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Dynamics of size–density fractions of soil organic matter following the addition of tree litter to organic coffee farms

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Abstract

The addition of organic matter to soil is frequently viewed as a vital intervention to maintain soil quality. The aim of this study was to investigate the temporal response of the soil macroorganic fraction to different organic coffee farming practices (e.g., plant residue, earthworm and microbial inocula addition). Three density fractions of macroorganic matter (>150 μm) were studied during 1 year after adding shade tree (*Erythrina poeppigiana*) pruning residues to the soil (5 t ha^{-1} twice at 6 monthly intervals). Soil macroorganic matter represented only a small proportion of total soil organic matter (SOM) (3–6% of total). Even though the total amount of SOM did not change over time, significant temporal changes in the size of the macroorganic fraction were observed that appeared to be largely independent of the management regime. The light density fraction seemed to be the most responsive fraction and this study suggests that it may provide a qualitative indicator of the 'active' fraction of SOM; the size of the macroorganic fraction did not provide a reliable indicator of the rate of litter decomposition or nutrient release. The addition of microbial inoculants and earthworms had only a small and inconsistent effect on macroorganic matter dynamics and these practices appeared to offer little agronomic benefit. This study highlights the need for continued organic matter inputs to maintain soil C reserves and preserve soil organic quality in tropical organic farming systems.
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Keywords: *Coffea arabica*; Litter decomposition; Mineralization; Organic farming; Shade trees; Soil organic matter; Soil quality

1. Introduction

Due to its rapid turnover rate, the most biologically available fraction of soil organic matter (SOM) is often referred to as the "active" fraction (Duxbury et al., 1989). The size of this fraction has been linked with the rate of SOM mineralization, water availability and nutrient supply to both plants and microorganisms (Phiri et al., 2001). This active fraction in soil, is however, difficult to quantify and typically its size is estimated with operationally defined procedures which isolate the low density fraction (LF) or particulate organic matter (POM) fraction of SOM. Both of these SOM fractions are composed largely of unprotected fragmented plant residues together with small amounts of microbial debris (Gregorich and Ellert, 1993; Six et al., 2002). The LF has been hypothesized to be a more sensitive indicator of microbially available C and N than measurements of total SOM (Cambardella and Elliot, 1992; Hassink, 1995; Meijboom et al., 1995; Phiri et al., 2001). Management induced changes in total SOM may occur rapidly; measurement of these active fractions, compared to SOM, may offer a more sensitive indicator of changes in soil quality.

Meijboom et al. (1995) developed a method to separate soil macroorganic matter (SOM > 150 μm) into three density fractions using a non-toxic silica suspension (Ludox™). This method separates a low density fraction (LF; density < 1.13 g cm^{-3}), a medium density fraction (MF; density 1.13 to 1.37 g cm^{-3}) and a heavy density fraction (HF; density > 1.37 g cm^{-3}). The technique relies upon the premise that as SOM progressively decomposes it becomes more humified, more closely associated with mineral particles and hence becomes gradually denser (Barrios et al., 1996a). This method has been used successfully to compare the differential effects of plant residue addition on soil macroorganic matter formation (Hassink, 1995) and to compare size–density

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macroorganic matter fractions from organic and conventional farming systems (Flieβbach and Mäder, 2000).

Traditionally, measurement of total soil organic C has been used as a principal indicator of the effects of different agronomic management strategies on soil quality. However, some studies have indicated that individual SOM fractions (e.g., LF or POM), compared to total soil organic C, may reflect better the beneficial effects of mulching or crop rotations on soil quality (Cambardella and Elliot, 1992; Barrios et al., 1996a; Neufeldt et al., 1999; Phiri et al., 2001). More field data, however, are needed to confirm that the active fraction of SOM is effectively measured. It has been hypothesized that the size of the LF provides a sensitive measure of the rate of nutrient cycling in the soil (Sierra, 1996; Barrios et al., 1996b, 1998; Phiri et al., 2001; Salas et al., 2003). However, its small size in comparison with total SOM and the lack of information on N release rates from the LF raises doubts about its role as the most important active pool in SOM models. More data on the biological characteristics and dynamics of these fractions are therefore required.

In tropical coffee farms, the addition of green manures from shade trees (e.g., the leguminous N fixing tree *Erythrina poeppigiana*) is a common agronomic practice in both organic and conventional systems. This practice promotes soil biological activity, provides plant available nutrients, enhances soil structure and reduces the risk of water erosion (Lyngbaeck et al., 2001). Other soil amendments, such as the addition of microbial inocula and earthworms, have been recommended to enhance nutrient cycling and soil quality in organic coffee farms. Although widely adopted, the effect of these practices on soil organic matter dynamics has rarely been tested under field conditions (Gilot et al., 1996; Soto and Muschler, 2001). The first aim of this study was therefore to follow the dynamics of soil macroorganic matter fractions after the addition of *E. poeppigiana* pruning residues to on organic coffee farm. The secondary aim was to assess the sensitivity of macroorganic matter fractions to different organic farming practices (i.e., microbial inocula and earthworm addition).

