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Kinetics of phosphorus forms applied as inorganic and organic amendments to a calcareous soil II: effects of plant growth on plant available and uptake phosphorus

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ABSTRACT

The forms of phosphorus (P) in animal manure composts are different from that of synthetic P fertilizers, and this affects how soil P chemistry will be altered when they are used as P amendments. This study is an extension of a previously reported incubation study, where the net changes in the nature and dynamics of plant available P forms applied either as inorganic P (KH_2PO_4) or turkey litter compost (TLC) without plant growth were analyzed. The objective of this study was to analyze the net changes in the nature and dynamics of plant available P forms with plant growth in the greenhouse. The amounts of various P forms dependent on their solubility in soils were measured by a sequential fractionation method after 4, 8, 12 and 16 weeks incubation. The majority of TLC-P (brushite and newberyite) was recovered in the moderately labile P extracted with a weak acid. Though the labile P fraction in the TLC-treated soil was smaller than that in the fertilizer-treated soils, ryegrass growth was greater. Net transformation/plant uptake of the labile/moderately labile P was faster in the TLC-treated soil than the fertilizer-treated soil. A weak acid extractable inorganic P fraction should be considered as plant available P, especially in the compost-treated soil, which would be converted into plant available P through direct and/or indirect root-induced acidification in the rhizosphere.

1. Introduction

1.1. Animal manures and composts as a soil amendment

Organic amendments, such as animal manures and composts, are alternatives to synthetic mineral fertilizers for use in enhancing soil fertility. Organic amendments provide the soil with plant-available nutrients and organic matter (OM), resulting in benefits to both soil fertility and quality. Land application of animal manures and composts for use in crop production is the common fate of the large amounts of manure that are produced (Pagliari and Laboski, 2012). However, repeated application of animal manures and composts to agricultural fields can increase risks of nutrient leaching and runoff, especially P (Hunger et al., 2005; Sims et al., 2000). Therefore, organic amendments must be properly managed so as to avoid environmental concerns.

Amendments with animal manures and composts affect the chemistry of the soil, which alters both the amounts and distribution of the various soil P fractions (He et al., 2004; Pagliari and Laboski, 2012; Sato et al., 2005). There are several factors influencing soil P chemistry, which are potentially affected differently by animal manures and composts versus inorganic fertilizers (e.g. OM additions, macro- and micronutrients, and the different forms of P). Pagliari and Laboski (2012) analyzed 42 manure samples from seven animal species and found that a large fraction of manure-P was moderately stable or stable in non-ruminant animal species, while a labile P fraction was the dominant form of P in ruminant animal species and horses. A recent study of a turkey litter compost (TLC) showed that it contained mainly brushite ($CaHPO_4 \cdot 2H_2O_{(s)}$) and newberyite ($MgHPO_4 \cdot 3H_2O_{(s)}$) as forms of inorganic P, which were extractable with a weak acid extractant and considered as moderately labile P (Audette et al., 2016a). When applied to a calcareous soil, TLC increased the soluble P fraction extractable with ammonium acetate (NH_4Ac, pH 4.2) the most, while application of synthetic P fertilizer, in the form of KH_2PO_4, increased both a labile P fraction extracted by $NaHCO_3$ and a weak acid soluble P fraction during the 18-week incubation. Addition of synthetic fertilizer-P, in contrast to TLC, resulted in more labile P initially, with faster net transformation to a moderately labile P pool. TLC-P was recovered in a moderately labile P fraction initially, which was relatively constant during the entire incubation period. This incubation study, however, did not directly assess

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Abbreviations: OM, organic matter; TLC, Turkey litter compost; NH_4Ac, ammonium acetate; CD, citrate dithionite.

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the plant availability of the soil P fractions or the potential impact of plant roots on the kinetics of the forms of soil P.

