Applied Soil Ecology 119 (2017) 286–293

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Spatial variation of soil macrofauna and nutrients in tropical agricultural systems influenced by historical charcoal production in South Nandi, Kenya

Solomon Kamau[a,b,*], Edmundo Barrios[b], Nancy K. Karanja[a], Fredrick O. Ayuke[a], Johannes Lehmann[c,d]

[a] *Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya*

[b] *World Agroforestry Centre,United Nations Avenue, P.O. Box 30677-00100, Nairobi, Kenya*

[c] *Soil and Crop Science, Cornell University, Ithaca, NY 14853, USA*

[d] *Atkinson Center for a Sustainable Future, Cornell University, Ithaca, NY 14853, USA*

ARTICLE INFO

Keywords:
Charcoal-making spots
Pyrogenic carbon (PyC)
Pyrogenic organic matter (PyOM)
Soil macrofauna

ABSTRACT

The charcoal sector constitutes an important source of employment and revenue for many tropical agroecosystems. Better understanding of the effects of charcoal-making is thus warranted to guide actions aimed at minimising environmental externalities. Conversion of trees to charcoal eliminates canopy effects associated with the living trees while at the same time creates new conditions in and around spots where the charcoal is produced due to increased concentration of pyrogenic organic matter (PyOM). It is unclear, whether such unintentional PyOM additions play a role in the abundance and distribution patterns of soil macrofauna. A study was conducted in South Nandi (Kenya) to assess effects of PyOM on soil macrofauna, taking advantage of abandoned traditional earth-mound charcoal kilns, where *Croton megalocarpus* Hutch. and *Zanthoxylum gilletii* (De Wild.) P.G.Waterman trees were used in charcoal making. Soil and soil macrofauna samples were collected at increasing distances from the centre of the spots. Total C, non-pyrogenic C (non-PyC) and total N progressively increased with increasing distance from the centre of the spots, whereas soil pH, pyrogenic C (PyC), available P and exchangeable K decreased. The number of earthworms and centipedes in *Z. gilletii* spots (119 and 14 individuals m^{-2}, respectively) was twice as high as in kilns where *C. megalocarpus* was used. Notably, while the number of earthworms in spots rich in *Z. gilletii* PyOM significantly increased with increasing distance from the centre of the spots, the opposite trend was observed for centipedes. In contrast, no significant differences in the spatial distribution of earthworms or centipedes were found in spots rich in *C. megalocarpus* PyOM. Furthermore, beetles, termites and crickets were significantly higher in *C. megalocarpus* than *Z. gilletii* spots, but sampling distance also had no significant influence. As hypothesised, source of PyOM played a major role in determining soil properties and macrofauna distribution patterns thus showing the value of abandoned charcoal-making spots in contributing to a mosaic of soil conditions that could ultimately affect soil productivity in tropical agricultural systems.

1. Introduction

Similar to many tropical agroecosystems world-wide, the charcoal sector significantly contributes to Kenya's economy with 1.6 billion US dollars per year, employing close to 900 000 in production and trade (SEI/UNDP, 2016). In these agroecosystems, it is a common practice that trees are felled and charcoal made on site (). Smallholder farmers deliberately retain indigenous trees during conversion of forest to cultivated land or intercrop trees with annual crops for fuel, fodder, timber and fruits among other products (Nyaga et al., 2015; Kamau et al., 2017). Some trees are harvested to make charcoal for household consumption or for sale to supplement household income. Charcoal making is usually done by traditional earth-mound kilns, where pieces of felled trees and branches are carbonised at 360 °C to 470 °C for several days (Coomes and Miltner, 2016). Once charcoal making is complete, these kilns are usually abandoned. This practice possibly creates a mosaic of soil conditions in such areas because during the process of charcoal production a substantial amount of soil organic

* Corresponding author at: Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya.
E-mail address: solkam08@gmail.com (S. Kamau).

http://dx.doi.org/10.1016/j.apsoil.2017.07.007
Received 17 March 2017; Received in revised form 30 June 2017; Accepted 4 July 2017
Available online 18 July 2017
0929-1393/

matter (SOM) is lost in and around the charcoal-making spots (kilns) (Ketterings and Bigham, 2000; Knicker, 2007). Furthermore, large amounts of pyrolysed materials, often referred to as pyrogenic organic matter (PyOM), also remain *in situ* after charcoal production (Güereña et al., 2015) which may bring about changes in the structure and composition of soil biota. On the other hand, soil biota could modify the properties of PyOM/biochar through, for example, fragmentation into smaller pieces after ingestion by large organisms such as earthworms which increases their surface area and thus enhances or limits further effects of PyOM on other soil biota (Gomez-Eyles et al., 2013). Apart from the effects of PyOM, operations during kiln construction or the intense heat during charcoal production could also cause soil biota to suffer dramatic short or long-term alteration in such areas. Soil biota are essential components of the soil ecosystem as they drive vital soil functions such as nutrient cycling, soil structure modification, biological control of soil borne pests and diseases among others (Barrios, 2007; Brussaard et al., 2007). Thus, changes in soil biota could have profound effects on productivity of low-input farming systems which are characteristic to agriculture in tropical Africa.

