

## Organic matter and physical attributes of Latosols 30 months after uses in the sugarcane fallow-period

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**ABSTRACT:** The objective this work was to evaluate the organic matter content and the physical attributes of two Red Latosols 30 months after use in the sugarcane fallow-period. The long-term experiment was conducted on two Red Latosols. The design was in blocks, with four treatments and five replications. The treatments were soybean/millet/soybean; soybean/sunn hemp/soybean; soybean/fallow/soybean and soybean. At 30 months after the fallow-period the layers of 0.00-0.10 and 0.10-0.20 m were sampled for the determination of the weighted average diameter of the aggregates; and the layers 0.00-0.10; 0.10-0.20; 0.20-0.40 and 0.40-0.60 m for the determination of organic matter, aggregate stability index, soil density, porosity and resistance to penetration. The uses promoted an increase in organic matter and porosity, a reduction in the aggregation of soils evaluated 30 months after the fallow-period of the cane in relation to that determined after the fallow-period. At 30 months, the resistance to penetration of acric Red Latosol was different among the uses, and soybean/fallow/soybean yielded the lowest value in relation to the soybean and soybean/sunn hemp/soybean use. Uses had no effect on attributes assessed after 30 months.

**Key words:** aggregation; cover crops soil; soil penetration resistance; soil porosity

## Matéria orgânica e atributos físicos de Latossolos 30 meses após usos na reforma de canaviais

**RESUMO:** Objetivou-se neste trabalho avaliar o conteúdo de matéria orgânica e os atributos físicos de dois Latossolos 30 meses após usos na reforma do canavial. O experimento de longa duração foi conduzido em dois Latossolos Vermelho. O delineamento foi em blocos, com quatro tratamentos e cinco repetições. Os tratamentos foram: soja/milheto/soja; soja/crotalária/soja; soja/pousio/soja e soja. Aos 30 meses após a reforma foram amostradas as camadas de 0,00-0,10 e 0,10-0,20 m para a determinação do diâmetro médio ponderado dos agregados; e as camadas de 0,00-0,10; 0,10-0,20; 0,20-0,40 e 0,40-0,60 m para a determinação da matéria orgânica do índice de estabilidade de agregados, densidade do solo, porosidade e resistência à penetração. Os usos do solo promoveram aumento na matéria orgânica e porosidade, redução da agregação dos solos avaliados 30 meses após a reforma do canavial em relação ao que foi determinado após a reforma. Aos 30 meses a resistência à penetração do Latossolo Vermelho ácrico foi diferente entre os usos, sendo que soja/pousio/soja proporcionou o menor valor em relação ao uso com soja e soja/crotalária/soja. Os usos durante a reforma não apresentaram efeito sobre os atributos avaliados após 30 meses.

**Palavras-chave:** agregação; plantas de cobertura; resistência à penetração; porosidade do solo

## Introduction

Sugarcane (*Saccharum officinarum* L.), an important crop for Brazilian agribusiness, whose main derivatives are sugar and ethanol. The estimate for the 2017/18 harvest is 648 million tons of sugarcane, with most of the production in the southeast region, concentrating about 62% of Brazilian sugarcane plantations (CONAB, 2017).

Because it is a semi-perennial crop, the soil under sugarcane field is not inverted during the period of cultivation, which can vary from 4 to 8 years, yielding from 4 to 6 cuts. These soils are subject to intense traffic of machinery, which can lead to compaction, resulting in increased density and reduced porosity (Arvidsson et al., 2012), compromising the physical quality of soils under cane fields in Brazil (Lima et al., 2013). An economically viable alternative to recover the soils from the possible damage that sugarcane cultivation may entail is the diversification of crops during the sugarcane fallow-period season. It is known that crop diversification leads to more improvements in soil physical attributes than cultivation with a single plant species (Loss et al., 2011, Torres et al., 2015). Torres et al. (2000), using sorghum, crotalaria, millet and brachiaria as cover crops under no-tillage system (NTS), concluded that the uses of these plants improved the physical attributes of a medium-textured dystrophic Red Latosol, such as aggregation, density and porosity in relation to fallow treatment.

In this context, there are various plant species that can be used as cover during sugarcane fallow-period, but most farmers make use of crops with some economic value in order to increase profits during the fallow-period, with peanuts and soybeans being the most common ones. However, only one crop during sugarcane fallow may not be enough to improve the physical attributes of soils (Loss et al., 2011). Studies on different uses of the soil during the fallow-period should be made in long-term experiments because of the long cycle of the crop and because results on the physical attributes of the soil are contradictory (Santos et al., 2011; Bettioli Júnior et al., 2012).

