Comissão 3.5 - Poluição, remediação do solo e recuperação de áreas degradadas

CHANGES IN SOIL ACIDITY AND ORGANIC CARBON IN A SANDY TYPIC HAPLUDALF AFTER MEDIUM-TERM PIG-SLURRY AND DEEP-LITTER APPLICATION[1]

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SUMMARY

Successive applications of liquid swine waste to the soil can increase the contents of total organic carbon and nutrients and change acidity-related soil chemical properties. However, little information is available on the effects of swine waste application in solid form, as of swine deep-litter. The objective of this study was to evaluate alterations of organic carbon and acidity-related properties of a soil after eight years of pig slurry and deep-litter application. In the eighth year of a field experiment established in Braço do Norte, Santa Catarina (SC) on a sandy Typic Hapludalf samples were taken (layers 0-2.5; 2.5-5; 5-10; 10-15; 15-20 and 20-30 cm) from unfertilized plots and plots with pig slurry or deep-litter applications, providing the simple or double rate of N requirement of *Zea mays* and *Avena strigosa* in rotation. Soil total organic carbon, water pH, exchangeable Al, Ca and

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Mg, and cation exchange capacity ($CEC_{effective}$ and $CEC_{pH7.0}$), H+Al, base saturation, and aluminum saturation were measured. The application of pig slurry and deep-litter for eight years increased total organic carbon and CEC in all soil layers. The pig slurry and deep-litter applications reduced active acidity and aluminum saturation and increased base saturation down to a depth of 30 cm. Eight years of pig slurry application did not affect soil acidity.

Index terms: manure, water pH, base saturation, aluminum saturation, no tillage.

RESUMO: *ALTERAÇÕES NA ACIDEZ DO SOLO E NO CARBONO ORGÂNICO EM UM ARGISSOLO COM HISTÓRICO DE APLICAÇÃO DE DEJETOS LÍQUIDOS DE SUÍNOS E CAMA SOBREPOSTA*

As aplicações sucessivas de dejetos de suínos, na forma líquida, podem incrementar os teores de carbono orgânico total no solo e de nutrientes, bem como alterar os atributos relacionados à acidez do solo, porém há pouca informação acerca do efeito do uso de cama sobreposta de suínos sobre os atributos da acidez do solo e o carbono orgânico. Este trabalho objetivou avaliar a alteração nos teores de carbono orgânico e nos atributos relacionados à acidez em um solo com histórico de aplicação de dejetos líquidos de suínos e cama sobreposta. Após oito anos da instalação de um experimento localizado no município de Braço do Norte, Santa Catarina (SC), sobre um Argissolo Vermelho, foram coletadas amostras de solo nas camadas de 0-2,5, 2,5-5, 5-10, 10-15, 15-20 e 20-30 cm, em tratamentos sem aplicação de dejeto e com a aplicação de dejetos líquidos de suínos e de cama sobreposta de suínos em duas doses: para suprir uma e duas vezes a necessidade de N para a sucessão milho e aveia-preta. O solo foi seco, moído, passado em peneira e submetido à análise de carbono orgânico total, pH em água, Al, Ca e Mg trocáveis; com base nos dados obtidos, calcularam-se a capacidade de troca de cátions efetiva ($CTC_{efetiva}$) e a pH 7.0 ($CTC_{pH7,0}$), H+Al e a saturação por bases e Al. Os resultados mostram que as aplicações de dejetos líquidos de suínos e cama sobreposta durante oito anos aumentaram o teor de COT e a CTC no solo até a profundidade de 30 cm. A aplicação de cama sobreposta de suínos diminuiu os valores de acidez ativa e de saturação por Al e aumentou os valores de saturação por bases até 30 cm de profundidade. O uso de dejetos líquidos por oito anos não provocou nem acidificação nem correção da acidez do solo, indicando que o efeito desse resíduo nos atributos da acidez do solo foi pequeno ou nulo.

Termos de indexação: esterco, pH em água, saturação por bases, saturação por alumínio, sistema plantio direto.

