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Inorganic and organic phosphorus pools in earthworm casts (Glossoscolecidae) and a Brazilian rainforest Oxisol

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Abstract

We compared differences in soil phosphorus fractions between large earthworm casts (Family Glossoscolecidae) and surrounding soils, i.e., Oxisols in 10 year-old upland agroforestry system (AGR), pasture (PAS), and secondary forest (SEC) in the Central Brazilian Amazon. AGR and PAS both received low-input fertilization and SEC received no fertilization. We found that earthworm casts had higher levels of organic hydroxide P than surrounding soils, whereas fertilization increased inorganic hydroxide P. Inorganic P was increased by fertilization, and organic P was increased by earthworm gut passage and/or selection of ingested materials, which increased available P (sum of resin and bicarbonate fractions) and moderately available P (sum of hydroxide and dilute acid fractions), and P fertilizer application and land-use increased available P. The use of a modified sequential P fractionation produced fewer differences between earthworm casts and soils than were expected. We suggest the use of a condensed extraction procedure with three fractions (Available P, Moderately Available P, and Resistant P) that provide an ecologically based understanding of the P availability in soil. Earthworm casts were estimated to constitute 41.0, 38.2, and 26.0 kg ha^{-1} of total available P stocks (sum of resin and bicarbonate fractions) in the agroforestry system, pasture, and secondary forest, respectively.
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Keywords: Agroforestry; Amazonia; *Bactris gasipaes*; *Bertholletia excelsa*; Oxisol; Pasture; Secondary forest; Sequential phosphorus extraction

1. Introduction

Low soil fertility of the *terra firme* (upland) soils is a major constraint for sustaining the productivity of agroecosystems in the Amazon (Sanchez et al., 1982), especially because 96% of Amazon soils are phosphorus (P) deficient for agricultural productivity (Dematê and Dematê, 1997). Where P inputs are not available or locally affordable, tree-based cropping systems can be a sustainable alternative to annual cropping systems (Lehmann et al., 2001). However, research has focused little on the soil biological component of these systems, which has the potential for compensating some of the soil deficiencies, either of chemical or physical nature.

'The plow is one of the most ancient and most valuable of man's inventions, but long before he existed the land was in fact regularly plowed, and still continues to be thus plowed by earthworms (Darwin, 1881).' Not only have earthworms been recognized to improve soil physical characteristics, but they also impact soil chemical characteristics (Barois et al., 1999). Earthworms are among the most important soil macrofauna (>2 mm) influencing the soil, and may be highly influential in increasing soil P availability. Earthworms are abundant and are concentrated in the top 10 cm of soil, however they often occur in the top 40 cm of the soil profile (Fragoso and Lavelle, 1992). They can ingest 4–10% of the A horizon annually, depending on soil type (James, 1991). In a forest soil in central Amazonia, north of Manaus, Brazil, soil macroinvertebrate biomass was 54 g m^{-2}, which included large earthworms

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(Oligochaeta) measuring more than 1 m in length and accounting for more than 80% of the earthworm biomass (Barros et al., 2000). The Families Glossoscolecidae and Ocnerodrilidae dominate South American tropical forest earthworm communities (Fragoso and Lavelle, 1992). In an abandoned rubber tree system north of Manaus, Brazil, eight earthworm species were observed. They were mostly from the Family Glossoscolecidae, including earthworms of the genus *Rhinodrilus*, measuring up to 1.1 m long (Römbke et al., 1999).

Although the activities within the gut of an earthworm are not entirely understood, it is clear that the ingested soil and/or litter is broken down, rearranged, and re-aggregated (Barois and Lavelle, 1986). This restructuring of soil after its passage through the earthworm gut has been called 'regeneration' (Barois et al., 1993), which has been recognized to influence soil N availability (Barois et al., 1987; Pashanasi et al., 1992; Araujo et al., 2004), as well as soil P availability (Guerra, 1982). In a glasshouse experiment, Guerra (1982) found that plant P uptake was up to three times higher in the presence of *Pontoscolex corethrurus,* either from the labeled P added to the soil or stable soil P. Earthworms may affect P cycling in soils by concentrating P in their casts through ingestion of P-rich particles, modifying the relative proportions of different P forms, and modifying stability of P forms (Brossard et al., 1996).