The decrease in the stability of upper layer aggregates is the first indication of inadequate soil management (Shahbaz et al., 2017). Fernandes et al. (2012), when evaluating the physical attributes of an acric Red Latosol and an eutroferric Red Latosol after sugarcane fallow-period, concluded that a higher number of crops during the fallow-period did not promote the formation of larger aggregates. However, Silva & Fernandes (2014), when evaluating the physical attributes of the previously mentioned soils 18 months after the sugarcane fallow-period, concluded that a millet cultivation between two soybean crops during the sugarcane fallow-period promoted an increase of aggregation of the acric Red Latosol. Torres et al. (2015) observed that the average diameter of the aggregates of a medium-textured dystrophic Red Latosol increased after 12 years with the use of sorghum, sunn hemp, millet, and brachiaria as cover crops in NTS.

As for porosity, Fernandes et al. (2012) observed that, after fallow-period, two soybean crops had an increase in macroporosity in the 0.0-0.10 m layer of the eutroferric Red Latosol, a fact that was not found by Silva & Fernandes (2014) 18 months after the fallow-period. Torres et al. (2015), on the other hand, observed a reduction in macroporosity and increase in microporosity and total porosity of a dystrophic Red Latosol, under the previously described conditions.

There are few studies on the evaluation of physical attributes of soils during and after sugarcane fallow-period, mainly with periodic evaluations after fallow-period. The evaluation of the attributes is necessary to monitor the physical quality of the soil under sugarcane cultivation to determine the best use of the soil during sugarcane fallow-period, since this practice can provide improvements to the soil and potentiate the productivity of the next harvests.

Based on the above, the hypothesis tested in this work was that the use with crop diversification during sugarcane fallow-period positively affects the physical attributes and the content of organic matter of Latosols 30 months after this management. Thus, the objective was to evaluate uses with crop diversification during sugarcane fallow-period in the physical attributes and the organic matter content of two Latosols 30 months after this management.

## Material and Methods

The data presented in this work comes from a long-term experiment that occurred from October 2008 to February 2010, during the sugarcane fallow-period. The analyzes of the physical attributes of the soil correspond to the evaluations of the agricultural year 2012/2013 (30 months after the sugarcane fallow-period).

The experiment was located in two areas in the city of Jaboticabal - SP (21° 14' 05" S, 48° 17' 09" W, 615 meters high), one with an eutroferric Red Latosol (LVef) (140 g kg<sup>-1</sup> of sand, 180 g kg<sup>-1</sup> of silt and 680 g kg<sup>-1</sup> of clay), characterized as A environment for the production of sugarcane, and another with an acric Red Latosol - LVw (440 g kg<sup>-1</sup> of sand, 120 g kg<sup>-1</sup> of silt and 440 g kg<sup>-1</sup> of clay), characterized as environment C of sugarcane production. The climate, according to Köppen's climatic classification, is Aw, with an average temperature in the hottest month exceeding 22 °C and in the coldest month exceeding 18 °C. The average annual rainfall is 1400 mm, concentrated in the period from October to March.

The experimental design was in randomized blocks with four treatments and five replications. The treatments were constituted of the uses of the soil in the period of sugarcane fallow-period. The uses were soybean/millet/soybean (SMS), soybean/sunn hemp/soybean (SHS), soybean/fallow/soybean (SFS) and soybean (S). Before the fallow-period, the two areas were destined to the production of sugarcane for more than 30 years, with burning of the straw and manual harvesting until 1995. From that date, the harvest began to be mechanized without burning of the straw. For the

sugarcane fallow-period in both areas, the sugarcane ratoon was mechanically destroyed for sowing soybeans (*Glycine max* L.).

In the SMS, SHS and SFS treatments, soybean was cultivated from October 2008 to February 2009 and October 2009 to February 2010. In the months of March to September 2009, the soil was cultivated with millet (*Pennisetum americanum*) (SMS) or sunn hemp (*Crotalaria juncea*) (SHS) or remained in fallow (SFS). The sowing of millet, crotalaria and soybean occurred in no-tillage system (NTS). The density of soybean plants in both crops was estimated at 400,000 plants ha<sup>-1</sup>, millet in 3,000,000 plants ha<sup>-1</sup> and crotalaria in 555,500 plants ha<sup>-1</sup>. In the S treatment, soybean cultivation was carried out from October 2009 to February 2010. The dry matter yield of soybean, millet and sunn hemp was determined by Fernandes et al. (2012).