INTRODUCTION

Pig slurry, resulting from washing pens with water, and deep-litter manure, generated when animals are raised on a bedding layer of organic material, usually consisting of wood shavings or straw, are used as nutrient sources in different crop management systems, including in no-tillage. The amount to be applied is determined based on the dry matter percentage, the nutrient concentration and efficiency rate of the manure; the latter is related to the total nutrient amount contained in the manure that can be transformed from organic to mineral form after soil application (CQFSRS/SC, 2004). However, since the volume of manure produced on swine farms is usually great and crop fields are small, farmers frequently repeat applications of swine fertilizer on the same areas. Thus, nutrient contents in the soil are expected to increase over the years (Mcdowell et al., 2001; Basso et al., 2005; Gatiboni et al., 2008; Ceretta et al., 2010a,b; Girotto et al., 2010). The chemical properties related to soil acidity are also expected to change, e.g., with increases in soil pH and base saturation, as well as a decrease in aluminum saturation (Ceretta et al., 2003; Lourenzi et al., 2011). Although there is abundant literature on the effects of pig slurry, no information was found about the effects of swine deep-litter on soil acidity parameters.

In no-tillage systems, swine waste is applied in liquid or solid form on the crop residues lying on the soil surface. Therefore a small soil contact area is expected, with a consequent delay in the microbial biomass activity, which may stimulate total organic carbon (TOC) accumulation (Ceretta et al., 2003; Adeli et al., 2008; Lourenzi et al., 2011), particularly in the surface layers. However, increases in TOC contents are mainly associated to the manure composition, application frequency and amount (Falleiro et al., 2003; Lourenzi et al., 2011). These changes can increase the soil cation exchange capacity (CEC)

(Scherer et al., 2007). Moreover, manure can increase exchangeable aluminum adsorption, especially in the fractions of humic and fulvic acids of the organic matter (Ceretta et al., 2003), reducing the toxicity to plant roots and increasing H^+ adsorption (Hue & Licudine, 1999; Lourenzi et al., 2011). These changes may also be associated to an increase in soil water pH. The reduction of acidity by manure can also be incremented by the dissociation of $CaCO_3$, which is usually found in animal excreta (Whalen et al., 2000). As a result of these changes, an increase in the soil effective CEC ($CEC_{effective}$) is also to be expected.

Aside from other nutrients, swine manure contains calcium (Ca) and magnesium (Mg), originating especially from feed consumed by the animals and not absorbed by the digestive tract. Thus, in soils treated with pig slurry for some time, an increase of exchangeable contents of Ca and Mg is expected over the years in the soil profile (Ceretta et al., 2003; Assmann et al., 2007). This may be due to the migration of ions, as those linked to water-soluble organic substances, such as those originating from root senescence (Miyazawa et al. 1993; Oliveira & Pavan 1996; Franchini et al., 1999, 2000, 2001; Kaminski et al., 2005). Thus, it is believed that the sum of base cations increases along the soil profile, leading to an increase in $CEC_{effective}$, increasing base saturation, decreasing aluminum saturation, and resulting in soil chemical conditions that are more favorable for plant growth and development.

A significant amount of research evidences the improvement in soil properties after pig slurry application, but no information is available on the effect of swine manure applied in solid form, as deep-litter. The objective of this study was to evaluate alterations of acidity-related soil properties in a Sandy Typic Hapludalf fertilized with pig slurry and deep-litter for eight years.

MATERIALS AND METHODS

Site description and treatments

The experiment was established on a pig farm located in the municipality of Braço do Norte, in the South of Santa Catarina (SC), Southern region of Brazil (latitude 28º 14' 20.7"; longitude 49º 13' 55.5"; 300 m asl). The climate in the region is humid sub-tropical (Cfa), with annual averages of 18.7 ºC and 1,471 mm rainfall. The soil studied was a sandy Typic Hapludalf (Soil Survey Staff, 1999). Prior to the experiment, the soil properties (0-10 cm layer) in the area were as follows: water pH = 5.1; clay = 330 g kg^{-1}; organic matter = 33.0 g kg^{-1}; exchangeable, in $cmol_c$ dm^{-3}: Al = 0.8; and Mg = 0.8; Ca = 3.0; available P (19 mg dm^{-3}) and K (130 mg dm^{-3}) extracted by Mehlich-1.