2. Materials and methods

2.1. Site description

The field trials were conducted at CATIE, Turrialba, Costa Rica (9°55′N, 83°42′W; 600-m altitude) in a 30-year-old coffee plantation, which had been managed organically for the previous 8 years, located in the tropical premontane wet forest zone of the Atlantic region of Costa Rica (annual rainfall of 2650 mm; no well-defined dry seasons; mean annual temperature of 21.5°C) (MAG, 1990). The soil, classified as an Andic Dystrudept (Soil Survey Staff, 2003), had a poorly drained clayey surface layer (0–3% slope), clay texture (25% sand, 29% silt, 46% clay for 0–30 cm), pH (1:1, soil/water) of 4.3, total soil C content of 26 g kg^{-1}, bulk density of 1.26 g cm^{-3} and base saturation of 28%. Fertilization was provided by applying 226 kg ha^{-1} $year^{-1}$ of KMAG® (Mosaic Co, Plymouth, MN), equivalent to 50 kg K ha^{-1} $year^{-1}$, 24 kg Mg ha^{-1} $year^{-1}$, 50 kg S ha^{-1} $year^{-1}$ and 6 kg Cl ha^{-1} $year^{-1}$. The site was also limed at a rate of 1.6 t ha^{-1} every 3 years.

2.2. Field trial design

In September 2002, a randomized complete block trial, with three replicates, was established. Each block had five 2×2-m plots with each plot surrounded by an untreated 1-m buffer zone (four coffee plants were present within each plot). All treatments, except the bare soil controls, received coarsely chopped *E. poeppigiana* pruning residues (branch diameters <2.5 cm) at a rate of 25 t ha^{-1} (equivalent to 5 t ha^{-1} of dry matter) at the end of September 2002 and again in the middle of March 2003. The amount and timing of these pruning residue applications simulated local coffee agronomic practices (Beer, 1988). In each block, there was a control plot with no residue addition (BARE) and a plot with chopped pruning residues that did not receive any of the treatments mentioned below (RESID). The remaining three plots all received pruning residues at the same dose but additionally they received substances purported to enhance soil microbial activity; namely the addition of either two microbial inocula (MICROB-A or MICROB-B) or earthworms (EWORM). Newly fallen leaves and weeds were cleared weekly from all of the experimental plots.

Microbial mixture A (MICROB-A) was prepared 28 days before application to the residues in the plots by mixing 0.04 l of cooked rice (colonized by native microbial strains from a nearby secondary forest) with 12 l of water, 250 g of molasses, 250 g of yogurt and 227 g of soybean meal. This primary solution was diluted to a concentration of 2.5% v/v in tap water and 50 ml was sprayed onto the surface of the tree pruning residues in the respective plots. Microbial mixture "B" (MICROB-B) was prepared 7 days before application to the plots by mixing 250 g of molasses, 62.5 g of yogurt, 113 g of soybean meal and 5 kg of *E. poeppigiana* litter (collected from a nearby secondary forest and colonized by fungi) with 50 l of water. Again, 50 ml of this was sprayed onto the surface of the tree pruning residues in the respective plots. During the experiment, the pruning residues with microbial mixture "B" were turned over monthly to accelerate decomposition. The microbial mixtures were prepared and their application made following standard agronomic guidelines (Fishersworring and Roβkamp, 2001). The microbial mixtures contained fungi belonging to the genera *Aspergillus*, *Penicillium*, *Trichoderma*, *Gliocladium*, *Metarrhizium* and *Verticillium* (identified on either potato dextrose or nutrient agar at 10^{-8} dilution). Seven dominant bacterial species were also isolated on agar plates but were not identified. In the third treatment (EWORM), earthworms (*Eisenia foetida*) were added to the plots at a rate equivalent to 0.5 Mg ha^{-1}. To prevent earthworm escape, Zn sheets were buried in the soil around the plot edges. Nevertheless, during the second month it was observed that most of the earthworms had died or escaped from the plots. In the sixth month of the trial, the same weight of earthworms were nursed on fresh pruning residues for 2 months and then the earthworms transferred to the corresponding plots. The doses and preparation methods for the EWORM treatment were made following commercial guidelines (Lombritica SA, Cartago, Costa Rica).

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