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Contribution of legume tree residues and macrofauna to the improvement of abiotic soil properties in the eastern Amazon

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ABSTRACT

The potential advantages of positive interactions between the functional group components of the soil macrofauna and soil residue cover may increase the sustainability and efficiency of tropical agrosystems. The objective of this study was to link the ecological requirements of soil macrofauna with their impacts on the principal chemical and physical indicators of a hardsetting soil from a humid tropical region. The soil of a no-tillage system covered with legumes tree residues was subjected to the following treatments: *Leucaena* + *Clitoria* (L + C); *Leucaena* + *Gliricidia* (L + G); *Leucaena* + *Acacia* (L + A); *Gliricidia* + *Clitoria* (G + C); *Gliricidia* + *Acacia* (G + A); and a control with bare soil (BS) and no legumes. The application of leguminous tree residue with a high C/N ratio (G + A) extended essential ecosystem functions in the no-tillage agrosystem due to the favoring abundant functional groups, including soil engineers, predators and litter transformers. Litter transformers are associated with mulching effects that enhance multiple attributes, such as water infiltration, soil porosity, soil density, the litter carbon stock, the free light fraction (FLF) and total organic C. The use of fast-growing leguminous trees can increase soil acidity and decrease soil macrofauna diversity, but the harmful effects of leguminous tree cover are minor relative to the environmental benefits.

1. Introduction

In humid tropical regions, it is challenging to maintain the productive and sustainable agricultural systems continuously in the same area. Several factors result in challenges that can decrease soil quality and cause land degradation when continuous use is practiced (Basamba et al., 2006). In such regions, physical attributes play an important role in ecosystem degradation because repeated wetting and drying usually promote long-term hardening during drying in soils with low free iron and organic carbon contents. This process reduces the soil volume accessed by roots, decreases the nutrient use efficiency and reduces the agrosystem productivity (Mullins, 1999; Moura et al., 2010). Consequently, farmers have generally adopted shifting cultivation systems that negatively affect the local and global environment (Fearnside, 2002). Thus, soil fertility depletion is increasingly recognized as the fundamental cause of deforestation and declining food security for smallholder farms in the Amazon region (Moura et al., 2009).

To reduce cohesion and the subsequent degradation of soils that are susceptible to hardsetting, Becher et al. (1997) recommended mulching with surface residues to provide soil cover. Mulching with surface residues delays soil moisture loss, decreases the evapotranspiration rate and improves soil rootability (i.e., providing good conditions for root growth) (Lal, 1979; Moura et al., 2010). Conversely, according to Busscher et al. (2002), the direct impact of rainfall on uncovered sandy loam soils may harm the physical conditions of the soils by deteriorating their porous structure. Shepherd et al. (2002) noted that the continuous addition of residues can increase and maintain the labile organic matter fraction and promote the formation of an ephemeral structure of unstable aggregates that improves soil physical attributes and makes the root zone environment more favorable. Furthermore, the key to successful soil management is to use mixed cover that provides a combination of low and high-quality residues. The use of mixed cover ensures adequate nutrient release rates and helps maintain soil cover, which improves soil rootability and nutrient supplies throughout the crop cycle (Aguiar et al., 2010). However,

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Moura et al. (2013) observed that the direct effects of residues on soil attributes did not extend beyond the 10 cm surface layer, which was not sufficient for producing root growth that could increase the nutrient use efficiency and make fertilizer use profitable.

Many authors have reported that long-term soil cover provides a habitat for a large and diverse population of invertebrate fauna that can move through the soil and build organo–mineral structures that promote soil aggregation, porosity, and rootability (Tsukamoto and Sabang, 2005; Blouin et al., 2013). Macrofauna components mainly act on the soil structure through bioturbation and create biogenic structures and burrows. These structures help incorporate litter into the soil by mixing the mineral soil with organic materials, which can improve soil hydraulic properties (Jouquet et al., 2006). According to Lavelle et al. (2006), abundance of macrofauna and its influence on soil properties can be explained by their auto-ecological requirements. Thus, the quantity and quality of biomass applied to the soil surface affects macrofauna abundance due to variations in organic resources, temperature and moisture at the soil surface (Sileshi and Mafongoya, 2006).

To take advantage of the positive interactions between agro-system components and increase their sustainability, the long-term effects of residue cover on the diversity and abundance of macrofauna functional groups and their impacts on soil quality indicators must be studied. Thus, we hypothesize that on a sandy loam soil that is prone to cohesion and subjected to no-till cultivation the simultaneous use of high and low-quality alter the diversity and abundance of the soil macrofauna and will result in different soil abiotic attributes. If the abundance of functional groups, such as soil engineers, predators and litter transformers, is enhanced, essential soil ecosystem functions will also be enhanced (Sileshi and Mafongoya, 2006).