In December 2002, in a Natural Field area with predominantly *Paspalum notatum, P. plicatulum, Eryngium ciliatum,* and *Stylosanthes montevidensis*, after sporadic spreading of pig slurry on the soil surface, 6 Mg ha^{-1} limestone (PRNT = 87.5 %) was surface-applied, without incorporation, to raise the water pH to 6.0 (CFSRS/SC, 1994). In January 2003, the pasture was desiccated and five treatments were installed: control (C); annual pig slurry fertilization at rates of 90 and 180 kg N ha^{-1} (PS90 and PS180) and annual fertilization with deep-litter at rates of 90 and 180 kg N ha^{-1} (DL90 and DL180). The recommended nutrient quantity in pig slurry and deep litter is 90 kg N ha^{-1} $year^{-1}$ for no-tillage successions of *Zea mays - Avena strigosa*, according to the Commission of Soil Fertility (CFSRS/SC, 1994) and the Commission of Chemistry and Soil Fertility of Rio Grande do Sul and Santa Catarina (CQFSRS/SC, 2004). To calculate the manure doses, the total N content of each manure type was used and no residual effect of these materials on N availability in the second year was taken into consideration. The composition, rate and amounts of K, Ca and Mg applied in the experiment are shown in table 1. Aside from the pig waste, no other nutrient source was provided over the years. The experiment was arranged in a randomized block design with three replicates on experimental plots of 27 m^2 (4.5 x 6.0 m).

Pig slurry was fertilized 32 times from 2002 to 2010 (four applications per year during the growing seasons of *Zea mays* and *Avena strigosa*). The waste was spread on the soil surface four times per year: before corn sowing, 51 and 95 days after corn sowing and 15 days after black oat sowing. In the same period (2002-2010), deep-litter was spread on the soil surface eight times, once a year, between 15 and 30 days before corn sowing.

Soil collection and analysis of soil chemical properties related to acidity

In March 2010, a trench (40 x 40 x 40 cm) was opened in the center of each experimental unit and soil samples were collected (layers 0-2.5, 2.5-5, 5-10, 10-15, 15-20, and 20-30 cm). The samples were air dried, sieved through a 2-mm mesh, ground in a mortar, sieved through a 1-mm mesh and stored for analysis.

The particle size distribution of soil constituents was determined by the Pipette Method (Embrapa, 1997). The soil pH was measured in water (1:1 soil:solution ratio), exchangeable Ca, Mg and Al were extracted by 1.0 mol L^{-1} KCl, in which Ca and Mg were quantified by atomic absorption spectrometry and exchangeable Al was determined by base titration. Organic carbon content was determined by sulfocromic wet digestion, according to the method proposed by Tedesco et al. (1995). The pH-SMP value was used to estimate H+Al by the equation proposed by Kaminski et al. (2001) and adopted by CQFSRS/SC (2004): $H+Al = [(e^{10.665-1.1483SMP})/10]$. The effective cation exchange capacity ($CEC_{effective}$), cation exchange capacity at pH 7.0 ($CEC_{pH\ 7.0}$), base $CEC_{pH7.0}$

saturation and $CEC_{effective}$ aluminum saturation were computed by equations proposed by CQFSRS/SC (2004).

Statistical treatment of the data

Total organic carbon content, water pH, contents of exchangeable Al, Ca and Mg, $CEC_{effective}$, $CEC_{pH7.0}$, base $CEC_{pH7.0}$ saturation, $CEC_{effective}$ aluminum saturation and H+Al in different layers and treatments were subjected to analysis of variance ($p < 0.05$); soil depth data were analyzed as a split-plot using SAS 9.1.3 (SAS, 2003). As the interaction between treatments and soil layers was significant for all studied parameters, the averages in different layers in the same treatment and in the same layer among treatments were compared by the Tukey test ($p < 0.05$).

