corroborate the results of our study. In practice, the knowledge of the relationship between PR and the water content is very important for a proper soil management because it helps to specify the conditions which impair or reduce root growth of plants.

Macroporosity (Ma), microporosity (Mi) and total porosity (TP)

In general, it was noted that Ma values decreased in the top layers, and increased in deeper layers, because the lowest values after the 5th (4.63%) and the 6th (4.33%) harvest were observed at the depth of 0.0-0.10 m and the highest values (8.03 % and 7.44%) at the depth of 0.50-0.60 m. Regarding Mi and TP, an opposite pattern was observed i.e. the values increased in the surface layers and decreased in deeper layers after both harvests (Table 2). Ma and Mi values tended to have smaller variations at depths up to 0.40 m, once there are no differences ($p \leq 0.05$) between variables and evaluated harvests. Analyzing the values in Table 2, degradation of Ma, Mi and PT was observed in the surface layer after both harvests, because values are significantly ($p \leq 0.05$) lower for Ma and higher for Mi and TP after both harvests, and tend to decrease after the 6th harvest. Associating these changes with increased PR and Sd in the surface layer (Table 1), it can be assumed that there are restrictions to the development of the root system, such as reduced aeration which causes changes in water dynamics in soil rendering the soil more susceptible to erosion problems (Hickmann et al., 2012). The critical limit of Ma, which is considered as an impediment to the growth of roots, is 10% for annual crops. The ideal soil should contain 1/3 of Ma (34%) and 2/3 of Mi (66%), according to Kiehl (1979). It was observed that the pore size distribution mainly in the superficial layer (from 0.0 to 0.10 m) was distant from the ideal, showing values of 12% and 88% of Ma after the 5th harvest, and 8% and 92% of Mi after the 6th harvest, respectively (Table 2). Pore distribution by size improved with increasing depths, however it did not reach the ideal arrangement. In a similar study, Souza et al. (2006) found that the traffic of agricultural machines and implements increased PR, Sd and Mi, and decreased Ma in the surface layer. The same study also pointed out that Mi means were significantly higher after the 6th harvest, reaching 46.83% at the depth of 0.0-0.10 m, versus 34.22% at the same depth after the previous harvest.

Indicators of soil aggregation

Mean weight diameter (MWD), Geometric mean diameter (GMD), Aggregate stability index (ASI) and Diameter greater than 2.0 mm (AGRI).

Regarding soil aggregation, we observed that the MWD, GMD, ASI and AGRI values were significantly higher at the depth of 0.0-0.10 m (Table 3) what proves the stability of the system in this layer. It can be explained by the presence of organic matter (thrash) on the surface after each harvest and the effect of the fasciculated root system on soil aggregates. Pereira et al (2010) point out that the higher values of MWD and GMD show the contribution of the soil management system to stabilize soil aggregates. All indicators (MWD, GMD, ASI and AGRI) were higher ($p \leq 0.05$) after the 6th harvest, proving that the soil was protected against breakdown caused by the impact of rain drops and sudden moisture changes, while the deposition of organic matter on the soil surface accelerated microbial activity. Wendling et al. (2005), in a study evaluating five systems of soil management and analyzing the same traits of aggregation highlighted that microbial activity produces substances which help form and stabilize aggregates.

Analyzing the values of the AGRI index at the evaluated depths it can be noted that there was a better distribution of aggregates between sieve screens after the 6th harvest, which can be explained by further development of the root system of the crop. Evaluating MWD, GMD, ASI and AGRI values in five soil management systems, Demarchi et al. (2011) observed that the best results occurred on the pasture with another grass (*Urochloa brizantha*), whose results (4.12 and 2.96 mm, 92.9% and 79.7%) were significantly higher than the results (3.43 and 2.04 mm, 88.4 and 63.7%) of the native forest (control), respectively. The authors explained that this was due to higher soil aggregation promoted by the roots of plants grown in the area.

Sensitivity index (Si)

Regarding the sensitivity index (Si) applied to the MWD, when comparing the results after the 5th and 6th harvest, it

Table 1. Values of soil penetration resistance, soil density and volumetric humidity of sugarcane interrows evaluated after the 5th and 6th harvest.

