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ORIGINAL RESEARCH

Soil aggregation indexes and chemical and physical attributes of aggregates in a Typic Hapludult fertilized with swine manure and mineral fertilizer

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Abstract

Purpose The objective was to evaluate the effects of mineral fertilizers and swine manure fertilization on soil aggregation indexes and on chemical and physical attributes of aggregates in Typic Hapludult managed under minimum tillage system.

Method Experiment was implemented in 2013, in southern Brazil. The treatments were control, mineral fertilization (MF), swine manure compost + MF (SMC+MF); pig slurry + MF (PS+MF); PS to supply N for maize and black oat (PS100). In May 2015 and 2016, undisturbed soil samples were collected to obtain soil aggregates. Aggregates stability was evaluated through the mean weight diameter (MWD) and mean geometric diameter (MGD) indexes and aggregate distribution by diameter classes. In macroaggregates, total organic carbon (TOC), total nitrogen (TN), clay flocculation degree (CF%) and ΔpH were evaluated.

Results The use of swine manure, associated or not to MF, increases TOC and TN contents in soil aggregates in 67.02 and 125.87%, respectively, for SMC+MF treatment. However, it was not efficient in improving soil physical attributes, reducing soil aggregation indexes, mainly in the 5-10 cm layer, by the decreased values of MWD and MGD. This result corroborates with the increase in microaggregates in all treatments. This was a result of the negative ΔpH values and the increased CF%.

Conclusion Despite the increase in organic matter contents observed in this study, this was not enough to guarantee an improvement in soil physical attributes over 4 years. These results show that management must be supported by several conservationist techniques in order to have soil quality.

Keywords Organic fertilization, Macroaggregates, Mean geometric diameter, Organic carbon, Clay flocculation

Introduction

Swine production stands out in Brazil southern region, especially on Santa Catarina (SC) state, which, in 2016, was the largest pig producer, with about 10.73 million swine heads (Marcondes 2017). The activity is one of the main income sources in small farms, administered predominantly by family labor (Ceretta et al. 2010). In SC, Braço do Norte city is located in the south of the state, which has one of the largest pigs per area concentrations in the country, and one of the largest in the world, with a 314,810 pigs herd, representing a density of 1.485 animals per km^2 and 10.85 animals per inhabitant (Marcondes 2017). As the breeding system is intensive with animal confinement, a large animal waste volume is generated in a daily basis (Couto et al. 2010), which can reach a mean of 8.6 liters animal^{-1} day^{-1} on a complete production cycle farm (Diesel et al. 2002).

One of swine manure main destinations in Santa Catarina is its use as a nutrients source for agricultural crops, with positive effects on edaphic properties. Swine manure application in soil influences microbial activity, soil properties (physical, chemical and biological), nutrient availability and crop productivity (Agele et al. 2005). These aspects support soil quality and produc-

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tivity, favoring soil aggregation (Blanco-Canqui et al. 2009; Comin et al. 2013; Loss et al. 2017; Viana et al. 2011), maximizing cycling nutrients, including C and N (Blanco-Canqui et al. 2009; Brunetto et al. 2013, Comin et al. 2013; Mafra et al. 2014; Viana at al. 2011), and promoting increased microbial activity and population (Eaton 2001; Plaza et al. 2004).

Regarding soil aggregation, in order of aggregates to form, two steps are necessary: soil particles unit approximation, followed by soil stabilization through cementing agents. Thus, clay fraction, oxides, carbonates, polysaccharides, arbuscular mycorrhizal fungi and, mainly, soil organic matter presence (SOM), play an important role in the formation and stabilization of soil structure with aggregation (Carter 2004). The SOM has a direct and indirect influence on all soil characteristics, (Blanco-Canqui et al. 2009; Viana et al. 2011), being the main agent for soil aggregates formation and stabilization (Six et al. 2004).

During the soil aggregates formation process, part of SOM is physically protected inside these aggregates, reducing its mineralization due to smaller microbial attack and less O_2 and water diffusion (Christensen 2001; Al-Kaisi et al. 2014). Thus, SOM protection inside soil aggregates is dependent on its formation and their binding agents stability, whereas aggregates fragmentation will lead SOM exposure to decomposition due to greater oxidation and microorganisms presence (Adu and Oades 1978). Also, due to the greater lability of SOM present in macroaggregates, its stability is dependent on plants presence and the constant residues contribution to soil, for example through animal wastes.

Successive swine manure applications in soil can promote changes in soil chemical and physical attributes such as, for example, total organic carbon (TOC) (Brunetto et al. 2013; Comin et al. 2013) and total nitrogen (TN) (Dortzbach et al. 2013; Giacomini et al. 2013), with management system also having an influence on soil TOC and TN dynamic. Several studies demonstrate the benefits of swine manure use for soil physical attributes, such as bulk density (BD) and particle density (PD) decrease, increase in total soil porosity, aggregation indexes and aggregates stability in water (Tavares Filho and Ribon 2008; Tavares Filho and Tessier 2010; Comin et al. 2013; Agne and Klein 2014; Loss et al. 2017). Comin et al. (2013) in a study conducted in the municipality of Braço do Norte, Santa Catarina State, Brazil, after 8 years of cultivation of black oats and maize, aimed to evaluate the effect of the continuous application of pig slurry (PS) and pig deep litter (PL) on the total organic carbon (TOC) content and physical properties of soil under NTS. The authors used the following treatments: a control plot (without manure application), plots with PS applications equivalent to one and two times the recommended rate of nitrogen (N) for maize and black oats (PS1X and PS2X, respectively), and plots with PL equivalent to one and two times the recommended rate of N for maize and black oats (PL1X and PL2X, respectively). As conclusion, the authors found that the application of PL produced improvements in physical attributes of the soil, such as bulk density, macro and microporosity, pore diameter, soil aggregation, and penetration resistance, and increased soil TOC.

On the other hand, other studies have shown that animal waste application can lead to physical and chemical changes in soil, depending on soil type, precipitation rate, waste amount and time between applications (Choudhary et al. 1996; Zhou et al. 2013), resulting in decreased aggregation and stability index of aggregates in water (Benites and Mendonca 1998; Wuddira and Camps-Roach 2007; Barbosa et al. 2015). However, it should be pointed out that, in a large part of studies addressing swine manures effects on soil physical attributes, the studies are not long-term, and it is known that soil effects are cumulative over time (Agne and Klein 2014). Thus, the objective was to evaluate the effects of swine manure fertilization and mineral fertilizers on soil aggregation indexes and on chemical and physical attributes of aggregates in a Typic Hapludult managed under minimum tillage system.