RESULTS AND DISCUSSION

Changes in total organic carbon

The contents of total organic carbon (TOC) in the soil of the control and the pig slurry (PS90 and PS180) as well as deep-litter (DL90 and DL 180) treatments were highest in the top soil layer (0-2.5 cm) and decreased in the deeper layers (Table 2). This may be due to the shoot dry matter yield of black oats over eight years, which accumulated a total of 64, 76, 84, 86 and 81 Mg ha^{-1}, in the treatments control, PS90, PS180, DL90 and DL180, respectively. Corn residues left on the soil surface after grain harvest must also be considered since a lower decomposition rate can stimulate TOC accumulation in no-till soils (Falleiro et al., 2003; Jantalia et al., 2007; Leite et al., 2010). The greatest TOC contents were found to a depth of 30 cm in PS180, DL90 and DL180, which exceeded the contents in the soil with no manure application and of treatment PS90, which did not differ from each other. The highest TOC contents, particularly in the treatments PS180, DL90 and DL180, may be caused by the high crop biomass production and also by the application of pig waste to the soil surface. Also, assuming that the mean TOC content in dry matter of pig slurry and deep-litter over the years was 6.75 and 23% (data not shown), respectively, and considering 32 applications of pig slurry and 8 applications of deep-litter, the total amount of TOC input was 34, 54 and 68 Mg ha^{-1}, in the treatments PS180, DL90 and DL180, respectively. It should be mentioned that the TOC increase in the soil profile in PS180, DL90 and DL180 may be due to a possible saturation of functional groups of relative particles in the soil surface by organic compounds, especially because the soil texture is sandy and/or to the cover of soil aggregates by organic particles; these processes could stimulate the migration of organic particles along the soil profile. Similar results were found by Lourenzi et al. (2011), who found an increment in TOC to 60 cm deep in the same sandy Typic Hapludalf of this study, after pig slurry applications of 0, 20, 40 and 80 m^3 ha^{-1} $year^{-1}$, for eight years.

Changes in soil acidity properties

The values of water pH were > 5.5 in all treatments, to a depth of 15 cm, and therefore, values of exchangeable Al were equal to zero, since above this value, monomeric Al no longer exists (Table 2), but is transformed into Al hydroxyl forms. The highest water pH to a depth of 15 cm in all treatments can be explained partially by the surface liming prior to the experiment. However, in all layers, the soil water pH was highest in treatment DL 180, showing that this material raises the soil pH. Animal manure, as for example swine deep-litter, which is solid and has a greater percentage of dry matter than pig slurry (Table 1), is likely to have greater contents of carbonate, promoting the consumption of H^+ after being dissolved in the soil, which is reflected in an increase of water pH (Whalen et al., 2000; Anami et al., 2008). In addition, the increase in water pH may be associated to the increase in the content of TOC in the soil to a depth of 30 cm, which stimulates H^+ adsorption, therefore raising the water pH (Hue & Licudine, 1999; Lourenzi et al., 2011). Similar results were reported by Lourenzi et al. (2011), who found increased water pH to a depth of 8 cm, under different pig slurry applications (0, 20, 40 and 80 m^3 ha^{-1}), for eight years in a no-till soil.

