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Soil organic matter and nutrient accumulation in areas under intensive management and swine manure application

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Abstract

Purpose Land use change and soil management are frequently associated to land degradation and soil organic matter (SOM) losses in tropical regions. In Brazil, in order to avoid this process, different management strategies have been applied, such as no-tillage and agricultural disposal of swine manure (SM). This study was carried out to evaluate the quantity and quality of SOM, as well as the occurrence of nutrient accumulation in soils of areas under contrasting management systems that have received consecutive applications of SM over the last decades in Brazil.

Materials and methods Five land uses were sampled: native vegetation (NV), pasture with SM application (PA + SM), no-tillage with SM application (NT + SM), no-tillage (NT), and conventional tillage with SM application (CT + SM). Soil organic carbon (SOC), N, labile C, C management index (CMI), P, Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+}, Fe, Zn, Mn, Cu, and H + Al were quantified.

Results and discussion Except for PA + SM, the agricultural land uses caused decreases in SOC contents comparing to NV. PA + SM showed the highest C stocks, 138.9 ± 3.4 Mg ha^{-1} down to 0.4 m. The application of SM can be associated to the greater C stocks in PA + SM, NT + SM, and CT + SM and to the higher N contents in all land uses under this practice. Land uses which receive higher rates of swine manure application (PA + SM and CT + SM) have shown CMI greater than 100. However, this practice is associated to the accumulation of P, Cu, Na, and Zn in these soils.

Conclusions The SM application is associated to improvement on C stocks and SOM quality in area under pasture, no-tillage, and conventional tillage in Paraná State, Brazil. However, this practice is the main driver of nutrient accumulation in these areas.

Keywords Animal manure · C sequestration · C management index · N balance · Soil pollution

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1 Introduction

The intensive use of soil is essential, but it must be associated to conservation practices (Lal 2006). One of the main consequences of agricultural land degradation is the C depletion in soils (Don et al. 2011). Besides the negative impacts on the global C cycle, decreases on the amount and quality of soil organic matter (SOM) could spoil the agricultural productivity and food security, mainly in tropical regions (Lal 2006). In Brazil, Moraes Sá et al. (2014) found a strong relation between C stocks, labile C fractions, and the grain yield of wheat and soybean. In this sense, reestablishing the quality and the quantity of SOM in tropical areas is imperative.

In Brazil, studies have shown the effectiveness of pasture to improve the soil quality when compared to other land uses

(Bayer et al. 2011; Salton et al. 2011). Notably, the no-tillage also has been detached as a win-win strategy for soil management in areas under annual crops (Bayer et al. 2006; Boddey et al. 2010). Recently, some questions about the effectiveness of no-tillage to increase the C stocks have been brought out, mainly in tropical environment. It was observed that only the absence of tillage would be not enough for increasing C stocks in areas under this practice (Conceição et al. 2013; Alburquerque et al. 2015) and that C inputs via crop residues or alternatives sources would have an essential role on this dynamic.

Animal manures, initially used as fertilizers, have emerged as an important source for soil C accretion in agricultural lands (Zhang et al. 2012; Maillard and Angers 2014). Brazil produces more than 38 million kg of swine annually, the fourth largest producer worldwide, and about 300 million liters of liquid swine waste is generated every day. The use of swine manure (SM) as an agricultural fertilizer is a simple and inexpensive solution to dispose and recycle this manure on the agricultural property, besides its positive effects on SOM. However, it must be highlighted that, although the mentioned benefits, repeated annual applications of large amounts of SM may lead to excessive nutrient accumulation (Luo et al. 2009; Broetto et al. 2014) and environmental damages by nutrient leaching (Bai et al. 2014; Broetto et al. 2014).

Shifts on SOM can be accessed by changes on the soil C stocks, on its chemical and physical fractions, or by the combination of both. However, the soil C stocks may be less sensitive to changes on land use and soil management (Blair et al. 1995). In this sense, the labile C (LC) has been used as an indicator of soil quality regarding agricultural management changes. Besides, the use of indices, such as the C management index (CMI), may be quite elucidative about alterations on SOM regarding agricultural practices (Vieira et al. 2007; Conceição et al. 2013). The CMI expresses the soil quality in terms of increments in the total C and in the proportion of LC compared to a reference soil, generally that under native vegetation, which arbitrarily has a CMI of 100.

Except India, studies that assess SOM dynamics and possible nutrient accumulation in agricultural sites under different management and animal manure application are scarce in tropical regions. Besides, soil management practices associated with various C inputs (e.g., litter fall, crop residues, root biomass, and manure) influence the quantity and quality of SOM. In this context, this study was designed to evaluate the quantity and quality of SOM, as well as the occurrence of nutrient accumulation in soils of areas under contrasting management systems that have received consecutive applications of swine manure over the last decades in Brazil.

2 Material and methods

2.1 Site localization and sampling

The study was carried out in Arapoti, Paraná State, Brazil. The sites are located at 24° 09′ 28″ S and 49° 49′ 37″ W (Fig. 1), with 960 m of altitude. The yearly local average rainfall is approximately 1.330 mm. The climate is classified as Cfa according to Köppen.