The objective of this study was to establish a link between the ecological soil macrofauna requirements and their impacts on soil quality indicators through the establishment of potential relationships among the macrofauna (mainly those known as “ecosystem engineers”), the labile organic matter fractions and the principal chemical and physical indicators of soil quality in a cohesive soil from a humid tropical region.

2. Materials and methods

2.1. Site experiment

The experiment was conducted from 2002 to 2009 in northern Brazil. This region presents a hot and semi-humid equatorial climate with 1200 mm of an average annual precipitation and two well-defined seasons, including a rainy season that extends from January to June and a dry season with a marked water deficit that extends from July to December. Soil liming was performed twice, once in January 2002 and once in 2007, by applying slaked lime at a rate of 1 Mg ha^{-1} to the surface (corresponding to 279 and 78 kg ha^{-1} Ca and Mg, respectively).

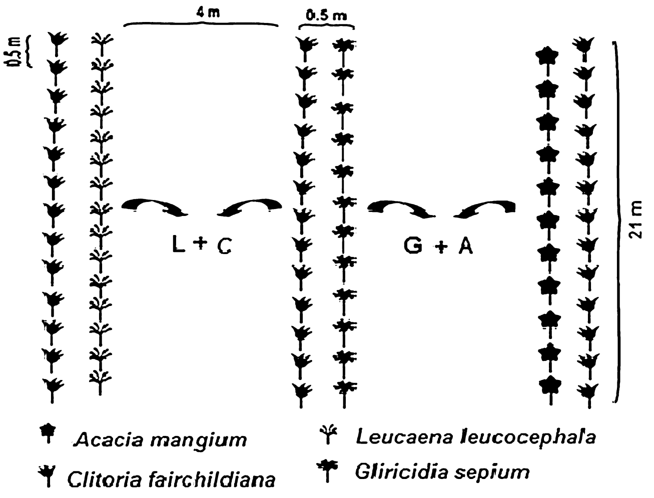

Fig. 1. Diagram of two experimental plots showing the double row of trees that was divided in the treatments.

The alley cropping system included six treatments with four replicates in a randomized block design. Four leguminous species were tested, including two that produce higher-quality residue (*Leucaena leucocephala* (*Leucaena*) and *Gliricidia sepium* (*Gliricidia*)) and two trees that produce lower-quality residue (*Clitoria fairchildiana* (*Clitoria*) and *Acacia mangium* (*Acacia*)) (Aguiar et al., 2010; Vanlauwe et al., 1997).

The experiment was established in 2002 using pigeonpea, a biennial specie. In 2007, the pigeonpea was replaced with *Gliricidia*. The legumes were planted with a spacing of 0.5 m × 0.5 m in double rows, such that each 21 m × 4 m plot received two types of residues (low and high-quality residues resulting from combinations of the two legumes). The following treatments were performed: *Leucaena* + *Clitoria* (L + C); *Leucaena* + *Gliricidia* (L + G); *Leucaena* + *Acacia* (L + A); *Gliricidia* + *Clitoria* (G + C); *Gliricidia* + *Acacia* (G + A); and a control with bare soil (BS) and without legumes (Fig. 1). The C/N ratio of the residues was 12 to *Leucaena*, 23 to *Clitoria*, 27 to *Acacia*, 13 to *Gliricidia*, according to Aguiar et al. (2010).

In January of each year, maize (*Zea mays* L.) was sown with an inter-row spacing of 90 cm and an inter-plant spacing of 20 cm. Immediately, after planting the maize, the biomass produced from pruning the legumes was distributed homogeneously throughout the plots with the same treatments. The amounts of dry biomass that resulted from the leguminous plant combinations that were applied to the soil between 2004 and 2009 were quantified (Table 1).

Table 1
Amounts of the dry biomass of leguminous plant combinations (Mg ha^{-1}) applied to the soil since 2004 up to 2009, under different cover types in the system of alley cropping.

	Leucaena + Clitoria (Mg ha^{-1})	Gliricidia + Clitoria (Mg ha^{-1})	Leucaena + Gliricidia (Mg ha^{-1})	Gliricidia + Acacia (Mg ha^{-1})	Leucaena + Acacia (Mg ha^{-1})
2004	3.3	2.3	2.4	7.0	8.0
2005	11.2	13.4	10.5	14.3	12.0
2006	8.9	5.5	4.9	14.6	18.0
2007[a]	12.9	8.5	7.6	18.1	19.4
2008	16.4	9.8	6.6	28.1	34.6
2009	10.5	9.5	10.6	20.4	22.6
Total	63.2	49.0	42.5	102.5	114.8

[a] *Gliricidia* leguminous.