The highest exchangeable Ca concentrations in the soil with manure application or in the control treatment were found in the 0-2.5 cm layer, due to the liming prior to the experiment. Higher exchangeable Ca in PS90, PS180 and DL90 was found to a depth of 5 cm, but down to 10 cm in the soil in treatment DL180 (Table 2). However, the highest exchangeable Ca concentrations to a depth of 30 cm were found in treatment DL180. On the other hand, the highest exchangeable Mg concentrations were recorded in the 0-2.5 cm layer of soil with no manure application and in treatment PS90, but to a depth of 5 cm in the treatments PS180 and DL90, and to a depth of 10 cm in treatment DL 180 (Table 2). The exchangeable Mg concentrations to a depth of 20 cm were equal among treatments, except for treatment DL 180. The highest exchangeable Ca concentrations in treatment DL 180 may be due to the higher application of the nutrient over the years, because the total accumulation of Ca applied was 549, 1,099, 2,579 and 5,159 kg ha^{-1}, in PS90, PS180, DL90, DL180, respectively (Table 1). This may be one of the possible explanations for the increase in the exchangeable Mg concentrations to a depth of 30 cm in treatment DL180, since the accumulated amount of Mg applied over the years was 1,366 kg ha^{-1}, more than the amounts applied in PS90, PS180, DL90, which were 210, 420 and 683 kg ha^{-1}, respectively (Table 1). It is important to highlight that the increase of exchangeable Ca in the soil treated with manure, especially of deep-litter (DL 180), may be due to the migration of Ca ions in deeper layers through biopores (Kaminski et al., 2005; Lourenzi et al., 2011). However, water-soluble organic substances, especially in cultivation systems with crop residues left on the soil surface, as in no-tillage, may also intensify Ca migration to deeper soil layers (Miyazawa et al., 1993; Oliveira & Pavan, 1996; Franchini et al., 1999, 2000, 2001; Kaminski et al., 2005). In other studies with application of pig waste, for example slurry, an increase in exchangeable Ca concentrations was observed in the deeper soil layers, e.g., in Ceretta et al. (2003), where an increment in Ca was detected to a depth of 5 cm. Likewise, Lourenzi et al. (2011) reported an increase in Ca content to a depth of 16 cm in a sandy Typic Hapludalf.

Table 1. Characteristics of pig slurry (PS) and deep-litter (DL) applied for eight years at annual rates of 90 kg N ha^{-1} (PS90 and DL90) and 180 kg N ha^{-1} (PS180 and DL180)

Source	Year	Dry matter	Application rate	Nutrient input		
				Ca	Mg	K
		%	m^3 ha^{-1}	kg ha^{-1}		
PS90	2003	2.94	20.0	21	8	25
	2004	3.00	24.4	25	10	30
	2005	1.63	78.5	80	31	74
	2006	2.54	59.5	61	23	68
	2007	2.32	63.3	65	25	69
	2008	2.10	67.0	68	26	70
	2009	0.20	176.0	180	69	101
	2010	3.28	49.5	50	19	65
		Total		549	210	502
PS180	2003	2.94	40.6	41	16	50
	2004	3.00	48.8	50	19	61
	2005	1.63	157.0	160	61	147
	2006	2.54	119.0	121	46	136
	2007	2.32	126.6	129	49	138
	2008	2.10	134.0	137	52	140
	2009	0.20	352.0	359	137	202
	2010	3.28	99.0	101	39	130
		Total		1,099	420	1,003
			Mg ha^{-1}			
DL90	2003	69.20	13.0	306	81	232
	2004	38.10	44.1	571	151	238
	2005	43.80	20.9	311	82	149
	2006	41.10	23.7	331	88	149
	2007	39.00	25.6	339	90	145
	2008	61.00	10.7	222	59	146
	2009	69.90	8.1	193	51	148
	2010	45.00	20.0	306	81	149
		Total		2,579	683	1,358
DL180	2003	69.20	26.0	612	162	465
	2004	38.10	88.2	1,143	302	476
	2005	43.80	41.8	622	165	299
	2006	41.10	47.4	662	175	299
	2007	39.00	51.2	679	180	291
	2008	61.00	21.4	444	117	292
	2009	69.90	16.2	385	102	296
	2010	45.00	40.0	612	162	299
		Total		5,159	1,366	2,716