Soil sampling was carried out in January 2012, and five land uses were sampled: natural vegetation (NV), pasture with SM application (PA + SM), no-tillage with SM application (NT + SM), no-tillage (NT), and conventional tillage with SM application (CT + SM). A brief description of management practices in these land uses is given in Table 1. These land uses are located near and in similar landscape portions, and have shown high similarity between some of its soil physical attributes (Table 2), aspects that corroborates the suitability of these areas for studies comparing different land uses and management strategies. The soil is classified as clayey Red Latosol (Brazilian classification, i.e., Typic Hapludox, Oxisol, Soil Taxonomy, USDA classification). The description of soil physical attributes may be seen in Oliveira et al. (2015), which is assumed here as being homogeneous, with exception to bulk density. Besides, XRD analysis of these samples showed that hematite, goethite, and kaolinite are the minerals making up the clay fraction of these soils (Abdala et al. 2015). Additionally, the chemical composition of swine manure samples from the same region of this research is shown in Table 3.

Each one of the land uses were divided in three areas, considering each one of this subdivision area as a block. For each block, 10 soil samples were collected, assembled, and mixed in order to obtain a composite sample (3 composite samples per land use). The samples were collected at 0.0–0.10, 0.10–0.20, and 0.20–0.40-m depths, using an auger Dutch.

2.2 Chemical analysis and statistical procedures

All the soil samples were air dried, mixed, and sieved through a 2-mm sieve. The soil pH was determined in water (soil/solution ratio 1:2.5 *v*/*v*). Al^{3+}, Ca, and Mg were extracted with a 1 M KCl solution. Phosphorus, K, Fe, Zn, Mn, and Cu were extracted by Mehlich I. Total acidity (H + Al) was extracted at pH 7.0 with calcium acetate. H + Al and Al^{3+} were quantified by titration with a 0.025 M NaOH solution. Ca, Mg, Fe, Zn, Mn, and Cu soil contents were quantified by atomic absorption spectroscopy. P was quantified by colorimetry and Na and K soil contents by flame photometry. For more details about these procedures, see Silva (2009). With exception to the plant nutrients likely to accumulate as

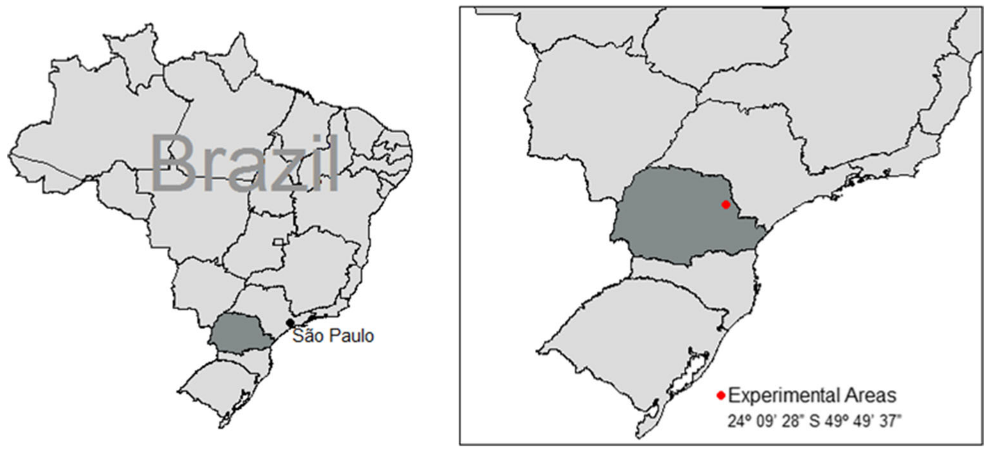

Fig. 1 Geographic location of the study site in Paraná State, Brazil

assumed in this research (Na, P, Cu, and Zn), the soil chemical attributes are shown in Table 4.

Soil subsamples were grinded and sieved through 60 mesh (0.25 mm) to determine the soil organic carbon (SOC) using wet oxidation with external heating (Yeomans and Bremner 1988). Soil N was quantified by Kjeldahl distillation (Bataglia et al. 1983). The equivalent soil mass technique, which considers soil mass differences among the layers, was applied to the C stocks, as described in Eq. (1) (Ellert and Bettany 1995):

$$C = \sum_{i=1}^{n-1} (CTi \cdot MTi) + \left[MTn - \left(\sum_{i=1}^{n} MTi - \sum_{i=1}^{n} MSi \right) \right] CTn \quad (1)$$

where C = total soil C stocks on a mass equivalent basis for the soil profile under land use change, C_{Ti} = carbon content (Mg C Mg soil^{-1}) in each layer i above the deepest layer n, M_{Ti} = soil mass (Mg ha^{-1}) in each layer i above the deepest layer n, M_{Tn} = soil mass (Mg ha^{-1}) in the deepest layer of the soil profile under changed land use, C_{Tn} = carbon content (Mg C Mg soil^{-1}) in the deepest layer of the soil profile under changed land use, and M_{Si} = soil mass (Mg ha^{-1}) in each layer i under native vegetation.

