

DOI: <http://dx.doi.org/10.1590/1807-1929/agriambi.v25n2p109-115>

Accumulation of humic substances in an Oxisol fertilized with pig slurry for 15 years¹

Acúmulo de substâncias húmicas em Oxisol adubado com dejetos líquidos de suíno durante 15 anos

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HIGHLIGHTS:

The increase in the soil organic carbon stock stands out as a benefit promoted by long-term annual application of pig slurry. The annual soil fertilization with pig slurry for 15 years can change the proportion of fractions of soil humic substances. Pig slurry and mineral fertilizer have similar effect on the degree of humification of soil humic substances.

ABSTRACT: The growth of swine production in Brazil has increased the amount of production and use of pig slurry (PS) as soil fertilizer. This product provides nutrients to plants, and a continuous application of this residue usually increases total soil organic carbon (SOC) content. The objective of this study was to determine the SOC content and its distribution into humic substance fractions (humic acids, fulvic acids, and humin) in an Oxisol annually fertilized with PS for 15 years. The experiment was implemented in 2001 with a maize and oat crop rotation under no-tillage system in Campos Novos, SC, Brazil. The treatments used were: PS at rates of 0 (Control), 25, 50, 100, and 200 m³ ha⁻¹ year⁻¹, mineral fertilizer, and PS combined with mineral fertilizer, applied on the soil surface once a year. The 0-2.5, 2.5-5, 5-10, 10-20, 20-40, and 40-60 cm soil layers were evaluated for SOC content in the fractions humic acid, fulvic acid, and humin, and E4/E6 ratio of humic substances. Increases in PS rates up to 100 m³ ha⁻¹ increased the SOC content in the 5-10 cm soil layer; however, decreased the proportion of the soil fulvic acid and humic acid fractions, favoring the accumulation of organic carbon in the humin fraction. The E4/E6 ratio was higher when using the soil mineral fertilizer than that found in treatments with PS.

Key words: *Zea mays*, organic fertilizer, organic matter, no-tillage system

RESUMO: O crescimento da suinocultura no Brasil tem aumentado a produção e consequente aplicação de dejetos suínos nos solos. Além de fornecer nutrientes, a aplicação continuada desse resíduo geralmente aumenta o teor de carbono orgânico. Objetivou-se neste estudo determinar o teor de carbono orgânico e sua distribuição nas frações de substâncias húmicas (ácidos húmicos, ácidos fúlvicos e huminas) num Oxisol, após 15 anos de aplicações de dejetos líquidos suíno. O experimento foi implantado em 2001 cultivado com a sucessão milho-aveia sob plantio direto no município de Campos Novos, SC. Os tratamentos foram: dejetos líquidos suíno nas doses 0 (Testemunha), 25, 50, 100 e 200 m³ ha⁻¹ ano⁻¹; adubo mineral, e dejetos líquidos suíno complementado com adubo mineral, aplicados superficialmente uma vez ao ano. Foram determinados os teores de carbono orgânico nas frações ácidos húmicos, ácidos fúlvicos e humina e índice de cor da razão E4/E6 do solo nas camadas de 0-2,5; 2,5-5; 5-10; 10-20; 20-40 e 40-60 cm. O aumento das doses de dejetos líquidos suíno até 100 m³ ha⁻¹ aumentou o teor de carbono orgânico total na camada de 5-10 cm, entretanto, diminuiu a proporção das frações de ácidos fúlvicos e ácidos húmicos no solo, favorecendo a acumulação de carbono orgânico na fração humina. A razão E4/E6 foi maior no adubo mineral em comparação aos tratamentos com dejetos líquidos suíno.

Palavras-chave: *Zea mays*, adubo orgânico, matéria orgânica, plantio direto

• Ref. 227772 – Received 22 Aug, 2019

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• Accepted 11 Nov, 2020 • Published 07 Dec, 2020

Edited by: Walter Esfrain Pereira

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INTRODUCTION

Swine production is economically important in Brazil, which is the fourth largest pork producing country, with 3.98 million Mg, and 861,000 Mg exported. However, the number of swine animals in Brazil, above 40 million units (EMBRAPA, 2019), raises concerns about the expressive production of pig slurry (PS) in regions with intensive breeding, since each swine at finishing stage generates approximately 7 L per day of residues (Oliveira, 1993). In this context, the use of PS as soil fertilizer in agriculture is an alternative for the disposal of this residue and reduction of costs with commercial fertilizers.