Planting of sugarcane occurred in February 2010 in the semi-mechanized system, with soil rotation only in the planting line, using the variety SP 87-365 in LVef and BR 83-5054 in LVw and the harvest was mechanized in all cuts.

Each plot comprised an area of 270 m<sup>2</sup> (18 m wide × 15 m long). The useful area of the plot corresponded to 8 lines of sugarcane, spaced by 1.5 m, 10 m long.

Soil sampling occurred 30 months after the sugarcane fallow-period (August 2012), in the interlining, at three points in the useful area of each plot. In the 0.00-0.10 and 0.10-0.20 m layers, samples were collected with preserved structure for the evaluation of the weighted mean diameter of the aggregates (WMD) (Nimmo & Perkins, 2002). In the 0.00-0.10, 0.10-0.20, 0.20-0.40 and 0.40-0.60 m layers, deformed samples were collected to evaluate the aggregate stability index (ASI) using a method proposed by Nimmo & Perkins (2002) and the determination of organic matter

(OM) content was made by chemical etching in potassium dichromate in sulfuric medium (Walkley-Black). In the 0.00-0.10, 0.10-0.20, 0.20-0.40 and 0.40-0.60 m layers, undeformed soil samples were collected in volumetric cylinders (0.05 × 0.0475 m) to determine the soil bulk density ( $\rho$ ) (ratio of soil dry matter by cylinder volume), total porosity (TP), macroporosity (MAC) and microporosity (MIC) (Embrapa, 1997). The penetration resistance (PR) was determined after the undeformed samples were subjected to -100 hPa in tension table, as described by Serafim et al. (2013), using a bench penetrometer with 4 mm tip, 60° angle and tip penetration velocity of 10mm min<sup>-1</sup>.

The variables were submitted to analysis of variance, following the randomized block design in sub-divided plots, where the main treatments were the soil uses in the sugarcane fallow-period and the secondary treatments were the soil layers evaluated. We performed the analysis of the interaction between the factors, main treatment × secondary treatment and the joint analysis of data of the two experiments (comparing the two soils), and the means were compared by the Tukey test at 1 and 5% of significance.

## Resultas and Discussion

Soil uses with crop diversification during the sugarcane fallow-period did not promote significant differences in the organic matter (OM) content of eutroferic Red Latosol (LVef) and acric Red Latosol (LVw) evaluated 30 months after the sugarcane fallow-period (Table 1).

The diversity of plant material, at different stages of decomposition, may have been insufficient to promote significant differences in OM content between treatments in the studied areas. The millet and sunn hemp residues from

**Table 1.** Organic matter (OM), weighted mean diameter (WMD), soil aggregate stability index (ASI), penetration resistance (PR), soil bulk density ( $\rho$ ), total porosity (TP), macroporosity (MAC), microporosity (MIC) of the eutroferic Red Latosol (LVef) 30 months after the sugarcane fallow-period.