The LC quantification was carried out using the oxidation by $KMnO_4$ (33 mmol L^{-1}), according to Shang and Tiessen (1997). The non-labile carbon (NLC), which is equivalent to the residual C not oxidizable by $KMnO_4$ (33 mmol L^{-1}), was determined by subtraction (NLC = SOC − LC). The CMI (Blair et al. 1995) was calculated using Eq. (2):

$$\mathrm{CMI} = \frac{\mathrm{SOClu}}{\mathrm{SOCnv}} \times \frac{\frac{\mathrm{LClu}}{\mathrm{NLClu}}}{\frac{\mathrm{LCnv}}{\mathrm{NLCnv}}} \times 100 \quad (2)$$

Table 1 Historical characterization and brief description of studied sites in agricultural areas under intensive management and swine manure (SM) application in Brazilian Oxisols

Land use	Management practice description
Native vegetation (NV)	Native vegetation nearby the agricultural land uses, classified as seasonal semideciduous forest, Atlantic forest biome. Transitional region, where the forest has more xeromorphic species than the wetter areas of the Atlantic forest
Pasture + SM (PA + SM)	Tifton pasture for 20 years. Annual fertilization is 200 kg ha^{-1} of urea and 200 kg ha^{-1} of KCl, besides 30 m^3 ha^{-1} cut^{-1} of SM (180 m^3 ha^{-1} year^{-1}). About 6 cuts per year to hay production
No-tillage + SM (NT + SM)	No-tillage for 21 years. Crop succession of soybean–wheat–maize. Annual fertilization is 300 kg ha^{-1} of NPK 10-20-20, 200 kg ha^{-1} of urea, and 50 m^3 ha^{-1} of SM
No-tillage (NT)	No-tillage for 33 years. Crop succession of maiz–oatmeal–soybean. Annual fertilization is 300 kg ha^{-1} of NPK 10-30-10, 100 kg ha^{-1} of urea, and 100 kg ha^{-1} of KCl
Conventional tillage + SM (CT + SM)	Conventional tillage for about 40 years. Crop succession of maize–ryegrass–maize. Annual fertilization is 200 kg ha^{-1} of DAP, 200 kg ha^{-1} of KCl, 250 kg ha^{-1} of urea, and 120 m^3 ha^{-1} of SM

NV native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

Table 2 Soil texture and particle density of soils in agricultural areas under intensive management and swine manure (SM) application in Brazilian Oxisols

Land use	Sand (%)	Silt (%)	Clay (%)	Particle density (g cm^{-3})
	0–0.1 m			
NV	18.7 ± 0.6	11.0 ± 1.0	70.3 ± 1.2	2.44 ± 0.1
PA + SM	21.4 ± 0.6	13.3 ± 1.0	65.3 ± 1.5	2.44 ± 0.1
NT + SM	18.3 ± 0.6	12.3 ± 1.5	69.3 ± 1.5	2.62 ± 0.1
NT	17.0 ± 2.6	12.0 ± 2.6	71.0 ± 1.0	2.51 ± 0.1
CT + SM	19.7 ± 1.5	12.3 ± 1.5	68.0 ± 2.0	2.58 ± 0.1
	0.1–0.2 m			
NV	16.3 ± 0.6	11.7 ± 2.0	72.0 ± 2.7	2.54 ± 0.0
PA + SM	17.3 ± 2.5	10.0 ± 1.0	72.7 ± 3.2	2.54 ± 0.1
NT + SM	19.0 ± 1.7	11.0 ± 1.0	70.0 ± 2.7	2.67 ± 0.1
NT	16.7 ± 1.1	8.7 ± 1.1	74.7 ± 2.3	2.62 ± 0.1
CT + SM	19.0 ± 1.0	10.7 ± 2.5	70.0 ± 3.2	2.51 ± 0.1
	0.2–0.4 m			
NV	14.3 ± 1.2	10.7 ± 2.1	75.0 ± 1.6	2.67 ± 0.1
PA + SM	16.0 ± 2.0	11.7 ± 1.1	72.3 ± 1.2	2.54 ± 0.1
NT + SM	17.1 ± 2.4	11.3 ± 0.6	71.7 ± 3.5	2.64 ± 0.0
NT	17.0 ± 2.6	9.0 ± 1.0	74.0 ± 3.1	2.59 ± 0.1
CT + SM	18.0 ± 1.0	11.7 ± 1.5	70.3 ± 2.1	2.65 ± 0.0

NV native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

Where,

CMI	C management index
SOClu	Total organic carbon in the soil from a land use
SOCnv	Total organic carbon in the soil from native vegetation
LClu	Labile carbon in the soil from a land use
NLClu	Non-labile carbon in the soil from a land use
LCnv	Labile carbon in the soil from native vegetation
NLCnv	Non-labile carbon in the soil from native vegetation

The experimental area is located in a regular farm and therefore was not set up for scientific purposes. This approach was chosen by the absence of experimental fields which contemplated the situation proposed in this study. As stressed, the land uses were located near each other, with similar topography, soil, and climate conditions, differing only in management practices.

The statistical analysis of data was performed on a completely randomized sampling design (three blocks per land use), with the assumption that the land uses studied had the same topographic, edaphic, and climatic conditions. The data were analyzed using analysis of variance (ANOVA). If the ANOVA *F* statistic was significant at $p < 0.05$, the means were compared using Tukey's test ($p < 0.05$).

