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Water-stable aggregates and aggregate-associated organic carbon and nitrogen after three annual applications of poultry manure and spent mushroom wastes

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ABSTRACT

Water stable aggregates influence mechanisms for both water and fertility conservation and nutrient release in the soil. The effect of application of different organic amendments on aggregate stability and carbon-nitrogen storage within aggregates of a degraded soil was studied. The treatments were: control (P0S0), no amendments, 5 t ha^{-1} poultry manure (P5S0), 10 t ha^{-1} poultry manure (P10S0), 5 t ha^{-1} spent mushroom waste (P0S5), 10 t ha^{-1} spent mushroom waste (P0S10) and 5 t ha^{-1} each of poultry manure and spent mushroom waste (P5S5) applied in three consecutive years. These were arranged in randomized complete block design in five replicates. Soil samples were collected from the topsoil (0–20 cm), air-dried and separated into 4.75–2.0, 2.0–1.0, 1.0–0.5, 0.5–0.25, and <0.25 mm aggregate classes by dry sieving. Results showed that P5S5 increased macro aggregates >0.25 mm and mean weight diameter (MWD) over other treatments. Saturated hydraulic conductivities (K_{sat}) were 17.55 cm hr^{-1} and 16.28 cm hr^{-1} in P5S0 and P0S10 amended soils, respectively. Generally, spent mushroom waste (SMW) and poultry manure (PM) significantly ($p < 0.05$) reduced bulk density and increased total porosity, indicating positive effects of SMW and PM as soil amendments. Total nitrogen (N) concentrations in aggregate classes were significantly higher in soils amended with PM and SMW than the control. The P10S0 treatment had the highest concentrations of N (1.51 g kg^{-1}) in 1.0–0.5 mm aggregates size class. Soil organic carbon (SOC) was preferentially higher in larger aggregates >2 mm and in smaller aggregates <0.25 mm irrespective of treatments, whereas, total N was higher in aggregates >0.5 mm in PM amended soils. In all the treatments, SOC was enriched in larger aggregates than smaller aggregates. Poultry manure improved soil structure, aggregate-associated OC and total N than SMW. However, SMW has the potentials for use as soil amendment because it showed positive effects on soil structure and soil C-N storage.

1. Introduction

Degradation of soil physical and chemical properties is closely linked with the reduction in soil organic matter, which is essential to aggregation (Zeytin and Baran, 2003). Soil aggregation is critical to stabilization of carbon pool through its physical protection within the aggregates (Balabane and Plante, 2004). The stability of soil aggregates depends on the quantity and quality of input of organic matter into the soil (Razafimbelo et al., 2008). Application of manure has been considered as a valuable source of soil organic matter and plant nutrients (Udom and Ogunwole, 2015). It improves soil quality and reduces the contribution of agriculture to CO_2 emission. Nicholas and Tora (2011) observed that sustained applications of manure increased soil organic carbon (SOC) content, particularly in the surface layer of the soil, which supported the formation of a new soil layer with better and more stable aggregates. Soil scientists agree that mean weight diameter (MWD) of water stable aggregates and SOC sequestration are suitable indicators for evaluating changes in soil quality after manure application (Unger, 1997; Ogunwole, 2008; Udom and Ogunwole, 2015). Water stability of aggregate is important because it maintains the surface integrity of the soil thus facilitating infiltration rather than runoff (Franzluebbers et al., 2000). However, long-term application of manure can increase dispersion of large aggregates (Whalen et al., 2000; Udom and Nuga, 2014).

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Literature showed that application of amendment improved soil aggregation and MWD of water stable aggregates (Goebel et al., 2005), increased the macro aggregates and resistance of aggregates to slaking. It also decreased the susceptibility of soil aggregates to dissolution and disruption (Whalen and Chang, 2002). Soil aggregates are important agents of soil organic carbon retention (Carter, 2002) and protection from decomposition (Six et al., 2000). Generally, SOC protected by the macro aggregates has short term storage and the most stable carbon is stored in the smallest silt + clay size (<0.053 mm) fraction (Six et al., 2002). On the other hand, SOC affects soil quality by positively influencing water retention, bulk density and resistance of aggregate to destruction under wet conditions, and also as a major repository and source of organic carbon and nitrogen (Bandarayake et al., 2003; Abid and Lal, 2008; Kasper et al., 2009).

Within the study area, mushroom wastes are largely generated by mushroom industries and disposed freely on lands with less interest in its potential as soil amendment. It is composed mainly of sawdust and nutrient substrates with high C:N ratio. Although the effects of manure on soil physical and chemical properties have been widely reported, data on the use of mushroom wastes or in combination with poultry manure as soil amendments to enhance soil quality is not common. A few earlier studies (Beyer, 1996) reported that application of spent mushroom waste (SMW) to nutrient poor soils improved its health by improving the aggregation, water holding capacity, aeration, porosity, and nutrient status.