Material and methods

The experiment was conducted from September 2013 to May 2016 in a pig farm located in Braço do Norte city (49º 09' 56" W, 28º 16' 30" S, 300 m altitude, undulating relief), Santa Catarina State, Brazil. Region climate, according to Köppen-Geiger classification, is subtropical humid (Cfa) (Alvares et al. 2013). The monthly average values of precipitation and temperature of the period of conduction of the experiment are presented in Fig 1. Soil was classified as Typical Hapludult (Soil Survey Staff 2014), presenting, at the time of experiment installation, the following physical-chemical attributes in the 0-10 cm layer: 503, 198 and 299 g kg^{-1} sand, silt and clay content; pH$_{H2O}$ 5.37; SMP index 6.24; 5.45 g kg^{-1} total organic carbon (TOC); 0.95 g kg^{-1} total nitrogen

(TN); exchangeable Al, Ca and Mg (extracted by KCl 1 mol L^{-1}) of 0.14, 1.62 and 0.69 $cmol_c$ dm^{-3}, respectively; P and K (extracted by Mehlich 1) of 31.8 and 60.7 mg kg^{-1}, respectively; cation exchange capacity ($CEC_{effective}$) 2.61 $cmol_c$ dm^{-3}; $CEC_{pH7,0}$ 5.78 $cmol_c$ dm^{-3}; 42.7% base saturation and 5.4% aluminum saturation. Prior to experiment implementation, liming was performed in the area to raise soil pH to 6.0 (CQFS-RS/SC 2004).

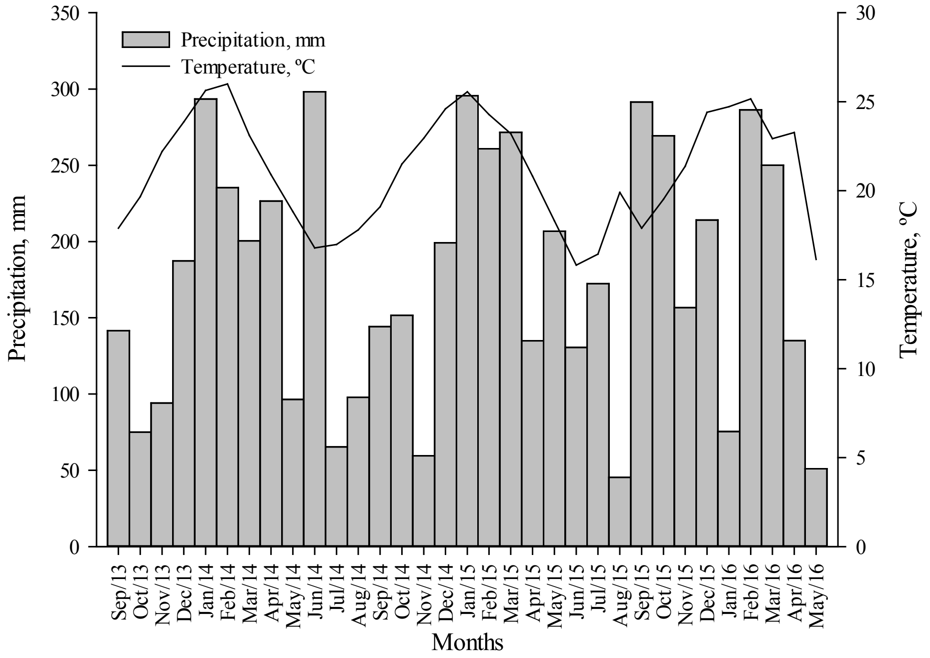

Fig. 1 Monthly precipitation and temperature data during the experimental period (September 2013 to May 2016) Data collected at the meteorological station of Epagri/Ciram in the municipality of Urussanga, located 40 km from the municipality of Braço do Norte, SC, Brazil.

Previously to experiment installation, the area was used for maize production (*Zea mays*) with black oat (*Avena strigosa*) succession in conventional tillage system (CTS). After experiment implantation, maize direct seeding and sowing of black oats with light harrowing was performed, characterizing minimum soil cultivation system. Black oat was cultivated until full bloom stage, when it was desiccated with glyphosate herbicide, and maize was cultivated for grains production.

Experimental design was of randomized blocks, with five treatments and four replications, with plots of 6.5 x 8.0 m dimensions (52 m²). Treatments used were: Control, without fertilization; mineral fertilization (MF), with urea, triple superphosphate and potassium chloride; swine manure compost (SMC) + MF (SMC+MF); pig slurry (PS) + MF (PS+MF); and pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively (PS100), according to CQFS-RS/SC (2004). In the SMC+MF and PS+MF treatments, swine manure amount applied was calculated to supply the first nutrient (N, P or K) that reached the fertilization recommendation for the crops (CQFS-RS/SC 2004), and the other nutrients supplied via MF. For this, before each application of treatments, a sample of SMC and PS was analyzed through acid digestion, according to Tedesco et al. (1995). The levels of N in the swine manure samples were determinate with a distillation in a Kjeldahl half-micron vapor distiller and the distilled material being collected in boric acid and the entitlement of the extract carried out with diluted H_2SO_4 (Tedesco et al. 1995). The P content was determined by the method of Murphy and Riley (1962), the K content was determined by flame spectrometry (B262 Micronal), and Ca and Mg contents were determined by atomic absorption spectrophotometer (AAnalyst 200).

Swine manure physicochemical characteristics and the amounts of nutrients applied in each crop are presented in Table 1. SMC was produced according to methodology proposed by Victoria de Oliveira and Higarashi (2006), while PS was obtained from anaerobic ponds located on the property, where the experiment was conducted. The treatments with the use of swine manure were applied during each crop cycle in a splitted way. For the SMC treatment, after calculating the amount of SMC that would be necessary to reach one of the macronutrients necessary for the development of these cultures, it was planned how to split this material (normally, two times during black oat cycle, and three times for maize cycle). For each application, the amount of SMC needed were weighed and applied it manually to the planting lines for maize and the whole area for black oat. For the PS treatment, the application was splitted in the same way that was for the SMC treatment (normally, two times during black oat cycle, and three times for maize cycle). The need volume was measured with the aid of a 50 L container. This container was carried by two people to the application area, which was then applied to the planting lines for corn and the whole area for black oat.

At black oat full bloom stage, in August 2014 and 2015, dry matter production (DM) was evaluated, randomly collecting three subsamples of 0.25 m^2 in each plot, which were collected in a composite sample. The material was dried at 65 °C in oven to constant weight, and DM determined.

In May 2015 and 2016, after 2014/15 and 2015/16 maize harvests, 40x40x40 cm trenches were opened and, with the aid of a straight blade and spatula, undisturbed soil samples (clods) were collected between maize cultivation lines in the 0-5, 5-10 and 10-20 cm layers in all experimental units, with each replicate consisting of three undisturbed simple samples. Soil samples were also collected in volumetric rings with a 50 cm^3 volume for further bulk density (BD) determination. For aggregates obtainment, samples were air-dried and manually dislodged following their lines of weakness, and undisturbed samples were passed in a set of 8.0 and 4.0 mm mesh sieves. All material that passed the 8.0 mm mesh and was retained in the 4.0 mm mesh was considered a soil aggregate (AGR) (Embrapa 2011).