Treatments	OM (g kg <sup>-1</sup> )	WMD (mm)	ASI (%)	PR (Mpa)	$\rho$ (kg dm <sup>-3</sup> )	TP	MAC	MIC
						(m <sup>3</sup> m <sup>-3</sup> )		
SMS	24.75	2.23	83.35	4.28	1.43	0.53	0.07	0.46
SHS	25.70	2.32	83.50	3.84	1.41	0.53	0.07	0.46
SFS	25.20	2.34	84.18	3.98	1.41	0.52	0.07	0.46
S	26.35	2.56	85.28	3.85	1.41	0.52	0.07	0.45
F <sup>(1)</sup>	1.16 <sup>ns</sup>	1.31 <sup>ns</sup>	0.39 <sup>ns</sup>	2.74 <sup>ns</sup>	0.33 <sup>ns</sup>	1.26 <sup>ns</sup>	0.42 <sup>ns</sup>	1.66 <sup>ns</sup>
MSD <sup>(2)</sup>	2.68	0.51	5.93	0.46	0.05	0.01	0.02	0.01
CV (%)	11.18	16.16	7.52	13.86	4.46	2.48	33.42	3.70
Layers								
0.0-0.10 m	33.75 a	2.47	85.35	4.02	1.40	0.54 a	0.05 b	0.48 a
0.10-0.20 m	29.95 b	2.25	82.84	3.79	1.41	0.52 b	0.07 a	0.45 b
0.20-0.40 m	22.25 c	-	85.75	4.03	1.41	0.53 ab	0.08 a	0.44 b
0.40-0.60 m	16.05 d	-	82.37	4.11	1.43	0.52 b	0.07 a	0.45 b
F <sup>(1)</sup>	264.18**	4.24 <sup>ns</sup>	2.16 <sup>ns</sup>	1.21 <sup>ns</sup>	1.35 <sup>ns</sup>	5.08**	10.46**	40.17**
MSD <sup>(2)</sup>	1.83	0.22	4.40	0.12	0.03	0.01	0.01	0.01
CV (%)	8.54	16.88	6.22	3.99	2.54	2.16	23.26	3.41
Interaction								
TxL	1.16 <sup>ns</sup>	0.86 <sup>ns</sup>	0.73 <sup>ns</sup>	0.67 <sup>ns</sup>	1.39 <sup>ns</sup>	1.25 <sup>ns</sup>	1.14 <sup>ns</sup>	0.68 <sup>ns</sup>

<sup>(1)</sup> ns = not significant; \*, \*\* = significant at 5 and 1% probability, respectively. Means followed by the same letter in the column do not differ by Tukey test. <sup>(2)</sup> Minimal significant difference.

the SMS and SHS treatments, respectively, were mixed with the partially decomposed soy residues from the first crop and, consequently, the soybean residues from the second crop were mixed to the partially decomposed soybean, millet, and crotalaria residues. In the SFS treatment, residues from the first soybean crop were maintained in the soil during the fallow period and mixed with the residues from the second soybean crop. Fernandes et al. (2012), after the sugarcane fallow-period, and Silva & Fernandes (2014), 18 months after the fallow-period, did not observe significant differences among the soil uses in promoting changes in the OM content of the studied soils.

In the 30 months after the sugarcane fallow-period with crop diversification, there was an increase in OM content in relation to the levels observed by Fernandes et al. (2012) in this same experiment soon after the sugarcane fallow-period. The SMS treatment presented an increase in OM of 73% in LVef and 81% in LVw; the SHS, of 76% in LVef and 76% in LVw; the SFS treatment, of 72% in LVef and 77% in LVw; and treatment S, of 69% in LVef and 84% in LVw. The highest values observed at 30 months after the fallow-period show the effect of the treatments used during the fallow-period, associated with the large amount of residues generated by sugarcane in two cuts, in increasing the OM contents of the studied soils, as discussed per Rossetti & Centurion (2015). The authors observed the OM content of a dystrophic Red Latosol, of medium texture under NTS increase from the 2008/09 agricultural year to the 2009/10 year, which was attributed to the climatic conditions of the city of Jaboticabal, characterized by dry autumn-winter with low temperatures and spring-summer with high rainfall indexes and high temperatures, which favors the alteration of the vegetal residues in OM of the soil.

The OM contents were significant between the layers of the two soils, being the highest OM contents found in the 0.00-0.10 m layer and decreasing with depth (Tables 1 and 2). The higher root density and greater accumulation of plant material at the soil surface provide higher OM contents in the soil surface layers (Loss et al., 2011; Shahbaz et al., 2017). Shahbaz et al. (2017) emphasized that the biological activity of the soil is more intense in the upper layers, so the biological processes that degrade plant material into OM are accelerated, providing a decreasing increment of OM from the soil surface to the deeper layers.

Soil uses with crop diversification during the sugarcane fallow-period did not promote significant changes in soil aggregation, characterized by aggregate weighted mean diameter (WMD) and aggregate stability index (ASI), 30 months after sugarcane fallow-period (Tables 1 and 2). After sugarcane fallow-period, Fernandes et al. (2012) observed that two soybean cultivars did not promote the formation of larger aggregates in LVef and LVw in relation to a soybean crop due to the more intense mobilization of the soil for the planting of two soybean crops. At 30 months after the fallow-period, there is probably no more influence on soil mobilization actions for soybean planting. The roots of cover plants left under the soil are efficient for the stabilization of soil aggregation, because together with the organic C, the action of the root exudates of the cover plants are the main cementing agents of the soils (Shahbaz et al., 2017). In the SFS treatment, the root system of the first soybean crop was maintained in the soil during the fallow period and, as the second soybean crop was in NTS, this treatment had the presence of the root system of two soybean crops. Therefore, as all treatments remained with the root system of the crops in the soil and as the sugar cane produces a

**Table 2.** Organic matter (OM), weighted mean diameter (WMD), soil aggregate stability index (ASI), penetration resistance (PR), soil bulk density ( $\rho$ ), total porosity (TP), macroporosity (MAC), microporosity (MIC) of the acric Red Latosol (LVw) 30 months after the sugarcane fallow-period.

