Phosphorus distribution in soil aggregate size fractions in a poultry litter applied soil and potential environmental impacts

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ABSTRACT

Long-term poultry litter (PL) application in pasture soil was found to enhance accumulation of certain phosphorus (P) forms in soil micro-aggregate fractions and have potential impacts on non-point water pollution by wind erosion or run-off. A P fractionation method was utilized to identify P forms in aggregate fractions derived from a long-term PL applied pasture soil. Enrichment of surface soil P by PL application has considerable effects on increasing specifically the labile P forms in surface soil micro-aggregates. Particular concern is of accumulation of water soluble and labile inorganic P forms in micro-aggregate particles susceptible to wind and soil erosion. Continuous application of PL to pasture fields for at least 15 years at a rate of 2.3 T ha^{-1} y^{-1} resulted in a considerable increase in inorganic P forms including Mehlich-3, water soluble and labile bicarbonate P (NaHCO$_3$–P) forms in most aggregate size fractions. Mehlich-3-P was highest in <0.053 mm micro-aggregates (223.8 mg kg^{-1}) and relatively high amounts ranging from 145.5 to 170.4 mg kg^{-1} were found in 0.053–1.0 mm micro-aggregates. High levels of water soluble P were found in majority of micro-aggregate particles in PL applied soil, which amounts to 11–18% of total inorganic P in these particles. Bicarbonate–P or labile inorganic P forms were at elevated levels in 0.125–0.25, 0.053–0.125 and <0.053 mm micro-aggregates, which amounts to approximately 11–22% of total inorganic P in these particles. The PL application also increased the NaOH extractable P (NaOH–P) or Al/Fe bound P in soil aggregate fractions (192–347 mg kg^{-1}). Notable increase in labile organic P forms in certain micro-aggregate size fractions may be of concern due to ease of P mineralization.

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1. Introduction

Poultry litter (PL) is widely used as an excellent source of phosphorus (P) fertilizer for agricultural crops, pasture and hay fields in many parts of the United States. Thus, land application is considered as a major PL management method in many broiler producing regions in the United States (Moore et al., 1995; Sauer and Meek, 2003; Sharpley et al., 1993, 2007; Sistani et al., 2004, 2008). Nevertheless, many studies indicate that land application of PL results in excessive accumulation of nutrients, specifically P enrichment in soil, and non-point source pollution of water through leaching and run-off of excess nutrients (Dutta et al., 2010; He et al., 2009; Kingery et al., 1994; Mitchell and Tu, 2006; Moore et al., 1995; Sauer and Meek, 2003; Sauer et al., 1994). Environmental implications associated with land application of PL are well-documented (Dutta, et al., 2010; Moore et al., 1995; Robinson and Sharpley, 1995; Schomberg et al., 2007; Sharpley et al., 2007). Aggregation is considered as an important physical property affected by manure addition in agricultural soil (Wei et al., 2006; Whalen and Chang, 2002; Wortman and Shapiro, 2008). Several studies indicate that soil aggregate formation has an impact on P sorption, as well as bio-availability of P. Distribution of P forms among aggregate fractions

may depend on the type of manure or fertilizer applied, as well as management practices (Bhatnagar et al., 1985; Green et al., 2005; Whalen and Chang, 2002). In addition, P attachment to soil aggregates depends on the particle size (Hao et al., 2004; Linquist et al., 1997; Whalen and Chang, 2002; Wiersum, 1962).

Phosphorus-enriched soil aggregates entering surface water via run-off or wind erosion may have potential long-term effects on water quality due to slow release of P attached to such particles over time (Hao et al., 2004). Specifically, labile P forms bound to fine soil fractions are believed to have impact on water quality since the fine soil fraction is preferentially transported to surface water through run-off and wind erosion (He et al., 1995; Uusitalo et al., 2001; Whalen and Chang, 2002; Zhang et al., 2003). Contamination of water from P attached sediments entering waterways depends on amount of bio-available P present and on the rate of transformation of P forms to bio-available P forms over time (Green et al., 2005).

Understanding the distribution of different P forms in soil aggregate fractions in long-term manure applied soils is important in evaluating the risk of P run-off and leaching in agricultural soils. However, little information is available on such studies, in particular, accumulation of P in different aggregate size fractions in long-term PL applied soils. We hypothesized that long-term PL application in pasture or agricultural lands will have considerable effects on accumulation of P forms in different size aggregate fractions. Thus, the major objective

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of our study is to investigate accumulation of different P forms in surface soil aggregate size fractions from a long-term PL applied pasture soil to understand the potential of P release from soil aggregates to the environment. This study was carried out using long-term PL applied soil from pasture lands located in Crossville, Alabama in southeastern USA.

2. Materials and methods

2.1. Study site

Soils for this study were collected from pasture fields in Sand Mountain Research Extension Center located in Crossville, Alabama, USA. Soil in this area is classified as Hartselle (fine sandy loam, siliceous, Typic, Hapludults). Poultry litter has been surface applied to the pasture fields for at least 15 years at a rate of 2.3 T ha^{-1} y^{-1}. Poultry litter in this area is obtained from broiler houses and generally contains wood shavings and other bedding materials. Control soil samples were collected from adjacent areas in which PL has not been applied over the years.