In order to evaluate aggregates classes distribution, 25 g of soil from samples that were retained in the 4 mm sieve were weighed. Subsequently, samples were transferred to a set of sieves with 2.00, 1.00, 0.50, 0.25, 0.105 and 0.053 mm meshes, moistened with a hand sprayer and subjected to vertical stirring in the Yoder apparatus (Yoder 1936) for 15 min. After the determined time, material retained in each sieve was removed, separated with the aid of water jet, placed in petri dishes and dried in an oven at 105 °C, until constant mass. Based on aggregate mass data, the mean weight diameter (MWD) and mean geometric diameter (MGD) of aggregates were calculated (Embrapa 2011), according to equations 1 and 2, respectively. Also, with aggregates mass, in each sieve, its distribution was evaluated in the following classes of average diameter, according to Costa Junior et al. (2012): 8,00 > Ø ≥ 2.00 mm (macroaggregates); 2.00 > Ø ≥ 0.25 mm (mesoaggregates) e Ø < 0.25 mm (microaggregates).

$$MWD = \sum_{n=1}^{\infty} \left(\frac{mi}{m} \right) Di \qquad \text{Equation 1}$$

$$\mathrm{MGD} = \Pi_{i=1}^{\infty} Di \frac{mi}{m} = e^{\sum_{i=l}^{n} \frac{mi}{m}} . \ln(Di) \qquad \text{Equation 2}$$

Where:

n = number of aggregate size classes;
mi = mass of class i, in g;
m = total mass, in g;
ln = neperian logarithm
Di = arithmetic mean of upper and lower class limits, in g.

After assessing aggregates stability, part of macroaggregates between 8.00 > Ø ≥ 4.00 mm was used to evaluate some chemical and physical parameters. The aggregates were macerated in porcelain crucible, sieved in 2 mm mesh, and from this material TOC and TN contents were determined. The TOC was quantified according to Yeomans and Bremner (1988). For this, 0.5 g of the soil samples were weighed, macerated and passed through a 60 mesh sieve. The material was placed in a 250 ml conical flask and then 5 ml of potassium dichromate and 7.5 ml of sulfuric acid were added. Subsequently, the temperature of the digester block was raised to 170 ° C for 30 min. Then, 80 ml of distilled water and 0.3 ml of the indicator solution (phenanthroline) were added and then titrated with 0.2 mol L^{-1} ammoniacal ferrous sulfate solution. TN content was determined by the "Kjeldhal" method, by digestion with sulfuric acid and hydrogen peroxide and, subsequently, the obtained extract was subjected to steam distillation with sodium hydroxide and titration of the collected with boric acid, according to the methodology described by Tedesco et al. (1995). Clays flocculation degrees were also determined according to the methodology proposed by Embrapa (2011), according to the following equation 3:

$$CF = 100 \left(\frac{a-b}{a} \right). \qquad \text{Equation 3}$$

Table 1 Physicochemical characteristics and amounts of N, P, K, Ca and Mg applied to maize and black oat crops in the municipality of Braço do Norte, SC, Brazil, from 2013 to 2016

Treatments	DM	C	AA[1]	C/N	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	%	%			%					kg ha^{-1}				
Maize – 2013/14														
MF	-	-	469	-	-	-	-	-	-	100	75	52	-	-
SMC+MF	38.19	36.6	13461 (154)[2]	17.5	2.09	2.21	0.53	0.76	0.60	54 (47)	79	22 (30)	31	24
PS+MF	1.12	32.1	167 (255)	11.2	2.88	6.40	7.09	1.95	0.74	14 (86)	46 (29)	52	10	4
PS100	1.12	32.1	354	11.2	2.87	6.52	7.04	2.85	1.10	30	103	110	196	78
Black oat – 2014														
MF	-	-	165	-	-	-	-	-	-	30	30	20	-	-
SMC+MF	24.41	27.6	12500	13.8	2.00	1.37	0.72	0.96	0.71	31	28	22	60	44
PS+MF	26.70	23.1	25 (31)	5.0	4.64	1.48	5.90	3.19	3.98	33 (9)	31 (22)	36	6	7
PS100	23.08	23.1	34	5.4	4.24	1.20	11.70	3.19	3.98	29.2	10	72	14	18
Maize – 2014/15														
MF	-	-	469	-	-	-	-	-	-	100	75	52	-	-
SMC+MF	28.00	33.4	15385 (96)	10.4	3.20	0.70	0.80	0.95	0.64	103	32 (44)	48	112	76
PS+MF	1.19	23.7	173 (255)	4.8	4.93	3.03	9.10	2.49	1.06	17	28 (86)	51 (29)	17	6
PS100	1.19	23.7	288	4.8	4.96	3.00	8.94	2.49	1.06	27	45	79	69	29
Black oat – 2015														
MF	-	-	165	-		-	-	-	-	30	30	20	-	-
SMC+MF	23.23	29.3	5769	4.2	6.99	4.20	2.10	1.20	1.54	55	46	33	22	13
PS+MF	24.89	25.6	18 (37)	6.0	4.26	1.63	7.69	2.23	1.16	18 (13)	8 (24)	38	2	1
PS100	24.89	25.6	32	4.8	5.26	2.00	6.82	2.23	1.16	33	14	55	2	1
Maize – 2015/16														
MF	-	-	469	-	-	-	-	-	-	100	75	52	-	-
SMC+MF	21.05	26.8	25000 (211)	9.3	2.88	0.95	1.27	1.05	0.51	48 (52)	33 (44)	50	136	66
PS+MF	1.69	20.6	577 (135)	7.2	2.86	1.74	1.47	2.41	3.55	49 (52)	76	38 (11)	94	138
PS100	1.69	20.6	1038	7.3	2.82	1.69	1.40	2.41	3.55	86	133	65	105	156

AA = amount applied. DM = Pig slurry dry matter. (1) The AA values for MF, SMC+MF and PS treatments are expressed in kg ha^{-1}, Mg ha^{-1} and m^3 ha^{-1}, respectively. (2) Values in parentheses represent supplemental MF for SMC+MF and PS+MF treatments, expressed in kg ha^{-1}.

Where:

CF = clay flocculation, in %;

a = value of the total clay, that was obtained by the pipette method, using 10 ml of NaOH 10 mol L^{-1} concentration, according to the methodology proposed by Embrapa (2011);

b = the clay dispersed in water

The pH in water ($pH_{H20)}$) and in KCl (pH_{KCl}) values were determinate according to methodology proposed by Tedesco et al. (1995), to later calculate ΔpH values (pH_{KCl} - pH_{H20}). Table 2 presents pH_{H20}, pH_{KCl} and ΔpH values.

For BD evaluation, soil collected with the aid of a 50 cm^3 volumetric ring (Embrapa 2011) was transferred to an aluminum crucible of known mass, which was weighed, placed in a circulating air oven at 105ºC and, after reaching constant weight, removed, allowed to cool and then weighed again. The BD was determined by equation 4:

$$BD = \frac{ma}{va} \qquad \text{Equation 4}$$

Table 2 pH_{H2O} values, pH_{KCl} and ΔpH in the 0-5, 5-10 cm and 10-20 cm depth layers, in soil submitted to different fertilizer sources in the municipality of Braço do Norte, SC, Brazil

Treatments	Depth (cm) 0-5		5-10		10-20	
	2015	2016	2015	2016	2015	2016
			pH_{H2O}			
Control	5.12	4.93	4.87	4.81	4.74	4.57
MF	4.98	4.55	5.16	4.66	4.96	4.9
SMC+MF	5.32	5.22	5.38	5.28	5.27	5.31
PS+MF	4.75	4.60	4.91	4.77	4.70	4.68
PS100	5.21	4.54	4.95	4.64	4.86	4.57
			pH_{KCl}			
Control	4.86	4.33	4.32	4.14	4.12	3.91
MF	4.01	4.48	4.03	4.22	4.02	4.08
SMC+MF	5.07	4.69	4.83	4.85	4.64	4.54
PS+MF	4.29	4.70	4.20	4.31	4.08	4.21
PS100	4.49	4.29	4.20	3.93	4.07	4.03
			pHΔ			
Control	-0.26	-0.60	-0.55	-0.67	-0.62	-0.66
MF	-0.97	-0.07	-1.13	-0.44	-0.94	-0.82
SMC+MF	-0.25	-0.53	-0.55	-0.43	-0.63	-0.77
PS+MF	-0.46	+0.10	-0.71	-0.46	-0.62	-0.47
PS100	-0.72	-0.25	-0.75	-0.71	-0.79	-0.54

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively.

