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SOIL PHYSICAL PROPERTIES IN A LONG-TERM CONSERVATION SYSTEM FOR ONION

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ABSTRACT

The objective of this study was to evaluate soil physical properties under different cropping systems for onion. The study was conducted on an Inceptisol in Ituporanga, Santa Catarina state, Brazil. We evaluated eight cropping systems for onion: T1: maize-onion succession; T2: common vetch-maize/rye+fodder radish-onion-maize/rye+fodder radish-common bean; T3: rye-onion-maize/black oat-maize; T4: onion-velvet bean succession; T5: rye-onion-millet/black oat-onion-millet; T6: rye-onion-velvet bean succession; T7: onion-velvet bean+millet+sunflower succession. Treatments from T1 to T7 were conducted under no-tillage system (NTS) and T8: maize-onion succession under a conventional tillage system. We used the randomized complete block design, with five replications. Undisturbed soil samples were collected at the 0-5, 5-10 and 10-15 cm soil layers and we evaluated the following soil physical properties: geometric mean diameter of aggregates, total porosity, macroporosity, microporosity, bulk density and the ratio macroporosity/ total porosity. The data analysis was performed using univariate statistics, principal components analysis (PCA) and cluster analysis (CA). Based on the cropping systems characteristics, the CA divided them into three groups: group 1: T7; group 2: T1, T2, T3, T4, T5, T6; and group 3: T8. T8 showed evidence of soil physical quality deterioration at the soil surface, T7 presented the best soil physical properties.

Keywords: Cropping systems, cover crops, clustering, soil structure

PROPRIEDADES FÍSICAS DO SOLO EM SISTEMA DE LONGA DURAÇÃO PARA A CEBOLA

RESUMO

O objetivo foi avaliar atributos físicos do solo em diferentes sistemas de cultivo para cebola. O estudo foi conduzido em um Cambissolo Húmico Distrófico, em Ituporanga, SC, Brasil. Os seguintes tratamentos foram avaliados: T1: sucessão milho e cebola, T2: ervilhaca-milho/centeio+nabo-cebola-milho/centeio+nabo-feijão; T3: centeio-cebola-milho/aveia-milho; T4: sucessão cebola-mucuna; T5: centeio-cebola-milheto/aveia-cebola-milheto; T6: sucessão centeio-cebola-mucuna; T7: sucessão cebola-milheto+mucuna+girassol. Os tratamentos de T1 até T7 foram conduzidos em sistema plantio direto, e T8 sucessão milho-cebola, foi conduzido em preparo convencional. O delineamento usado foi o de blocos completos casualizados, amostras de solo indeformadas foram colhidas nas camadas de 0-5, 5-10 e 10-20 cm e as variáveis analisadas foram: diâmetro médio geométrico de agregados, porosidade total, macroporosidade, microporosidade, densidade do solo e a relação macroporosidade/porosidade total. A análise de dados foi feita por meio da estatística univariada, análise de componentes principais e análise de agrupamento. Baseado nas características dos tratamentos, a análise de agrupamento definiu 3 grupos: grupo 1: T7; grupo 2: T1, T2, T3, T4, T5, T6; e grupo 3: T8. O preparo convencional apresentou indícios de degradação estrutural na camada superficial do solo. A melhor qualidade estrutural do solo foi observada no T7.

Palavras-chave: Sistemas de cultivo, plantas de cobertura, agrupamento, estrutura do solo

INTRODUCTION

Onion plays a significant economic role in Brazil corresponding to the main activity for nearly 60.5 thousand households. The Santa Catarina state is the leading onion grower in Brazil (KURTZ et al., 2019) and this activity is dealt by small and medium farmers, playing a significant role in the local socio-economic development, contributing to the generation of incomes, employment, and people establishment in rural areas (MENEZES JÚNIOR et al., 2014).

In Santa Catarina State, the conventional tillage system (CTS) is the dominant system used to grow onion (MENEZES JÚNIOR et al., 2014). Therefore, soils under this management are intensively degraded by the use of chisel and rotary tiller (EPAGRI, 2013; LOSS et al., 2015) which causes water, nutrients and soil losses by erosion (PANACHUKI et al., 2011) and can negatively affect soil physical properties (ARCOVERDE et al., 2019).

