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Original article

Effects of residue quality and soil mineral N on microbial activities and soil aggregation in a tropical sandy soil in Senegal

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ABSTRACT

The role played by organic residues and exogenous mineral N in the formation of stable soil aggregates in nutrient-poor, tropical sandy soils of Senegal is relatively unclear. This study assessed the effect of two representative low and high quality residues (*Zea mays* and *Crotalaria retusa* respectively) on the formation and stability of soil aggregates. The formation and stability of aggregates, soil biomass, root biomass, fungal hyphae length, C mineralization and chitinase activity, as a specific biomarker of the activity of fungal populations, were measured under controlled conditions over 120 days. In both the control and amended soils, there were more macroaggregates (>2000 μm) and mesoaggregates (250–2000 μm) than microaggregates (50–250 μm and <50 μm). The formation of macroaggregates and stability (MWD) were not significantly affected by the quality of residues. Amendment with organic residues shifted the distribution of the aggregate fractions. The macroaggregates increased by 26% with crotalaria and by 35% with maize residues while mesoaggregates decreased by 18% with crotalaria and by 26% with maize residues and microaggregates decreased by 8% with crotalaria and by 9% with maize residues. This study also confirmed that macroaggregates are formed from micro- and mesoaggregates. The total microbial biomass was significantly higher in soil amended with maize residues compared to soil with crotalaria residues and the control soil although the fungal hyphae length decreased when the soil was amended with either crop residue. Chitinase activity is the most pertinent indicator associated with macroaggregation stability. Adding mineral N (equivalent to 120 kg N ha^{-1} as urea) to the residue increased microbial biomass and reduced fungal hyphae length but had no effect on macroaggregate formation and fungal activity. These observations suggested that, for short term incubation of soil amended with residues, fungal activity plays a greater role in aggregation in sandy soils than the fungal population density.

1. Introduction

The role of soil organic matter in the formation and stabilization of the structure of most soils has been well established [1]. The relationships between the aggregation factors resulting from decomposition of organic inputs (binding agents and biomass decomposers) and the stability of the aggregates formed have been widely studied (see reviews [2,3]). Recently, Cotrufo et al. [4] proposed a Microbial Efficiency-Matrix Stabilization (MEMS) framework and suggested that microbial products of decomposition would be the main precursors of stable SOM by promoting aggregation, through strong chemical bonding to the mineral soil matrix. However, soil matrix stabilization should be dependent on the specific characteristics of different types of soil and the MEMS framework does not apply in western central Senegal which is dominated by tropical sandy and mixed haplic ferric lixisols. This could be attributed to their higher soil pH, low Al-toxicity, low CEC, high permeability for roots, low C content and high concentrations of alkyl C [5].

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It has been argued that, in tropical sandy soils, the aggregate stabilization is controlled mainly by the specific fungal taxa that act as aggregating agents in these soil systems [6] although this depends on the decomposability of the organic matter. The development of hyphal networks can aggregate large numbers of solid particles into macroaggregate structures, which can, in turn, affect more general soil properties such as water infiltration [7]. Roots can also provide the mechanical framework for the initial formation of macroaggregates by trapping particles and producing root exudates which act as binding agents, stimulating microbial activity [3].

Recent studies have highlighted the importance of understanding how the quality of residues interacts with the use of mineral fertilizers to determine the structure of fungal communities and how this interaction affects the mechanisms of soil aggregation and decomposition [2,8]. The results presented in the literature are conflicting. There is extensive literature on the importance of mineral N input for fungal communities. It is recognized that, when applied with organic residues, mineral N can improve mineralization [9] through the stimulation of microbial activities. Other studies, however, have shown that the addition of exogenous N decreased microbial decomposition of residues [10,11] by reducing fungal communities [12].

This discrepancy arises largely from the diversity and quality of the organic residues [13], or the initial soil N content in the study [14,15]. It is, therefore, very important to understand the interaction between the quality of organic residues and mineral N on the formation and stabilization of soil aggregates, particularly in nutrient-poor, tropical sandy soils of western central Senegal, where soils are less structured. Very little is known about these soils and how root and fungal aggregation mechanisms are affected by mineral N fertilization. In these soils, the optimal management of organic resources is limited by a deficit in the amount and N content of available organic inputs [16]. Combining residues of different qualities with added mineral N to ensure the synchronization of nutrient release to plants has been suggested as a means of managing this deficit [8,13].

This study set out to: (1) investigate the relationships between organic residues and water stable aggregates; (2) determine the contribution of soil fungi and roots to these relationships and (3) assess the effects of mineral N input on the formation of soil aggregates.

