Applied Soil Ecology 99 (2016) 40–50

Contents lists available at ScienceDirect

Applied Soil Ecology

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

The impact of charcoal and soil mixtures on decomposition and soil microbial communities in boreal forest

Nathalie Pluchon*, Andrea G. Vincent, Michael J. Gundale, Marie-Charlotte Nilsson, Paul Kardol, David A. Wardle

Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, SE 901 83 Umeå, Sweden

ARTICLE INFO

Article history:
Received 27 February 2015
Received in revised form 6 November 2015
Accepted 17 November 2015
Available online 28 November 2015

Keywords:
Charcoal trait
Priming effect
Fire
Black carbon
CP-MAS ^{13}C NMR
PLFA

ABSTRACT

Fire is a natural disturbance that operates as a major ecological driver in many ecosystems worldwide, and it produces charcoal which is incorporated into soil in significant quantities. Charcoal can serve as a long-term carbon (C) sink, but it is not inert, and could potentially impact native soil organic matter and decomposer micro-organisms. However, studies have shown contrasting results for how charcoal impacts the belowground subsystem, and the mechanisms involved are poorly understood, especially in pyrogenic ecosystems. We performed a laboratory experiment in which six contrasting boreal forest soil types and nine charcoal types (each from different woody plant species) were incubated for 9.5 months, both by themselves and in 50:50 mixtures for all possible soil–charcoal combinations. At harvest we measured mass loss, and for several charcoal-soil combinations, we measured microbial properties, and composition of C compounds using ^{13}C CP-MAS nuclear magnetic resonance (NMR) spectroscopy. Overall, mixtures of charcoal and soil lost more mass than expected based on when the components were incubated separately. The magnitude of increased soil mass loss in mixtures did not differ among charcoal types, but varied among soil types, because greater mass loss occurred when soil from a site dominated with herbaceous vegetation was used, relative to other soil types. The use of NMR spectroscopy showed that enhanced mass loss in mixtures was due mainly to mass loss of soil organic matter rather than charcoal. However, mixing of charcoal and soil did not influence key decomposer microbial groups compared with expected values derived from when components were incubated alone, irrespective of charcoal and soil type. This study shows that when charcoal is incorporated into boreal forest soil (e.g., after wildfire), there is enhanced loss of total C (arising primarily from mass loss of soil organic matter), with this effect being relatively consistent across contrasting charcoal and soil types. This effect, in combination with recently documented impacts of charcoal on aboveground processes, reveals important but largely overlooked legacy effects of charcoal on forest processes that contribute to ecosystem C balance and ecosystem functioning.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The main natural disturbance in much of the boreal forest is fire, which converts a proportion of standing plant biomass into charcoal (Bond-Lamberty et al., 2007; Forbes et al., 2006). This charcoal is then incorporated into the soil, with amounts frequently exceeding 1000 kg/ha, and sometimes reaching over 4000 kg/ha (Ohlson et al., 2009; Zackrisson et al., 1996). Much of the charcoal mass in soil is highly resistant to decomposition (Lehmann and Joseph, 2009) and can remain in soil for long periods, with a residence time of up to 8000 years (DeLuca and Aplet, 2008; Preston and Schmidt, 2006). Because of its persistence, charcoal in boreal forests serves as a long term carbon (C) sink, and the amount of C stored in charcoal in the entire boreal region is estimated to be in the order of 1 Pg (Ohlson et al., 2009). More generally, there is widespread recognition of the potential of charcoal to contribute to C sequestration in many ecosystems, to the extent that it is now frequently advocated as a soil amendment in the form of 'biochar' (Lehmann and Joseph, 2009). However, charcoal is not inert in soils, and to understand its ecological role, there is a need to investigate the effects that charcoal addition has on soil abiotic and biotic properties, including those that can also impact on soil C sequestration (Biederman and Harpole, 2013; Hart and Luckai, 2013).

Charcoal addition to soils can impact on the breakdown of unburnt organic matter, with potential consequences for soil C

* Corresponding author.
E-mail address: Nathalie.pluchon@slu.se (N. Pluchon).

http://dx.doi.org/10.1016/j.apsoil.2015.11.020
0929-1393/© 2015 Elsevier B.V. All rights reserved.

