



Agronomic effectiveness of a granular poultry litter-derived organomineral phosphate fertilizer in tropical soils: Soil phosphorus fractionation and plant responses

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ABSTRACT

Production of organomineral phosphate fertilizers (OMF) from poultry litter (PL) has been suggested to reduce the dependence on phosphorus (P) reserves. Here, we compared a granular PL-derived OMF to triple superphosphate (TSP) in two contrasting tropical soils (Oxisol and Entisol) by using isotope dilution with ³²P. Our study aimed to gain insight into soil P fractionation, and P availability to maize plants achieved by P fertilization (0, 25, 50, 75 and 100 mg kg⁻¹ of soil), in order to investigate the agronomic effectiveness of OMF. Despite μ -XRF maps revealing that the mixture of PL and TSP as OMF resulted in P hot spots disseminated in a low-concentration background, whereas for the TSP treatment higher P concentration was uniformly distributed in the granules, there was no difference in maize yield and fertilizer P recovery (%R) between P sources in both soils. In the Oxisol, there was no difference between fertilizers in any of the soil P pools, but larger readily phytoavailable P and smaller moderately labile P fractions were obtained with OMF. In the Entisol, the labile P pool was larger with TSP. Nevertheless, acid and alkaline phosphatase activity and microbial biomass were affected by P rate and P source. The results show that OMF is an effective substitute for conventional phosphate fertilizers, since OMF promotes P recovery, plant P uptake and biomass yields compared to those obtained with TSP.

1. Introduction

Phosphorus (P) is an essential element for plant growth, and its deficiency in weathered tropical soils is often reported (Rodrigues et al., 2016). Such soils have a high content of strong P-adsorbing minerals such as hematite, goethite and gibbsite (Parfitt et al., 1975), which results in poor fertilizer P recovery by crops. Thus, frequent P fertilization is required for the maintenance of crop yields, which reduces finite non-renewable resources of P. In this context, the use of organic manures like poultry litter (PL) is an alternative to reduce dependence on mineral P resources.

According to the United States Department of Agriculture, in 2017, world poultry production was approximately 90.72 million metric tons (USDA, 2018). Considering that to produce 1 ton of poultry, 0.76 tons of PL (on a dry basis) is generated (Migliavacca and Yanagihara, 2017), about 68.95 million tons of PL is produced annually. Furthermore, PL

contains on average 1.77% P (Rogeri et al., 2016), representing a large P pool which can be recycled and used in cropping systems. However, inadequate disposal of PL on the soil surface is often reported to cause serious environmental problems like eutrophication of water bodies (Schroeder et al., 2004). Thus, strategies to increase the utilization of PL associated with reduction of environmental risks are fundamental. In this context, the use of PL for production of granular organomineral P fertilizers (OMF) is a promising option, from both environmental and economic aspects.

The association of mineral P sources with PL in OMF reduces P adsorption by soil minerals since organic compounds interact positively with P (Koch et al., 2018), consequently improving the efficiency of inorganic P fertilizers. Although several authors have evaluated the response of many crops to application of OMF produced from different organic wastes (Antille et al., 2017; Corrêa et al., 2016; Mazeika et al., 2016), the potential for improvement of P fertilization has been poorly

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studied. Gondok and Filippek-Mazur (2005) observed a higher plant P content in maize and sunflower fertilized with OMF compared to mineral fertilization. However, in a more recent study, Sakurada et al. (2016) found that granular OMF did not increase either the shoot dry matter yield or P recovery by maize in two consecutive cropping cycles in a clayey Oxisol.

These contrasting results on the effectiveness of OMF may partly be explained by differences in soil P-adsorption capacity, which directly affects soil P availability, and plant and microbial mechanisms to mobilize soil P, such as the activity of phosphatase enzymes (Richardson et al., 2011). However, it has not yet been investigated. The objective of this study was to assess the efficiency of a granular OMF in two contrasting soils in terms of P-adsorption capacity using the isotopic dilution method with ^{32}P . We hypothesized that OMF is more efficient than a water-soluble P fertilizer (triple superphosphate) in a highly P-adsorbing soil (Oxisol), and less efficient in sandy soil (Entisol).

2. Materials and methods

2.1. Organomineral fertilizer production

Production of the granular organomineral fertilizer was performed in three steps. First, both organic (PL) and mineral (triple superphosphate, TSP) P sources were oven-dried at 60 °C until constant weight, ground separately in an industrial mixer and sieved (60 mesh). Based on the total P (Pt) content of each P source, the organomineral mixture (PL plus TSP) was formulated to have 20% P, and then was homogeneously mixed in an industrial mixer with bentonite (2%). The OMF granules were obtained by placing the mixture in a disk granulator with a diameter of 75 cm rotating at 20 rpm at an angle of 38.2° with the addition of a 2% sodium silicate solution spray.

Granules were oven-dried at 60 °C until constant weight, sized between 3 and 4 mm, and chemically characterized (Table 1) according to the method described in the Brazilian Ministry of Agriculture manual (BRASIL, 2014). In summary, fertilizers were ground (0.5 mm sieve) and digested in a mixture (2.5:1) of HNO_3 and HClO_4 . Potassium (K), Copper (Cu), manganese (Mn), zinc (Zn), sodium (Na) and iron (Fe) in the extracts were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES; iCAP 7000 series, 140 Thermo Fisher Scientific Inc.). Boron (B) content was determined by the azomethine-H method. Phosphorus content was determined by the gravimetric Quimiac method. Nitrogen (N) and organic carbon content were determined by dry combustion on a LECO CN-2000 elemental analyser.

