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Agronomic Effectiveness of Phosphorus Materials Recovered from Manure

Abstract

Land application of large amounts of manure from confined livestock facilities is an environmental concern often associated often associated to excess phosphorus (P) in soils and potential pollution of water resources. Recovery of P from livestock manure is an attractive approach when on-farm application of manure is limited by strict nutrient management plans. New treatment processes have been developed to recover P from manure in concentrated solid form. We have recovered P from liquid pig manure and poultry litter. The high P concentration of these recovered P materials suggests that they likely have utility as a fertilizer source. A study was conducted to evaluate these materials as fertilizer sources. The study was conducted under greenhouse conditions. Annual ryegrass was the test crop. The two recovered P materials from pig manure (26% P_2O_5) and broiler litter (11% P_2O_5) were compared to commercial triple super phosphate (TSP). Treatments were three fertilizer sources and five fertilizer rates (0, 22, 44, 88, and 176 mg P/kg soil). Three harvests of plant tissues were made in each trial. Plant tissues were oven-dried and acid digested. Phosphorus from soil collected at the end of each trial was extracted using the Mehlich 3 procedure. Both plant tissue digest and soil extracts were analyzed for P using colorimetric analysis. Plants fertilized with recovered P from pig manure or broiler litter had P uptake responses almost as good as TSP. Although further research is needed under field conditions and on various soil types for fertilizer application recommendation, both recovered P materials appear to have potential as fertilizer source.

Introduction

Continued land application of excessive amounts of manure saturate soils with P and is a pollution threat if this nutrient enters water resources. Effective P management is then required to reduce agricultural runoff and protect surface waters. Therefore, alternative animal waste methods that include P recovery from manure are an option that could resolve problems of excess manure P on agricultural lands (Greaves et al., 1999).

Two new treatment processes have been developed to recover P from manure in concentrated solid form. One of these new treatments recovered P from liquid pig manure (Vanotti et al., 2003) while the other new process extracted and recovered P from poultry litter (Szogi et al., 2008). Although much of the literature on recovered P from animal manure has been concerned with their production and potential reuse in agriculture (Greaves et al., 1999; Ward and Ritter, 2003), there are very few reports on agronomic effectiveness of recovered P materials (Bauer et al., 2007; Johnston and Richards, 2003). The objective of this study was to evaluate the agronomic effectiveness of P recovered from pig liquid manure and solid poultry litter in comparison to a commercial P fertilizer.

Material and Methods

Phosphorus recovery. 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, USA. 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. (2006b).

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; unnecessary carbon (C) and nitrogen (N) transformations are prevented by dewatering the residue. In step 2, P is precipitated by addition of lime to the liquid extract to form an alkaline earth metal-containing P product. In step 3, an organic poly-electrolyte is added to enhance the P grade 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.

Greenhouse study. A greenhouse study was conducted with annual ryegrass. Temperature was 25.5-32.0 °C during the study. A sandy-textured soil [Uchee sand (loamy, siliceous, thermic, Arenic Paleudult)] was used. Two 100-g samples of the soil were air dried, ground, and then chemically analyzed at Clemson University's Agricultural Service Laboratory. Results from this analysis are shown in Table 1. After analysis, the soil was mixed with $Ca(OH)_2$ to raise the pH to about 6.5.

The recovered P materials from the pig wastewater and poultry litter were ground and sieved to select particles between 0.5 and 1.0 mm. Treatments were three fertilizer sources: recovered P from pig manure (RPM), recovered P from poultry litter (RPL) and commercial triple super-phosphate (TSP) and five fertilizer rates (0, 22, 44, 88, and 176 mg P kg^{-1} soil). Nitrogen, potassium, and sulfur were added to all treatment combinations as follows: 1.36 kg soil, 2 g of 15–0–15 (N–P_2O_5–K_2O), and 0.12 g of $(NH_4)_2SO_4$ were thoroughly mixed and placed in 15-cm diameter pots on greenhouse benches. Pots were then watered to 100 g water kg^{-1} soil and kept moist. About 3 wk later, 1.1 g of annual ryegrass seed was planted in each pot.

Three harvests of plant shoot tissues were made by cutting plants about 2.5 cm above the soil surface. Shoot tissue was collected at 19, 34, and 47 d after planting. Plant tissue samples were dried at 60 °C and then weighed and ground. After the last cutting, three 2.5-cm soil cores were collected from each pot and air dried. The soil samples were then ground for P analysis.

Chemical analysis. Total elemental analysis of the recovered P material was determined with an inductively coupled plasma–atomic emission spectrometer (ICP) after digestion with nitric acid and hydrogen peroxide (Peters et al., 2003). Total C and N contents were determined by dry combustion.