Another cropping system that can be used to grow onion is the no-tillage system (NTS). NTS has long been regarded as one of the most crucial cropping systems to enable sustainable cropping intensification to meet future agricultural demands (DERPSCH et al., 2014). In the NTS, soil disturbance is restricted to the planting rows, and cover crops are used to produce plant biomass, which is rolled down and left on the soil surface during the flowering period with the use of a knife-roller (SANTOS et al., 2017).

Crop residues and biomass accumulated by the cover crops are essential for the maintenance or recovery of soil physical and chemical properties in NTS (MENDONÇA et al., 2013). The decomposition of the cover crops straw increases biological activity (BABUJIA et al., 2010), nutrients, and soil organic matter (SOM) accumulation in the soil surface layer (LIMA FILHO et al., 2014). This cropping system also increases and promotes nutrients cycling, soil physical protection on the surface, soil aggregates formation (LOSS et al., 2015, 2017), and, therefore, promotes plant health (NICHOLLS et al., 2019).

The NTS includes crop rotation systems (CRS), which allow the inclusion of species with different root systems and crop residues with different C/N ratios. CRS contribute to the alterations of decomposition rates and nutrients cycling. The crop residues at the soil surface benefit other crops in succession, improving the soil physical, chemical and biological properties (COSTA et al., 2015). Because of the soil conservation importance for onion growers some experiments are being conducted using different cropping systems. The use of cover crop residues increased water use and onion yields cultivated in NTS in comparison with CTS in Brazilian cerrado condition (MAROUELLI et al., 2010). In an agro-ecological NTS in Ituporanga's region the addition of cover crop residues in no-tillage contributed to the growth and onion yields over the years (SOUZA et al., 2013). This conservation system improves soil aggregation and organic carbon concentrations associated with use of cover crops for onion production (GIUMBELLI et al., 2020).

Therefore, understanding the changes which occur on the soil physical properties under NTS associated with crops rotation systems and the formation of cover crops are essential for the soil physical quality improvement in onion growing fields such as in Santa Catarina ones. This study aimed to evaluate soil physical properties in an experiment on onion cultivated under different cropping systems.

MATERIAL AND METHODS

The experiment was established in 2007 in Ituporanga (27º24'52" S e 49º36'9" W, 475 m altitude), Santa Catarina State, Brazil, on a Humic Dystrudept (SOIL SURVEY STAFF, 2014). This area had been previously cultivated under no-tillage system (NTS) since 1995, when the soil was limed to 6 pH. The climate is a humid mesothermal with hot summers, Cfa, according to the Köppen classification (EMBRAPA, 2004). It has an average annual temperature of 17.6 °C and an average annual precipitation of 1400 mm (COMIN et al., 2018). The soil particle size distribution is characterized by 430, 300 and 270 g/kg respectively of sand, clay and silt and 31 g/kg of total organic carbon. The experiment was conducted in a randomized complete block design, with 5 replications and 8 treatments. The treatments were comprised by different cropping systems (Table 1).

All the treatments were cultivated under the no-tillage system (NTS) from 2007 to 2011. Since then, T8 has been managed under CTS (chisel and rotary tiller) to evaluate soil degradation after a previous conservation management. Each plot had an area of 8.7 m², with seven planting rows of onion variety Epagri 352 with a planting distance of 0.4 x 0.1 m. The selection of the cover species was based on traditional use, adaptation, seed availability, easiness to grow, and suitable mass production.

For soil physical analyses, undisturbed soil samples were collected in 2014 at the 0-5, 5-10 and 10-15 cm layers, using volumetric rings (internal diameter of 6 cm, and height of 5 cm). The following soil physical properties were evaluated: geometric mean diameter of aggregates (GMD), total porosity (TP), macroporosity (Macro), microporosity (Micro) and soil bulk density (BD). The GMD was determined according to Kemper and Chepil (1965). The soil samples were weighed and oven-dried at 105 ^{0}C for 48 h to quantify the soil bulk density (BD), soil particles density (SPD) was determined according to the volumetric balloon method (EMBRAPA, 2011). For the soil microporosity determination, the undisturbed soil samples were subject to water saturation and maintained on a suction table at a 60 cm suction, being the microporosity calculated by: $Micro = \frac{SW_{60\,cm} - SDW}{V}$, where SDW is the soil dry weight at 105 ^{0}C, V is the volumetric ring volume (cm^{3}) and SW_{60cm} is the soil weight at 60 cm suction. Then the soil total porosity (TP) was obtained by the relationship between BD and SPD $\left(TP = 1 - \frac{BD}{SPD}\right)$, and the macroporosity (Macro) by

$Macro = TP - Microporosity$ (EMBRAPA, 2011). Using the treatments means, we calculated the porosities ratio (PR) by $PR = Macro/PT$.