The continuous use of animal residues, such as PS, at adequate rates contributes to the maintenance of soil organic matter (SOM) contents (Conceição et al., 2013; Mafra et al., 2014; Weyers et al., 2018). In addition, it provides essential nutrients to plants, contributing to increases in crop yields (Cassol et al., 2012; Lourenzi et al., 2013), and adds carbon compounds with nutrition effects that stimulate microbial activity (Singh et al., 2016), contributing to a good quality soil that can be used continuously with sustainability (Mensik et al., 2018).

SOM is composed of particulate matter, macromolecules, and humic substances (HS) (Guerra et al., 2008). HS are formed by the humification process and can be separated into three fractions: fulvic acids (FA), humic acids (HA), and humin (HU). The distribution of the SOC content into these fractions is affected by the soil management (Novotny et al., 1999), and the soil organic carbon accumulation can increase by applying organic compounds to the soil (Lima, 2011). Soils with continuous additions of PS and/or poultry litter usually have high SOC in the HU fraction, which is more stable and has higher resistance to biodegradation (Borges et al., 2015). The E4/E6 ratio is an indicator of stability and maturity of HS or any organic compound (He et al., 2016) and shows the SOM humification degree, which is higher in soils fertilized with NPK and lower in those fertilized with organic residues (Mensik et al., 2018).

The objective of this study was to evaluate the dynamics of the SOM by determining the SOC content and its distribution into humic substance fractions (humic acids, fulvic acids, and humin) in an Oxisol annually fertilized with PS for 15 years, mineral fertilizer (MF), or PS combined with MF, under no-tillage system for summer maize and winter oat crop rotation.

MATERIAL AND METHODS

The experiment was conducted in Campos Novos, Santa Catarina (SC), Brazil (27° 23' 33" S, 51° 21' 48" W, and altitude of 862 m), from October 2001 to June 2016. The climate of the region is Cfb, mesothermal wet with mild summer, according to the Köppen classification. The rainfall is distributed throughout the year with mean annual depths of 1,480 mm and temperature of 16 °C (EPAGRI/CIRAM, 2013).

The soil of the area was classified as Oxisol and presented the following chemical characteristics in the 0 to 20 cm layer: pH = 6.1, SMP index = 6.0, and base saturation = 87%;

exchangeable Al, Ca, and Mg of 0.01, 8.2, and 4.6 cmolc kg⁻¹, respectively; P (Mehlich) = 6.4 mg kg⁻¹, K = 97 mg kg⁻¹; clay = 680 g kg⁻¹, and total organic carbon = 25 g kg⁻¹ on wet basis (Walkley-Black). The area had been used for maize, soybean, wheat, bean, and oat crops in no-tillage system. The soil of the area had been fertilized with approximately 25 m³ ha⁻¹ of pig slurry in the 2000-2001 crop season, before the implementation of the experiment.

The experiment was conducted in a randomized block design with four replications, consisting of plots of 75.6 m² with an evaluation area of 58.3 m². The treatments consisted of applications of soil fertilizers: pig slurry (PS) at rates of 0 (Control), 25 (PS25), 50 (PS50), 100 (PS100), and 200 (PS200) m³ ha⁻¹ year⁻¹; soluble mineral fertilizer combined with pig slurry (MF+PS) at rate of 25 m³ ha⁻¹, and soluble mineral fertilizer (MF).

The PS used was from animals at finishing and/or breeding stage; it was collected and stored for approximately 120 days before the applications to the soil in an uncovered pound, where it passed through an anaerobic digestion. The mean composition of the PS over the years was: 45.5, 18, 3.3, 1.4, and 1.6 kg m⁻³ of dry matter, total organic carbon contents, N, P, and K, respectively.