Layer	PR	Sd	VHC	PR	Sd	VHC
	5th harvest			6th harvest		
m	MPa	kg dm^{-3}	cm^3 cm^{-3}	MPa	kg dm^{-3}	cm^3 cm^{-3}
0.00-0.10	2.87 Cb	1.67 Ba	0.22 Aa	3.83 Ca	1.68 Ba	0.21 Aa
0.10-0.20	4.32 Ab	1.73 Aa	0.21 Aa	5.78 Aa	1.75 Aa	0.20 Aa
0.20-0.30	3.63 Bb	1.69 Bb	0.23 Aa	4.56 Ba	1.70 Bb	0.21 Aa
0.30-0.40	2.63 Db	1.65 Cb	0.21 Aa	3.09 Da	1.66 Cb	0.21 Aa
0.40-0.50	1.97 Ea	1.60 Dc	0.23 Aa	2.25 Ea	1.62 Dc	0.23 Aa
0.50-0.60	1.69 Ea	1.60 Dc	0.23 Aa	1.78 Ea	1.61 Dc	0.23 Aa
CV (%)		9.70			6.89	

^{ns} = not significant; * Significant ($p \leq 0.05$). Means followed by the same capital letters in the line compare the 5th and 6th harvest, and lower case letters in the column compare the depths, which do not differ by Scott-Knott test ($p \leq 0.05$). PR: Penetration Resistance; Sd: Soil Density; VWC: Volumetric water content.

Table 2. Values of macroporosity, microporosity and total porosity of sugarcane interrows after the 5th and 6th harvest.

Layer	Ma	Mi	TP	Ma	Mi	TP
	5th harvest			6th harvest		
m	................................%................................					
0.00-0.10	4.63 Aa	34.22 Ab	38.85 Ab	4.33 Aa	46.83 Aa	51.16 Aa
0.10-0.20	6.48 Ba	31.00 Ab	37.49 Ab	6.01 Ba	37.37 Ba	43.38 Ba
0.20-0.30	7.62 Ca	32.30 Ab	39.92 Aa	6.86 Bb	37.58 Ba	44.44 Aa
0.30-0.40	8.33 Ca	32.50 Aa	40.83 Aa	6.36 Bb	35.42 Ba	41.78 Ba
0.40-0.50	8.03 Ca	32.34 Aa	40.37 Aa	7.44 Ca	35.11 Ba	42.54 Ba
0.50-0.60	8.03 Ca	31.14 Aa	40.15 Aa	7.44 Ca	35.00 Ba	41.35 Ba
CV (%)		6.70			8.17	

^{ns} = not significant; * Significant ($p \leq 0.05$). Means followed by the same capital letters in the line compare the 5th and 6th harvest, and lower case letters in the column compare the depths, which do not differ by Scott-Knott test ($p \leq 0.05$). Ma: Macroporosity; Mi: Microporosity; TP: Total Porosity.

Table 3. Values of mean weight diameter, geometric mean diameter, aggregate stability index, aggregate percentage index with a diameter greater than 2 mm.

Layer	MWD	GMD	ASI	AGRI	Si
m	............mm............		..................%.....................		
			5th Harvest		
0.00-0.10	2.18 aB	1.05 aB	57.37 aB	36.00 aB	-
0.10-0.20	0.95 bB	0.63 bB	60.88 aA	25.93 bB	-
0.20-0.30	0.98 bB	0.57 bB	33.89 bB	18.41 bB	-
0.30-0.40	1.07 bB	0.62 bB	47.42 aB	19.65 bB	-
			6th Harvest		
0.00-0.10	4.33 aA	3.50 aA	83.02 aA	84.37 aA	1.99 b
0.10-0.20	3.28 cA	2.03 cA	67.99 aA	59.47 cA	3.46 a
0.20-0.30	3.78 bA	2.65 bA	73.56 aA	71.39 bA	3.85 a
0.30-0.40	3.77 bA	2.42 bA	64.97 aA	71.64 bA	3.56 a
CV (%)	6.57	12.94	15.68	9.23	12.19

* Significant ($p \leq 0.05$). Means followed by the same lowercase letters in columns compare depths after each harvest and capital letters in the columns compare values at the same depths between harvests (the 5th and 6th harvest), which do not differ by Scott-Knott test ($p \leq 0.05$). MWD: Mean Weight Diameter; GMD: Geometric mean diameter; ASI: Aggregate stability index; AGRI: Diameter greater than 2.0 mm; Si: sensitivity index.