The fertilizers were examined using scanning electron microscopy (SEM; LEO 435 VP, Carl Zeiss, Jena, Germany), and the phosphorus

Table 1
Chemical composition of the fertilizers.

Property	OMF ^a	TSP ^b
pH (0.01 M CaCl_2)	4.3	3.05
Organic carbon (%)	20.75	0
P_{total} (%)	9.57	20.73
P_{water} (%)	4.77	17.27
P_{NAC}^c (%)	9.25	20.47
P_{CA}^d (%)	8.24	18.14
N_{total} (%)	2.14	0
K_2O (%)	2.44	0
B (mg kg^{-1})	15.3	0
Cu (mg kg^{-1})	360	59.5
Mn (mg kg^{-1})	506	595
Zn (mg kg^{-1})	442	382
Na (g kg^{-1})	14.13	0
Fe (g kg^{-1})	10.78	15.78

^a Organomineral phosphate fertilizer.

^b Triple superphosphate.

^c P soluble in neutral ammonium citrate plus water.

^d P soluble in 2% citric acid.

Table 2
Chemical and physical properties of the selected soils.

Property	Oxisol	Entisol
pH (0.01 M CaCl_2)	4.5	4.3
Organic matter (g kg^{-1})	5	5
Resin P (mg kg^{-1})	2	6
MPAC ^a (mg kg^{-1})	2048.6	270.3
Exchangeable Ca^{2+} ($\text{mmol}_c \text{dm}^{-3}$)	4	3
Exchangeable Mg^{2+} ($\text{mmol}_c \text{dm}^{-3}$)	1	1
Exchangeable K^+ ($\text{mmol}_c \text{dm}^{-3}$)	0.1	0.1
$\text{H}^+ + \text{Al}^{3+}$ ($\text{mmol}_c \text{dm}^{-3}$)	42	22
Zinc (mg dm^{-3})	0.2	0.3
Sulphate (mg dm^{-3})	30	7
CEC ^b ($\text{mmol}_c \text{dm}^{-3}$)	47	26
Clay (g kg^{-1})	667	62
Silt (g kg^{-1})	123	8
Sand (g kg^{-1})	210	930

^a Maximum phosphate adsorption capacity.

^b CEC, cation exchange capacity.

distribution of the cross section was analysed by X-ray fluorescence microanalysis ($\mu\text{-XRF}$; Orbis PC EDAX, Mahwah, USA).

2.2. Experimental setup

The experimental design was completely randomized with $2 \times 4 + 1$ factorial treatments and four replications. The factors corresponded to two P sources: i) OMF and ii) TSP, and five P rates: 0, 25, 50, 75 and 100 mg kg^{-1} soil. We selected two contrasting soils in terms of P-adsorption capacity (Table 2): an Oxisol (Typic Hapludox, 47°33'W, 22°43'50" S) and an Entisol (Typic Quartzipsamment, 47°53'23" W, 22°34'00" S) (Soil Survey Staff, 2014).

The soils were collected from the top layer (0–20 cm), air-dried and sieved to < 2 mm before use. Samples from each soil were used for chemical (van Raij et al., 2001), particle-size (Bouyoucos, 1926) and mineralogical (X-ray diffraction, XRD) analyses (Table 2 and Fig. A.1). The maximum phosphate adsorption capacity (MPAC) was determined by shaking 2.5 g of soil at 147 rpm for 36 h in 25 mL of 0.01 M $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ with increasing levels of P (added as KH_2PO_4) (0, 5, 10, 25, 50, 75, 100, 200, 300 and 500 mg L^{-1}). Soil samples were prepared in triplicate. The MPAC was obtained after fitting to the Langmuir isotherm (Fig. A.2).

A pot trial was carried out in a glasshouse, using sealed plastic bags filled with 5 kg of soil (dry weight) from the surface layer (0–20 cm). Soil acidity was corrected with CaCO_3 to achieve a base saturation of 70% (van Raij et al., 1997) by incubating the soil for 30 days at 70% water-holding capacity (WHC). The air temperature in the glasshouse ranged between 20 and 40 °C, with a relative air humidity of 60.5%.

To quantify accurately the P taken up by the plants from the fertilizers, the isotopic dilution method with ^{32}P (indirect method) was used (Fig. A.3). For this, soils were uniformly labelled with 1.76 MBq kg^{-1} of carrier-free ^{32}P -orthophosphate by incorporating 20 g of dry sand previously labelled with ^{32}P , and then the soil was thoroughly mixed and incubated for 10 days to allow isotopic equilibrium between ^{32}P and ^{31}P . The soil moisture was adjusted daily to 70% WHC.

The treatments were applied in deep bands (7 cm), in which five maize seeds (*Zea mays* L., cv. Pioneer P4285H) were sown at 1 cm intervals in the fertilizer row. Plants were thinned to two plants per pot 5 days after sowing. Soil fertility was corrected by applying a nutritive solution containing the following nutrients (mg kg^{-1} soil): N (150), K (150), Cu (2), Fe (5), Mn (1), Mo (1), Zn (5) and B (1.5). N and K doses were parcelled out at 7 and 25 days after sowing (DAS) (70 and 80 mg kg^{-1} soil, respectively). The other nutrients were applied at 7 DAS. In order to assess the isolated effect of P addition, we balanced the input of macro- and micronutrients (through a nutritive solution) between treatments considering their chemical composition (Table 1).

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