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Nitrogen mineralization dynamics of different valuable organic amendments commonly used in agriculture

Raphael Habai Masunga[a,e], Veronica Nwakaego Uzokwe[b,*], Peter Deusdedit Mlay[a], Inakwu Odeh[c], Ajay Singh[d], David Buchan[e], Stefaan De Neve[e]

[a] Lake Zone Agricultural Research and Development Institute, Ukiriguru, P.O.Box 1433, Misungwi District, Mwanza, Tanzania
[b] International Institute of Tropical Agriculture, Eastern African Hub, Plot No. 25, Mikocheni Light Industrial Area, Mwenge-Coca Cola Road, Mikocheni B, P.O. Box 34441, Dar es Salaam, Tanzania
[c] Department of Environmental Sciences, The University of Sydney, Rm 409, Biomedical Building C8, 1, Central Avenue, Australian Technology Park, Eveleigh, Sydney, NSW 2006, Australia
[d] Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal, 721 302, India
[e] Faculty of Bioscience Engineering, Ghent University, Coupure Links, 653, 9000 Ghent, Belgium

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ABSTRACT

Sustainable agriculture requires the careful optimization of the use of organic amendments to improve soil fertility while minimizing any harmful environmental effects. To understand the events that occur in soil after the addition of different organic amendments, we evaluated the nitrogen (N) mineralization dynamics in soil after adding organic amendments, and evaluated changes in the microbial population. The four organic amendments were fresh dairy cattle manure, fresh white clover, vegetable, fruit, and yard waste compost, and poplar tree compost. The N mineralization potential of each organic amendment was determined by analyzing total mineral nitrogen during a 97-day laboratory incubation experiment. Soils amended with clover released 240 $\mu g\,N\,g^{-1}$ soil during the 97-day incubation, more than twice as much as that released from soils amended with manure or composts (76–100 $\mu g\,N\,g^{-1}$ soil). At the end of the incubation, the net N mineralization in clover-amended soils was 54%, more than five times higher than that in soils amended with composts or manure (4%–9%). Nitrogen was mineralized faster in clover-amended soil (1.056 $\mu g\,N\,g^{-1}$ soil day^{-1}) than in soil amended with composts (0.361–0.417 $\mu g\,N\,g^{-1}$ soil day^{-1}). The microbial biomass carbon content was higher in clover-amended soil than in the soils amended with manure or composts. We monitored changes in the microbial population in amended soils by a phospholipid fatty acid (PLFA) analysis. On day 97, there were higher concentrations of total PLFAs in soils with organic amendments (e.g., 14.41 nmol g^{-1} in clover-amended soil) than in control soil without amendments (9.84 nmol g^{-1}). Bacteria (Gram-positive and Gram-negative), actinomycetes, and fungi were more abundant in clover-amended soils than soils amended with manure or composts. The N mineralization potential varied among the four organic amendments. Therefore, the timing of application and the type of organic amendment should be matched to the nutrient needs of the crop.

1. Introduction

To increase crop yields, reduce environmental pollution, and achieve sustainable agriculture, soil fertility needs to be maintained at an appropriate level, or restored if it has decreased (Diacono and Montemurro, 2010; Fageria, 2007). In farming systems with low inputs of chemical fertilizers and pesticides, this can be achieved by rotating leguminous and non-leguminous crops, and by addition of organic amendments (OA). These OAs can be composted or non-composted organic wastes from agriculture, industry, municipal operations, seaweed, or blood and bone meal (Quilty and Cattle, 2011).

Abbreviations: AMF, arbuscular mycorrhizal fungi; CLO, fresh white clover; COI, poplar tree compost; COV, vegetable, fruit, and yard waste compost; ILVO, Institute for Agriculture and Fisheries Research; MAN, cattle manure; OA, organic amendments; PLFA, phospholipid fatty acid; SOM, soil organic matter; TOC, total organic carbon.

* Corresponding author. Fax: +255 22 2775021.
E-mail addresses: v.uzokwe@cgiar.org, uzokwene2008@googlemail.com (V.N. Uzokwe).

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The application of OAs is common in organic farming systems. These OAs enhance plant growth and may reduce the need for mineral fertilizers (Mohanty et al., 2011), which reduces costs for farmers. Organic amendments restore and reclaim degraded soils by maintaining organic matter and sustaining soil fertility for agricultural production, particularly in the long-term, by slowly releasing nutrients (Tejada et al., 2009). Thus, OAs recycle nutrients and organic matter to support crop productivity and maintain soil quality (Whalen et al., 2001).

Soil organic matter (SOM) is a storehouse and supplier of nutrients such as nitrogen (N), phosphorus, and sulfur to crops (Schulten and Schnitzer, 1998), and it improves the physical, chemical, and biological properties of soils (Diacono and Montemurro, 2010). The growth and activity of soil microbes are stimulated by SOM, leading to efficient mineralization of crop nutrients (Tejada et al., 2009). The SOM is derived from plants, animals, and microbes. These organic materials, either added to the field or already on-site, decompose via mineralization to release the nutrients required for crop growth and development (Diacono and Montemurro, 2010). The recent popularity of OAs in agriculture represents an alternative strategy to manage wastes and improve the SOM content in low-fertility soils (Flavel and Murphy, 2006).