Table 1. Treatments description in a long-term conservation system for onion, in Ituporanga, Santa Catarina State, Brazil (November, 2014).

Treatments	Cropping system	Description	Crops family
T1	Crops succession, under NTS	Maize (*Zea mays* L.) - onion (*Allium cepa* L.)	Poaceae and Liliaceae
T2	Crops rotation, under NTS	Common vetch (*Vicia sativa* L.) - maize/rye (*Secale cereale* L.) + fodder radish (*Raphanus sativus* L.) - onion-maize/rye+fodder radish-common bean (*Phaseolus vulgaris* L.)	Fabaceae, Poaceae Brassicaceae and Liliaceae
T3	Crops rotation, under NTS	Rye-onion-maize/black oat (*Avena strigosa* Schreb.) -maize	Poaceae and Liliaceae
T4	Crops succession, under NTS	Onion-velvet bean (*Stizolobium aterrimum* Piper and Tracy)	Liliaceae and Fabaceae
T5	Crops rotation, under NTS	Rye-onion- pearl millet (*Pennisetum americanum* L.)/black oat-onion-pearl millet	Poaceae and Liliaceae
T6	Crops succession, under NTS	Rye-onion-velvet bean	Poaceae, Liliaceae and Fabaceae
T7	Crops succession, under NTS	Onion-velvet bean+pearl millet+sunflower (*Helianthus annuus* L.)	Liliaceae, Fabaceae, Poaceae and Asteraceae
T8	Crops succession, under CTS	Maize-onion	Poaceae and Liliaceae

NTS stands for no tillage system and CTS conventional tillage system

The results in each layer were submitted to the Bartlett test of homogeneity of variances and Shapiro-Wilk normality test. Afterward, analysis of variance was performed. In cases of significant differences, treatment means comparison was performed using the Duncan test at 5% significance level. In order to group the treatments based on their similarities, we performed the K-means clustering approach, using the R packages ggpubr and factoextra, according to our classification purpose, we predefined three groups. Principal components analysis was conducted to reduce the dimensionality of the data and to describe the variation observed on the data. This analysis was based on the correlation matrix. All the data analysis was performed on the R programming language. Useful details on cluster analysis and principal components analysis are available on Everitt and Hothorn (2011) and Härdle and Simar (2014).

RESULTS AND DISCUSSION

The geometric mean diameter of aggregates (GMD) at the 0-5 cm layer (Table 2), the cropping systems differed ($p<0.05$), T8 had the lowest GMD and was similar to T1, in the same experiment, Giumbelli et al. (2020) found similar results, they attributed this result to the absence of cover crops in Summer and Winter, what reduces roots activity when compared to all the other treatments using cover crops. Besides, the lowest GMD observed in T8 also influenced by soil tillage which deteriorates the soil aggregates stability at the soil surface. Silva et al. (2016) studying physical properties of a Hapludox after three decades under different soil cropping systems found that CTS decreased aggregate stability to the depth of 10 cm when compared to the NTS.

According to Vezzani and Mielniczuk (2011), in the NTS the soil is not turned over, there is a maintenance of crop residues on the soil surface, and thus, higher contribution of organic matter throughout the years, thus the NTS contributes to recovery of soil structure in the long term. Loss et al. (2017) studying soil physical attributes of onion cultivation under NTS and CTS verified lower GMD in the treatment under CTS. Similar results were also observed by Loss et al. (2015), in a similar study by Comin et al. (2018) the use of NTS for onion generated higher soil aggregates stability than the CTS, however, in the present work there were no significant differences between T1 (NTS) and T8 (CTS). In this study, the GMD value presented by T2 in the 0-5 cm layer may be explained by the presence of rye+ fodder radish, fodder radish root system is pivoting and aggressive, thus when the roots grow, they press the soil particles around them, favouring the formation of more resistant and larger soil aggregates (GUEDES FILHO et al., 2013). Rorick and Kladivko (2017) studying rye cover crop effects on soil carbon and physical properties in Indiana (USA), discovered that rye after four years increased in 55% the GMD when compared to the no cover control in the 0 to 10 cm soil layer. Rye has vigorous rooting (LIESCH et al., 2011), fibrous root system (VILLAMIL et al., 2006) must be considered to justify the GMD observed in the treatments which have rye in their composition (T2, T3, T5 and T6). The higher GMD values observed in T3, T4, T5, T6 than the CTS may be also explained by the effect of cover crops over the soil structure and the absence of soil tillage. Significant differences were not observed at the 5-10 and 10-15 cm layers.