Ryegrass shoot tissues were digested with concentrated sulfuric acid (Gallaher et al., 1976) and P concentration determined in the digest by automated ascorbic method. Phosphorus from soils at the end of the experiment was extracted using the Mehlich 3 procedure and P content was determined in the digest using colorimetric analysis (Tucker, 1992).

Statistical analysis. Experimental design was a randomized complete block with four replicates. Statistical analysis was performed using the GLM procedure of SAS (SAS Institute, Cary, NC). Soil extractable P responses to application rate for each fertilizer material were determined using linear regression analysis.

Results and Discussion

Composition of the recovered P materials. The two major elemental components of the RPM material were P and Ca (Table 2). Concentrations of other plant nutrients were low. These results relates to the $Ca(OH)_2$ used in the treatment plant to selectively precipitated P from wastewater in the form of calcium phosphate. Our results show that the RPM material had a total P content of 26% P_2O_5 (% P_2O_5 = g 114 P kg^{-1} × 0.229), which is between the total P content of single superphosphate (SSP) (16 to 22% P_2O_5) and

Table 1. Chemical properties of the soil used in the greenhouse study before amending with hydrated lime. Data are mean of two samples ± standard deviation

Soil properties	Value
pH in water	4.9 ± 0.1
Cation exchange capacity, cmol kg^{-1}	2.0 ± 0.4
Exchangeable acidity, cmol kg^{-1}	1.8 ± 0.3
Phosphorus, mg kg^{-1}	1.7 ± 0.1

Table 2. Selected elemental analysis of the recovered phosphorus materials from pig (RPM) and poultry litter (RPL). Mean of duplicate samples ± standard deviation

Element	Composition (g kg^{-1})	
	RPM	RPL
Total Phosphorus	114 ± 3	46 ± 1
Calcium	319 ± 1	119 ± 10
Total Carbon	64 ± 0.4	356 ± 1
Total Nitrogen	6.4 ± 0.1	36 ± 1
Magnesium	17.6 ± 0.2	7.0 ± 0.5
Potassium	8.7 ± 0.1	9.0 ± 0.2
Sodium	2.5 ± 0.1	3.0 ± 0.1

TSP (44 to 53% P_2O_5). Analysis by x-ray diffraction of the same material (Szogi et al., 2006a) indicated that this is amorphous calcium phosphate (ACP), which typically is more soluble than crystalline calcium phosphates such as hydroxylapatite.

On average, the RPL contained relatively large amounts of P, Ca, C and N and small amounts of other elements (Table 2). The P grade of the RPL product was on average about 11% P_2O_5. These results show that the quick wash approach can extract and recover P from poultry litter in a concentrated product that has the potential of being reused as fertilizer.

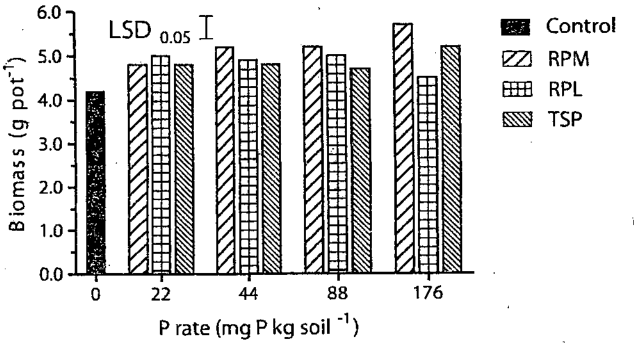

Fig. 1. Effect of fertilizer material and P rate on ryegrass biomass. RPM, phosphorus recovered from pig manure; RPL, phosphorus recovered from poultry litter; TSP, triple superphosphate. Difference between two means is not significant when the difference is smaller than the least significant difference (LSD $_{0.05}$ = 0.6 g pot^{-1}).

Greenhouse study. Biomass production was generally lower for plants fertilized with TSP. Only the 176 mg pot^{-1} rate of TSP had higher biomass than the control. In contrast, plants fertilized with RPM or RPL had greater biomass production than the control at three of the four P application rates (Figure 1).

Similar concentrations of P in plant tissues were found for RPM and RPL at same treatments P rates (Figure 2A). On the other hand, much higher P concentrations in plant tissue were obtained with TSP than with RPM or RPL treatments. At the highest application rate, P concentrations in plant tissues were 10 mg kg^{-1} for TSP and about 5 mg kg^{-1} for both RPM and RPL.