3 Results

3.1 SOC, N contents and C stocks

The agricultural land uses were associated with decreases on SOC content comparing to NV at the 0–0.1-m depth, except for PA + SM. In NT and NT + SM, decreases of about 35 and 15 % on SOC content were observed, respectively (Fig. 2a). CT + SM also determined significant decreases on SOC contents in the first layer evaluated comparing to NV. However, SOC contents in CT + SM were 30 % higher than NT at the 0–0.1-m depth. For the 0.1–0.2-m depth, only the SOC contents in NT differed statically ($p < 0.05$) from the other land uses, being 30.6 % lower than those observed in areas under NV (Fig. 2a). At the 0.2–0.4-m depth, all the land uses caused SOC decreases comparing to NV and the lowest SOC content was observed in NT.

In land uses under SM application, high N contents were observed at the 0–0.1-m depth (Fig. 2b). These areas showed higher N contents than NV and NT. This trend was also observed in the subsequent layer (0.1–0.2 m). However, PA + SM did not present the higher N content comparing to the other land uses which receive SM. At the 0.2–0.4-m depth, N contents in NV did not differ from those in NT, NT + SM, and CT + SM.

In land uses under successive application of SM, increases in C stocks down to 0.4-m depth were observed (Fig. 3). However, between the land uses which receive SM, only the C stock in PA + SM differed from NV, with values greater than 138 Mg ha^{-1}. NT had the lowest C stock, with values 34.0 and 14.6 % lower compared to PA + SM and NV, respectively.

3.2 Soil organic matter lability

The LC levels in PA + SM were superior to all land uses in all depths evaluated (Fig. 4). At the 0–0.1-m depth, the LC content in PA + SM was 4.26 g kg^{-1}, followed by CT + SM and NV, which did not differ statistically ($p < 0.05$) from each

Table 3 Average chemical composition of swine manure applied in agricultural areas in southern Brazil

pH[a]	N	K	P	Ca	S	Mg	OC	DM	Fe	Cu	Zn	Mn
	kg m^{-3}								g m^{-3}			
7.2	3.6	1.61	1.46	1.91	0.66	0.8	20.5	59	7.87	2.81	4.08	9.2

OC organic C, *DM* dry matter

[a] Based on yearly sampling during 10 years. Adapted from Cassol et al. (2012)

Table 4 Soil chemical attributes of agricultural areas under intensive management and swine manure (SM) application in Brazilian Oxisols

Land use	pH (H_2O)	K cmolc kg^{-1}	Ca	Mg	Al^{3+}	H + Al	Fe mg kg^{-1}	Mn	m %	V
	0–0.1 m									
NV	4.3c	0.4c	0.1d	0.2c	4.1a	24.3a	309.2a	27.4d	83.6a	3.2c
PA + SM	6.4a	0.8a	2.8a	1.7a	0.1b	6.6c	78.4b	67.6a	0.9b	45.4a
NT + SM	6.2a	0.2c	2.4b	1.5a	0.1b	6.0c	68.6b	42.8b	1.1b	40.4a
NT	5.9b	0.6b	1.5c	0.8b	0.1b	7.8b	53.6c	33.4c	1.0b	27.7b
CT + SM	5.7b	0.6b	1.8c	0.9b	0.1b	8.5b	67.7b	42.8b	1.4b	28.7b
	0.1–0.2 m									
NV	4.4c	0.2c	0.1c	0.1c	3.7a	21.3a	287.5a	42.2a	88.2a	2.2c
PA + SM	6.3a	0.6a	1.2b	0.8ab	0.0c	5.9b	65.6b	31.9a	1.0b	31.6a
NT + SM	5.8b	0.2c	1.7a	0.9a	0.1b	7.7b	77.2b	36.2a	3.1b	26.8ab
NT	5.9b	0.3b	1.1b	0.5b	0.0c	7.3b	52.6b	21.8a	1.7b	21.1b
CT + SM	5.7b	0.4ab	1.8a	0.8ab	0.1b	8.1b	70.6b	35.7a	2.8b	28.2ab
	0.2–0.4 m									
NV	4.5b	0.1c	0.1c	0.1c	2.6a	14.0a	158.4a	9.5b	89.9a	2.03c
PA + SM	6.4a	0.4a	2.0a	1.3a	0.0b	4.3b	59.7bc	13.2ab	0.7c	45.3a
NT + SM	6.0a	0.1c	1.1b	0.6b	0.1b	5.7b	70.6b	12.5ab	3.0b	25.5b
NT	6.1a	0.3b	1.5b	0.6b	0.0b	5.5b	44.4c	9.9b	0.3c	29.7b
CT + SM	6.1a	0.3b	1.3b	0.7b	0.0b	4.8b	74.0b	15.8a	1.3bc	33.0b

Letters represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %). Na, P, Cu, and Zn are included in Table 5 (nutrient accumulation)

NV native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage, *m* aluminum saturation [$m = 100 \times (Al^{3+} / (Na + K + Ca + Mg + Al^{3+}))$], *V* base saturation [$V = 100 \times ((Na + K + Ca + Mg) / (Na + K + Ca + Mg + H + Al))$]

other. The areas under no-tillage had the lower LC contents at the 0–0.1-m depth. For the 0.1–0.2-m depth, the results were similar to 0–0.1 m. PA + SM still presented the highest LC content at 0.2–0.4-m depth, while the LC values in CT + SM are 35.5 % higher than those observed in NV for this depth. Both areas under no-tillage had the lowest values, about 1.6 g kg^{-1} for the 0.2–0.4-m depth (Fig. 4).

