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Soil macrofauna abundance under dominant tree species increases along a soil degradation gradient

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ABSTRACT

Soil macrofauna contribute to key soil functions underpinning soil-mediated ecosystem services. There is limited understanding about the role of trees as 'resource islands' for soil macrofauna in agricultural landscapes and how this interaction is affected by soil degradation status. The study assessed the spatial influence of three dominant trees namely, *Croton megalocarpus*, *Eucalyptus grandis* and *Zanthoxylum gilletii*, on soil macrofauna abundance, along a soil degradation gradient resulting from continuous cultivation for 10, 16 and 62 years. It was hypothesised that spatial variation in soil macrofauna abundance is affected by duration of cultivation, tree species and distance from the tree trunk. Soils cultivated for 10 years showed highest soil nutrient levels. Notably, soil C and N were higher below the canopy of *C. megalocarpus* (64.6 g kg^{-1} C; 6.7 g kg^{-1} N), than *E. grandis* (58.7 g kg^{-1} C; 5.9 g kg^{-1} N) and *Z. gilletii* (54.5 g kg^{-1} C; 5.6 g kg^{-1} N) after 10 years of cultivation. Similar trends were also found after 16 and 62 years of cultivation, although the mean values for the two elements were below 40.0 g kg^{-1} and 4.0 g kg^{-1}, respectively. Higher soil macrofauna abundance was found after 16 and 62 years of cultivation, though this was dependent on tree species and soil macrofauna group. Earthworm abundance was highest below the canopy of *Z. gilletii* averaging 389 individuals and 160 individuals m^{-2}, respectively, compared to 14 individuals m^{-2} after 10 years of cultivation. Conversely, beetles showed higher numbers under *E. grandis* and *C. megalocarpus* than under *Z. gilletii*. Highest numbers of termites and centipedes were found under *E. grandis* after 16 years of cultivation. These findings support the importance of a diverse tree cover in agricultural landscapes to conserve soil macrofauna communities and the contribution of their activity to soil ecological functions.

1. Introduction

Soil biota is a central constituent of any ecosystem, whether natural or managed, due to their role in regulating key soil functions such as organic matter decomposition, nutrient cycling and soil structure maintenance (Brussaard et al., 1997; Barrios, 2007). Soil macrofauna constitute an important component of soil biota given the significant impact of their activities on soil properties (Lavelle, 1997; Ayuke et al., 2009). Earthworms and termites, for example, have earned recognition as 'ecosystem engineers' due to their significant effects on soil structure and functions through their soil-feeding, nesting and burrowing habits (Jones et al., 1994). However, their activities could be affected by management practices largely through changes in organic inputs to soil which affect food availability, and through soil disturbance (e.g. tillage) which often kill the larger species (e.g. earthworms) or the structures they inhabit and interfere with their activities (Lavelle et al., 2003; Ayuke et al., 2011; Mbau et al., 2015). Furthermore, these management practices can also contribute to the spatial heterogeneity in soil properties which underlies the distribution of soil macrofauna. Consequently, soil macrofauna are usually not uniformly

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distributed within the soil in any given space and time, but rather, aggregated in 'hotspots' of carbon-rich areas such as the rhizosphere, soil aggregates and organic detritus (Beare et al., 1995; Lavelle, 1997; Barrios et al., 2012a; Kuzyakov and Blagodatskaya, 2015). Therefore, farmer practices involving tillage, application of agricultural inputs and/or the types of plants grown on their farms may have significant positive or negative effects on soil macrofauna abundance and distribution in any given location.