The greatest values of effective cation exchange capacity were found in the soil surface layers (0-2.5 and 2.5-5 cm) (Table 3) in all treatments. Moreover, the highest values of effective cation exchange capacity were found to a depth of 30 cm in the treatment DL 180 (Table 2). However, the greatest values of H+Al were found in the deepest layer (20-30 cm) in all treatments, which can be associated to the highest concentration of H^+, reflected in the lowest values of water pH and also in the greatest exchangeable Al concentrations (Table 2). On the other hand, the $CEC_{pH7.0}$ was highest in the surface layers (0-2.5 and 2.5-5 cm) in the deep-litter treatments (DL90 and DL180) (Table 3). However, the $CEC_{pH7.0}$ was highest in treatment DL180 in all layers. This is probably associated to the highest TOC (Table 2), which agrees with results of Scherer et al. (2007), who tested the application of increasing doses of pig slurry to an Oxisol in two experiments in the western region of Santa Catarina. Higher values of $CEC_{pH7.0}$ in the soil can result in a greater adsorption of cations, e.g., of exchangeable Ca and Mg.

Base saturation was highest in the surface layers (0-2.5 and 2.5-5 cm) in all treatments (Table 3), which is associated, particularly in the 0-2.5 cm layer, to the higher TOC contents, which potentiates cation adsorption, as for example Ca and Mg, applied to the soil in the manure (Table 2). However, base saturation was highest to a depth of 30 cm in treatment DL 180, which can be attributed to the highest TOC contents in this treatment (Table 2). The values of base saturation in the layers 10-15 cm and 15-20 cm of treatment DL 90 were higher than in the soil with and without pig slurry application. The increase in base saturation in the deeper layers agrees with the data obtained by Lourenzi et al. (2011), who found increases in base saturation in soil treated with pig slurry to 12 cm deep, also in a sandy Typic Hapludalf. It is however worth mentioning that base saturation was greater than 65 % to a depth of 15 cm in treatment DL90 and to 30 cm in DL180. The base saturation of 65 % was associated with a water pH of 5.5 (CQFSRS/SC, 2004).

The Al saturation was zero to a depth of 15 cm in soil of the treatments control, PS90, PS180 and DL90 (Table 3). Nevertheless, in the soil of treatment DL 180, Al saturation was zero to a depth of 30 cm, which is associated to the greatest values of water pH, causing Al complexation by OH^- when above 5.5. This is reflected in the saturation values, but also in the greater content of organic carbon in the soil (Table 2),

Table 2. Total organic carbon, water pH, exchangeable aluminum, calcium and magnesium in soil layers subjected to applications of pig slurry (PS) and deep-litter (DL) for eight years at annual rates of 90 kg N ha^{-1} (PS90 and DL90) and 180 kg N ha^{-1} (PS180 and DL180)