The CMI values were greater than 100 in all measured depths in PA + SM and CT + SM (Fig. 5). At the depths of 0–0.1 and 0.2–0.4 m, the CMI values were notably superior in PA + SM. At 0–0.1-m layer, the CMI values were equal to 73.9 and 78.6 in NT + SM and NT, respectively, and remained close between these two areas in the other evaluated depths (Fig. 5). At the 0.2–0.4-m depth, the high CMI values in PA + SM and CT + SM were highlighted, equal to 155.4 and 143.5, respectively.

3.3 Nutrient accumulation

The P content was quite superior in PA + SM and CT + SM, reaching values of 252 and 108 mg kg^{-1} at the 0–0.1-m depth, respectively. In areas under no-tillage, the P contents in the area that received SM (NT + SM) were higher than those in areas with only chemical fertilization (NT), at 0–0.1- and 0.1–0.2-m depths (Table 5). The highest levels of Na were observed in PA + SM and CT + SM, not differing each other in the first depth assessed (Table 5). In deeper layers, PA + SM presented greater amounts of Na than the other land uses, with values 250 % higher than NV.

Soil Cu concentrations in PA + SM were greater than those observed in the other land uses, followed by CT + SM (Table 5). At the 0–0.1-m depth, the Cu concentration in PA + SM was 111 % higher than CT + SM. Comparing to NV, Cu concentrations were 15 and 7 times greater in PA + SM and CT + SM, respectively. However, at the 0.1–0.2-m depth, the Cu contents did not differ between PA + SM and CT + SM. Despite receiving SM, increases in Cu concentrations in soils of NT + SM were not observed (Table 5). The Zn levels were also higher in PA + SM and CT + SM compared to other land uses. The Zn concentrations in PA + SM and CT + SM were about 20 times higher than NV at the 0–0.1-m depth and remained notably greater in the others depths (Table 5).

4 Discussion

4.1 SOC and N contents and C stocks

In general, except for pasture with swine manure application (PA + SM), the different land uses caused decreases on SOC

