Distribution of phosphorus in an Ultisol fertilized with recovered manure phosphates

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Abstract

Phosphorus (P) can be recovered in concentrated form from livestock manure and poultry litter. A greenhouse study was conducted to evaluate the the short-term leaching potential and plant availability of P from recovered P materials from liquid pig manure (SRP) and broiler litter (LRP) in a characteristic sandy soil of southern U.S. and compared to triple superphosphate (TSP) and raw broiler litter (BL). Cotton (*Gossypium hirsutum* L.), a major crop in the southern U.S., was used as the test species. The vertical soil P distribution showed that most of plant available P applied with RP and SP materials remained within the top 15-cm soil. In the short-term (8 weeks), soil leaching potential of both LRP and SRP was lower than more soluble forms of P fertilizers such as TSP. The use of recovered P could minimize manure P losses into the environment, promote long-term sustainability of poultry and pig production, and provide a P fertilizer source for crop production.

Key Words

Phosphorus, manure, poultry litter, phosphorus recovery, soil leaching, cotton.

Introduction

The continual land application of animal manure promotes accumulation of soil P to elevated levels in regions with intense confined livestock production (Ribaudo *et al.* 2003). Although P is an essential element for crop and animal production, soil P surplus has the likelihood to pollute water resources by means of field runoff and soil leaching (Johnson *et al.* 2004; Kaiser *et al.* 2009). This environmental concern has stimulated interest into cleaner options to dispose and reuse livestock manure (Szogi *et al.* 2006; Szogi and Vanotti, 2009). Since mineral P is a non-renewable resource, the aspect of P recycling and transfer of manure P is important for crop production because of increasing global demand and soaring fertilizer costs (Cordell *et al.* 2009). Therefore, P recovery from livestock manure has the potential to promote sustainable animal production by both reducing P losses into the environment and recycling P in the form of a valuable fertilizer by-product.

Given that both manure and poultry litter are bulky materials, a more effective P transfer to cropland can be achieved by creating by-products with less volume than raw manure or litter. Recently, two new treatment processes have been developed to recover manure P in a concentrated solid form. One of these new treatments recovered P from liquid pig manure (Vanotti *et al.* 2003; Szogi and Vanotti, 2008) while the other new process extracted and recovered P from poultry litter (Szogi *et al.* 2008). Both materials appear to have potential as effective P fertilizers according to results from trials with annual ryegrass (*Lolium multiflorum* Lam.) reported by Bauer *et al.* (2007) and Szogi *et al.* (2010). Yet, their environmental fate in sandy soils of southern U.S. needs to be evaluated in order to develop recommendations for their optimal use in cropping systems. The objective of this study was to evaluate the short-term leaching potential and plant availability of P from both recovered P materials from swine manure and broiler litter in a characteristic sandy soil of southern U.S. Cotton, a major crop in the southern U.S., was used as the test species.

Methods

Phosphorus sources

The recovered P material from pig manure was obtained from a full-scale liquid manure treatment facility located on a 4360-head finisher pig production unit in Duplin County, North Carolina, U.S. The treatment facility consisted of three modules. In the first module, the solid phase of the waste was mechanically separated from the liquids. The wastewater after separation in the first module was pumped into the second module, where ammonia was converted to nitrogen gas in an aerobic biological reactor. The wastewater then went to the final module, where soluble P was recovered as calcium phosphate precipitate by increasing the pH with controlled amounts of hydrated lime (Vanotti *et al.* 2007). Further details of the process extraction of P from wastewater and dewatering of the precipitate are given in Vanotti *et al.* (2003) and Szogi *et al.* (2006).

A new treatment process, called "quick wash," was developed for extraction and recovery of P from poultry litter and animal manure solids (Szogi *et al.* 2008). The quick wash process consists of three consecutive steps: 1) P extraction, 2) P recovery, and 3) P recovery enhancement. In step 1, organically bound P is converted to soluble-P by rapid reactions using selected mineral or organic acids. This step also releases P from insoluble inorganic phosphate complexes. The washed litter residue is subsequently separated from the liquid extract and dewatered. In step 2, P is precipitated by addition of lime to the liquid extract to form a P precipitate. In step 3, a flocculant is added to enhance the P concentration of the product. This approach of extracting and recovering P from poultry litter using the quick wash process produces a final P product that can be reused as fertilizer. The P content of all fertilizer sources used in this study is shown on Table 1.