The MF was applied at rates of 130 (N), 100 (P₂O₅), and 60 kg ha⁻¹ (K₂O) from 2001 to 2007, considering an expected maize grain yield of 8 Mg ha⁻¹; and at rates of 170 (N), 130 (P₂O₅), and 80 kg ha⁻¹ (K₂O) from 2008 to 2015, considering an expected maize grain yield of 11 Mg ha⁻¹ (CQFS-RS/SC, 2004); this adjustment was required due to the improved maize genetic materials used, which could reach high yields. The fertilizers sources used were urea (N), triple superphosphate (P), and potassium chloride (K). The MF+PS was applied together at the rate of 25 m³ ha⁻¹ of PS, adding approximately 75 (N), 16 (P₂O₅), and 15 (K₂O) kg ha⁻¹ which represent 80% of the crop demand and is within the margin for posterior correction of the nutrients applied, according to the soil chemical analyses, considering the quantity of nutrients added by the PS and the recommendation for the crop. The two last treatments were defined based on the recommendations of the Soil Chemistry and Fertility Commission of the States of Rio Grande do Sul and Santa Catarina, Brazil (CQFS-RS/SC, 2004). In the treatment MF, N was applied to plots using 20% at planting, and 80% divided into two topdressings at the maize crop stages V5 and V9, as described by Ritchie et al. (1993). In the treatment MF+PS, all the N of soluble mineral source was applied as topdressing at the maize stage V5. All the treatments were manually applied to the soil surface.

The soil was sampled in May 2016, using a spade (0-20 cm) and Dutch auger (20-60 cm layer), in the following layers: 0-2.5, 2.5-5, 5-10, 10-20, 20-40, and 40-60 cm.

The SOM was fractionated by determining the SOC content in the fractions fulvic acids (FA), humic acids (HA), and humin (HU), according to the methodology described by Benites et al. (2003).

The E4/E6 ratio of humic substances was determined by dividing the absorption into 465 and 665 nm, using the reading of humic acids in a double beam spectrophotometer in the visible ultraviolet region (Canellas, 2005).

The data were subjected to analysis of variance by the F test and significant means were subjected to the Tukey's test at $p \leq 0.05$, using the program SAS (2008).

RESULTS AND DISCUSSION

The effect of the treatments on the variables evaluated were, in general, significant. Table 1 shows the probability (p-values) of differences for soil organic carbon (SOC) content, fulvic acids (FA), humic acids (HA), humin (HU), and E4/E6 ratio.

The application of pig slurry (PS) and soluble mineral fertilizer (MF) increased the SOC content relative to the control treatment in the layers within 0 to 20 cm (Table 2). In these layers, the applications of PS at rates of 100 and 200 $\text{m}^3 \text{ha}^{-1}$ resulted in a higher SOC than the other treatments; however, the SOC varied significantly only in the control. The deeper soil layers (20-40 and 40-60 cm) presented no significant variation in SOC.

The differences within the 0-20 cm layer may be related to the higher volume of plant roots in this layer. A research on the same area after 10 years of PS applications found that the treatments PS200, PS100, and MF had more addition of dry matter by the phytomass produced (summer maize and winter oat crop residues) (Mafra et al., 2014), which corroborates the results found by Agne et al. (2014). Moreover, the high addition of dry matter on the soil surface in these treatments, combined with the PS applied over 15 years, may have contributed to increases in SOC and variations between the treatments (Lorenzi et al., 2014). The higher SOC content in surface layers and the decreasing gradient in depth was probably an effect of the soil management adopted (no-tillage system). It is highlighted that the increases in SOM improve soil chemical, physical, and biological characteristics, and soil fertility (Bayer et al., 2004).

The carbon stocks are the result of the balance between humification and mineralization processes of the SOM. When plants residues are added and the humification rate is higher

than the mineralization rate, carbon stocks increase. This favors soil aggregation processes, increasing the stability of the system (Mazurana et al., 2013). Silva et al. (2015) evaluated an Oxisol two months after PS application and found no increases in SOC content due to the use of such residue. However, studies conducted with long-term applications of PS have shown increases in SOC in Oxisols (Mafra et al., 2014; Lorenzi et al., 2016).