Where:

BD = bulk density, in kg dm^{-3};

ma = mass of sample dried at 105ºC, in g;

va = volumetric ring volume, in cm^3.

Results from physical and chemical parameters were analyzed for data normality and homogeneity by Lilliefors (Lilliefors 1967) and Bartllet (Bartlett 1937) tests, respectively. Subsequently, data were submitted to analysis of variance with F test application and mean values, when significant between treatments, they were compared by Scott-knott test with a 5% probability of error, and, when significant between years, they were compared by t-Test (LSD) with a 5% probability of error using Sisvar Software 5.6.

Results and discussion

Different nutrients sources evaluated presented significant effects on black oat dry matter (DM) production, TOC and TN contents in aggregates, MGD and MWD, aggregates classes distribution and soil clay flocculation degree. No effect of treatments was observed on BD. The highest DM production of black oat was observed in MF and PS100 treatments in 2014, and in MF treatment in 2015. It is important to highlight that from 2014 to 2015, there was a decrease in black oat production in some treatments (Table 3).

Table 3 Black oat dry matter (DM) submitted to different sources of fertilization in the municipality of Braço do Norte, SC, Brazil, during the evaluation period (2014 and 2015)

Treatments	Black oat dry matter, Mg ha^{-1}		(%) CV
	2014	2015	
Control	2.44 dA	2.29 cA	7.86
MF	5.49 aA	4.25 aB	12.89
SMC+MF	3.20 cB	3.62 bA	4.09
PS+MF	3.90 bA	3.39 bB	8.07
PS100	5.80 aA	3.56 bB	6.63
(%) CV	4.18	12.98	

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively. CV = Coefficient of variation. Averages followed by the same lower case letter in the column do not differ from each other by the 5% Skott-knott Test. Averages followed by the same capital letters in the line do not differ from each other by the LDS Test at 5% probability.

The highest values of black oat DM production in 2014 for the PS100 treatment was due to the high nutrient load present in the PS (Table 1), equaling MF treatment. In 2015, it was observed that the climatic variation affected the production of cover plants, decreasing their production mainly in MF, PS+MF and PS100. During the cycle of cover crops, there was a period of prolonged drought, which impaired their development (Fig 1). Similar results were obtained by Ciancio et al. (2014), when evaluating crop responses to different application rates of animal manure sources (10, 20 and 30 m^3 ha^{-1} of pig slurry, and of 1 and 2 t ha^{-1} of turkey manure) used alone and supplemented with mineral N topdressing, in a no-tillage system. The authors observed that the use of animal waste equaled the NPK treatment for the DM production by black oat. In the third year, this production was superior for the treatment with animal waste, when compared to the NPK treatment.

Regarding soil aggregation, there was no differences for MWD in the 0-5 and 10-20 cm layer, but only in the 5-10 cm layer in the evaluation performed in 2015, with the highest value for SMC+MF treatment, and the lowest values in Control and MF treatments (Table 4). In 2016, there was no differences for MWD in the 0-5, 5-10 and 10-20 cm layer. Considering evaluation epochs, the highest MWD values were observed in 2015 for SMC+MF treatment, in the 0-5 cm layer; for SMC+MF, PS+MF and PS100 treatments, in the 5-10 cm layer, and Control e SMC+MF, in the 10-20 cm layer. For MGD, also in 2015, SMC+MF and PS+MF treatments had the highest values in the 0-5 cm layer. In the 5-10 cm layer, the highest MGD value for 2015 was observed for SMC+MF treatment, and for the 10-20 cm layer, there was no differences between treatments. In 2016, for the 0-5 cm layer, Control, MF and PS100 treatments presented the highest values. In the 5-10 and 10-20 cm layers, there was no differences between treatments. Between evaluation epochs, we observed the highest MGD values in 2015 for SMC+MF and PS100 treatments, in the 0-5 cm layer, for SMC+MF, PS+MF and PS100 treatments, in the 5-10 cm layer, and for SMC+MF in the 10-20 cm layer, whereas the other treatments did not differ among themselves (Table 4).

The highest MWD and MGD values for treatments with swine manure application are due to SOM content increase in these areas, when compared to Control and MF. The SOM plays a fundamental role in the formation and management of soil structure with aggregation (Carter 2004). In addition, the higher black oat plants DM contents in these treatments, and soil exploration by roots, which exert pressure on mineral particles promoting their approximation (Guedes Filho et al. 2013), as well as organic compounds exudation that have agglutinating effect on soil particles (Vezzani and Mielniczuk 2011).

Related to aggregate class distribution, macroaggregates presented no differences between treatments in the 0-5 cm layer, in both evaluation epochs (Fig. 2A). In the 5-10 and 10-20 cm layers only in 2015, there were differences between treatments, with the highest values observed for SMC+MF in 5-10 cm (Fig. 2B), and in Control, SMC+MF and PS100 treatments of 10-20 cm (Fig. 2C). Comparing evaluation epochs, it

Table 4 Mean weighted (MWD) and mean geometric diameter (MGD) of aggregates in the soil profile submitted to different fertilizer sources in Braço do Norte, SC, Brazil, in the evaluation carried out in 2015 and 2016

Treatments	MWD, mm								
	0-5 cm		CV	5-10 cm		CV	10-20 cm		CV
	2015	2016	(%)	2015	2016	(%)	2015	2016	(%)
Control	4.20 $^{\text{nsNS}}$	3.85 $^{\text{ns}}$	3.38	3.38 c$^{\text{NS}}$	3.49 $^{\text{ns}}$	7.86	3.23 $^{\text{ns}}$A	2.39 $^{\text{ns}}$B	7.16
MF	4.13 $^{\text{NS}}$	3.77	7.45	3.35 c$^{\text{NS}}$	3.66	3.66	2.62 $^{\text{NS}}$	2.95	13.81
SMC+MF	4.53 A	3.76 B	6.50	4.45 aA	3.45 B	3.76	3.69 A	2.76 B	11.37
PS+MF	4.02 $^{\text{NS}}$	4.13	14.17	4.04 bA	3.39 B	7.71	3.23 $^{\text{NS}}$	2.78	14.30
PS100	4.14 $^{\text{NS}}$	3.92	8.47	4.07 bA	3.28 B	5.63	2.9 $^{\text{NS}}$	3.24	17.46
CV(%)	10.59	5.96		5.72	7.93		14.08	12.46	
	MGD, mm								
	0-5 cm		CV	5-10 cm		CV	10-20 cm		CV
	2015	2016	(%)	2015	2016	(%)	2015	2016	(%)
Control	3.42 b$^{\text{NS}}$	2.87 a	10.06	2.30 c$^{\text{NS}}$	2.63 $^{\text{ns}}$	10.85	2.17 $^{\text{ns}}$	1.41 $^{\text{ns}}$	9.09
MF	3.07 b$^{\text{NS}}$	2.91 a	7.75	2.30 c$^{\text{NS}}$	2.61	16.27	1.66 $^{\text{NS}}$	1.75	18.48
SMC+MF	4.11 aA	2.63 bB	5.05	3.92 aA	2.39 B	7.39	2.73 A	1.72 B	17.41
PS+MF	3.84 a$^{\text{NS}}$	3.24 a	14.38	3.21 bA	2.29 B	14.37	2.29 $^{\text{NS}}$	1.65	22.74
PS100	3.35 bA	2.25 bB	15.80	3.20 bA	2.20 B	10.82	2.66 $^{\text{NS}}$	1.72	28.11
CV(%)	12.36	8.93		11.47	12.62		21.41	19.13	