Table 1. Phosphorus content and particle size of source materials. Water-soluble (%) is the fraction of water-extractable P with respect to total P.

Source	Total P	Water-extractable P	Water-soluble	Particle Size
	(g P/kg)	(g P/kg)	(%)	(mm)
Recovered from pig manure (SRP)	114	1	1	2.0 – 4.0
Recovered from broiler litter (LRP)	46	0.5	1	0.5 – 1.0
Raw broiler litter (BL)	12	2.2	18	0.5 – 1.0
Triple superphosphate (TSP)	201	46	23	0.1 – 5.8

Phosphorus leaching study

A greenhouse study was conducted that consisted of two soil leaching experiments – one without and one with cotton (cv. DPL 555) plants – that received four P fertilizer materials (SP, RP, BL and TSP) as treatments and a control with no P addition. Each experiment was conducted twice. Temperature was in the range of 25.5 to 32.0°C during the study. A sandy-textured soil [Uchee sand (loamy, kaolinitic, thermic Arenic Kanhapludult)] low in P was used in all experiments. Chemical properties of the soil are shown in Table 2. The soil was limed with $Ca(OH)_2$ to raise the pH to about 6.5 and fertilized prior to pouring it into the soil columns. The soil columns used in the leaching experiments were made of PVC pipe 15-cm wide × 76-cm long and closed in the bottom with a cheese-cloth. The columns were filled with the Uchee sand up to a height of 71 cm and packed to a bulk density of about 1600 kg/m^3.

Table 2. Chemical properties of the soil used in the greenhouse study before liming. Data are mean of two samples ± standard deviation.

Soil properties	Value
pH in water	4.9 ± 0.1
Cation exchange capacity, cmol/kg	2.0 ± 0.4
Exchangeable acidity, cmol/kg	1.8 ± 0.3
Phosphorus, mg/kg	1.7 ± 0.1

The four P fertilizer materials were added at a fixed rate of 0.134 g P per soil column. This application rate corresponds to about 170 kg P_2O_5/ha when applied on a ground area basis. The P was mixed into the surface 15 cm of soil. Each treatment had four replicates per experiment. In addition, each soil column received 2.73 g of 15–0–15 ($N–P_2O_5–K_2O$) fertilizer (about 225 kg N and K_2O/ha) and 0.16 g of technical grade $(NH_4)_2SO_4$. After allowing P materials to react with soil for about one month, cotton was planted into designated soil columns. Then, all soil columns were leached with 2 L of distilled water once a week for eight weeks. Soil columns with plants were lightly watered between leaching events to keep plants from wilting. After eight weeks, plants were harvested and soil columns sampled by depth. Inductively coupled plasma – atomic emission spectrometry was used to determine both P in soil leachates and total P soil concentration of samples digested with nitric acid and hydrogen peroxide (Peters *et al.* 2003). Plant available P concentration in soil Mehlich3 extracts and P concentration in cotton plants digested with sulfuric acid (Gallaher *et al.* 1976) were determined by automated colorimetric analysis (ascorbic acid method).

Statitstical analysis

Experimental design for each set of experiments was a randomized complete block, and there were four replications in each experiment. Aboveground biomass, P concentration in the plant biomass, and soil P were analysed across experiments using a mixed model analysis with the GLIMMIX procedure of SAS (SAS

Institute, Cary, NC). Experiments and replicates were considered random. Treatments and depth (for the soil P analysis) were considered fixed. Biomass least square means were compared using the pdiff option, and means were considered different when the probability of greater *t* values were ≤0.05.