Figure 1A shows the SOC content in humic substances (HS) based on the mean of the layers within 0-60 cm, which represents an overall view of the sum and distribution of the soil HS fractions. The treatments with applications of 100 and 200 $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ of PS had HS contents 17% and 23% higher and HU 13% and 23% higher, respectively, than the control. These relative increases in HS and HU may be related to the addition of higher amount of carbon (C), mainly by the phytomass added in these treatments (Agne et al., 2014).

The distribution of HS fractions was relatively even within the different treatments with PS application (Figure 1B). The HU fraction represented 60 to 70% of the total HS, and the HA and FA fractions had similar participation, with approximately 20%. The HA fraction had increases of 47, 46, 43, 39, 33, and 32%, respectively, in the treatments PS100, MF+PS, MF, PS200, PS25, and PS50 when compared to the control. Predominance of more recalcitrant fractions was also shown by Lüttke et al. (2016), who found more than 50% for the HU fraction in an Ultisol and relative increases in concentrations of HA and HU in treatments with PS application.

Borges et al. (2015) found increase in HS in low-size aggregates when comparing soil aggregates of different sizes. Ventura et al. (2018) observed improvements in soil quality caused by increases in SOC, mainly HS in HU and FA fractions evaluated in biogenic aggregates. Beck et al. (2018) found higher P availability in soils with application of P at rates higher than that recommended, combined with HU, in soil with pH 4.5. Organic compounds affect microbial activity and nutrient availability in the long-term (Dall'Orsoletta et al., 2018). Thus,

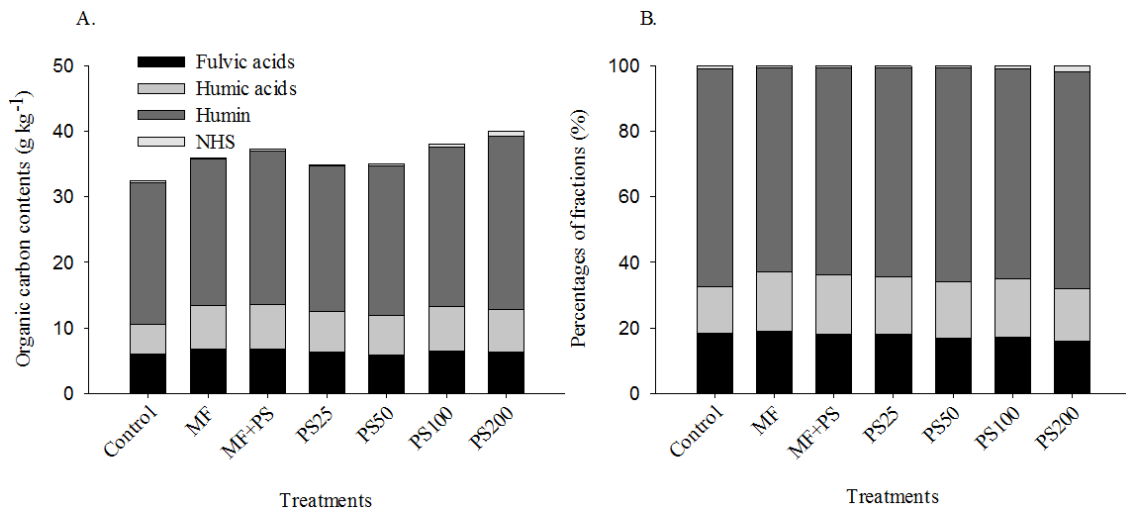
Table 1. Values of probability of difference between treatments for total soil organic carbon (SOC) content, fulvic acids (FA), humic acids (HA), humin (HU), and E4/E6 ratio in six layers of an Oxisol with crops under no-tillage system, annually fertilized with pig slurry for 15 years

Layer (cm)	SOC	FA	HA	HU	E4/E6
0-2.5	0.0259	0.0021	0.0047	0.0003	< 0.0001
2.5-5	0.0218	0.0145	0.0017	0.2111	0.0949
5-10	0.0010	0.0132	0.2599	0.0475	0.2797
10-20	0.0050	0.4977	0.0221	0.0744	0.2908
20-40	0.0041	0.0030	0.4369	0.0121	0.0115
40-60	0.0685	0.0234	0.0045	0.0512	0.1228