Studies carried out on the role of organic matter in aggregate characteristics have raised certain controversies. For example, Yuan et al. (2004) observed significant influence on organic carbon (OC) distribution within aggregates, with particular gains in OC fractions in the relatively larger aggregates after 22 consecutive years of application of organic manure. Zhu et al. (2008) reported that application of organic manure to soil increased the proportion of large aggregates, and that OC content was higher as size of water stable aggregates increased. Xu and Shen (2000) observed that carbon and nitrogen contents in different aggregate size groups increased with the application of large amounts of organic manure. Six et al. (2004) observed that after incorporation of fresh residues, microorganisms produce mucilage that resulted in formation of macro aggregates, which after further decomposition formed the stable core of micro aggregates.

According to a model by Tisdall and Oades (1982), macro-aggregates (>0.25 mm) were less effective in protection of organic carbon, whereas, micro aggregates (<0.25 mm) provided the greatest protection of organic carbon. There are also contentions that stable macro-aggregates may exist for only a few years, but micro-aggregates may exist for decades (Puget et al., 2000).

Investigations of Puget et al. (1995) observed that stable (slake-resistant) macro-aggregates were enriched in SOC, and related the increase in aggregate size to increase in SOC content. Hence, aggregate-associated SOC and N which provides information on C-N sequestration are vital, particularly when dealing with some tropical soils. Therefore, this study investigated possible improvement of aggregate stability and carbon-nitrogen storage within aggregates of a tropical ultisol treated with different organic amendments viz, poultry manure and spent mushroom waste.

2. Materials and methods

2.1. Description of study site and sampling

The experiment was carried out at the Teaching and Research Farm in University of Port-Harcourt (Lat 4°45[1]N and Long 6°15[1]E) in the rain forest zone of Nigeria. The total annual rainfall in the area is 2400 mm, with peaks in the months of June and September. Mean monthly temperatures range from 22 °C to 32 °C, with minimum and maximum relative humidity of 35% and 90% respectively, (FORMECU, 1998). The soil is sandy loam, highly weathered, low in organic matter, and classified as Arenic acrisol (Food and Agricultural Organization, 1990). The area was used for field trials for maize crop, and amended with different rates of poultry manure (PM) and spent mushroom wastes (SMW), or their combinations in 2012, 2013 and 2014. The field was divided into six plots of 270 m^2 each, arranged in a randomized complete block design (RCBD) in five replications, giving a total of 30 plots that had the following treatments:

P0S0: a control plot receiving neither PM nor SMW for three years.

P5S0: plots amended with 5 t PM ha^{-1} $year^{-1}$ for three years.

P10S0: plots amended with 10 t PM ha^{-1} $year^{-1}$ for three years.

P0S5: plots amended with 5 t SMW ha^{-1} $year^{-1}$ for three years.

P0S10: plots amended with 10 t SMW ha^{-1} $year^{-1}$ for three years.

P5S5: plots with 5 t PM ha^{-1} + 5 t SMW ha^{-1} $year^{-1}$ for three years.

The PM and SMW for this experiments were sourced from the Poultry Unit and Mushroom Farm of the Faculty of Agriculture. These units are also the major source of supply of PM to farming communities around the area, but the SMW is often neglected by the farmers. Organic matter, total nitrogen, C:N ratio, and pH of the poultry manure were 32.2 g kg^{-1}, 4.08 g kg^{-1}, 3.1, and 7.5, and those of spent mushroom were 51.1 g kg^{-1}, 1.6 g kg^{-1}, 18.5, and 6.5, respectively. Five disturbed and five undisturbed core soil samples were collected per plot size of 270 m^2 at 0–30 cm depth in 3 replications. In total, 150 bulk and 150 core samples were collected from the area. The 150 soil samples were air-dried, sieved through 2 mm mesh sieve and used for laboratory analysis.

2.2. Soil sample analysis

2.2.1. Water stable aggregates

The distribution of aggregates by wet sieving was measured as described by Kemper and Rosenau (1986), while aggregate stability was evaluated by the mean-weight diameter (MWD) as index. In this procedure, bulk soil samples were air-dried and sieved to obtain <4.75 mm natural aggregates then 50 g of <4.75 mm dry sieved aggregates were placed on the top most of sieves of different openings sizes 2.0, 1.0, 0.5, and 0.25 mm, presoaked by capillary at 0 kpa in distilled water for 5 min before oscillated vertically in water 20 times, using 4 cm amplitude in a mechanical agitator. The stable aggregates remaining on each sieve were oven-dried at 50 °C for 24 h and weighed. The mass of aggregates <0.25 mm were obtained by the difference between mass of sample and the sum of sample weights collected on the 2.0, 1.0, 0.5, and 0.25 mm nest of sieves. The percentage of the stable aggregates on each sieve representing the water stable aggregates was calculated as:

$$\%\mathrm{WSA} = \frac{\mathrm{MR}}{\mathrm{MT}} \times \frac{100}{1} \tag{1}$$

where MR is the mass of resistant aggregates (g) and MT is the total mass of wet-sieved soil (g). The mean weight diameter (MWD) of the water stable aggregates was calculated by the following equation (Hillel, 2004):

$$\mathrm{MWD} = \Sigma_i^n = \mathrm{xiwi} \tag{2}$$

where xi is the mean diameter of each size fraction, and wi is the weight of aggregates in that size range as a fraction of the total dry weight of the samples analyzed.