The Hedley fractionation is a sequential P extraction used to quantify plant-available inorganic P, Ca-associated inorganic P, Fe- and Al-associated inorganic P and labile and more stable forms of organic P (Hedley et al., 1982). This approach is thought to be the only sequential fractionation that can evaluate available organic P with moderate success (Tiessen and Moir, 1993). We designed this study to compare the Hedley P fractions between earthworm casts of the large earthworms (Family Glossoscolecidae) and surrounding soils.

2. Materials and methods

2.1. Site description

The study area is located in central Amazonia at the EMBRAPA-CPAA field station located along highway BR-174, 53 km north of Manaus (2°30′36″ S and 2°30′42″ S and 60°01′29″ W and 60°01′46″ W (Coolman, 1994)), in the State of Amazonas, Brazil. The natural vegetation is upland Evergreen Tropical Rainforest and the soil is a fine, isohyperthermic, Xanthic Hapludox (US Soil Taxonomy) with a pH of 4.3, available P of 2.5 mg P kg^{-1} soil (Mehlich-1), organic C of 26 mg g^{-1}, total N of 2.0 mg g^{-1}, and 356.7, 77.8, and 35.2 mg of Ca, Mg and K, respectively, kg^{-1} soil in the top 15 cm (McKerrow, 1992). Soil bulk density is 0.96 g cm^{-3} (Coolman, 1994). The climate is humid tropical, the mean annual rainfall is 2500 mm, and mean annual temperature is 26.2 °C. The mean relative air humidity is 83.9% (Tapia-Coral et al., 1999).

2.2. Site history

The site is a former *Brachiaria decumbens* pasture that was grazed for 4–8 years prior to being abandoned. The scrub forest that regenerated on the abandoned pasture was slashed and burned in 1991, 3–5 years post-abandonment and four agroforestry prototype systems were established (Fernandes et al., 1995). Of the four systems, three systems were selected, with sampling focused on soils beneath specific trees and grasses, chosen to represent useful and profitable species for local economies. The species sampled in the agroforestry system (AGR) were *Theobroma grandiflorum* Schumann, *Bactris gasipaes* Kunth, *Bertholletia excelsa* Humb. and Bonpl., and *Eugenia stipitata* McVaugh. The pasture (PAS) was sampled beneath *Brachiaria humidicola* Rendle, and the secondary forest (SEC) was sampled around the base of *Vismia* and *Cecropia* trees.

AGR was fertilized with Triple Super Phosphate (20.1% P), KCl (49.8% K), lime (40.0% Ca), and urea (45% N) to provide 15.8 kg N ha^{-1} y^{-1}, 23.7 kg P ha^{-1} y^{-1}, 12.3 kg K ha^{-1} y^{-1}, and 4.7 kg Ca ha^{-1} y^{-1} for the period from 1991, when the systems were established, to 2001, when sampling was conducted. PAS received fertilization over the same time period with the same products, in addition to ammonium sulfate (21% N; 23% S), at the rate of 4.6 kg N ha^{-1} y^{-1}, 5.7 kg P ha^{-1} y^{-1}, 0.5 kg K ha^{-1} y^{-1}, 1.6 kg S ha^{-1} y^{-1}, and 80.0 kg Ca ha^{-1} y^{-1}. PAS was originally grazed for 7 days with a 21-day rest period. Stocking rates and grazing periods were adjusted with varying plant-growing conditions. SEC was left to grow post-burn since 1991, without chemical amendments.

2.3. Sample collection

Earthworm cast and soil samples were taken within a 1 m radius from the base of tree and grass species. Each soil sample was a composite of five soil samples (0–15 cm depth) ('soil' is used to distinguish earthworm casts from adjacent soil substrate that did not visibly constitute earthworm casts). Earthworm casts from large earthworms, approximately 1–1.5 m long (personal observation), of the Family Glossoscolecidae, locally referred to as 'minhocuçus', were taken from the soil and litter surface. Beneath each of the tree species in AGR and SEC, nine earthworm cast samples and nine soil samples were taken from the entire sampling area, with three earthworm cast samples and three soil samples per block. In PAS, 18 earthworm cast samples and 18 soil samples were taken from the entire sampling area, with six earthworm cast samples and six soil samples per block. The sampling of earthworm casts and soils was random by tree species in each land-use system. The representative species in AGR sampled were