Table 4. Pearson's correlation coefficients between physical traits of soil in sugarcane after the 5th and the 6th harvest.

Varible	5th harvest									
	PR	VWC	Ma	Mi	TP	MWD	GMD	ASI	AGRI	Si
.	0.99*	-0.58*	-0.48*	-0.03*	-0.71*	-0.37*	-0.27*	0.31*	-0.39*	-
PR		-0.51*	-0.39^{ns}	-0.10^{ns}	-0.73^{ns}	-0.42^{ns}	-0.42^{ns}	0.16*	-0.52*	-
VWC			0.24*	0.01*	0.42*	0.15*	0.06*	-0.71*	0.19*	-
Ma				-0.57^{ns}	0.70^{ns}	-0.84^{ns}	-0.89*	-0.63*	-0.82*	-
Mi					0.13^{ns}	0.89^{ns}	0.83*	-0.01**	0.91**	-
TP						-0.12^{ns}	-0.24*	-0.71*	-0.09*	-
MWD							0.99^{ns}	0.39*	0.99*	-
GMD								0.51*	0.98*	-
ASI									0.34^{ns}	-
AGRI										-
					6th harvest					
	PR	VWC	Ma	Mi	TP	MWD	GMD	ASI	AGRI	Si
Sd	0.99*	-0.94*	-0.50*	0.32*	0.31*	-0.71*	-0.54*	-0.15*	-0.73*	0.24*
PR		-0.92*	-0.48^{ns}	0.32**	0.32^{ns}	-0.67^{ns}	-0.49^{ns}	-0.08*	-0.69*	0.24^{ns}
VWC			0.63*	-0.39*	-0.36*	0.79*	0.66*	0.37*	0.80*	-0.20*
Ma				-0.92*	-0.88**	-0.65^{ns}	-0.74^{ns}	-0.75*	-0.64*	0.99^{ns}
Mi					0.99^{ns}	0.78*	0.89*	0.95^{ns}	0.77^{ns}	-0.95*
TP						0.79*	0.91*	0.98^{ns}	0.78^{ns}	-0.91**
MWD							0.97^{ns}	0.80*	0.99*	-0.75^{ns}
GMD								0.91*	0.97*	-0.82^{ns}
ASI									0.78^{ns}	-0.80*
AGRI										-0.74*

PR: Penetration Resistance; VWC: Volumetric water content; Ma: macroporosity; Mi: microporosity; TP: total pore volume;: MWD: Mean Weight Diameter; GMD: Geometric mean diameter; ASI: Aggregate stability index; AGRI: aggregates percentage index with a diameter greater than 2 mm; Si: sensitivity index; Sd: Soil density; ^{ns} = not significant, * and ** = significant at $p \leq 0.01$ and $p \leq 0.05$ by Scott-Knott test, respectively.

was observed that the variations are greater ($p \leq 0.05$) in the subsurface layer (0.10-0.40 m) because this layer underwent soil restructuring due to a high input of organic matter, the activity of the root system and the lack of soil disturbance. Evaluating two vegetation covers (sugarcane and pasture with Brachiaria), Fontana et al. (2010) observed that the Si values of soils under the pasture were higher than under sugarcane. They explained that lower Si values found in the sugarcane area reflected the damaging effect of conventional tillage system used in this culture. When analyzing the correlations between all the indicators, it was observed that the Sd and VWC were significantly, positively or negatively, correlated ($p \leq 0.05$) with all other indicators (Table 4).