Table 2. Geometric mean diameter of soil aggregates (GMD), soil bulk density (BD), microporosity (Micro), macroporosity (Macro), total porosity (TP) and porosities ratio (PR) under different cropping systems for onion, in Ituporanga, Santa Catarina State, Brazil (November, 2014).

Treatments	GMD mm	BD Mg/m^3	Micro m^3/m^3	Macro m^3/m^3	TP m^3/m^3	PR
	0-5 cm layer					
T1	4.16 ab	1.34 a	0.38^{WD}	0.04 b	0.43 b	0.11^{WD}
T2	5.24 a	1.28 ab	0.39	0.04 b	0.44 b	0.11
T3	4.93 a	1.21 abc	0.38	0.10 ab	0.49 ab	0.22
T4	4.68 a	1.23 abc	0.38	0.08 ab	0.46 ab	0.18
T5	4.92 a	1.17 bc	0.39	0.08 ab	0.47 ab	0.17
T6	4.66 a	1.25 ab	0.38	0.08 ab	0.47 ab	0.18
T7	4.78 a	1.11 c	0.36	0.16 a	0.53 a	0.31
T8	3.15 b	1.29 ab	0.36	0.13 a	0.50 ab	0.28
	5-10 cm layer					
T1	5.07^{WD}	1.38^{WD}	0.37^{WD}	0.05^{WD}	0.43WD	0.13^{WD}
T2	4.77	1.39	0.37	0.05	0.42	0.12
T3	5.23	1.38	0.37	0.05	0.42	0.12
T4	4.56	1.40	0.37	0.03	0.41	0.10
T5	5.08	1.41	0.38	0.02	0.40	0.05
T6	5.08	1.37	0.37	0.05	0.42	0.13
T7	4.67	1.39	0.36	0.06	0.42	0.14
T8	4.17	1.36	0.37	0.06	0.43	0.14
	10-20 cm layer					
T1	4.38^{WD}	1.36^{WD}	0.35^{WD}	0.06^{WD}	0.42^{WD}	0.16^{WD}
T2	3.73	1.41	0.37	0.06	0.44	0.15
T3	4.74	1.38	0.37	0.05	0.42	0.12
T4	2.76	1.44	0.39	0.02	0.42	0.06
T5	4.49	1.4	0.38	0.02	0.40	0.06
T6	3.42	1.43	0.37	0.05	0.42	0.12
T7	4.24	1.39	0.37	0.07	0.45	0.17
T8	3.84	1.37	0.38	0.06	0.44	0.14

T1: maize-onion succession, T2: common vetch-maize/rye+fodder radish-onion-maize/rye+fodder radish-common bean, T3: rye-onion-maize/black oat-maize, T4: onion-velvet bean succession, T5: rye-onion-millet/black oat-onion-millet, T6: rye-onion-velvet bean succession, T7: onion-velvet bean+millet+sunflower succession, conventional tillage T8: maize-onion succession WD stands for without significant differences at 5%

For soil bulk density (BD), significant differences were only observed at the 0-5 cm layer, T1 presented the highest BD value, despite being similar to some other treatments (T2, T3, T4, T6 and T8). T1 BD value may be explained by the absence of cover crops and thus reduced roots diversity. The absence of soil tillage in T1 is also a factor to be considered to explain its BD value. T8 BD value was affected by soil tillage, as soil tillage reduces the BD mainly at the soil surface, but even so, T7 presented lower BD than T8, T7 presented the lowest BD (despite being similar to T5), the BD in T7 may be explained by the soil conjoint exploration of three different crops families, Fabaceae (velvet bean), Poaceae +Asteraceae (pearl millet +sunflower), these groups of crops own different roots systems which after the roots mass decomposition contribute to the formation of an architecture of permanent pores, decreasing the BD and increasing PT and macroporosity (MENDONÇA et al., 2013).