Table 2. Total soil organic carbon (SOC) content in six layers of an Oxisol with crops under no-tillage system, annually fertilized with pig slurry at rates of 0 (Control), 25 (PS25), 50 (PS50), 100 (PS100), and 200 (PS200) $\text{m}^3 \text{ha}^{-1}$, soluble mineral fertilizer (MF), and soluble mineral fertilizer combined with pig slurry (MF+PS)

Layer (cm)	Control	MF	MF+PS	PS25 (g kg^{-1})	PS50	PS100	PS200	CV (%)
0-2.5	57.5 b	61.2 ab	66.0 ab	59.7 ab	58.8 ab	75.7 a	75.5 a	12.9
2.5-5	44.4 b	51.2 ab	50.1 ab	48.9 ab	57.9 a	59.1 a	57.1 a	12.8
5-10	34.5 c	39.8 abc	38.4 bc	37.1 bc	37.3 bc	44.8 a	40.3 ab	9.7
10-20	30.2 b	32.2 a	31.0 ab	31.7 ab	30.6 ab	32.3 a	30.8 ab	3.6
20-40	25.2 a	27.2 a	26.6 a	27.0 a	25.5 a	27.4 a	26.2 a	8.1
40-60	22.2 a	23.2 a	22.8 a	22.3 a	22.0 a	21.7 a	22.1 a	6.5

Means followed by the same letter in the rows are not different by the Tukey's test at $p \leq 0.05$. CV - Coefficient of variation



Values represent the mean of soil layers within 0-60 cm

Figure 1. Organic carbon contents (A) and percentages of fractions (B) in humic substances (fulvic acids (FA), humic acids (HA), humin (HU)) and non-humic substances (NHS) in an Oxisol with crops under no-tillage system, annually fertilized with pig slurry at rates of 0 (Control), 25 (PS25), 50 (PS50), 100 (PS100), and 200 (PS200) m³ ha⁻¹, soluble mineral fertilizer (MF), and soluble mineral fertilizer combined with pig slurry (MF+PS)

increases in HS contents are important for soil aggregation and nutrient availability.

The SOC content in the FA fraction (Table 3) was lower in deeper layers. This result was also found by Canellas & Façanha, (2004), with higher magnitude. SOC content in the FA fraction in surface layers (0-2.5 cm) was higher in the treatments MF, MF+PS, and PS100. In the 2.5-5 cm layer, the SOC content in

the treatments with application of higher rates of PS differed only from the control. In the layer of 40-60 cm, a lower SOC content in the FA fraction was also found in the treatment PS200, although it differed only from the treatment MF.

The FA fraction contributes to the movement of carbon to deep soil layers, since it is a more mobile organic fraction that presents polar functional groups relatively more soluble

Table 3. Soil organic carbon (SOC) content in the fulvic acid, humic acid, and humin fractions, and E4/E6 ratio of humic substances in soils treated with pig slurry at rates of 0 (control), 25 (PS25), 50 (PS50), 100 (PS100), and 200 (PS200) m³ ha⁻¹, soluble mineral fertilizer (MF), and soluble mineral fertilizer combined with pig slurry (MF+PS)