Smallholder farmers often intercrop trees with annual crops for various reasons such as provision of food, forage, wood and/or charcoal, among other products (Akinnifesi et al., 2010; Nyaga et al., 2015). In some occasions, farmers deliberately retain indigenous trees during conversion of forest to cultivated lands for similar reasons (Fonte et al., 2010; Pauli et al., 2012). Trees are known to modify conditions beneath the canopy through shading, root turnover and litter inputs which significantly influence soil moisture, temperature, carbon substrate availability and nutrient regimes (Lavelle et al., 2003; Lin, 2010; Barrios et al., 2012a). Earlier research has shown predictable patterns in the variation of soil properties resulting from individual trees where litter deposition around the trees produces characteristic concentric rings of influence that are proportional to the size of the crown (Rhoades, 1997). Other studies have shown gradual decline in the content of organic carbon, nitrogen, phosphorus and exchangeable bases with increasing distance from the tree stem due to differences in litter deposition (Kater et al., 1992; Tomlinson et al., 1998; Jonsson et al., 1999). Root turnover is also a critical component of soil carbon and nutrients and therefore an important driver of belowground processes and ecological functions (Gill and Jackson, 2000; Iversen and O'Brien, 2010). Due to the feeding preference of some soil macrofauna groups for specific organic substrate types, the quality of litter and its deposition patterns as well as root turnover may therefore affect their distribution (Lavelle et al., 2003; Pauli et al., 2010). For instance, Warren and Zou (2002), Caner et al. (2004) and Frouz et al. (2013) have reported differential effects of litter quality on soil macrofauna in different systems. Further, in their recent review, Korboulewsky et al. (2016) highlighted that the litter quality from a given tree species can significantly contribute to the changes observed in soil fauna communities. Besides tree leaf litter and root turnover, stemflow could also contribute nutrients to the soil at the base of trees through the washing of dust, insect remains or bird droppings from the leaves and bark (Rhoades, 1997). Changes in soil chemistry beneath the tree could potentially affect the occurrence of soil macrofauna since soil chemical properties have been used to partially explain the variations in distribution of soil macrofauna (Ayuke et al., 2009; Pauli et al., 2011; Mbau et al., 2015). The spatial patterns of soil macrofauna abundance are thus expected to be structured in a manner that corresponds to the heterogeneity of soil resources around the tree (Korboulewsky et al., 2016). The soil beneath tree canopy can therefore be hypothesised as a distinct area of favourable or unfavourable conditions to the abundance of some soil macrofauna group(s), thus becoming an important determinant of their spatial distribution patterns. As such, in-depth research that addresses spatial-temporal patterns of soil macrofauna abundance as affected by tree attributes under contrasting soil degradation levels could significantly contribute towards the design of sustainable farming systems (Barrios et al., 2012a). Though the spatial arrangement of single trees has been shown to affect soil properties (Belsky et al., 1989; Kater et al., 1992; Rhoades, 1997; Tomlinson et al., 1998; Jonsson et al., 1999; Amiotti et al., 2000), little is known about the magnitude and pattern of their influence on soil macrofauna abundance in agricultural landscapes particularly in tropical Africa.

In this study, we assessed effects of three dominant tree species; *Croton megalocarpus* Hutch., *Eucalyptus grandis* W.Hill and *Zanthoxylum gilletii* (De Wild.) P.G.Waterman, on soil macrofauna abundance and biomass across three catchments that represent a soil degradation gradient resulting from different times since conversion from primary forest to agriculture (Kimetu et al., 2008). This provided a chronosequence experimental set-up where short/medium term effects of tree species and long-term effects of land-use change could be systematically studied. It was hypothesised that i) soil nutrient stocks and availability would decrease with increasing duration of cultivation and distance from the tree trunk, and ii) soil macrofauna abundance and biomass would decrease with increasing distance from the tree trunk and duration of cultivation but the magnitude of these effects would be modulated by tree identity.

2. Materials and methods

2.1. The study sites

The study site is located in Kapchorwa, Nandi County in several farms along the Kakamega-Nandi forest complex which lies at Latitude 0° 10′ 00″ N and Longitude: 35° 0′ 00″ E. Altitude ranges between 1600 and 1900 m above sea level. The area receives an annual precipitation of approximately 2000 mm; the rainfall is bimodal, with 'long rains' occurring between April and June (approximately 1200 mm), and 'short rains' between August and October (approximately 800 mm) (Güereña et al., 2015). Being near the equator, temperatures are relatively constant throughout the year with an average maximum daily temperature of 26 °C, an average minimum of 11 °C and a mean annual temperature of 19 °C. Soils are classified as kaolinitic Acrisols (FAO/UNESCO classification) or Ultisols (USDA classification) showing deep reddish-brown coloration and thick humic topsoil with 45–49% clay, 15–25% silt and 26–40% sand on predominantly heavier-textured Ultisols and 11–14% clay, 21–27% silt and 59–68% sand, on lighter-textured Ultisols (Kimetu et al., 2008). The indigenous vegetation is primarily highland rainforest, an extension of Guinean-Congolian belt, and dominated by *Funtumia africana* (Benth.) Stapf, *Prunus africana* (Hook.f.) Kalkman, *Ficus* spp., *Croton* spp. and *Celtis* spp. (Glenday, 2006). The farms are dominated by cereal cultivation and rarely use any form of inorganic inputs. If applied, the amounts used are barely enough to meet crop needs. Farmlands are therefore characterised by low soil fertility and crop productivity. Study farms were selected from three catchments which were under continuous cultivation for 10 years, 16 years and 62 years, since conversion from primary forest to agricultural lands. The three catchments are located within an area of 6 km^2, with their sizes ranging from 9 to 14 ha. Detailed description of these catchments can be found in Recha et al. (2013) and Güereña et al. (2015).

2.2. Identification and selection of tree species

Selection of tree species of interest was conducted using participatory action research tools in the context of focus group discussions involving randomly-selected farmers from all the three catchments (Barrios et al., 2012b). A ranked list of the most common trees within the area of study was identified and the top three most abundant trees were selected, namely, *Croton megalocarpus*, *Eucalyptus grandis* and *Zanthoxylum gilletii*. Selection of trees to be sampled within the three catchments was based on the following criteria: (i) dominance: for each species selected, at least three single trees could be located within each catchment. Each tree species represented a treatment; (ii) distribution: the selected trees occurred singly within the farms and were located at least 4 times their crown diameter from other trees, thus free from tree interferences; (iii) attributes: the height, shape and age of the single