Layer	Control	PS90	PS180	DL90	DL180	CV
cm			Total organic carbon, g kg^{-1}			%
0-2.5	33.23 aB[1]	34.67 aB	40.65 aA	43.55 aA	53.90 aA	4.63
2.5-5	22.15 bB	24.37 bB	29.47 bA	31.95 bA	46.60 bA	3.39
5-10	19.20 cB	18.53 cB	21.30 cA	25.67 cA	27.00 cA	4.29
10-15	15.02 cB	15.27 dB	16.60 dA	15.53 dA	15.40 dA	5.44
15-20	12.10 dB	13.20 dB	14.70 dA	13.73 dA	13.47 dA	6.40
20-30	8.54 eB	10.90 eB	11.80 eA	11.50 eA	12.50 eA	5.15
CV %	3.67	3.42	4.33	5.22	5.75	
			Water pH			
0-2.5	6.57 aA	6.28 aA	5.89 aA	6.31 aA	6.45 aA	5.01
2.5-5	6.47 aA	6.28 aA	5.80 aA	6.28 aA	6.44 aA	2.63
5-10	6.15 bA	6.19 aA	5.73 aA	6.26 aA	6.40 aA	2.51
10-15	5.79 cB	5.89 aB	5.69 aB	6.14 aA	6.35 aA	3.31
15-20	5.31 dB	5.06 bB	5.12 bB	5.65 aB	6.34 aA	2.14
20-30	4.94 dB	5.09 bB	4.84 bB	5.33 bB	5.88 bA	3.15
CV %	1.08	3.78	5.62	3.90	1.32	
			Exchangeable aluminum, cmol$_c$ dm^{-3}			
0-2.5	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
2.5-5	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
5-10	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
10-15	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
15-20	0.53 aA	0.40 aA	0.33 aA	0.00 bB	0.00 aB	19.01
20-30	0.40 aA	0.43 aA	0.60 aA	0.70 aA	0.00 aB	24.10
CV %	12.47	16.40	12.72	0.00	0.00	
			Exchangeable calcium, cmol$_c$ dm^{-3}			
0-2.5	8.17 aC	9.19 aC	7.44 aC	12.22 aB	14.60 aA	6.66
2.5-5	6.83 bB	7.81 aB	8.09 aA	11.02 aA	13.83 aA	22.06
5-10	5.24 bC	4.53 bC	3.48 bC	7.58 bB	11.57 aA	9.84
10-15	3.51 cB	3.27 bB	3.19 bB	4.63 cB	6.09 bA	12.27
15-20	2.55 dB	1.40 cB	1.86 cB	1.99 dB	6.95 bA	19.74
20-30	1.77 dB	1.23 cB	1.23 cB	1.70 dB	5.98 bA	19.63
CV %	14.64	13.46	9.35	9.57	20.30	
			Exchangeable magnesium, cmol$_c$ dm^{-3}			
0-2.5	4.35 aA	3.48 aA	3.04 aA	4.23 aA	5.67 aA	22.54
2.5-5	2.47 bA	2.23 bA	2.77 aA	3.73 aA	3.50 aA	26.32
5-10	1.28 bA	2.03 bA	0.86 bA	1.82 bA	2.45 aA	24.93
10-15	0.96 bA	0.95 bA	0.93 bA	1.42 bA	1.22 cA	24.52
15-20	0.73 bA	0.63 cA	1.30 bA	0.45 cA	1.74 cA	20.16
20-30	0.39 bB	0.35 cB	0.63 bB	0.12 cB	1.17 cA	18.34
CV %	17.38	18.29	19.48	13.86	12.95	

(1) Mean values with the same lower case letter in a column and the same capital letter in the soil layer column are not significantly different (Tukey test, $p<0.05$).

enabling Al adsorption, particularly to the fulvic and humic fraction (Ceretta et al., 2003). These authors also reported a reduction in Al saturation to a depth of 20 cm, in a typical sandy Typic Hapludalf with natural pasture and treated with 0, 20 and 40 m^{-3} ha^{-1} of liquid swine manure. Accordingly, Assmann

Table 3. Effective cation exchange capacity, potential acidity (H+Al), cation exchange capacity at pH 7.0, base saturation and aluminum saturation, in soil layers treated with pig slurry (PS) and deep-litter applications (DL) for eight years at annual rates of 90 kg N ha^{-1} (PS90 and DL90) and 180 kg N ha^{-1} (PS180 and DL180)