These results differ from the ones obtained by Loss et al. (2017), where the CTS presented lower BD than the NTS at the 10- 15 cm layer. These authors attributed the result to soil tillage which overturns the soil. Costa et al. (2003) studying the effects of 21 years of cropping systems on the soil physical properties in an Oxisol observed that the CTS presented higher BD values than the NTS at the 10-20 cm layer. These authors attributed this result to the pressure from agricultural machinery which is transmitted to the soil deeper layers. The same authors reported that the soil type, the soil moisture condition in which the operations are performed along the crops cycle, and the length of time that soil management practices are adopted are important variables that must considered on evaluating soil structure.

For soil microporosity (Micro), the cropping systems were similar in all the layers ($p>0.05$). In this case, the reduced variation observed in the microporosity possibly indicates that the cropping systems had less influence on this soil property. Similar results were also observed by Bertol et al. (2001, 2004) in an Inceptisol and by Loss et al. (2017) in a Humic Cambisol. Silva et al. (2016) reported higher microporosity in the NTS than in the CTS especially at the 0-10 cm layer.

For the soil macroporosity (Macro), significant differences were only observed at the 0-5 cm layer. T7 and T8 had the highest values. The higher macroporosity observed in T7 is related to the lowest BD observed in this layer. For T8, macroporosity was influenced by soil tillage, because soil tillage at the surface layer increases soil macroporosity and total porosity. The lowest macroporosities observed in T1 and T2 are related to the higher BD values observed in both treatments. Silva et al. (2016) reported higher macroporosity down to a depth of 10 cm in the CTS than in the NTS. These authors attributed this result to the soil mobilization in Winter and Spring-Summer in the CTS.

For total porosity (TP) significant differences were only observed at the 0-5 cm layer, where T7 presented the highest value, being significantly higher than T1 and T2. TP presented the same trend observed by soil macroporosity. Loss et al. (2017) observed lower TP in the CTS than in the NTS at the 0-5 cm layer and in the deeper layers differences were not observed as in our study. For TP, we can also observe the advantages of NTS, despite the absence of soil tillage, the permanent soil cover stimulates soil biota activity which is responsible for the soil pores formation and consequently the increase of soil TP (T3, T4, T5, T6 and T7). These results differ from the ones obtained by Silva et al. (2016), where TP was similar between the cropping systems, except for the 60-100 cm soil layer. According to these authors, these differences can be related to the distinct soil moisture conditions at the time of soil tillage, to the different crop treatments applied, and to the diverse contributions of biomass addition from different crops.

For the porosities ratio (PR) which is a soil compaction indicator, treatments were similar in all the layers (p>5%), PR followed the same trend as TP and macroporosity, as all these three variables are positively correlated (Table 3). It is also important to consider that T8 (CTS) was established in 2011 and the other treatments in 2007, which may be insufficient time to observe changes in this property.

For principal components analysis (Table 3), the principal component 1 (PC 1) and PC 2 explained nearly 96% of the total variability observed on the data. PC 1 explained 72.8% of the total variability and is comprised mainly by TP, Macro, Micro, BD, PR. PC 2 explained 24% of the total variability and is comprised mainly by GMD.

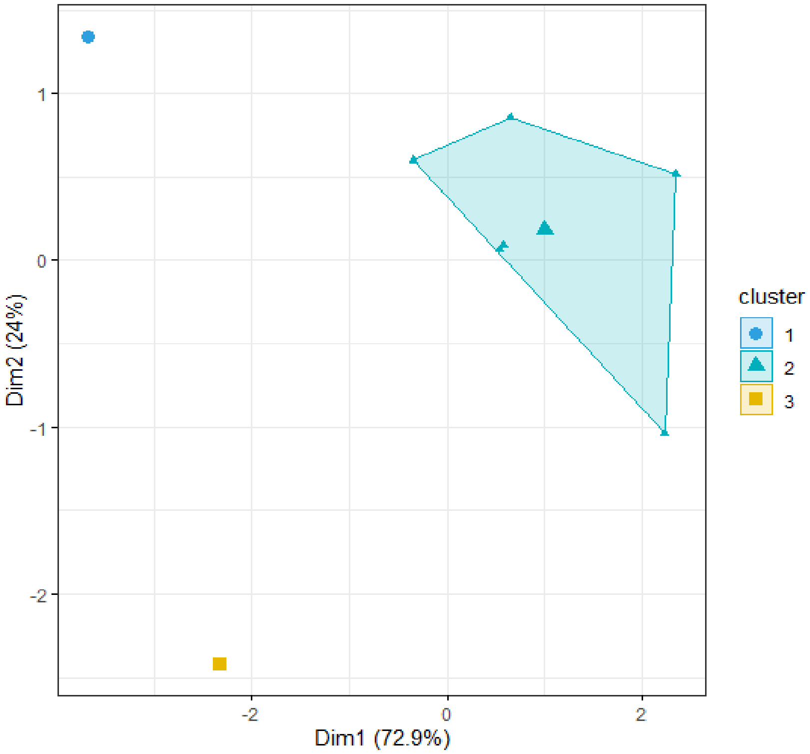
The PCA revealed strong positive correlations among Macro, TP and PR (group 1 of variables), positive correlations between BD and Micro (group 2 of variables) and negative correlations between group 1 and group 2 of variables, GMD by itself forms a unique group (group 3).