Layer (cm)	MF	MF+PS	Control	PS25	PS50	PS100	PS200	CV (%)
Fulvic acids								
0-2.5	10.0 a ¹	9.8 a	8.2 bc	8.1 c	7.8 c	9.1 ab	8.4 bc	11.29
2.5-5	8.7 a	7.6 ab	6.4 b	7.7 ab	7.5 ab	8.2 a	8.7 a	12.05
5-10	6.8 ab	6.1 ab	6.7 ab	5.8 b	5.6 b	7.0 a	6.5 ab	10.32
10-20	5.8 a	6.0 a	5.7 a	5.8 a	5.2 a	5.1 a	5.7 a	10.57
20-40	6.0 a	6.1 a	5.9 a	6.2 a	6.0 a	6.1 a	5.5 a	10.14
40-60	4.9 a	4.9 ab	4.2 ab	4.7 ab	4.5 ab	4.4 ab	4.1 b	10.02
Humic acids								
0-2.5	12.2 a ¹	11.8 ab	8.9 c	9.4 bc	10.0 abc	12.7 a	10.3 abc	16.07
2.5-5	10.2 a	9.0 a	6.1 b	8.5 ab	9.4 a	10.4 a	10.1 a	18.42
5-10	8.0 a	7.9 a	5.9 a	7.6 a	8.0 a	8.7 a	6.9 a	18.43
10-20	4.3 ab	4.6 a	3.4 b	4.3 ab	4.2 ab	4.4 ab	4.8 a	13.53
20-40	4.9 a	4.5 a	3.7 a	4.5 a	4.3 a	4.3 a	3.4 a	22.26
40-60	2.3 bc	2.7 abc	2.1 c	3.2 ab	3.2 abc	3.5 a	3.7 a	22.16
Humin								
0-2.5	33.8 bc	36.7 abc	30.5 c	34.4 bc	40.0 ab	42.6 a	43.9 a	14.78
2.5-5	28.7 a	28.0 a	26.8 a	28.5 a	32.3 a	31.2 a	32.1 a	12.29
5-10	23.3 a	23.7 a	22.1 a	22.2 a	26.0 a	26.7 a	25.2 a	13.03
10-20	21.5 a	21.1 a	21.5 a	21.1 a	21.7 a	21.9 a	22.8 a	6.07
20-40	17.4 ab	16.3 ab	17.0 ab	16.2 ab	15.9 b	16.8 ab	18.4 a	7.98
40-60	15.1 a	14.7 a	15.6 a	14.4 a	14.0 a	14.6 a	15.2 a	7.61
E4/E6 ratio								
0-2.5	2.89 a	2.52 ab	1.19 c	0.93 c	1.59 bc	2.35 ab	2.36 ab	36.35
2.5-5	2.37 a	2.23 a	0.99 a	1.78 a	1.68 a	2.19 a	1.89 a	33.12
5-10	2.99 a	2.42 a	1.95 a	2.29 a	2.31 a	2.70 a	2.35 a	22.81
10-20	3.09 a	3.17 a	2.20 a	2.90 a	2.77 a	2.78 a	2.85 a	18.38
20-40	4.30 a	3.28 ab	3.52 ab	3.42 ab	2.74 b	2.83 b	3.28 ab	19.93
40-60	4.96 a	4.70 a	4.88 a	4.79 a	4.04 a	4.32 a	4.18 a	15.36

Means followed by the same letter in the rows are not different by the Tukey's test at $p \leq 0.05$; E4/E6 ratio from readings of humic acids with an atomic-absorption spectrophotometer in the wavelengths of 465 and 665 nm, respectively; CV - Coefficient of variation

and susceptible to drag by percolating water than the other fractions (Miranda et al., 2007). These compounds are the main responsible for mechanisms of transport of cations in the soil, through an organometal complex that characterizes the cheluviation process (Gomes et al., 1998; Murano et al., 2018).

The SOC content in the HA fraction was lower in the control treatment, confirming the trend of lower accumulation of SOC in this treatment (Table 3). In the surface layers (0 to 5.0 cm), the SOC content in the HA fraction of all treatments were similar. However, in the 40-60 cm layer, the soil treated with the two highest rates of PS (PS100 and PS200) presented higher SOC content in the HA fraction than the treatment MF and the control.

Mensik et al. (2018) evaluated soils of temperate climate and found that the use of bovine organic compost increased HA contents in the soil relative to the mineral fertilizer. This result was not found in the present study; the treatment MF and the treatments with PS were similar in HA, differing only from the control. However, this different dynamic is explained by the use of an organic compost that, in general, contains compounds already partly humified, whereas the PS used in the present study was only partially stabilized through an anaerobic digestion process, resulting in compounds with lower stabilization degree than that compost.

The SOC content in the HU fraction (Table 3) was significantly higher than that in the other two humic fractions. This result was also found by Rossi et al. (2011), who reported predominance of SOC content in the HU fraction. It is probably related to the larger size and greater stability of molecules in this fraction, as described by Six et al. (2002).