Treatments	OM (g kg <sup>-1</sup> )	WMD (mm)	ASI (%)	PR (Mpa)	$\rho$ (kg dm <sup>-3</sup> )	TP		MIC
						MAC (m <sup>3</sup> m <sup>-3</sup> )		
SMS	18.00	1.86	72.40	3.96 ab	1.62 ab	0.43ab	0.07	0.36
SHS	18.00	1.81	74.65	4.23 a	1.64 a	0.42b	0.06	0.36
SFS	19.00	1.92	71.64	3.62 b	1.60 b	0.44a	0.08	0.36
S	17.90	2.21	74.56	4.22 a	1.59 b	0.44a	0.08	0.36
F <sup>(1)</sup>	0.51 <sup>ns</sup>	2.71 <sup>ns</sup>	1.40 <sup>ns</sup>	3.72*	5.80*	5.24*	2.03 <sup>ns</sup>	0.07 <sup>ns</sup>
MSD <sup>(2)</sup>	3.10	0.46	5.41	0.55	0.03	0.01	0.02	0.02
CV (%)	17.95	17.93	7.86	16.32	2.35	3.63	28.69	5.51
Layers								
0.0-0.10 m	23.25 a	2.06	77.63 a	4.16	1.61	0.44	0.07	0.37 a
0.10-0.20 m	21.10 b	1.84	74.79 ab	3.99	1.63	0.44	0.07	0.35 b
0.20-0.40 m	16.25 c	-	71.63 bc	4.03	1.62	0.44	0.07	0.36 ab
0.40-0.60 m	12.95 d	-	69.18 c	3.81	1.60	0.44	0.08	0.35 b
F <sup>(1)</sup>	158.15**	4.24 <sup>ns</sup>	9.94**	0.98 <sup>ns</sup>	0.94 <sup>ns</sup>	1.63 <sup>ns</sup>	0.46 <sup>ns</sup>	6.32**
MSD <sup>(2)</sup>	1.39	0.22	4.40	0.55	0.04	0.01	0.01	0.01
CV (%)	9.01	16.88	7.13	4.01	3.00	3.70	26.06	2.98
Interaction								
TxL	0.94 <sup>ns</sup>	0.86 <sup>ns</sup>	1.23 <sup>ns</sup>	0.65 <sup>ns</sup>	0.99 <sup>ns</sup>	0.76 <sup>ns</sup>	1.30 <sup>ns</sup>	1.59 <sup>ns</sup>

<sup>(1)</sup> ns = not significant; \*, \*\* = significant at 5 and 1% probability, respectively. <sup>(2)</sup> Minimal significant difference.

great mass of roots, there was no significant difference between treatments for the aggregation because the root system of the cover plants promotes the protection of the structure and maintains the soil aggregated (Shahbaz et al., 2017). Torres et al. (2015) emphasized that the maintenance of aggregation is a consequence of the restructuring of the particles and aggregates that the NTS imposes on the soil. Thus, the similarity between the treatments in the aggregation is due to the action of the root system of the crops and the sugarcane, which stabilize the aggregation.

The ASI of the LVw was higher in the 0.00-0.10m layer compared to the other layers of the same soil and there was a reduction of the indices in depth (Table 2). The explanation for a higher ASI value in the 0.00-0.10m layer of LVw is due to the effect of OM being more pronounced in this soil with higher sand content ( $440 \text{ g kg}^{-1}$ ) than the LVef ( $140 \text{ g kg}^{-1}$ ) (Garcia et al., 2013). As in the LVw, the 0.00-0.10m layer is the one with the highest OM content, the ASI was higher in this layer.

