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Aggregation and clay dispersion of an oxisol treated with swine and poultry manures

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ABSTRACT

Fertilisation using animal manure can improve soil structure. However, the positive and negative effects of this practice remain inconclusive, and manure application can change the superficial electric potential, thereby increasing the dispersible clay content, disaggregation and susceptibility of soil to erosion and contamination of surface water. The objective of this study was to evaluate a water-dispersible clay and the aggregation of an oxisol over time with the application of different doses of swine and poultry manure. The experiment was conducted in a very clayey dystroferric red latosol, and the treatments consisted of the superficial application of 33 and 66 $m^3 ha^{-1}$ swine manure and 1920 and 3840 $kg ha^{-1}$ poultry manure for corn production. A treatment without fertiliser (mineral or organic) was used as a reference. Soil samples from 0.00 to 0.10 m layer were collected at 0, 15, 30 and 60 days after manure application to determine the soil aggregate classes, weighted mean diameter (WMD), aggregate stability index, dispersible clay content, pH_{H_2O} and pH_{KCl}. The ΔpH was also determined. The application of swine manure led to rapid and dynamic changes in the dispersible clay content as well as the aggregation process compared to the application of poultry manure. The effects of the application of 33 or 66 $m^3 ha^{-1}$ swine manure can be divided into three phases: (i) immediate increases in the pH_{H_2O} resulting in an increase in dispersible clay content and the mass of aggregates <0.250 mm immediately after the application of the manure at 0 days after application (DAA); (ii) a decrease in the pH_{H_2O} as well as flocculation and restructuring of the soil between 15 and 30 DAA; and (iii) a further increase in the mass of aggregates <0.250 mm between 30 and 60 DAA. In contrast to the swine manure applications, a cementation effect of organic carbon was observed in the poultry manure applications, and clay flocculation and soil aggregation occurred after the application of 1920 $kg ha^{-1}$ or 3840 $kg ha^{-1}$ poultry manure, thereby increasing the WMD at 15 DAA. However, the aggregation effect was ephemeral, and at 30 and 60 DAA, decreases in the WMD and aggregates >2.00 mm were observed independent of the doses of applied poultry manure.

1. Introduction

The growing demand for food of animal origin has prompted pig and poultry farming systems to increase productivity, which is accompanied by risks concerning environmental pollution. Therefore, there is a trend towards shifting the production chain from developed to developing countries, mainly due to their less restrictive environmental policies (Kunz et al., 2009; Knox, 2014; Ramachandran, 2014). Swine and poultry manures are mainly disposed by application to soil, and in Brazil, there are no strict regulations regarding this type of disposal, increasing the potential for soil and water contamination (Kunz et al., 2009).

Soil aggregates are used as indicators of soil quality (Vrdoljak and Sposito, 2002) and can therefore be used to evaluate the effects of manure and sewage sludge disposal on soil quality (Hati et al., 2006; Lee et al., 2009; Bandyopadhyay et al., 2010; Tavares Filho et al., 2010; Watteau and Villemin, 2011 Watteau et al., 2012). Over time, soil fertilisation with manure or sewage sludge can improve the physical properties of soil (Hati et al., 2006; Bandyopadhyay et al., 2010). Zhou et al. (2013) observed that animal manure applied with mineral fertiliser was more effective at changing the microstructure dynamics and increasing soil aggregation than was

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the use of mineral fertiliser alone in an ultisol after 20 years. In addition to increasing the stability of the aggregates, this fertilisation can also increase the porosity, water-use efficiency and grain productivity (Hati et al., 2006; Bandyopadhyay et al., 2010). However, soil chemical alterations that occur due to the application of swine and poultry manures are strongly influenced by the soil type, precipitation, quantity and time between application and sampling (Choudhary et al., 1996 Zhou et al., 2013). Therefore, the relationship between the temporal stability of aggregation and carbon inputs to the soil immediately after application remains poorly understood.

Benites and Mendonça (1998) observed that the addition of more than 15 Mg ha^{-1} of non-humified organic matter (manure) to soil changed the superficial electric potential and increased the dispersible clay content. In addition, Tavares Filho et al. (2010) observed that doses of up to 48 Mg ha^{-1} sewage sludge increased the ΔpH (pH_{H_2O}–pH_{KCl}), indicating a change in the superficial electric potential, while not demonstrating an increase in clay dispersion compared to no application of sewage sludge.

Soon after soil application, swine and poultry manure can promote rapid changes in the superficial electric potential, thereby increasing the clay dispersion and reducing the aggregation of the soil due to the effect of the large amount of carboxyls per atom of carbon (17.2–22.7 (R-COO$^-$) COOH/mmol$_{(-)}$ g^{-1} C) in these types of manures (Ohno et al., 2007). However, this effect is ephemeral because these carboxyls are easily decomposed (Gerzabek et al., 1997).