Correlations between the quality indicators

The correlations show that the Sd was positively correlated with PR and ASI after the 5th harvest and with PR, Mi, TP and Si after the 6th harvest. The same correlation was found between VWC and Ma, Mi, TP, MWD, GMD, ASI, and AGRI after the 5th and the 6th harvest respectively, i.e., these variables increased simultaneously (Table 4). These results show the compaction caused by successive harvest system of sugarcane, which alter the physical structure of the soil, influencing virtually all other indicators.

However, there were negative correlations of Sd with VWC, Ma, Mi, TP, MWD, GMD, ASI, and AGRI. Also VWC was negatively correlated with ASI, Mi, TP and Si, after the 5th and 6th harvest, respectively, i.e. while these variables increased the others decreased. These correlations show that there is a decreasing soil aeration capacity in depth, influencing water infiltration, as evidenced by Hickmann et al. (2012) in a similar study with no-till system over a long period of time. Wendling et al. (2005), studying Latosols under different soil management systems, found positive correlations among MWD, GMD, AGRI and ASI indexes. The correlations among Sd and the other evaluated parameters prove their importance as indicators of soil quality because they are sensitive to changes caused by management, as highlighted by Torres et al. (2015). Beutler et al. (2004) found negative correlations of Sd with TP and Ma and positive correlations with Mi. The authors explained that this was due to the proximity of the particles caused by increasing mechanical pressure on the soil, which reduced the proportion of pores of larger diameter, and slightly increased the proportion of smaller ones.

The correlations between VWC and all other parameters show their importance at the time of tilling or harvest, since they directly influence PR and Sd, which affect root growth and crop yields.

Materials and Methods

Site description

The study was conducted in the commercial area of a sugar and alcohol plant in Uberaba, Minas Gerais, located at the geographical coordinates of 19º39'19"S and 47º57'27"W at an altitude of 795m. Sampling was carried out soon after harvest held in December 2013 (5th harvest) and December 2014 (6th harvest).

Soil type

The soil was classified as Oxisol, with medium texture (Embrapa, 2013), in a wavy soft spot relief, presenting in the layer of 0.00 - 0.20 m: 210 g kg^{-1} of clay; 710 g^{-1} kg of sand; 80 g kg^{-1} of silt; pH ($CaCl_2$) 5.5; 76 mg dm^{-3} of P (Resin); 0.2 $cmol_c$ dm^{-3} of K; 2.2 $cmol_c$ dm^{-3} of Ca; 1 $cmol_c$ dm^{-3} of Mg; 1.7 $mmol_c$ dm^{-3} of H + Al; and 3.27% of organic matter.

Local climate

The climate is classified as Aw, tropical and warm according to Köppen (1948), with cold and dry winters. The mean annual rainfall is 1600 mm, temperature 22.6 ºC, and relative humidity 68%. (Inmet, 2015).

Experimental design and treatments

The experimental design was completely randomized blocks with two treatments: 1 - sugarcane area after the fifth harvest; 2 - sugarcane area after the sixth harvest. The following physical traits: soil penetration resistance (PR), soil density (Sd) volumetric water content (VWC), macroporosity (Ma), microporosity (Mi) and total porosity (TP) were evaluated at six depths (0.00-0.10; 0.10-0.20; 0.20-0.30, 0.30-0.40, 0.40-0.50 and 0.50-0.60 m), while stability of aggregates (AS), mean weight diameter (MWD) and geometric mean diameter (GMD) were evaluated at four depths (0.00-0.10; 0.10-0.20; 0.20-0.30; 0.30-0.40 m), with four replications each. Each plot consisted of 10 rows of sugarcane each 50 meters long (15 x 50 m) and spaced 1.50 m apart, totaling 750 m^2 per plot.

Evaluated traits

Soil compaction indicators

The PR of sugarcane interrows was determined at 12 points per plot, using impact penetrometer Model IAA / Planalsucar with conical tip angle of 30°. The results were obtained by counting the number of impacts. Then the data were converted to kgf cm^{-2} using the equation R (kgf cm^{-2}) = 5.6 + 6.98 N (Sene et al. 1985). The results were multiplied by the constant 0.098 for processing in MPa units.