At 30 months after sugarcane fallow-period, LVef presented the highest aggregation indices when compared to LVw, except for WMD in the 0.00-0.10 m layer that was statistically the same in both soils (Table 3). The same WMD among the soils in this layer evidences the influence that this attribute has of the OM in soils with weaker structure, in relation to the mineral fraction (Souza et al., 2009). As LVw has more sand than LVef, aggregation is more affected by OM, by the action of the root system of the plants and microbial activity, which secretes substances that aid in the aggregation of the soil (Torres et al., 2015; Shahbaz et al., 2017), since in the layer of 0.00-0.10 m the activity of the organisms is more intense and similar in the two soils. The reduction of the OM values in depth of the LVw results in a decrease of the WMD. The highest ASI in all layers and the

highest WMD in the 0.10-0.20m layer is due to the higher clay and OM content of LVef, which promotes aggregate stability  $<2\text{mm}$ . Souza et al. (2009) observed that the aggregation of an eutrophic Red Latosol ( $622 \text{ g kg}^{-1}$  of clay and  $25.04 \text{ g kg}^{-1}$  of OM) was greater than that of a dystrophic Red Latosol ( $354 \text{ g kg}^{-1}$  clay and  $15.05 \text{ g kg}^{-1}$  of OM) due to the higher content of clay and OM. Silva & Fernandes (2014), at 18 months after the use of the soil in the sugarcane fallow-period, observed higher ASI in LVef when compared to LVw, confirming the information discussed previously.

There was a reduction of WMD of the studied soils at 30 months after the sugarcane fallow-period in relation to the WMD values observed by Fernandes et al. (2012) after the fallow-period in this same experiment. The reduction in SMS treatment was 21% in LVef and 51% in LVw; in the SHS treatment, it was 25% in LVef and 35% in LVw; in SFS treatment, it was 9% in LVef and 12% in LVw; and in S treatment, it was 33% in LVef and 88% in LVw. The WMD observed after the fallow-period decreased over time due to the transit of machinery and the sugarcane root growth itself, which promoted aggregation fragmentation and particle rearrangement. Reichert et al. (2016) observed that the results determined in the early years of NTS may be ephemeral and probably do not last in time. The authors pointed out that changes in soil physical attributes may change over time depending on the attribute assessed. In this same experiment, Silva & Fernandes (2014) already observed a reduction in WMD of the soils assessed in relation to the values observed by Fernandes et al. (2012).

Soil uses did not change the penetration resistance (PR) of LVef (Table 1), but had changed the PR of LVw (Table 2). The PR values observed in the LVef of this work (3.84 - 4.28 MPa) were similar to those found by Ohland et al. (2014) in an entroferric Red Latosol ( $576 \text{ g kg}^{-1}$  clay) submitted

**Table 3.** Organic matter (OM), weighted mean diameter (WMD), soil aggregate stability index (ASI), penetration resistance (PR), soil bulk density ( $\rho$ ), total porosity (TP), macroporosity (MAC), microporosity (MIC) of the entroferric Red Latosol (LVef) and the acric Red Latosol (LVw) 30 months after the sugarcane fallow-period.

Treatments	OM ( $\text{g kg}^{-1}$ )	WMD (mm)	ASI (%)	PR (Mpa)	$\rho$ ( $\text{kg dm}^{-3}$ )	TP	MAC	MIC
0.00-0.10 m								
LVef	33.75 a	2.47	85.35 a	4.16	1.40 b	0.53 a	0.05 b	0.48 a
LVw	23.25 b	2.06	77.64 b	4.02	1.61 a	0.44 b	0.07 a	0.37 b
F(1)	62.05**	8.57 <sup>ns</sup>	40.71**	0.17 <sup>ns</sup>	255.88**	252.14**	15.96*	1430.37**
0.10-0.20 m								
LVef	29.95 a	2.25 a	82.84 a	3.79	1.41 b	0.52 a	0.07	0.45 a
LVw	21.10 b	1.84 b	74.79 b	3.98	1.63 a	0.43 b	0.07	0.35 b
F(1)	233.22**	14.02*	20.48*	0.41 <sup>ns</sup>	134.24**	151.03**	0.16 <sup>ns</sup>	750.86**
0.20-0.40 m								
LVef	22.25 a	-	85.74 a	4.02	1.41 b	0.53 a	0.08	0.44 a
LVw	16.25 b	-	71.63 b	4.03	1.62 a	0.43 b	0.07	0.36 b
F(1)	100.00**	-	79.58*	0.00 <sup>ns</sup>	147.17**	189.03**	0.86 <sup>ns</sup>	288.22**
0.40-0.60 m								
LVef	16.05 a	-	82.37 a	4.11	1.43 b	0.52 a	0.07	0.45 a
LVw	12.95 b	-	69.19 b	3.81	1.60 a	0.44 b	0.08	0.36 b
F(1)	320.33**	-	265.25**	4.00 <sup>ns</sup>	177.87**	219.21**	4.66 <sup>ns</sup>	442.63**