Phosphorus uptake by the ryegrass was dependent on fertilizer material and rate of application (Figure 2B). For TSP, plant uptake increased 0.17 mg pot^{-1} per each mg kg^{-1} increase in applied P. Phosphorus uptake with the RPM increased 0.13 mg pot^{-1} for each mg kg^{-1} increase in applied P. The lowest P uptake was observed at all rates of the RPL material. Phosphorus uptake in pots containing RPL increased only 0.07 mg pot^{-1} per each mg kg^{-1} increase in applied P (Figure 2B). At the highest application rate, total P uptake was 38.0 mg pot^{-1} for TSP, 30.4 mg pot^{-1} for RPM, and 20.2 mg pot^{-1} for RPL.

Mehlich-3 extractable soil P at the end of the experiment is shown in Figure 3. Mehlich-3 P for RPL was lower than RPM and TSP at the higher P rates of 88 and 176 mg kg soil^{-1}. This lower extractable soil P response of RPL is probably due to lower solubility

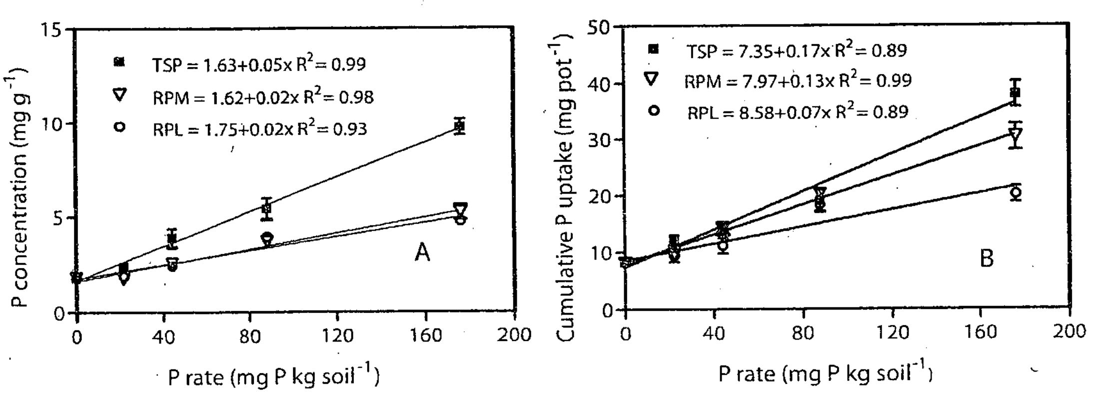

Fig. 2. Effect of fertilizer material and application rate on A) P concentration of ryegrass plant tissues and B) total P uptake by ryegrass. Standard error bars are shown when their size was larger than that of the symbol

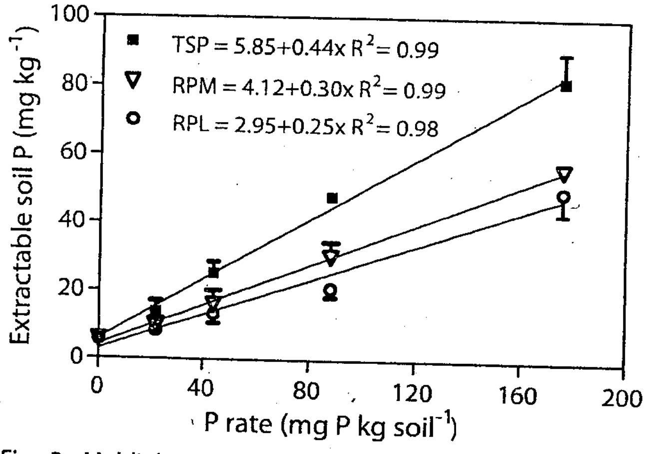

Fig. 3. Mehlich-3 extractable phosphorus concentration remaining in the soil after 47 days of ryegrass growth as affected by fertilizer material and application rates. Standard error bars are shown when their size was larger than that of the symbol

controlled by the insoluble inorganic and organic P fractions of this material. Interestingly, the highest response of TSP to Mehlich-3 extractable P explains the high P concentrations found in plant tissue and P uptake (Figure 2).

Conclusions

Our experimental results indicate that the recovered P materials may have different uses depending on its origin. Where more readily available P fertilizer is needed, the RPM material is a better choice. On the other hand, a less readily available P source, such as the RPL material, is better suited for applications that may require a slow release P fertilizer. Although further research is needed under field conditions and on more soil types for fertilizer application recommendations, the recovered P materials from pig liquid manure and poultry litter both have the potential as a fertilizer source without further chemical processing into other P materials, such as the acid treatment typically used to process rock phosphate for fertilizer use.

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