The negative charge and salts in swine and poultry manures can alter the superficial electric potential of the soil and cause clay dispersion, such as that observed by Benites and Mendonça (1998). The dispersion process caused by swine and poultry manures, even within a short time period, increases the susceptibility of the soil to erosion and surface water contamination due to the increasing levels of salts in the soil solution (Munodawafa, 2007; Chen et al., 2012; Hahn et al., 2012).

The dispersible clay content and aggregate stability reveals structural modifications caused by soil management. Analysis of the potential soil disaggregation, even within a short period of time (Watteau et al., 2012), can indicate the correct management of the application of swine and poultry manures. Therefore, the objective of this study was to evaluate the water-dispersible clay content and aggregation of an oxisol over time following the application of different doses of swine and poultry manures.

2. Material and methods

2.1. Experimental design

The experiment was conducted at the experimental station of the Agricultural Research Institute of Paraná State (23°22 ′S and 51°10 ′W), Brazil. The altitude of this location is 585 m, and the area receives an average annual rainfall of 1588 mm. The climate is humid and subtropical, with temperatures between 16 and 27 °C.

The soil is a very clayey dystroferric red latosol (Santos et al., 2006) or Ferralsol (IUSS, 2006), originating from weathered basalt. The main characteristics of the soil are its advanced degree of weathering and high contents of iron oxides (greater than 180 g kg^{-1}), aluminium, 1:1 clay minerals (kaolinite) and quartz (Reatto et al., 2008), which are characterised by low-activity clay, little differentiation among horizons, and a strong and well developed microgranular structure comprising angular and sub-angular microaggregates (Reatto et al., 2009; Brossard et al., 2012). These microaggregates are organised into micropeds that are smaller than 1 mm, with a porous massive structure according to Volland-Tuduri et al. (2005). The physical and chemical characteristics of the soil are shown in Table 1.

The experimental area was managed using a disk plough (0.30 m depth) followed by a disk harrow (0.15 m depth) until 2007. Since 2008, the site has been under no-till, with soybean and corn grown in the summer and oat and wheat grown in the winter. Lime was applied using dolomitic limestone at 3 Mg ha^{-1} without incorporation prior to the initiation of the no-till system.

For corn, oat and wheat, the manure doses were calculated based on the nitrogen levels; for soybean, the doses were based on the phosphorous levels. Corn was grown during the assessment year of this study, and 150 kg N ha^{-1} nitrogen was applied using mineral fertiliser and swine and poultry manures.

The following treatments were established: no application of mineral or organic fertiliser (reference, T1), the application of 33 (T2) and 66 m^3 ha^{-1} (T3) swine manure, and the application of 1920 (T4) and 3840 kg ha^{-1} (T5) poultry manure. Treatments T2 and T4 are equivalent to 150 kg N ha^{-1}, and T3 and T5 correspond to 300 kg N ha^{-1}.

The experimental design used a complete randomised block with four replications in 50 m^2 (5 × 10 m) plots. The manures were applied to the soil surface without incorporation on 03 November 2011. The temperature and rainfall data for the period are presented in Fig. 1. The chemical properties of the swine and poultry manures are presented in Table 2.

2.2. Procedures for soil sampling and analysis

The soil samples were collected using a straight shovel from 0 to 0.10 m depth. The samples were collected on 04 and 19 November 2011, 04 December 2011 and 04 January 2012 at 0, 15, 30 and 60 days after manure application (DAA). Four points were collected per each plot that comprised a sample.

The distribution of the aggregate size classes was determined through wet sieving according to the method of Yoder (1936) as adapted by Castro Filho et al. (1998) using 8.0, 4.0, 2.0, 1.0, 0.5 and 0.25 mm diameter sieves. The corresponding aggregate size classes were >2.00, 2.00–1.00, 1.00–0.50, 0.50–0.25 and <0.25 mm.

The weighted mean diameter (WMD) was calculated according to Kemper and Rosenau (1986), and the aggregate stability index (ASI) was calculated according to Castro Filho et al. (1998) with the following equations:

$$WMD = \sum_{i=1}^{n} (xi \cdot wi)$$

$$ASI = \left(\frac{\text{weightofdrysample} - wp25 - \text{sand}}{\text{weightofdrysample} - \text{sand}} \right) \cdot 100$$

Table 1
Physical and chemical characteristics of the soil study.

Layer	Clay	Sil	Sand	P	C	pH_{H_2O}	Al	H + Al	Ca	Mg	K	S	T	V	Al
m	g kg^{-1}			Mg kg^{-1}	g kg^{-1}		cmol kg^{-1}							(%)	
0–0.10	83	14	3	18.30	17.23	4.97	0.05	6.05	4.37	2.25	0.55	7.17	13.22	54.01	0.86