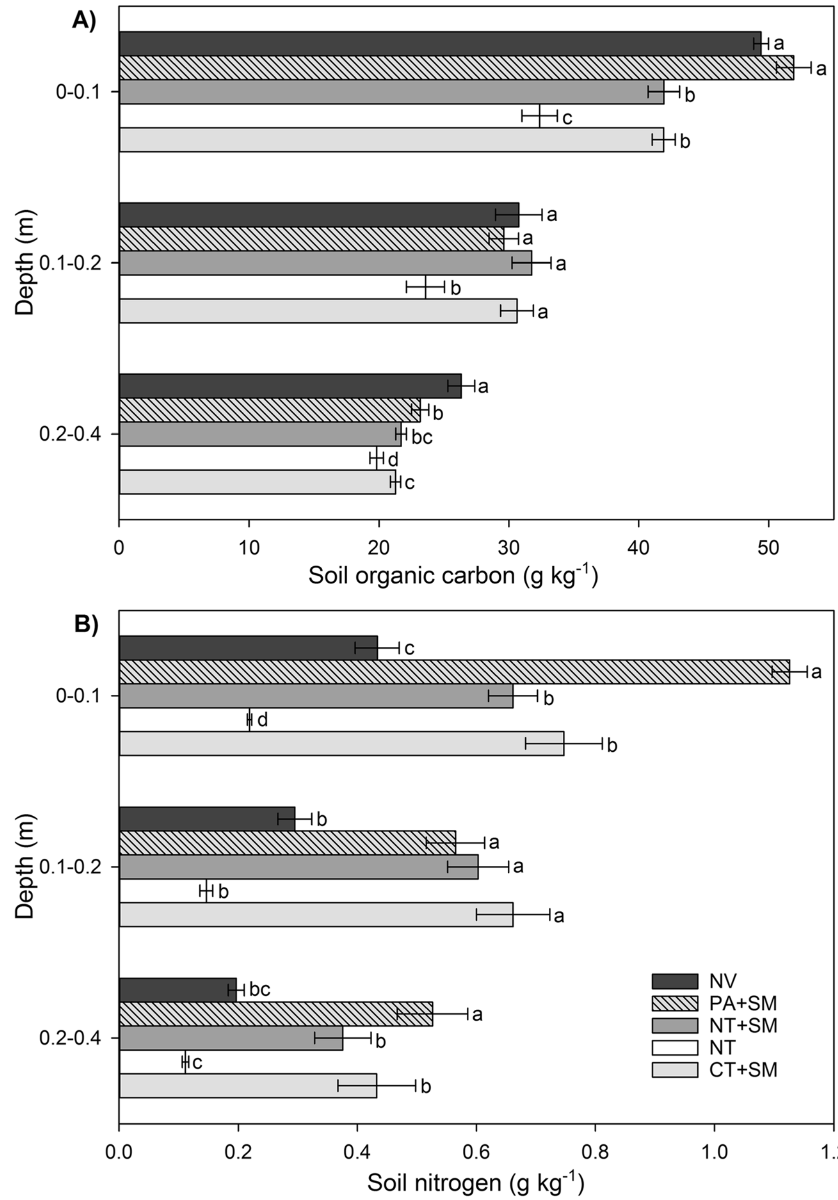

Fig. 2 **a** Soil organic C (g kg^{-1}) and **b** soil nitrogen (g kg^{-1}) in soils of agricultural areas under intensive management and swine manure (*SM*) application in Brazilian Oxisols. *Bars* represent the standard deviation from the mean values. *Letters* represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %). *NV* native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

contents comparing to NV (Section 3.1, Fig. 2a). In addition to greenhouse gas emissions from deforestation and biomass burning, the land use change determines, in most of cases, decrease on soil C levels in tropical regions (Don et al. 2011). The SOC content in PA + SM differed from those NV only in the deepest soil layer evaluated (0.2–0.4 m), demonstrating the effectiveness of this land use in storage C in the soil (Section 3.1, Fig. 2a).

Areas which received SM application showed higher N content at all depths evaluated (Section 3.1, Fig. 2b). The application of inorganic nitrogen sources (Table 1) certainly contributed to these increases. Additionally, we suggested that the application of SM also contributed to the increment of N contents in these land uses. The SM is rich in N (Table 3), and its application on the soil is based on the supply of this nutrient for the plants. N limitation is one of the main factors constraining the C sequestration (Wieder et al. 2015). In this sense, N depletion stands out as one of the most limiting factors associated with the decline and the negative balance of C on pastures in Brazil (Boddey et al. 2004). As well as the insufficient C input, the low input of N in the system is also associated with the occurrence of low C content in some areas under no-tillage in Brazil (Bayer et al. 2011). In this scenario, the application of SM could have an important role regarding the plant nutrition and C sequestration, by the input of higher amounts of N in these areas.

The PA + SM area showed greater C stocks compared to the other land uses and NV (Section 3.1, Fig. 3). Some studies

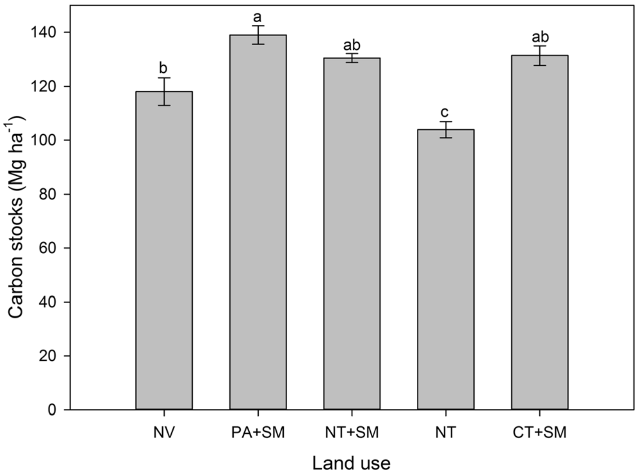

Fig. 3 Carbon stocks (Mg ha^{-1}) at 0–0.4-m soil depth in agricultural areas under intensive management and swine manure (*SM*) application in Brazilian Oxisols. *Bars* represent the standard deviation from the mean values. *Letters* represent statistically significant differences between land uses, according the Tukey test (5 %). *NV* native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

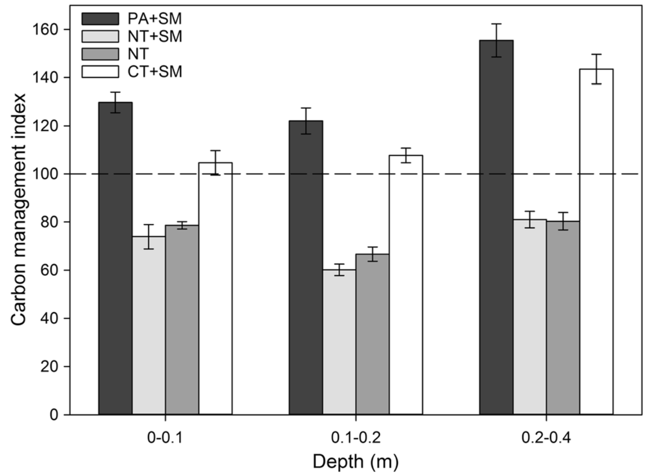

Fig. 5 Carbon management index in soils of agricultural areas under intensive management and swine manure (*SM*) application in Brazilian Oxisols. *Bars* represent the standard deviation from the mean values. *NV* native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

in well-managed pastures also demonstrated that these areas can have greater C stocks than those observed in native vegetation (Maia et al. 2009; Braz et al. 2013) and areas under no-tillage (Santos et al. 2011). Different studies worldwide (Conant et al. 2001; Guo and Gifford 2002) or in Brazil (Braz et al. 2013; Maia et al. 2009) pointed to the potential of pasture in accumulating C in soil.