Soil macrofauna constitute an important component of soil biota given the significant impact of their activity on soil properties (Lavelle, 1997) and their role as bioindicators of potential unintended impacts of biochar applications to soil (Castracani et al., 2015). Given their larger body size, soil macrofauna are more susceptible to physical damage or destruction, loss of their habitat, and even removal of food substrates (Ayuke et al., 2009; Mbau et al., 2015). For instance, the loss of existing SOM during charcoal making, and its replacement with PyOM, could alter the soil microbial communities and dynamics, and change the carbon substrates and nutrients available for soil macrofauna through a cascade of effects within the soil food web. As noted by Lehmann et al. (2011), if a large proportion of C in pyrolysed materials is chemically stable, the microbes may not be able to readily utilise the C as an energy source. Chemical composition of feedstock also greatly affects the quality of pyrolysed materials (Warnock et al., 2007; Downie et al., 2009; Laird et al., 2009) and thus persistence of C which influence the growth of soil microorganisms. Such changes may in turn affect the abundance and diversity of the soil macrofauna which benefits from feeding on microorganisms found on the PyOM (Domene et al., 2015). High concentration of PyOM in charcoal-making spots may also cause changes in soil physico-chemical properties (Glaser et al., 2002; Oguntunde et al., 2004), which could further affect soil macrofauna. For instance, addition of pyrolysed materials has been shown to alter tensile strength and bulk density of the soil, which can affect the soil water dynamics and gas transport (Lehmann et al., 2011; Masiello et al., 2015). In addition, application of these materials has also been shown to affect soil pH and therefore the amounts of available nutrients such as N, P and cations (Warnock et al., 2007; Ippolito et al., 2015). Therefore, tree-felling and concomitant charcoal production may trigger significant changes in soil chemical and physical properties as well as shifts in soil macrofauna abundance and diversity on these soils for extended periods of time. Such changes, with potential negative effect on soil productivity thus impacting socio-economic welfare of millions of people in Africa, are rarely addressed. In addition, soil fauna are among the least well-studied components of soil biota as affected by PyOM and biochar (Lehmann et al., 2011; Ameloot et al., 2013; Castracani et al., 2015).

Therefore, this study aimed at investigating spatial effects of PyOM on the abundance and distribution patterns of seven key soil macrofauna groups: earthworms, beetles, centipedes, millipedes, spiders, termites and ants. We took advantage of existing charcoal-making spots derived from traditional earth-mound kilns where *Croton megalocarpus* Hutch. and *Zanthoxylum gilletii* (De Wild.) P.G.Waterman had been used for charcoal making *in situ*. We hypothesised that PyOM additions modify soil chemical properties and consequently soil macrofauna abundance and spatial distribution. Given the significant differences in plant tissue quality reported by Kamau et al. (2017) for the same tree species, we expected that this would likely be reflected in charcoal-making spots and hence influence the abundance and spatial distribution of soil macrofauna.

2. Materials and methods

2.1. Description of the study site

The study was conducted in the Kapchorwa region of Nandi County (Kenya) on farmers' fields, approximately 20 km Southwest of Kapsabet town. The region lies along the Kakamega-Nandi forest complex, an extension of the Guinean-Congolian forest (Latitude 0° 10′ 00″ N and Longitude 35° 0′ 00″ E), at an average altitude 1800 m above sea level (Güereña et al., 2015). Rainfall occurs in a bimodal pattern, with an annual total of about 2000 mm, distributed between April and June (1200 mm) and August and October (800 mm). Temperatures are fairly constant throughout the year with mean minimum and maximum annual temperatures of about 18 and 27 °C, respectively. Soils are classified as kaolinitic Acrisols based on the FAO/UNESCO classification (Recha et al., 2013). The indigenous vegetation is dominated by *Funtumia africana* (Benth.) Stapf, *Prunus africana* (Hook.f.) Kalkman, *Ficus* spp., *Croton* spp., and *Celtis* spp. (Glenday, 2006). The area was originally occupied by a sparse population of former forest dwelling human communities who practiced shifting cultivation, hunting and gathering (Mbau et al., 2015). However, high population growth rate and immigration into the area has reduced average land holding to less than 0.5 ha per household. The farms are dominated by cereal cultivation, with maize and beans being the predominant crops often intercropped with indigenous and exotic trees (Kamau et al., 2017).

2.2. Selection of charcoal-making spots used in the study

Charcoal production in smallholder farms is mainly done onsite where the fuel wood is located (). Typically, wood is pyrolysed at temperatures between 360 °C to 470 °C using the traditional earth-mound kilns (Coomes and Miltner, 2016). Due to the poor conversion ratio and pyrolysis conditions in these kilns, many fragments of pyrolysed materials are left onsite and become incorporated into the soil through cultivation after the kilns are abandoned, creating characteristic concentric rings of PyOM-rich spots. Identification of such charcoal-making spots to be used in the study was guided by participatory action research tools involving randomly-selected farmers within the area of study (Barrios et al., 2012). A total of 52 spots were identified in this process, with an average diameter of about 15 m, which were spread at an area of 28.9 ha. The criteria used in selection of charcoal-making spots to be used in this study were: (i) history of the spots: the type of tree used and the time since charcoal making were known. Each tree species used in charcoal making represented a treatment; (ii) distribution: the charcoal-making spots selected occurred isolated within the farms and thus free from interferences by trees. Only spots where *C. megalocarpus* and *Z. gilletii* were used in charcoal making, fulfilled the selection criteria in the study area. Five spots of each tree type were selected for the study. All the charcoal-making spots had been abandoned 2 years before sampling was conducted. At the time of sampling, all the charcoal-making spots were under maize-beans intercrop.

2.3. Soil macrofauna sampling

The area around selected charcoal-making spots was subdivided into four concentric zones, W, X, Y and Z based on an adaptation of the sampling method used by Kamau et al. (2017). Zone W was located 0.25 m from the centre of the spot, X at the middle of the spot, and Y located at the edge. Zone Z was located away from edge of the charcoal-making spots at an equivalent distance to that between W and Y. Soil monoliths (0.25 × 0.25 × 0.30 m) were collected using the standard Tropical Soil Biology and Fertility Institute (TSBF) method as described