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively. CV = Coefficient of variation. Averages followed by the same lower case letter in the column do not differ from each other by the 5% Skott-knott Test. Averages followed by the same capital letters in the line, between evaluation times, do not differ from each other by the LDS Test at 5% probability. ns = not significant in the column. NS = not significant between evaluation times.

is verified that in the 0-5 cm layer, SMC+MF was the only treatment that decreased macroaggregates amount between 2015 and 2016 (Fig. 2A). While in the 5-10 cm layer, MF was the only treatment that did not decrease macroaggregates proportion (Fig. 2B), and in the 10-20 cm layer, there was a decrease in macroaggregates proportion in Control and SMC+MF treatments (Fig. 2C).

For mesoaggregates, in 2015, the lowest values were found for SMC+MF treatment in all evaluated layers and, also, for PS100 treatment in the 5-10 and 10-20 cm layers (Fig. 2E-F). In the 2016 evaluation, the lowest values were observed for PS treatments, in the 0-5 cm layer (Fig. 2D), for MF, in the 5-10 cm layer (Fig. 2E), and for PS100, in the 10- 20 cm layer (Fig. 2F). In the comparison between evaluation epochs, mesoaggregates proportion increased from 2015 to 2016 in SMC+MF treatment, in the 0-5 cm layer (Fig. 2D), in SMC+MF and PS100 treatments, in the 5-10 cm layer (Fig. 2E), and in SMC+MF treatment, in the 10-20 cm layer (Fig. 2F).

Regarding microaggregates, in 2015 no differences were observed between treatments in the 0-5 and 10-20 cm layers (Fig. 2G-I). In the 5-10 cm layer, in the same year, the largest microaggregates mass was observed in MF treatment, while the lowest values occurred in SMC+MF and PS100 treatments (Fig. 2H). In 2016, in the 0-5 cm layer, the highest value was observed in PS100 treatment (Fig. 2G), in the 5-10 cm layer, the lowest value was observed in Control treatment (Fig. 2H), and in the 10 -20 cm layer, the highest value was observed in MF treatment (Fig. 2I). Comparing evaluation epochs, there was an increase in microaggregates, from 2015 to 2016, in SMC+MF and PS100 treatments, in the 0-5 cm layer (Fig. 2G), for SMC+MF, PS+MF and PS100, in 5-10 cm layer (Fig. 2H), and in all treatments in the 10-20 cm layer (Fig. 2I).

Especially for the 2015 evaluation, it was observed, in general, that even in layers where there were no significant differences between treatments, SMC+MF presented, proportionally to the other treatments, higher MWD, MGD values (Table 4) and macroaggregates (Fig. 2). In this treatment, which presents a higher DM amount and a higher C/N ratio (Table 1) (Comin et al. 2013), the aggregation effect is longer lasting, generating more stable aggregates and, consequently, a lower proportion of smaller size aggregates (Fig. 2). On the other hand, in treatments with liquid manure, which present smaller DM amounts and C/N ratio values (Table 1) (Comin et al. 2013), the effect on soil structuring is lower compared to SMC+MF treatment. However, when comparing the effect of pig slurry in relation to Control, it can be verified that these treatments (PS+MF and PS100) may present better results in soil aggregation (Fig. 2, Table 4).