The soil density was determined using samples with undeformed structure and the volumetric ring method. The samples were collected into rings, 48 mm diameter and 53 mm height, with Uhland auger at the evaluated depths. The samples had been previously saturated for 24 hours. Consequently, the samples were evaluated in a suction unit at 0.60 m of water column, and finally they were dried at 105°C for 24 hours. The Ma was the difference between TP and Mi. Volumetric water content (VWC) was measured in the undisturbed samples using the volumetric ring method with the samples weighed, and placed in an oven at 105 ºC for 24 hours to determine the VWC.

Indicators of the stability of soil aggregates

Deformed samples were collected using a mattock from each plot at depths of 0.00-0.10; 0.10-0.20; 0.20-0.30 m, to analyze aggregate stability (AS) following the method described by Kemper and Chepil (1965). We calculated the mean weight diameter (MWD) (Eq. 1) and the geometric mean diameter (GMD) (Eq. 2) using the aggregate mass values. The aggregate stability index (ASI) (Eq. 3) is a measure of the total soil aggregation and does not consider the aggregate distribution by classes, therefore, the greater the amount of aggregates < 0.25 mm, the lower the ASI. The aggregate percentage index with a diameter greater than 2 mm (AGRI) represents the proportion of aggregates larger than 2 mm, (Eq. 4). The soil aggregation indexes were calculated as follows:

$$\mathrm{MWD} = \sum(\mathrm{xi} \times \mathrm{wi}) \qquad \text{Eq. 1}$$

Where xi is the mean diameter of classes (mm); and wi is the proportion of each class relative to the total (Wendling et al., 2005).

$$G\mathrm{AD} = \exp\{\sum[(\ln[\mathrm{xi}] * [\mathrm{pi}])]/\sum[\mathrm{pi}]\} \qquad \text{Eq. 2}$$

Where ln[xi] is the natural logarithm of the mean diameter of classes, and PI is the weight (g) retained in each sieve (Demarchi et al., 2011).

$$\mathrm{ASI} = \{(\mathrm{S.w.} - \mathrm{wp} < 0{,}25)/\ (\mathrm{S.w.})\} * 100 \qquad \text{Eq. 3}$$

Where Sw is the sample weight, and wp < 0.25 corresponds to the aggregates weight class < 0.25 mm, given in g (Demarchi et al., 2011).

$$\mathrm{AGRI} = \ \mathrm{wi} > 2\ x\ 100 \qquad \text{Eq. 4}$$

Where wi > 2 is the aggregate proportion > 2 mm (Wendling et al., 2005).

To compare the MWD values after the 5th and 6th harvest we used the sensitivity index (Si) suggested by Bolinder et al. (1999) which estimates the intensity of changes of the desired attribute.

$$\mathrm{Si} = \mathrm{as}/\mathrm{ac} \qquad \text{Eq. 5}$$

Where: Si is the sensitivity index; “as” is the value of MWD after the fifth harvest; and “ac” is the value of the same variable obtained after the sixth harvest. The changes in the evaluated attributes are smaller when the Si value is closer to 1.

Statistical analysis

The results were analyzed for normality and homogeneity of data through Lilliefors, Cochran and Barttlet tests. The physical attributes and the evaluated indexes were submitted to the Pearson correlation analysis and analysis of variance using the SISVAR statistical program. The F test was applied to calculate the significance, and the means were compared by Scott-Knott test ($p \leq 0.05$).

Conclusions

The results of this study indicate that degradation of soil physical properties occurs after the fifth and the sixth harvest of sugarcane. The area featured a compacted layer between 0.10 and 0.30 m deep, caused by the harvesting system and infield transport of sugarcane. In addition to this, we found that positive and negative correlations between Sd and the other evaluated parameters are important as soil quality indicators. Finally, positive and negative correlations between water content and other attributes highlight the need to evaluate soil moisture prior to performing tillage or harvest of sugarcane.

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