Results

Cotton plant biomass was significantly lower for plants grown with LRP or SRP than the other two common fertilizers, BL and TSP. However, P concentration in plant tissue was consistently uniform except for higher P concentration in plants with SRP (Table 3). Nevertheless, all plants developed deep roots that reached the bottom of the soil columns. The soil columns planted to cotton served the purpose to determine the potential effect of plant roots on distribution of soil P with depth.

Table 3. Aboveground biomass. Means followed by the same letter are not significantly different (P <0.05).

Source	Dry matter (g/soil column)	Concentration (mg/kg)
BL	1.97a	0.59b
LRP	1.38ab	0.64a
SRP	0.85b	0.58b
TSP	1.96a	0.57b

Soil leaching potential of recovered P materials, LRP and SRP, may be lower than more water soluble forms of P in fertilizer sources such as BL or commercial TSP (Table 1). However, results of P analysis in leachate samples showed no difference between P sources; cumulative P mass in leachates was <0.5 mg per soil column.

Fertilizer material and soil depth and their interaction (material × depth) had a significant effect on vertical soil P distribution (Figure 1). Since the interaction of plant with either material or depth was not significant, differences in plant available P concentration at the same depth were not significant in soil without and with cotton plants. The vertical distribution of total soil P (not shown) had trends similar to the plant available P distributions shown in Figure 1.

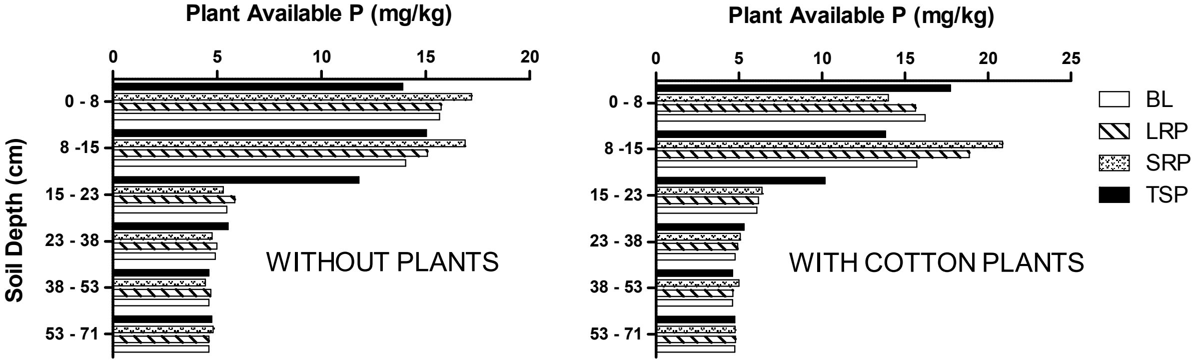

Figure 1. Plant available phosphorus concentration at different soil depths without and with cotton plants where BL = raw broiler litter, LRP = recovered P from broiler litter, SRP = recovered P from pig manure, TSP = triple superphosphate.

Except for the TSP source, the plant available P remained mostly concentrated on the top 15 cm where it was initially applied (Table 4). Within the top 15 cm, the highest P concentration was 18.9 mg/kg (SRP) and the lowest was 14.4 mg/kg (TSP). Below 15-cm depth, the significantly higher soil P concentration at 15-23 cm supplied by TSP vs. the lower P concentration with BL, LRP and SRP is likely influenced by the chemical properties of the soil and P fertilizer materials on both P solubility and soil adsorption. Given that P solubility and adsorption are controlled by pH, in our study the soil pH was corrected to about 6.5 units to favour P dissolution and availability to plants. Since TSP is highly soluble in water, it first dissolves rapidly in moist soil and subsequently reacts with soil and becomes available to plants with a favourable pH. Since LRP and SRP are less soluble in water, these results show that the LRP and SRP were less susceptible to leaching in the short term of this experiment. Below 23-cm depth, P concentrations were low (<5.4 mg/kg) with no significant differences among P sources. This explains the lack of significant differences on the soluble P measured in the leachates from soil columns treated with the four different P sources.