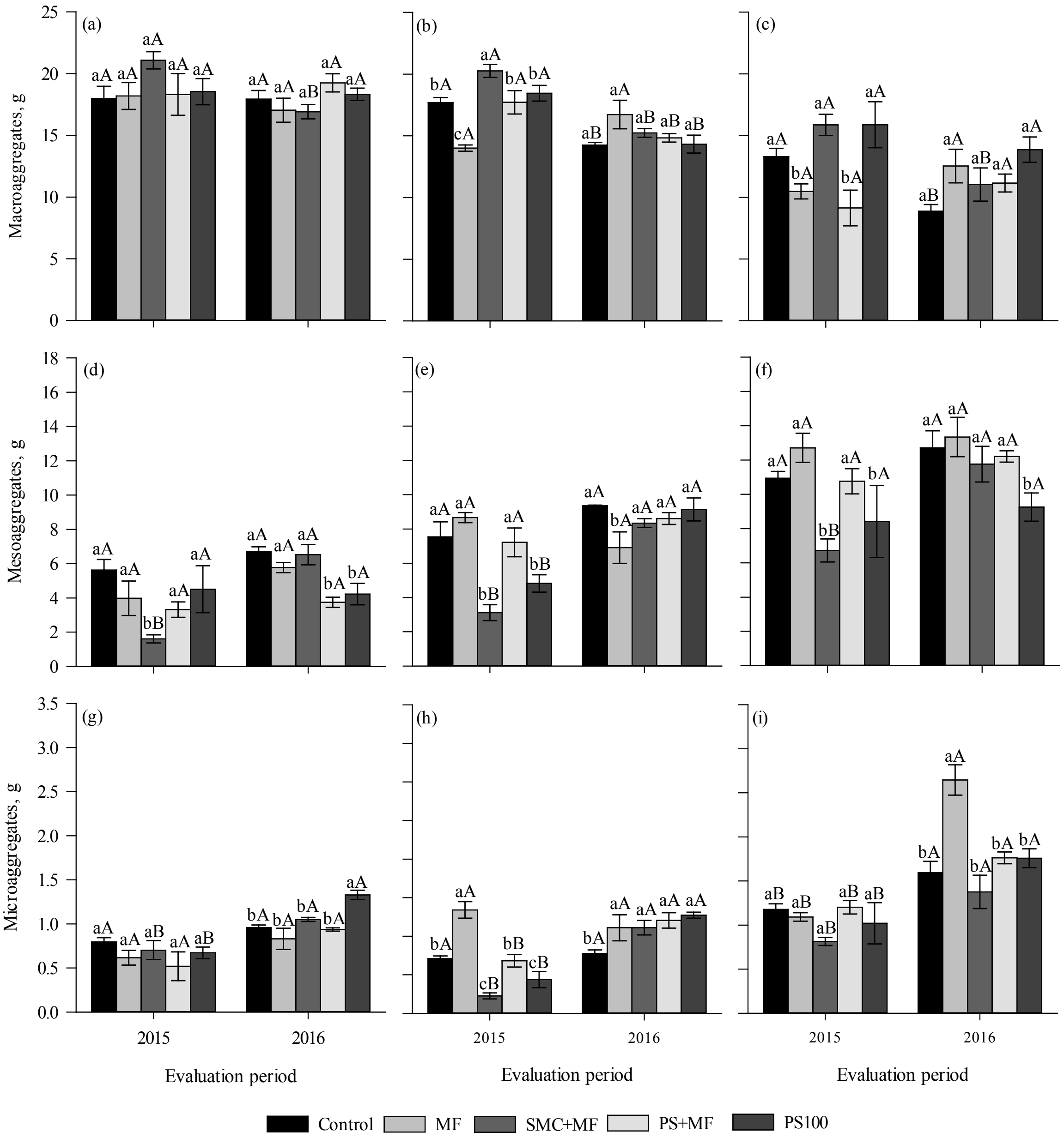

Fig. 2 Distribution of water stable aggregate classes: Macroaggregates in the 0-5 (a), 5-10 (b) and 10-20 cm (c) depth layers; mesoaggregated in the depth layers 0-5 (d), 5-10 (e) and 10-20 cm (f); micro-aggregates in the 0-5 (g), 5-10 (h) and 10-20 cm (i) depth layers, in soil submitted to different fertilizer sources in the municipality of Braço do Norte, SC

Mean values followed by the same lower cases letter, between treatments, do not differ from each other by the 5% Skott-knott Test. Capital cases letters between evaluation times do not differ from each other by the LDS Test at 5% probability

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively

These results corroborate those found by Schmitz et al. (2017), when evaluating physical attributes of an Inceptsol in an apple orchard under different nitrogen sources: control (without fertilization); common urea; pelleted urea; and organic fertilizer (superimposed pig slurry), at 33 kg N ha^{-1} year^{-1} doses, found that organic fertilization contributed to MGD increase and stability index of aggregates, being this effect more pronounced on the surface (0-5 cm). The lower MWD and MGD values observed for MF treatment, in the 5-10 cm layer of 2015 evaluation, may be due to the more pronounced SOM mineralization due to mineral nitrogen application in the form of urea, may lead to SOM content reduction, i.e., TOC, since this N becomes a raw material for decomposing microorganisms, accelerating SOM decomposition (Fonte et al. 2009; Souza et al. 2014). Among MWD and MGD indexes, MGD demonstrated to be more responsive evidencing differences between treatments, since the highest MGD values were observed in areas with swine manure (SMC+MF, PS+MF and PS100), followed by Control and MF, whereas for MWD, only differences between MF (lower value) and other treatments (higher values) were observed.

In the 2016 evaluation, the decrease in soil macroaggregates values and, consequently, increase of meso and microaggregates values can be due to the greater increase of negative charges in soil, demonstrated by ΔpH values (Table 2), repelling the organic matter that has been added over time, and causing a greater clay dispersion, as can be observed by clay flocculation degree values (Fig. 3). In this sense, organic matter addition in an equilibrated system will promote changes in the charge balance due to direct and indirect factors. Organic acids adsorption by mineral colloids will cause an increase in negative charges of the system and, therefore, decrease the point of zero charge (PZC) (Oades 1984). On the other hand, organic matter addition can promote changes in soil pH, favoring the manifestation of variable charges. Negative charge generation by dissociation of type -COOH groups present in organic matter and the coating of positive charges from oxides favor deprotonated sites predominance (Canellas et al. 2008).

Regarding flocculation degree, PS100 treatment, in 2015, presented the highest value in the 0-5 cm layer (Fig. 3A), while in the 5-10 cm layer, there was no differences between treatments (Fig. 3B); and in the 10-20 cm layer, the lowest flocculation degree was observed in Control treatment (Fig. 3C). In 2016, in the 0-5 cm layer, the highest flocculation degree value was observed for SMC+MF treatment (Fig. 3A), in the 5-10 cm layer, the highest values were observed in MF, PS+MF and PS100 treatments (Fig. 3B), while in the 10-20 cm layer, the highest value was in MF treatment (Fig. 3C). Comparing flocculation degree between evaluation epochs, in general, the highest values were observed in 2015, with a decrease in flocculation degree between evaluated treatments from 2015 to 2016, except for SMC+MF treatments, in the 0-5 layer cm, and Control, 10-20 cm, which remained constant (Fig. 3).

Results obtained for flocculation degree indicate that, at the end of two evaluation periods (2015 and 2016), there is a tendency of increasing the clay dispersed in water in relation to total clay. This effect can be caused by negative charges increase, which can be generated after swine manures application to soil surface. As this manure infiltrates in soil, a change occurs in the net load along soil profile, generating a balance of negative charges. With this, repulsion occurs between clay and added organic matter, leading to greater clay dispersion in water. Similar results were found by Benites and Mendonça (1998), who observed an increase effect on the net negative charge after manure addition to the soil originally with net positive charge. With the addition of higher doses of manure, they observed a dispersive effect caused by the negative balance of charges.

For TOC contents in aggregates, in the 2015 evaluation, there was difference only between treatments in the 0-5 cm layer, where the lowest levels were observed for Control treatment (Fig. 4A-C). In the 2016 evaluation, the highest TOC values were observed for SMC+MF and PS+MF treatments, in the 0-5 and 10-20 cm layers, while in the 5-10 cm layer, there was no difference between treatments (Fig. 4A-C). Similar to that observed for TOC levels, TN contents in aggregates in the 2015 evaluation only showed differences between treatments in the 0-5 cm layer, where the highest levels were observed in for MF, SMC+MF and PS+MF treatments (Fig. 4D-F). In the 2016 evaluation, only differences in the 5-10 cm layer were observed, with MF, SMC+MF, PS+MF and PS100 treatments presenting the highest values compared to Control (Fig. 4D-F). When comparing the two evaluation epochs, TOC and TN contents in aggregates presented increases, in most treatments and depths, from 2015 to 2016 (Fig. 4).