For the treatments clustering, the K-means clustering approach revealed the presence of three different clusters, namely: cluster 1: T7, cluster 2: T1, T2, T3, T4, T5, T6 and cluster 3: T8. Figure 1 presents graphically these results.

Table 3. Principal components analysis results under different cropping systems for onion, in Ituporanga, Santa Catarina State, Brazil (November, 2014).

Importance of principal components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Stan dev	2.09	1.2	0.34	0.26	0.02	0.00
Prop of var	0.72	0.24	0.02	0.01	0.00	0.00
Cumul prop	0.72	0.96	0.98	0.99	1	1
Correlation of the principal components with the response variables						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
TP	-0.98	0.15	0.16	-0.02	-0.01	-0.00
Macro	-0.99	0.02	0.07	0.03	-0.01	0.00
Micro	0.89	0.37	0.19	-0.16	0.00	0.00
GMD	0.36	0.92	0.03	0.16	0.00	0.00
BD	0.72	-0.66	0.19	0.14	-0.00	0.00
PR	-0.99	0.02	0.1	0.01	0.02	-0.00
Loadings of the response variables in each principal component						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
TP	-0.46	0.13	0.46	-0.07	-0.44	-0.6
Macro	-0.47	0.02	0.21	0.10	-0.35	0.77
Micro	0.42	0.31	0.57	-0.59	0.05	0.20
GMD	0.17	0.77	0.08	0.61	0.03	0.00
BD	0.34	-0.55	0.57	0.51	-0.01	0.00
PR	-0.47	0.02	0.30	0.03	0.83	-0.01

PC: Principal component, Stan dev: Standard deviation, Prop of var: Proportion of variance, Cumul prop: Cumulative proportion, BD: soil bulk density, TP: total porosity, Micro: microporosity, Macro: macroporosity and GMD: geometric mean diameter of soil aggregates



Cluster 1: T7; Cluster 2: T1, T2, T3, T4, T5, T6 and Cluster 3: T8

Dim1: Principal component 1, the same for Dim 2

Figure 1. Treatments clustering under different cropping systems for onion, in Ituporanga, Santa Catarina State, Brazil (November, 2014).

Interesting to note that T7 (onion-velvet bean+millet+sunflower) is separated from the other treatments, in general, when compared to all the other treatments, T7 presented better soil physical properties. Cluster 2 is comprised by all the other treatments conducted under NTS, some of these treatments, at the 0-5 cm layer, presented indication of structure deterioration (T1) evidenced by the reduced GMD (similar to T8). T8 is the unique treatment in cluster 3, at the 0-5 cm layer presented the lowest GMD but was better in some other soil physical properties when compared to other treatments in cluster 2, as seen previously in the univariate analysis (Table 2).

CONCLUSIONS

In general, significant differences were only observed at the 0-5 cm layer, meaning that more time may be needed to observe the behaviour of the deeper layers.

The use of NTS associated to cover crops was useful to maintain the soil physical quality, despite some significant differences observed among some of them.

The conventional tillage system showed evidence of soil structure deteriorating mainly at the soil surface layer.

The conjoint use of cover crops from different families (Liliaceae, Fabaceae, Poaceae and Asteraceae) observed in T7 (onion-velvet bean+millet+sunflower) was the best cropping system in terms of soil structure quality.

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