Layer	Control	PS90	PS180	DL90	DL180	CV
cm			Effective cation exchange capacity, cmolc dm^{-3}			%
0-2.5	13.67 aC	13.94 aC	12.18 aC	18.45 aB	22.96 aA	11.78
2.5-5	10.38 aB	10.89 aB	12.07 aB	16.31 aB	19.64 aA	19.09
5-10	7.37 bC	7.50 cC	4.92 bC	10.70 bB	15.53 bA	10.79
10-15	5.27 cB	5.01 dB	5.13 bB	7.27 bB	8.70 cA	13.57
15-20	3.89 cB	3.14 dB	3.72 bB	3.52 cB	9.87 cA	19.09
20-30	3.39 dB	2.65 dB	3.05 cB	3.22 cB	8.48 dA	14.29
CV %	18.44	11.95	8.69	12.79	15.66	
			H+Al, $cmol_c$ dm^{-3}			
0-2.5	2.53 bA	2.20 cA	2.79 cA	2.76 cA	2.33 bA	12.38
2.5-5	2.93 bA	2.24 cA	2.80 cA	2.83 cA	2.02 bA	12.57
5-10	2.08 bA	2.03 cA	2.90 cA	2.44 cA	2.31 bA	8.25
10-15	2.91 bB	2.20 cB	3.25 bA	2.61 bB	2.17 bB	3.86
15-20	3.15 aB	3.90 bB	4.16 bA	2.95 bB	2.10 bB	9.11
20-30	4.22 aB	4.26 aB	6.10 aA	3.37 aB	2.66 aC	7.59
CV %	9.53	4.37	11.82	4.37	4.07	
			Cation exchange capacity at pH 7.0, $cmol_c$ dm^{-3}			
0-2.5	16.20 aB	16.14 aB	14.97 aB	21.21 aB	25.29 aA	10.26
2.5-5	12.32 bB	13.13 bB	14.87 aB	19.14 aA	21.67 aA	16.45
5-10	9.45 bC	9.54 cC	7.82 bC	13.14 bB	17.84 bA	8.06
10-15	8.42 cB	7.21 cC	8.39 bB	9.88 bB	10.87 cA	9.11
15-20	6.81 cB	5.65 dB	7.54 bB	6.47 cB	12.03 cA	18.04
20-30	7.20 cB	6.48 dB	8.55 bB	5.89 dB	11.15 cA	8.09
CV %	13.49	9.06	5.42	9.69	13.38	
			Base saturation, %			
0-2.5	83.90 aB(1)	86.34 aB	81.33 aB	86.88 aB	90.73 aA	2.78
2.5-5	84.04 aB	82.89 aB	81.11 aB	85.12 aB	90.17 aA	2.88
5-10	77.90 bB	78.51 bB	62.82 bB	81.27 bB	87.04 bA	4.18
10-15	62.53 bC	69.34 cC	60.80 bC	73.32 bB	80.04 bA	5.33
15-20	57.12 bC	48.52 dC	44.81 cC	54.32 cB	81.08 bA	7.39
20-30	40.48 cB	34.14 eB	28.69 dB	42.77 dB	76.05 cA	12.12
CV %	7.81	3.57	6.64	2.87	2.86	
			Aluminum saturation, %			
0-2.5	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
2.5-5	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
5-10	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
10-15	0.00 bA	0.00 bA	0.00 bA	0.00 bA	0.00 aA	-
15-20	12.70 aA	12.83 aA	9.08 aA	0.00 bB	0.00 aB	19.00
20-30	13.2 aA	16.89 aA	19.52 aA	21.78 aA	0.00 aB	18.10
CV %	13.69	15.25	17.49	15.70	-	-

(1) Mean values with the same lower case letter in a column and same capital letter in the soil layer are not significantly different (Tukey test, p<0.05).

et al. (2007) reported a decrease in Al saturation in a pig slurry-treated Oxisol. This is in agreement with results of Lourenzi et al. (2011), who found reduced saturation values to a depth of 20 cm, in a pig slurry-treated soil (0, 20, 40 and 80 m^{-3} ha^{-1} $year^{-1}$). However, in the 15-20 cm layer of the treatments control and PS90, Al saturation exceeded 10 %, a value considered average by CQFSRS/SC (2004), and therefore with potential plant toxicity, which was repeated in the 20-30 cm layer in the same treatments, as well as in the others, except for DL180.

CONCLUSIONS

1. Application of deep-litter for eight years increased the TOC content and cation exchange capacity in soil down to a depth of 30 cm, whereas pig slurry had no effect on these properties.

2. Applications of pig slurry or swine deep-litter for eight years to a previously limed soil did not change active acidity, indicating a small or no effect of these residues on acidity-related traits.

3. Application of swine deep-litter reduced aluminum saturation and increased base saturation down to a depth of 30 cm while pig slurry only had this effect to a depth of 20 cm.

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