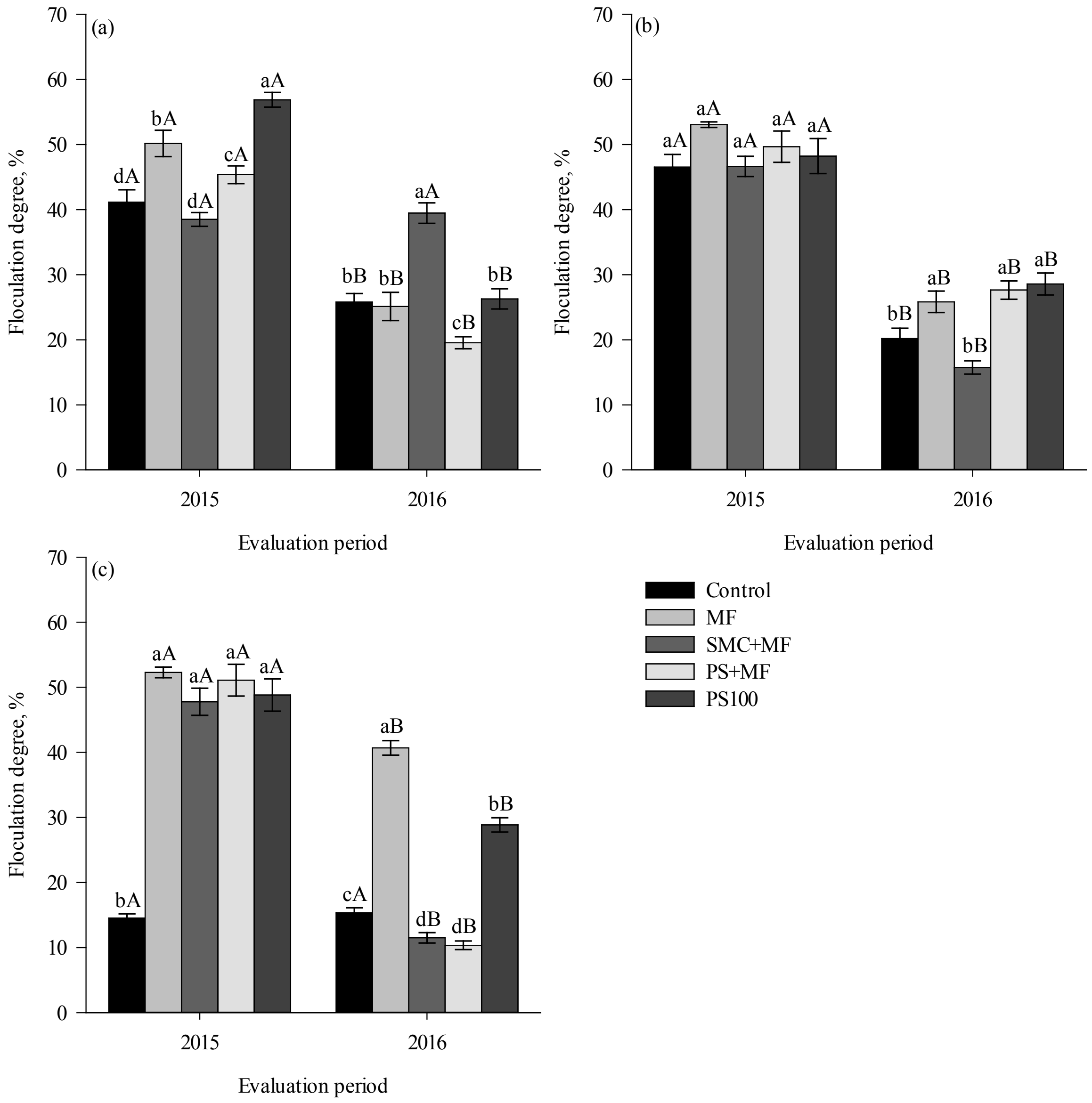

Fig. 3 Flocculation degree in the 0-5 (a), 5-10 (b) and 10-20 cm (c) depth layers in soil submitted to different fertilizer sources in Braço do Norte, SC

Mean values followed by the same lower cases letter, between treatments, do not differ from each other by the 5% Skott-knott Test. Capital cases letters between evaluation times do not differ from each other by the LDS Test at 5% probability

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for corn and oats respectively

The higher TOC content in aggregates observed in superficial layer (0-5 cm), compared to other layers, in all treatments, demonstrates a pattern in which there is a combined effect of vegetal residues addition (Table 3) on soil surface and swine manure application without incorporation (Table 1). In this sense, Comin et al. (2013) evaluated the effect of continuous application of pig slurry and deep litter on TOC levels and soil physical properties. These authors observed an increase in TOC in soil superficial layers in the treatment with deep litter application, justifying the results by the combined effect of vegetal residues addition on soil surface through crops and swine manure application (with high C/N) without incorporation to the soil, which favors the smaller SOM decomposition (Giacomini and Aita 2008). In addition, soil aggregation favors the physi-

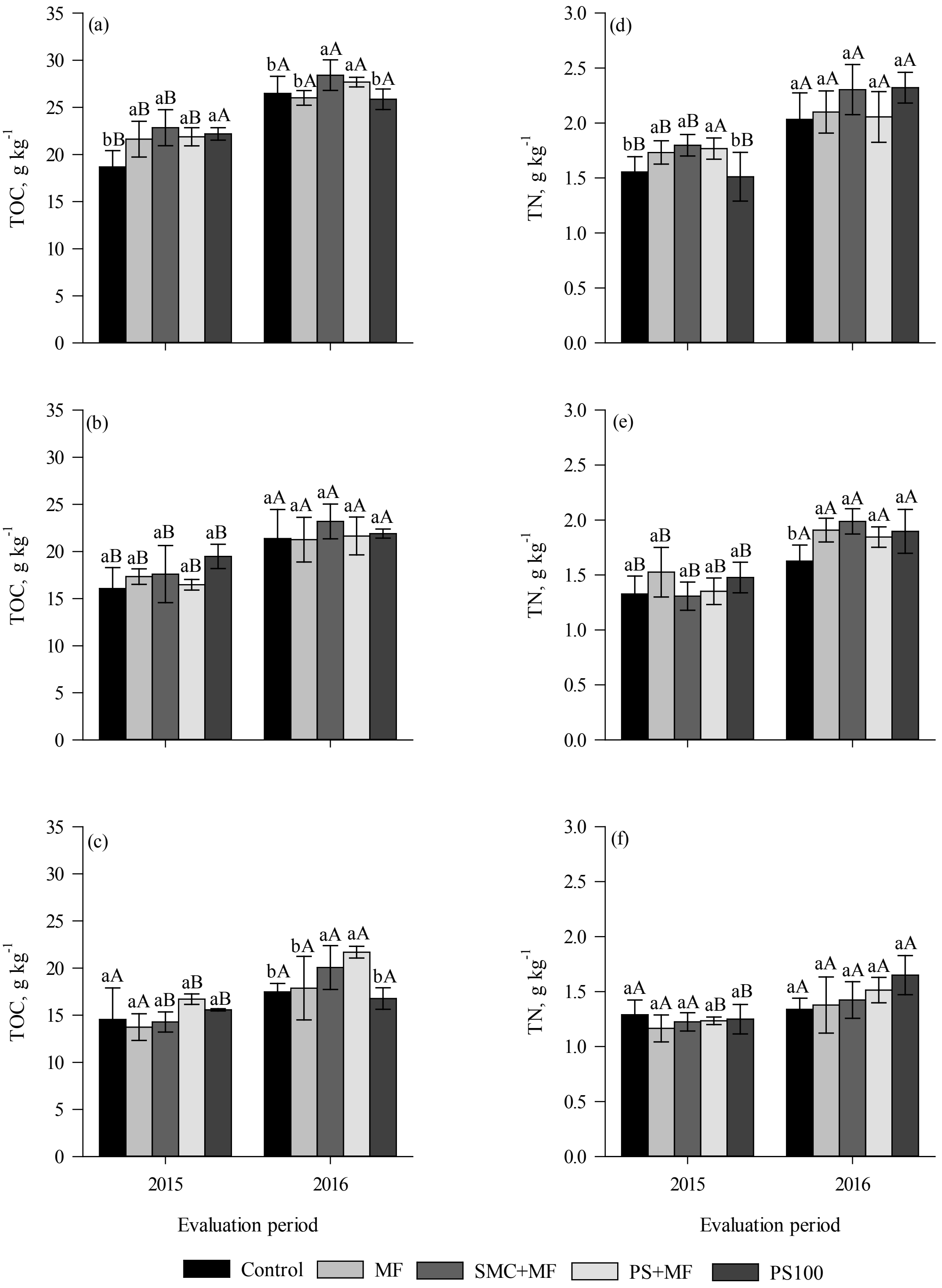

Fig. 4 TOC and TN contents in soil aggregates in the 0-5 cm (a, d), 5-10 cm (b, e), and 10-20 cm (c, f) depth layers, respectively, in soil subjected to different fertilizer sources in the municipality Braço do Norte, SC

Mean values followed by the same lower cases letter, between treatments, do not differ from each other by the 5% Skott-knott Test. Capital cases letters between evaluation times do not differ from each other by the LDS Test at 5% probability

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively cal-chemical protection mechanisms on SOM. Physical protection via SOM occlusion by soil aggregates makes it difficult for microorganisms and their enzymes to act on the organic substrate, acting as a physical barrier and decreasing O_2 availability for oxidative processes of decomposition (Baldock et al. 1992; Balesdent et al. 2000).