Table 4. Plant available phosphorus concentration at different soil depths, all experiments pooled where BL = raw broiler litter, LRP = recovered P from broiler litter, SRP = recovered P from pig manure, TSP = triple superphosphate. Means followed by the same letter are not significantly different (P <0.05).

Depth	Source			
	BL	LRP	SRP	TSP
(cm)	mg P/kg soil			
0 – 8	15.9bc	15.7bc	15.6bc	15.8bc
8 – 15	14.9bc	17.0ab	18.9a	14.4c
15 – 23	5.8d	6.0d	5.8d	11.0e
23 – 38	4.8d	5.0d	4.9d	5.4d
38 – 53	4.6d	4.7d	4.7d	4.6d
53 – 71	4.7d	4.7d	4.8d	4.8d

Conclusion

In this study, both recovered P materials from broiler litter (LRP) and liquid swine manure (SRP) provided sufficient plant available P for cotton plant growth. The vertical soil P distribution showed that most of plant available P supplied by LRP and SRP materials remained within the top 15-cm soil, where materials were initially applied. In the short-term, soil leaching potential of both LRP and SRP was lower than TSP, a more soluble form of P fertilizer. Although further research is needed under field conditions, more soil types, and additional crops, the recovered P materials from manure have the potential for use as plant fertilizers. The use of recovered P could minimize manure P losses into the environment, promote long-term sustainability of poultry and pig production, and provide a P fertilizer source for crop production.

References

Bauer PJ, Szogi AA, Vanotti MB (2007) Agronomic effectiveness of calcium phosphate recovered from liquid swine manure. *Agronomy Journal* **99**, 1352-1356.

Cordell D, Drangert J, Stuart W (2009) The story of phosphorus: Global food security and food for thought. *Global Environmental Change* **19**, 292-305.

Gallaher RN, Weldon CO, Boswell FC (1976) A semiautomated procedure for total nitrogen in plant and soil samples. *Soil Science Society of America Journal* **40**, 887-889.

Johnson AF, Victor DM, Rouquette FM, Harby VA (2004) Fate of phosphorus in dairy wastewater and poultry litter applied on grassland. *Journal of Environmental Quality* **33**, 735-739.

Kaiser DE, Mallarino AP, Haq MU (2009) Runoff phosphorus loss immediately after poultry manure application as influenced by the application rate and tillage. *Journal of Environmental Quality* **38**, 299-308.

Peters J, Combs SM, Hoskins B, Jarman J, Kovar JL, Watson ME, Wolf AM, Wolf N (2003) Recommended methods of manure analysis (University of Wisconsin-Extension Pub. A3769: Madison,WI).

Ribaudo MO, Gollehon NR, Agapoff J (2003) Land application of manure by animal feeding operations: Is more land needed? *Journal of Soil and Water Conservation* **62**, 375-389.

Szogi AA, Bauer PJ, Vanotti MB (2010) Fertilizer effectiveness of phosphorus recovered from broiler litter. *Agronomy Journal* **102**, 723-727.

Szogi AA, Vanotti MB, Hunt PG (2008) Phosphorus recovery from poultry litter. *Transactions of ASABE* **51**,1727-1734.

Szogi AA, Vanotti MB (2008) Removal of phosphorus from livestock effluents. *Journal of Environmental Quality* **38,** 576-586.

Szogi AA, Vanotti MB (2009) Prospects for the recovery of phosphorus from poultry litter. *Bioresource Technology* **100**, 5461-5465.

Szogi AA, Vanotti MB, Hunt PG (2006) Dewatering of phosphorus extracted from liquid swine waste. *Bioresource Technology* **97**, 183-190.

Vanotti, MB, Szogi AA, Hunt PG (2003) Extraction of soluble phosphorus from swine wastewater. *Transactions of ASAE* **46**, 1665-1674.

Vanotti MB, Szogi AA, Hunt PG, Millner PD, Humenik FJ (2007) Development of environmentally superior treatment system to replace anaerobic swine lagoons in the USA. *Bioresource Technology* **98**, 3184-3194.