Nitrogen mineralization is a biological process. The amount of N released to crops depends on the chemical composition of organic matter (e.g., N content, carbon:N ratio, and contents of cellulose and hemicelluloses, lignin, and polyphenols) (Calderón et al., 2005; Mohanty et al., 2011) and on the physical, chemical, and biological properties of soil microbes (Manojlović et al., 2010). Organic amendments with high N contents and low C:N ratios mineralize sufficient N to satisfy plant growth (Cordovil et al., 2005; Seneviratne, 2000). Conversely, N can be immobilized in OAs with lower N contents and higher C:N ratios (Manojlović et al., 2010).

It is important to manage OAs appropriately to avoid contaminating the environment (Manojlović et al., 2010). Groundwater and atmospheric contamination are the main impacts of excessive use of organic fertilizers in agriculture (Calderón et al., 2005). There are two main reasons for exploring the N mineralization dynamics of OAs used in agriculture; first, to avoid excess fertilizer application and reduce N losses to the environment; and second, to optimize residue management to maximize crop production, especially in low-input agriculture based on nutrient recycling (Bruun et al., 2006).

There have been some studies on the dynamics of N mineralization from OAs in agro-ecosystems; for example, animal manures, crop residues, and composts (Abbasi et al., 2007; Amanullah, 2007; Azeez and Van Averbeke, 2010; De Neve and Hofman, 1996; Van Kessel and Reeves, 2002). However, few studies have specifically compared the effects of various kinds of OAs (e.g., cattle manure, compost, and green manure) on N mineralization and on the microbial population as the main decomposers. In this study, we focused on the effects of various OAs on both N mineralization and the microbial population, which plays an important role in nutrient recycling, especially in organic farming systems. Two hypotheses were tested. First, we hypothesized that the N mineralization dynamics in soil will differ depending on the type of OA added. Second, we hypothesized that the addition of different OAs will have different consequences in terms of the size and composition of the microbial population.

2. Materials and methods

2.1. Soil collection and analysis

Sandy loam soil was collected from the surface layer (0–20 cm) at the Research Farm of the Institute for Agriculture and Fisheries Research (ILVO), Merelbeke, Belgium. White clover had been cultivated in this soil continuously for several years. The soil was obtained in September 2011 at 17% (w/w) field moisture content, and a subsample was taken for chemical analysis. Field-moist soil was passed gently through a 4.75-mm sieve to remove root materials, surface litter, and stones. The soil pH was measured with a pH meter in a potassium chloride suspension (1.0 g soil: 2.5 ml KCl). Total N and C contents were determined using a CNS Analyzer (Variomax CNS Elementar, Hanau, Germany). The soil had a pH_{KCl} of 5.5 (1:2.5 w/v), a bulk density of 1.3 g cm^{-3}, 0.09% total N content, and 1.12% total C content.

2.2. Organic amendments

We used four different OAs in the 97-day laboratory incubation experiment. Fresh dairy cattle manure (MAN) and fresh white clover (CLO) were obtained from the ILVO. The other two OAs were composts: vegetable, fruit, and yard waste compost (COV), produced from household wastes and obtained from Vlaamse Compostorganisatie (VLACO; Mechelen, Belgium); and poplar tree and grass compost (COI), which was obtained from the ILVO.

2.3. Laboratory incubation procedure

Before the incubation experiment, the fresh white clover was chopped into small pieces (with dimensions of approximately 2–10 mm) using a kitchen knife. Each OA was mixed with 200 g of moist soil at a rate indicated in Table 6 then placed in plastic tubes (7.2-cm length, 6.8-cm diameter). Then, the soil was compacted to give a bulk density of 1.3 g cm^{-3} (identical to that measured in the field). The tubes were covered with pin-holed parafilm to allow air circulation and minimize water evaporation, then incubated in the dark at 20 °C for 97 days. For the control, no OA was added to the soil, but the soil samples were mixed, compacted, covered, and incubated in exactly the same way as the soils in the OA treatments. During the incubation period, all soils were maintained at 55% water-filled pore space (WFPS), which was calculated from the bulk density and the gravimetric moisture content. The weight loss of each tube was checked daily, and distilled water was added to each tube to maintain a constant soil moisture content as required.

Four separate replicates of each of the four treatments and the control were analyzed at each sampling time (days 7, 21, 40, 68, and 97 days of incubation). All parameters (mineral N, microbial biomass C (C_{mic}), PLFA concentration, and moisture content) were measured for each replicate.

2.4. Measurements of mineral nitrogen and microbial biomass carbon

To measure mineral N, 30 g of soil was extracted in 60 ml 1 M KCl with shaking for 1 h. The mixture was filtered through mineral N filter paper (MN 616), then the extract was stored at −18 °C until analysis. Mineral N (NO_3^--N and NH_4^+-N) was determined with a continuous flow auto-analyzer (Chemlab System 4, Skalar, The Netherlands).

The net N mineralization of each OA was calculated as the difference in the amount of mineral N released between amended and control soil (Mohanty et al., 2011). The percentage of total N mineralized from each OA at each sampling time was calculated as described by Azeez and Van Averbeke (2010) and Abbasi et al.