Similar to TOC, the highest TN contents found in the superficial layer (0-5 cm) of all treatments, demonstrates a pattern in which there is a combined effect of vegetal residues addition on soil surface and swine manure application without incorporation. The use of MF with urea increased the N content in the 0-5 cm depth, but when mineral N was applied with swine manure (SMC+MF and PS+MF), it was observed a higher efficiency in TN content increase compared to exclusive PS100 use and Control. These results can be explained by the higher crops dry matter content in treatments with wastes (Mafra et al. 2014) (Table 2), as well as the minimum soil turnover, which provided an increase in SOM levels, as observed by Lourenzi et al. (2011). This is due to the fact that TN content has a close relationship TOC content (Baldi et al. 2010). These authors, studying different nutrients sources along eight years, observed that the increase in TOC promoted TN increase, with a 94% correlation. In addition, phytomass production increase in soils with minimal tillage (Sartor et al. 2012; Mafra et al. 2014), in which wastes are used in crop fertilization, may promote the increment of SOM fractions in medium and long term (Mafra et al. 2015), with emphasis on TOC and TN levels (Lourenzi et al. 2013).

These results show the importance of maintaining the soil well structured, since systems with soil tillage, which recommend plows and grids use in soil preparation, are responsible for TOC and TN losses, especially C and N that were protected in soil aggregates (Boddey et al. 2010; Costa Junior et al. 2011a, b). On the other hand, conservationist management systems, with the minimum soil turnover, associated to the maintenance of cultural residues on soil surface, contribute to soil aggregation improvement and, consequently, to soil organic matter increase, being more efficient when associated to cover crops use, either by crops rotation or succession (Costa Junior et al. 2011a, b; Loss et al. 2012; Gennaro et al. 2014) .

Studying C dynamics in soil aggregates, in soil managed with conventional tillage system (CTS) and in no-tillage system (NTS), Tivet et al. (2013) demonstrated that the conversion of native vegetation areas to CTS-managed agricultural areas, with plowing and harvesting, disrupts aggregate formation processes and promotes mineral particles dispersion (clay + silt), thus reducing new aggregates formation. However, NTS with intense aerial and radicular biomass accumulation contributes to the stimulation to the formation of new aggregates after their implantation in areas previously submitted to soil CTS. Thus, soil aggregation has an important role in SOM protection, and its increase is mainly determined by the link between macroaggregates recycling, microaggregates formation and carbon stabilization within microaggregates (Six et al. 2000). For aggregates formation and subsequent stabilization, the main agents are soil fauna, soil microorganisms, roots, inorganic agents and environmental variables (Six et al. 2004; Rillig and Mummey 2006).

Regarding soil BD, no effect of treatments was observed in any of the evaluated years (Table 5). Results obtained for BD indicate that experiment conduction time (4 years) was not enough to evidence the effects of swine manure use on this parameter, as also observed by Oliveira et al. (2015) which did not observe alterations in physical parameters evaluated (bulk density, total porosity, macroporosity, macro and microporosity, and penetration resistance), in the different management systems evaluated.

In an experiment in the same city where this experiment was conducted, with similar soil, climate and temperature conditions, when evaluating the use of different doses of pig slurry (PS) and pig deep litter (PL), Comin et al. (2013) found only showed differences in the PL treatment with 8 years of experimentation. In addition, the values found by Comin et al. (2013) were very similar to those in this study, ranging from 1.10 to 1.20 g cm^{-3}.

Conclusion

Continuous swine manure application during four years, in association or not with mineral fertilizers, increases TOC and TN contents in soil aggregates. When comparing TOC contents in the 0-10 cm layer with those verified at the beginning of the experiment, it is observed that the use of swine manure associated with plant residues (maize + black oat) in the minimum tillage system increased the TOC content of the soil, in the proportion of 67.02% in the SMC+MF, 59.64% in PS+MF and 54.56% in PS100 treatments. For TN contents the increase was in the proportion of 125.87%

Table 5 Bulk density in the soil profile submitted to different fertilizer sources in the municipality of Braço do Norte, SC, Brazil, during the evaluation period (2015 and 2016)

Treatments	Bulk density, g cm^{-3}								
	0-5 cm		CV (%)	5-10 cm		CV (%)	10-20 cm		CV (%)
	2015	2016		2015	2016		2015	2016	
Control	1.21 ^{ns}A	1.27 ^{ns}A	6.12	1.20 ^{ns} A	1.21 ^{ns}A	3.44	1.20 ^{nsA}	1.21 ^{ns}A	4.38
MF	1.22 A	1.23 A	3.04	1.20 A	1.22 A	2.89	1.20 A	1.20 A	1.86
SMC+MF	1.19 A	1.23 A	2.19	1.18 A	1.22 A	3.28	1.19 A	1.20 A	4.65
PS+MF	1.19 A	1.23 A	3.63	1.20 A	1.25 A	3.41	1.18 A	1.24 A	3.51
PS100	1.24 A	1.23 A	1.55	1.19 A	1.21 A	2.76	1.18 A	1.20 A	4.03
CV (%)	4.31	2.96		3.10	3.24		3.21	4.32	

MF = Mineral fertilization; SMC+MF = swine manure compost + MF; pig slurry + MF; and PS100 = pig slurry according to recommendation to supply 100 and 30 kg ha^{-1} N dose for maize and black oat, respectively. CV = Coefficient of variation. Averages followed by the same lower case letter in the column do not differ from each other by the 5% Skott-knott Test. Averages followed by the same capital letters in the line, between evaluation times, do not differ from each other by the LDS Test at 5% probability. ns = not significant.

in the SMC+MF, 105.26% in PS+MF and 122.00% in PS100, for soil aggregates.

However, this increase was not efficient in improving soil physical attributes, reducing the aggregation index (MWD and MGD), especially in the 5-10 cm depth layer, in addition to reducing macroaggregates proportion, and consequently increasing soil microaggregates. From 2015 to 2016, it was possible to observe a reduction in the MWD in the proportion of 22,47% in SMC+MF, 16,08% in PS+100 and 19,41% in PS100 treatments. For MGD, this reduction was observed in the proportion of 39,03% in SMC+MF, 28,66% in PS+100 and 31,25% in PS100 treatments.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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