1.2. Effects of plant growth on plant available P in soils

It is known that the biological interactions and biochemical processes occurring at the root surface influence the availability of P to plants (Richardson, 2001). Rhizosphere soil is significantly more active both chemically and biologically compared to bulk soil, and this influences the dynamics of plant P uptake significantly. A wide assortment of organic compounds, including aliphatic, amino, and aromatic acids and amides, sugars, amino sugars, cellulose, lignin, and protein, have been found in the rhizosphere (Frey, 2007), and they are produced by plant roots and/or microbial activity (Richardson, 2001). These organic anions and associated microorganisms are effective in releasing soil P through various mechanisms. The mechanisms include: (1) a reduction in rhizosphere pH due to H^+ ions released as counter ions in response to organic anion exudation, and this directly increases the solubility of P minerals (Hinsinger, 2001; Kovar and Claassen, 2005; Richardson, 2001; Shen et al., 2011), (2) desorption of P through ligand exchange reactions by inorganic ligands, such as sulphate and bicarbonate, or organic ligands, such as carboxylic anions (Hinsinger, 2001; Richardson, 2001), (3) acting as chelating agents to form complexes with Ca, Fe, or Al in soils, thereby releasing P into the soil solution (Kovar and Claassen, 2005; Plante, 2007; Richardson, 2001), and (4) increasing the accessibility of soil organic P to enzymatic hydrolysis (Richardson, 2001). Root-induced acidification of the rhizosphere can significantly increase the bioavailability of P especially in neutral to alkaline soils (Hinsinger, 2001). In fact, in calcareous soils significant accumulations of total P and Olsen P ($NaHCO_3$ extractable P) have been observed in rhizosphere soils from five different xeno-shrubs compared to their bulk soils, where soil pH in the rhizosphere decreased by 0.4 to 0.8 units (Ma et al., 2009).

1.3. Hypothesis and objective

This study is an extension of a previously reported incubation study, where the kinetics of labile/moderately labile P fractions applied either as inorganic P (KH_2PO_4) or organic P (TLC) without plant growth were analyzed (Audette et al., 2016a). It is hypothesized that forms of P present in TLC may be converted into plant available P with root-induced acidification in the rhizosphere faster than those in mineral P fertilizers. In addition, macro- and micronutrients, such as Ca^{2+} and Mg^{2+}, and OM present in the compost can affect the stabilization of P forms in soils. The proportion and the forms of plant available P in soils amended with compost may differ from those in the soil treated with mineral fertilizers. The objective of this study was to compare the effects of inorganic P (KH_2PO_4) and organic P (TLC) amendments on the uptake of P by ryegrass and on the distribution, transformation, and the forms of plant available P during ryegrass growth.

2. Materials and methods

2.1. Calcareous soil and turkey litter compost analyses

Topsoil (~15 cm) was collected in spring prior to planting from an organically-managed farm field located near Scotland, Ontario (43 00′ 18.5″N 80 25′02.1″W). The sandy loam soils in this area are classified as Brunisolic Gray Brown Luvisols and belong to the Breton series. The field-moist soil was sieved (<2 mm) to remove plant residues and coarse mineral particles and stored air-dried. The TLC was obtained from a composting facility processing a blend of turkey litter, softwood shavings, wheat straw bedding and spent mushroom substrate. In preparation for soil amendment the TLC was lyophilized and was ground to <0.15 mm. Lyophilization has been suggested to be the preferred treatment providing the best compromise for longer sample storage, and limiting oxidation of reduced Fe-phases (Condron and Newman, 2011). The chemical properties of the soil and TLC were determined by SGS Agri-Food Laboratories, Guelph Ontario (Table 1).

Table 1
Physical and chemical properties of the soil and turkey litter compost ($n = 5$).