Although it has low dry matter content (Table 3), swine manure can represent an important source of C to agricultural systems. In our study, for all land uses with SM application in the last decades, the C stocks did not differ from those observed in NV (Fig. 3). In a review worldwide, Maillard and Angers (2014) reported that soils receiving animal manure showed increases in C stocks of 9.4 ± 4.1 Mg ha^{-1}. In China, after 22 years of swine manure application, the surface soil layer (0–0.15 m) accumulated 3.8 Mg C ha^{-1} more than the area with mineral fertilizer alone (Huang et al. 2010). Summarily, the association between SM application and soil

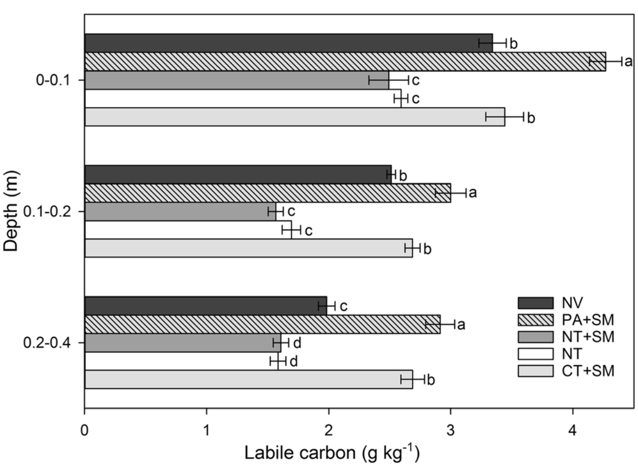

Fig. 4 Labile carbon (g kg^{-1}) in soils of agricultural areas under intensive management and swine manure (*SM*) application in Brazilian Oxisols. *Bars* represent the standard deviation from the mean values. *Letters* represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %). *NV* native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

Table 5 Nutrient accumulation in areas under intensive management and swine manure (SM) application in Brazilian Oxisols

Land use	Na cmolc kg^{-1}	P mg kg^{-1}	Zn	Cu
	0–0.1 m			
NV	0.0d	0.7e	2.1d	1.8d
PA + SM	0.3a	252.0a	33.2a	21.1a
NT + SM	0.1c	53.4c	24.4b	3.6c
NT	0.1c	22.0d	16.6c	3.7c
CT + SM	0.2b	108.6b	30.0a	8.9b
	0.1–0.2 m			
NV	0.1c	0.1d	1.4c	2.0b
PA + SM	0.3a	54.1a	30.5a	8.3a
NT + SM	0.1c	16.5b	11.9b	3.3b
NT	0.1c	9.8c	3.4c	2.4b
CT + SM	0.2b	55.6a	24.4a	6.7a
	0.2–0.4 m			
NV	0.1c	0.1c	0.7c	1.9b
PA + SM	0.3a	8.4a	8.7[a]	4.4a
NT + SM	0.1c	2.2b	2.2c	2.0b
NT	0.1c	1.5bc	0.7c	1.7b
CT + SM	0.2b	5.2a	5.2b	2.5b

Na as a functional plant nutrient (Subbarao et al. 2003). Letters represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %)

NV native vegetation, *PA* pasture, *NT* no-tillage, *CT* conventional tillage

C sequestration is mainly because of (i) its positive effects on plant nutrition, biomass production, and litter inputs and (ii) the role of the SM as a direct source of C and N to the soil (Zhang et al. 2012; Maillard and Angers 2014). Despite it is an on-farming assessment and there is no unfertilized plots as reference, our results allows to suggest that SM plays an important role in the C dynamics of these land uses, interfering positively in C sequestration.

The NT area showed the lowest C stocks compared to the other land uses (Section 3.1, Fig. 3). Recently, the role of the absence of soil tillage in the C dynamics in highly weathered soils has been discussed. It was suggested that the crop system adopted and C inputs to the soil are the main factors associated with the increases on C content in soils under no-tillage (Conceição et al. 2013; Alburquerque et al. 2015). Is possible that the adopted crop systems and its residues inputs are not sufficient to maintain a positive C and N balance in NT area. It reinforces the role of SM as an alternative source of C in regions of high swine production and large areas under no-tillage, such as southern Brazil. In Ohio, USA, the soil C stock at the 0.3-m depth of manure applied corn (119 Mg ha^{-1}) was 30 % higher than that areas under fallow (92 Mg ha^{-1}) (Shrestha et al. 2013). Disregarding the possible differences in C input by crop residues and comparing the C stocks between NT and NT + SM, the relative C stock change related to SM application was 1.26. This ratio was the same as ascertained by Maillard and Angers (2014) and lower than the relative C change (1.36) proposed by Ogle et al. (2005).