(1) <sup>ns</sup> = not significant; \*; \*\* = significant at 5 and 1% probability, respectively. Means followed by the same letter in the column do not differ by Tukey test.

to different levels of compaction and humidity for the cultivation of Pinhão-Manso. According to the authors, the PR is altered when the traffic of machinery occurs in humidities inappropriate to the traffic, which compacts the soil, decreasing the porous space and the humidity of the soils, raising the PR values.

The SFS treatment promoted the lowest PR index in LVw due to the lower number of agricultural operations. However, maintaining fallow land during sugarcane fallow-period is not a recommended management practice, since soil without vegetation cover is more susceptible to erosion (Lanzanova et al., 2013), and it may present a reduction in aggregation due to lower accumulation of OM (Garcia et al., 2013).

The SMS treatment presented intermediate PR to the other treatments due to the millet root system, which, due to being fasciculated, provides a reduction in  $\rho$ , influencing PR (Table 2). Torres et al. (2015) observed reduction in  $\rho$  of a dystrophic Red Latosol (710 g kg<sup>-1</sup> of sand, 80 g kg<sup>-1</sup> of silt and 210 g kg<sup>-1</sup> of clay) under fallow, millet and sorghum when compared to crotalaria as cover plants. Among the soils, the values of PR were not different, evidencing that there is no effect of the higher OM and clay content of LVef in decreasing PR in relation to LVw (Table 3). The PR values obtained in this work are within the critical limit proposed by Silva et al. (2004), who reported PR values between 3.5 - 6.5 MPa as the most limiting to root growth. Critical levels may vary according to the type of soil and the type of crop, and it is difficult to establish critical limits, since these parameters are always linked to other variables, such as soil density and humidity. The PR in all treatments, in both evaluated soils, did not reach the critical limit of root growth adopted for sugarcane, which can be 6.0 MPa in soils of medium texture to sandy (Sene et al. 1985) and around 4.40 MPa for soils with higher clay content (450 - 730 g kg<sup>-1</sup> of clay) (Lima et al., 2013). Moraes et al. (2017) have stated that the high PR in clayey soils is a natural process due to the greater cohesive strength among the clay particles, providing high PR values, even in low  $\rho$  conditions, without compromising the development of the root system of the crops.

The SFS and S treatments presented lower value of  $\rho$  of LVw due to the lower traffic of machines in these treatments in relation to the SHS and SMS treatments. In spite of having traffic of machines similar to the SHS treatment, the SMS treatment promoted a value of  $\rho$  intermediate to the others due to the action of the millet root system, as already discussed (Table 2). Between the LVef and LVw layers there was no significant difference in  $\rho$  (Table 2).

The values of  $\rho$  ranged from 1.40 to 1.43 kg dm<sup>-3</sup> in LVef and from 1.60 to 1.63 kg dm<sup>-3</sup> in LVw (Table 3). The higher OM content in the LVef contributed to the lower values of  $\rho$  in this soil, as the  $\rho$  decreases with increasing OM content in soils (Conte et al., 2011). The higher  $\rho$  in LVw is also because the sand mass is higher in this soil, providing higher values of  $\rho$  in sandy soils (Suzuki et al., 2007).

Soil uses with crop diversification during sugarcane fallow-period did not alter the volume of macro, micropores

and total porosity (MAC, MIC and TP, respectively) of LVef (Table 2). Fernandes et al. (2012) and Silva & Fernandes (2014) did not observe significant differences between soil uses in the MAC, MIC and TP determined after the sugarcane fallow-period and 18 months after the fallow-period, respectively. As the results presented correspond to 30 months after the uses, there is no effect of the treatments in promoting significant changes in MAC, MIC and TP of this soil, since the root system that remains is that of sugarcane. Santos et al. (2011) did not observe significant difference in the porosity of a Red Latosol with a very clayey texture consorted with soybean and brachiaria. According to these authors, the presence of the root system of the grass and the legume promoted the maintenance of soil porosity. Torres et al. (2015) did not observe reduction of the porosity of a dystrophic Red Latosol (710 g kg<sup>-1</sup> of sand, 80 g kg<sup>-1</sup> of silt and 210 g kg<sup>-1</sup> of clay) after a fallow period for the planting of corn. The authors explained that short fallow periods in NTS do not compromise soil porosity.