2.2. Soil sampling

Soil sampling was carried out from three pasture areas containing PL applied soils. From each area, samples were taken from three randomly selected locations (5 cores/location). Soil cores were thoroughly mixed to generate a composite sample for each area to generate total of three replicates of PL applied composite soil samples. A similar sampling pattern was used for control soils to generate total of three replicates of composite soils. Soils were taken from surface soils at a 0–15 cm depth.

2.3. Characterization of soils

Soil samples were ground and passed through a 2 mm sieve for characterization. Soil pH was measured in de-ionized water at a soil: solution ratio of 1:1 using a pH meter (Orion, Thermo Scientific). The cation exchange capacity (CEC) of soil was determined by the barium chloride method (Gillman, 1979). Total C and total N contents in finely ground soil samples were analyzed using a CNS analyzer (Vario Max, Elementar Americas).

2.4. Soil aggregate fractionation

Aggregate fractionation was carried out using a previously described method by dry sieving (Zhang et al., 2003). Air-dried samples were screened and fractionated into six different aggregate size fractions (>2.0, 2.0–1.0, 1.0–0.25, 0.25–0.125, 0.125–0.053, and <0.053 mm) using a Tyler Ro-Tap test sieve shaker equipped with US standard test sieves (ASTM E-11 specification).

2.5. Chemical analysis

Available P in soil aggregate fractions was extracted using Mehlich-3 extractant (Mehlich, 1984) followed by determination of P in the extracts using Murphy and Riley colorimetric method (Murphy and Riley, 1962).

Soil aggregate fractions were sequentially extracted for P using a modified Hedley method, which includes a water extraction step that replaces the resin extraction step in Hedley method (Hedley et al., 1982; Waldrip-Dail et al., 2009). This sequential extraction procedure includes water, 0.5 M NaHCO$_3$ (pH 8.5), 0.1 N NaOH, and 1 M HCl extractions. All extractions were carried out in a reciprocal shaker (for 2 h with water extraction and 16 h with other extraction steps) at a soil: extractant ratio of 0.5:30. The extracts were then centrifuged to separate the supernatant followed by filtration through Whatman 42 filter papers for P analysis. Residual P was determined after acid

digestion of residual soil (Hedley et al., 1982). Total P in NaHCO$_3$ and NaOH extracts was determined after digesting aliquots with ammonium persulfate and H$_2$SO$_4$ (Greenberg et al., 1992). Organic P (OP) in these extracts was calculated as the difference between total P and inorganic P. The inorganic P concentration in all extracts was analyzed using Murphy Riley colorimetric method (Murphy and Riley, 1962).

Sodium dithionite/citrate extraction of soil aggregate fractions was carried out according to a previously described method (Courchesne and Turmel, 2008). The Al and Fe contents were measured using PerkinElmer Optima 2100-DV inductively coupled plasma-optical emission (ICP-OES) spectrometer.

2.6. Statistical analysis

General linear model procedure of Statistical Analysis System (SAS Institute, 2004) was used to test the effect of treatments. Treatment means were separated at the 5% significance level using Fisher's protected LSD.

3. Results and discussion

Basic soil characteristics of whole soil show that pH of control and PL applied soils were 5.2 and 5.8, respectively. Total C in control and PL applied soils were 0.7% and 1.5%, respectively and the total N contents in control and PL applied soils were 0.06% and 0.15%, respectively. The CEC of control and PL applied soil were 1.73, and 5.16 cmol kg^{-1} showing that PL application resulted in significant increase in CEC of the soil ($P<0.05$), possibly due to increase in the soil organic matter content. Phosphorus availability of Hartselle soils in the study region is impacted by Fe and Al oxides present in soil, thus, manure or fertilizer is applied to enhance P availability in these soils (Senwo et al., 2003).

3.1. Soil aggregate size fractions

Soil macro and micro-aggregates are defined according to the diameter of the particles where soil aggregate size fraction containing particles with diameter of >2 mm consists of large macro-aggregates while small macro-aggregates have diameters in the range of 0.25–2 mm. Micro-aggregate size particle diameters are in the range of 0.053–0.25 mm. Particle sizes of <0.053 mm consist of mineral fractions (Márquez et al., 2004).

Distribution of aggregate size fractions separated from control and PL applied soil is given in Table 1. Bulk of the aggregate fractions from control soil in the study site consisted of a two major aggregate fractions which consisted of 0.50–0.25 mm particles followed by 0.25–0.125 mm particles which amounts to 36.7% and 30.2% of whole soil weight. The 0.125–0.053 mm and >0.053 mm micro-aggregates ranged from 13.8 to 14.9% of the whole soil weight. The distribution pattern in control soil is somewhat similar to a previous study, which reports that the dominant aggregate size fractions in a sandy soil are 0.50–0.25 mm, and 0.25–0.125 mm, accounting for 80.6% of the total dry soil weight (Zhang et al., 2003).

Table 1
Percent distribution of aggregate size fractions.

Aggregate size (mm)	% Distribution	
	Control soil	PL-soil
>2.0	0.9a†	1.8a
2.0–1.0	0.6b	1.7b
1.0–0.5	2.5a	3.5a
0.5–0.25	36.7a	9.7b
0.25–0.125	30.2a	37.5b
0.125–0.053	13.8b	22.7a
<0.053	14.9a	21.9a

† Means with the same letter within a row are not significantly different at $P<0.05$.