	Turkey litter compost	Calcareous soil
Texture (sand:clay:silt)[a]	N/A	Sandy loam (75:5:20)
pH[b]	7.06 ± *0.05*	7.18 ± *0.04*
Organic C (%)[c]	19.6 ± 0.6	1.3 ± *0.1*
CEC ($cmol_c\ kg^{-1}$)[d]	N/A	13.3 ± *0.6*
———— $mg\ kg^{-1}$ ————		
Total N[e]	$26.5 \times 10^3 \pm 1.5 \times 10^3$	N/A
NH_4–N[f]	$3.5 \times 10^3 \pm 0.1 \times 10^3$	N/A
Total P[g]	$34.1 \times 10^3 \pm 2.6 \times 10^3$	343 ($n = 1$)
Ca[h]	$96.8 \times 10^3 \pm 7.8 \times 10^3$	$1.77 \times 10^3 \pm 0.08 \times 10^3$
Mg[h]	$23.7 \times 10^3 \pm 5.2 \times 10^3$	347 ± *26*
Cu[h]	87.6 ± *9.5*	2.3 ± *0.2*
B[h]	16.4 ± 0.6	0.65 ± *0.03*
Mn[h]	457 ± *18*	24.2 ± *0.9*
Zn[h]	371 ± *26*	1.5 ± *0.2*

Values in italics indicate standard error.
N/A = not available.

[a] Texture was measured by the Bouyoucos Hydrometer Method (Bouyoucos, 1962).
[b] pH was measured using a 1:2 ratio of soil to Nanopure water.
[c] Organic C was measured by the wet-oxidation technique (Shaw, 1959).
[d] CEC was measured by the ammonium acetate (pH 7) method (Chapman, 1965).
[e] Total N was measured by the Dumas method (Dumas, 1831).
[f] NH_4-N was extracted with 2.0 M KCl and was measured by the modified Berthelot method (Rhine et al., 1998).
[g] Total P was measured by the perchloric acid digestion method (Olsen and Sommers, 1982).
[h] Micronutrients were extracted with 1.0 M NH_4Ac and measured by ICP-OES.

2.2. Greenhouse settings and treatments

The study was conducted during a 16-week period between June and September 2013, in a greenhouse at the University of Guelph, Ontario under natural lighting conditions. Temperatures were kept at 24/26 °C in the daytime and 19/22 °C in the nighttime. Soil (400 ± 1.0 g oven-dry weight) was placed in ~10 cm diameter pots. Four replicates of six treatments including lyophilized TLC amendment at a rate of 200 mg P kg^{-1} soil, and inorganic P fertilizer (a reagent grade chemical, KH_2PO_4) amendment at rates of 0 (control), 50 (F50), 100 (F100), 150 (F150) and 200 (F200) mg P kg^{-1} soil were prepared by mixing the amendment thoroughly with the soil. In order not to have K and N as limiting nutrients, the equivalent amounts of K as KCl, and N as NH_4NO_3 were mixed with the soil in each pot. It was assumed that all of the compost-derived K and NH_4^+-N were plant available, and 20% of organic N would be mineralized during this study period (Waldrip et al., 2011). The rates of 252 mg K kg^{-1} soil and 111 mg N kg^{-1} soil were added to each pot, and N supply was maintained through biweekly additions of NH_4NO_3 at the rate of 111 mg N kg^{-1} soil to all pots. Fifteen ryegrass (*Lolium perenne*) seeds (0.02 g) were planted at a depth of ~0.6 cm (equivalent to a seeding density of 25 kg per hectare). Treatment applications and ryegrass seeding occurred on day 0 of the experiment.

The soil moisture content in the pots was brought up to field capacity (~17%) at day 0 and it was maintained throughout the study period by daily weighing pots and addition of nanopure water. Pot positions on the growth bench were changed daily to minimize potential location effects within the greenhouse. To maintain a relatively constant rate of plant growth, the plant leaves were clipped to ~30 mm height and collected starting at day 17, and this was performed approximately biweekly for the duration of the study. Composites of the harvested plant tissue were analyzed after 4, 8, 12, and 16 weeks growth.