There was lower MAC volume and higher MIC volume in the 0.00-0.10m layer of LVef, compared to the other layers of the same soil, with TP being influenced by MIC (Table 2). Lower MAC volume in the upper layer of the soil is justified by the fact that this layer is more affected by the anthropic actions, so lower MAC values result in the increase of MIC in the same layer. Among the soils, there was a higher volume of MAC only in the 0.00-0.10m layer of LVw (Table 3), due to the higher sand content of this soil. The higher pore volume in LVef is due to the higher clay content and OM, which are responsible for decreasing  $\rho$ , thus increasing the porous spaces that can be occupied by air and water, in macro and micropores, respectively. However, because they have distinct textural constitution (very clayey LVef and clayey LVw), the porosity of the soils was different, since they form distinct structures. The LVef presents the highest aggregation indexes (WMD and ASI), favoring a structure more resistant to deformation, providing higher TP and MIC and higher MAC in the layers of 0.10-0.60 m. The LVw presents lower aggregation indexes, providing a weaker structure and favoring a reduced porosity, with the exception of MAC in the 0.0-0.10 m layer.

This work showed that the small reductions in MAC volume between the layers of LVef were not enough to increase  $\rho$ , differing from what was observed by Matias et al. (2012) who stated that any decrease in MAC will reflect an increase in  $\rho$ , requiring more detailed studies on the influence of MAC on  $\rho$ .

The SFS and S treatments promoted higher TP in LVw in relation to the SHS treatment, and the SMS treatment promoted an intermediate value to the other treatments (Table 2). The higher volumes of TP are due to less traffic of machines in these treatments, evidenced by the smaller  $\rho$  in these treatments. Soil uses did not alter the volume of MAC and MIC of LVw (Table 2). There was no significant difference between the LVw layers for the MAC and TP (Table 2).

The increase of OM contents at 30 months after the sugarcane fallow-period favored the maintenance of  $\rho$  and

MAC of L<sub>Vef</sub> and L<sub>Vw</sub>, since the values of these attributes practically did not change in relation to the values of  $\rho$  and MAC determined after the sugarcane fallow-period by Fernandes et al. (2012). The OM has the effect of dissipating the energy of traffic of the machinery in the soils, so the increase of its contents reduces the potential that those devices have in increasing the  $\rho$  (Reichert et al., 2016). Thus, the increase observed at 30 months after the fallow-period avoided changes in  $\rho$ . The similar values of MAC 30 months after sugarcane fallow-period can also be attributed to the biological action of the sugarcane root system that promoted the formation of new biopores (Reichert et al., 2016), which contributed to the MAC did not change over time.

There was an increase in TP 30 months after the sugarcane fallow-period in relation to the values determined after the sugarcane fallow-period. The increase in SMS treatment was 13% in L<sub>Vef</sub> and 18% in L<sub>Vw</sub>; in SHS treatment, of 13% in L<sub>Vef</sub> and 17% in L<sub>Vw</sub>; in SFS treatment, of 11% in L<sub>Vef</sub> and 18% in L<sub>Vw</sub>; and in S treatment, of 11% in L<sub>Vef</sub> and 16% in L<sub>Vw</sub>. The increase of the TP is due to the reduction of the diameter of the aggregates observed in this work and the rearrangement of the soil particles, which promotes greater microporosity resulting in an increase in TP over time.

## Conclusions

There was a reduction in the weighted mean diameter of the aggregates and an increase in the organic matter content and porosity of the eutroferic Red Latosol and the acric Red Latosol determined 30 months after the sugarcane fallow-period, in comparison with the evaluations made after and 18 months after the fallow-period.

Soil uses with crop diversification promoted differences in the resistance to penetration of the acric Red Latosol 30 months after the sugarcane fallow-period, in which soybean/fallow/soybean treatment provided the lowest PR in relation to soybean and soybean/sunn hemp/soybean treatments, but the values did not reach the limits considered critical for the development of the root system of the culture.

Soil uses with crop diversification did not change the organic matter content of the studied soils, but the organic matter content increased over two sugarcane crops.

Soil uses with crop diversification did not alter the aggregation of the studied soils.

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