In the 0-2.5 cm layer, the soils treated with 100 and 200 $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ of PS had higher SOC content in the HU fraction than the treatments MF, PS25, and control. In the layer of 20-40 cm, the treatment PS200 had higher C contents than the treatment PS50.

High SOC content in the HU fraction are usually found in soils with application of organic soil fertilizers. Borges et al. (2015) found that soils treated with PS and poultry litter had higher SOC in the HU fraction than those with mineral fertilizer or without fertilizer application. The compounds that constitute this fraction are more stable, they present higher resistance to biodegradation (Guerra et al., 2008). Thus, this fraction accumulates in the soil and is little consumed by soil microorganisms. A study about soil management systems that included eucalyptus forest, agrosilvopastoral system, and native fields, also showed higher accumulation of HU relative to other HS fractions (Santos et al., 2013).

The E4/E6 ratio of humic acids in the different treatments and depths varied. In the layer of 0-2.5 cm, the treatments MF, MF+PS, PS100, and PS200 presented higher values than the other treatments (Table 3). The E4/E6 ratio is associated to the SOM humification degree; the lower the E4/E6 ratio, the higher the proportion of aromatic constituents, which indicates that the material is at a more advanced stage of humification; and the higher the E4/E6 ratio, the higher the proportion of aliphatic structures, which are less humified (Canellas, 2005; Mensik et al., 2018). The lower E4/E6 ratio found in the control treatment is consistent with this affirmative, since it presented

lower crop phytomass added to soil and, consequently, lower cycling of organic carbon. Thus, the SOM in this treatment had higher proportion of aromatic constituents, which is typical of compounds in more advanced humification stages, since they denote the carbon uptake occurred throughout a longer time.

According to Mensik et al. (2018), a E4/E6 ratio lower than 4 denotes the existence of HS with high stability and quality. The E4/E6 ratios were, in general, below 4 up to the depth of 40 cm in all treatments, except for the treatment MF in the 20 to 40 cm layer (Table 3). This result indicates a lower humification degree in deeper soil layers. Canellas & Façanha (2004) evaluated an Ultisol and found increases in E4/E6 ratio as the soil depth was increased. Thus, organic compounds are, in general, in lower advanced humification stages because they are carried to deeper layers of the soil profile.

The highest E4/E6 ratios were found in the treatments MF, with significant difference from the control, PS25, and PS50 in the 0 to 2.5 cm layer, indicating a lower humification stage of the SOM. An experiment conducted for 64 years in the Czech Republic, using the E4/E6 ratio, reported a higher humification degree of the SOM when using NPK fertilizer applications, and a lower one in soil treated with organic residues at the recommended rates for crops in Vertisols (Mensik et al., 2018).

The E4/E6 ratio in the 20-40 cm layer of the treatments PS50 and PS100 were significantly lower than that in the treatment MF. This confirms that the mineralization of these HS fractions reaches a more advanced degradation stage in treatments without soil fertilizer or with PS at low rates. Thus, an alternative to maintain the levels of low-humification HS is the adoption of soil management systems with continuous addition of organic residues to the soil, as the no-tillage system, thus favoring the soil HS quality. Guareschi et al. (2013) evaluated areas with degraded pastures under different soil management systems and found higher E4/E6 ratios for the no-tillage system, which increased the E4/E6 ratios over time, as well as more stable fractions of HS, providing a higher stability to the no-tillage system, confirming the results found in the present study using PS.

CONCLUSIONS

1. Total organic carbon contents in the soil layers within 0-20 cm increase as the pig slurry rates are increased up to 200 $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ in Oxisols with crops under no-tillage system.
2. Annual additions of pig slurry at rates between 100 and 200 $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ for 15 years in Oxisols increase organic carbon contents in the humin fraction by 13% and 23%, respectively.
3. Applications of mineral and/or organic fertilizers to soils with summer maize and winter oat crops under no-tillage system increase the E4/E6 ratio of humic substances.

ACKNOWLEDGEMENTS

The authors thank the Graduate Program in Soil Science of the Universidade do Estado de Santa Catarina (UDESC), and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

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