4.2 Soil organic matter lability

The LC contents in PA + SM were superior to all land uses in all depths assessed (Section 3.2, Fig. 4). The labile C directly influences soil physical, chemical, and biological attributes as well as the soil quality (Moraes Sá et al. 2014), constituting an important emergent property of soil, highly sensitive to management. Evaluating different land uses in Mato Grosso do Sul, Brazil, Salton et al. (2011) also observed higher accumulation of labile forms of C in pasture areas. Thus, once again, it is evidenced that there are benefits of well-managed pastures to C sequestration by soil. Besides, the LC contents observed in PA + SM and conventional tillage with SM application (CT + SM) allow us to suggest that the application of high doses of SM promotes the accumulation of LC in the soil of these areas. Swine manure has high concentration of labile forms of C, besides related to increases in microbial biomass (Balota et al. 2014), an important pool of LC in the soil.

For PA + SM and CT + SM, the values of CMI were greater than 100 in all assessed depths (Section 3.2, Fig. 5). CMI values lower than 100 are indicative of negative impact of management practices on the SOM and soil quality; meanwhile, values greater than 100 are indicative of positive effects of the management practices on soil quality (Blair et al. 1995). In Brazilian Oxisols, Schiavo et al. (2011) also observed values of CMI higher for pasture compared to areas under no-tillage, exceeding 100 at 0–0.05-m soil layer. The values of CMI in the area under conventional tillage should be analyzed with discretion. Probably, the high C inputs by crop residues and SM application offset the C losses associated to the plowing. Future studies in these areas shall encompass, besides the C stocks in the soil, the greenhouse gas (GHG) emissions related to these management practices. Despite its C stocks and CMI values, the management practices in CT + SM could be associated with high GHG emissions.

4.3 Nutrient accumulation

The P increasing observed in land uses that received SM, especially in PA + SM, where SM is the only source of this nutrient, supports the use of this manure as a source of P in agricultural areas. Ceretta et al. (2010) reported increases of 1725 mg kg^{-1} on P content at 0–0.2-m soil depth after the application of 80 m^3 ha^{-1} year^{-1} of SM for 8 years. Despite the potential benefit to crops, the accumulation of P on soil surface is associated with environmental impacts, such as the increase of P transportation by surface runoff and potential eutrophication of adjacent water courses (Bai et al. 2014; Broetto et al. 2014). Even in the areas of this research, with clay Oxisols highly buffered to P (Abdala et al. 2015), the P extracted by Mehlich 1 reached high values, greater than the environmental critical limits suggested by Gatiboni et al. (2014).

The Cu and Zn contents founded in land uses which received SM are, on average, nine times higher than the critical level recommended for Oxisols (Ribeiro et al. 1999). The frequent SM application can be associated to the significantly increases on the contents of Cu and Zn extractable by Mehlich 1, in levels probably toxic to the plants and dangerous to adjacent water courses in case of transportation by surface runoff. Different studies have pointed out the risk of metal contamination resulting from the continuous application of SM (Luo et al. 2009; Legros et al. 2013; Broetto et al. 2014). The lower rate of SM applied in the NT + SM can be associated to a minor increase in Zn content, while the Cu contents remain high in this land use. Besides, based in the Zn contents of NT, the inorganic fertilizers are an important source of Zn in these areas.

Soil salinization is a frequently problem in areas under frequently manure application (Li-Xian et al. 2007). Cabral et al. (2011) observed values greater than 100 mg dm^{-3} of Na in pastures under SM application in Southern Brazil. It is necessary to assess other soil attributes to infer about the occurrence of this phenomenon, but the increase in Na contents is an indicative of possible soil salinization process in PA + SM and CT + SM.

In China, accounting for 51 % of swine world production (USDA 2016), application of high doses of swine manure to the soil is associated with serious environmental problems, such as resistance to antibiotics (Zhu et al. 2013), greenhouse gas emissions (Chen et al. 2014), P and N runoff and potential eutrophication of adjacent water courses (Bai et al. 2014), soil salinization (Li-Xian et al. 2007), and metal accumulation (Luo et al. 2009). The swine production in Brazil has expanded considerably in recent decades (USDA 2016). In this regard, efforts should be made in order to avoid that problems associated with SM management in China also occur in Brazil. It is mandatory to control the rates of SM application to counterbalance improvements on SOM and environmental impacts of SM fertilization in Brazil, as well as periodic assessments about its potential risks.

5 Conclusions

In general, except for pastures, the agricultural land uses cause decreases in SOC contents comparing to native vegetation in soils from Paraná State, Brazil. We highlighted the feasibility of well-managed pastures to improve soil organic matter, with soil C stocks of 138.9 ± 3.4 down to 0.4 m in our assessment. Compared to native vegetation and other land uses, no-tillage shows the lower SOC contents in all evaluated layers, suggesting that, even under absence of plowing, the lower C and N inputs imply a negative C balance in the no-tillage field. In this sense, the application of swine manure in the last decades is associated to the greater C stocks in areas under pasture, conventional tillage, and no-tillage. Besides, swine manure application results to higher N contents in all land uses under this practice.

The land uses which receive higher rates of swine manure application (pasture and conventional tillage) increase the soil organic matter lability, aspect shown by the C management index greater than 100. However, this practice can be also associated to nutrient accumulation in these areas. Despite being plant nutrients, the high contents of P, Cu, and Zn in areas under pasture and conventional tillage must be evaluated with concern.

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