2. Material and methods

The experiment was carried out over 120 days under glasshouse controlled conditions. Mineral N was added, at two different rates, to two biochemically different organic residues to quantify the effects on microbial activities and water-stable aggregation. The effect of roots as a factor controlling aggregation was determined by sowing maize (*Zea mays*) when the residue had been decomposing for 60 days. The maize was harvested 60 days after sowing.

2.1. Soil and organic residues

This study was conducted with soil from low-input agricultural systems near Nioro du Rip which is in the “peanut basin” in western central Senegal. In these low-input agricultural systems crop residues are removed from fields and the mineral fertilizer application rates are lower than the nutrient loss rates. Cultivation consists essentially of hand hoeing and planting with little or no mechanical tillage. The soil used in the experiment was taken in 2008 from the ISRA (Institut Sénégalais de Recherches Agricoles) experimental field research station (13°45 N, 15°47 W), at a height of 18 m above sea level. This area has a mean annual rainfall of 750 mm from July to September and mean air temperatures ranging from 20 °C to 35.7 °C. The soil is a loamy-sand, leached ferruginous tropical soil, known locally as a deck-dior soil [17], fine sandy, mixed Haplic Ferric Lixisol [18]. The soil samples were collected at depths of 0–10 cm and 10–30 cm in plots that had not been amended with organic or mineral fertilizer for 10 years. Several replicates were taken at each depth, pooled, air-dried, sieved to <2 mm and stored at room temperature pending processing. The soil composition was 48 g kg^{-1} clay, 129 g kg^{-1} silt and 823 g kg^{-1} sand, the total C was 3 g C kg^{-1} dw soil, the total N was 0.3 g N kg^{-1} dw soil and the total P was 66.0 g P kg^{-1} dw soil.

Two types of organic residue were used (*Crotalaria retusa* and *Zea mays*) that were representative of very different organic residue qualities in terms of nitrogen, lignin, and phenolic contents [19] with *Crotalaria retusa* being a high quality resource and *Zea mays* a low quality resource (Table 1).

2.2. Experimental design

The soil was placed in pots in a completely randomized design with two factors: organic residue type (crotalaria, maize and control) and mineral N amendment (0N and 120N). Each treatment was replicated 4 times. The experimental setup consisted of 24 pots filled with the soil samples from the 0–10 cm and 10–30 cm horizons. Each pot contained 10 kg of soil.

The organic residues ground to less than 3 mm, were mixed with the soil at a rate of 5 T ha^{-1} (equivalent to 4.17 g kg^{-1} soil in the top 10 cm soil). Mineral N was added as urea (46% N) at a rate of 120 kg N ha^{-1}, in two doses of 40 kg N ha^{-1} at the start of the experiment and 80 kg N ha^{-1} before sowing the maize (60 days after the start of the experiment).

The soil was incubated for 120 days with the soil water content maintained between 30% and 40% (dry weight) by adding water two or three times a week. The maize was sown when the residue had been decomposing for 60 days. The plants were harvested 60 days after sowing, 120 days after the start of the experiment.

Additional laboratory incubation was undertaken to evaluate the fraction of the residues that had decomposed when the maize was sown (Supplementary Information). Carbon mineralization was measured in amended soil samples incubated in sealed glass jars (four replicates per treatment) kept at 28 °C for 60 days. Before sowing, the decomposition of crotalaria and maize residues without added mineral N was 58% and 63% of the added C and decomposition with added mineral N was 57% and 74% of the added C, respectively.

2.3. Analysis

At the end of the experiment, the roots were washed gently, dried at 65 °C for 1 week and weighed. One 5 cm cube of soil was removed intact from the 0–10 cm horizon in each pot, close to the

Table 1
Characteristics of organic residues used. Values represented are the mean of 4 replicates. Values followed by different letters in each line are significantly different at $p < 0.05$ using Fisher's LSD test.

Characteristics	Organic residues	
	Crotalaria	Maize
Soluble (% OM)	70.34 ± 0.1 b	17.76 ± 0.1 a
Hemicellulose (% OM)	15.28 ± 0.3 a	31.85 ± 0.3 b
Cellulose (% OM)	10.83 ± 0.1 a	45.12 ± 0.4 b
Lignin (% OM)	3.55 ± 0.5 a	5.27 ± 0.0 b
Total Nitrogen (%)	2.57 ± 0.1 b	0.74 ± 0.2 a
Total Carbon (%)	38.58 ± 0.0 a	43.63 ± 1.5 b
C:N ratio	15.11 ± 0.9 a	58.75 ± 1.6 b