storage. A growing number of studies, mainly from non-pyrogenic systems, have investigated how charcoal addition affects native soil organic matter, with a variety of effects being reported. Some studies have measured C mineralization in incubation experiments with or without ^{13}C labelled charcoal to show that it has a positive effect on decomposition, i.e., that it enhances mineralization of native organic matter and loss of C (e.g., Hamer et al., 2004; Kuzyakov et al., 2009; Luo et al., 2011; Zimmerman et al., 2011). Further, it has been shown in a field experiment using mesh bags that mass loss of humus–charcoal mixtures was greater than expected based on mass loss from charcoal and humus considered separately (Wardle et al., 2008a), although some of this loss may have come from the charcoal itself (see Lehmann and Sohi, 2008; Wardle et al., 2008b). Other studies have demonstrated negative effects of charcoal on decomposition processes (i.e., where charcoal impedes loss of native organic matter; Abiven and Andreoli, 2011; Cross and Sohi, 2011; Jones et al., 2011; Keith et al., 2011; Zimmerman et al., 2011) as well as no effects (Abiven and Andreoli, 2011; Bruun and EL-Zehery, 2012; Cross and Sohi, 2011; Zimmerman et al., 2011). Studies that have explored the effects of charcoal on native soil organic matter have varied greatly in terms of soil type, charcoal type and time scale, which may help explain the contrasting results reported among studies. For example, it is recognized that charcoals from different sources or prepared under different pyrolysis conditions may vary in their effects on charcoal traits and, potentially, ecological processes (Keech et al., 2005; Lehmann and Joseph, 2009; Pluchon et al., 2014). However, studies exploring interactions of charcoal with native organic matter using contrasting charcoal or soil types are confined to agricultural conditions (Cross and Sohi, 2011; Zimmerman et al., 2011) and studies involving naturally pyrogenic ecosystems are scarce (e.g., Wardle et al., 2008a; Zackrisson et al., 1996).

Soil micro-organisms, which are the primary biotic drivers of organic matter decomposition, have been shown to be affected by charcoal addition in various ways (Lehmann et al., 2011). Some effects of charcoal on micro-organisms occur directly. For example, the pores in the charcoal serve as refugia for micro-organisms (Warnock et al., 2007), and the surface of charcoal allows for the formation of biofilms (Lehmann et al., 2011), and adsorption and accumulation of nutrients and labile organic compounds (Lehmann et al., 2011). Sorption of organic matter can also occur within charcoal pores which would serve to restrict microbial access (Cross and Sohi, 2011; Jones et al., 2011; Zimmerman et al., 2011). Charcoal also affects microbial communities indirectly through modifying the physical and chemical soil environment (notably soil pH) (Lehmann et al., 2011; Pietikäinen et al., 2000), adsorbing and inactivating secondary compounds which may otherwise inhibit micro-organisms (Zackrisson et al., 1996), and altering chemical signaling between plants and micro-organisms (Warnock et al., 2007). Many of these effects arise through the surface electrostatic properties of the charcoal that enables it to adsorb compounds and ions, and through its physical structure including its porosity (Lehmann et al., 2011; Tryon, 1948). The variety of positive and negative effects that charcoal can exert on the soil micro-organisms responsible for driving native organic matter dynamics will likely depend on the characteristics of the soil and charcoal types involved; however, this issue remains largely unexplored.

We performed an incubation experiment using mesh bags containing soil–charcoal mixtures, which involved combinations of soil from six boreal forest types with nine charcoal types derived from boreal woody plant species in a full factorial design. We focused on the effects of charcoal and soil type on mass loss of the mixtures through decomposition, and for a subset of the combinations we also studied the activity and community composition of the soil micro-organisms that drive decomposition processes. We also used ^{13}C CP-MAS NMR (cross-polarization magic-angle spinning nuclear magnetic resonance) spectroscopy to determine whether mass loss in the mixtures was due primarily to mass loss of charcoal or soil organic matter. Specifically, we sought to test three hypotheses: (i) the mixtures of charcoal with soil will show a greater net mass loss over time, and greater densities of soil micro-organisms and microbial activity, compared with what would be expected based on when charcoal and soil are not mixed; (ii) the synergistic effects of mixing charcoal with soil on mass loss, and soil microbial properties will be greatest for charcoals with a higher nutrient content, specific surface area, and cation exchange capacity. It will also be greatest for soil types with higher nutrient limitation, given the role that nutrient limitation has in driving decomposition processes in boreal environments; and (iii) the synergistic effects of mixing charcoal with soil on mass loss will occur primarily through accelerated mass loss of native soil organic matter, given greater amounts of more labile carbon forms present in soil organic matter compared to charcoal. Testing these hypotheses in combination will contribute to a greater understanding of the effect of charcoal on soil organic matter decomposition and the soil micro-organisms in naturally pyrogenic ecosystems, and how this effect is determined by charcoal properties and soil fertility.

2. Material and methods

2.1. Experimental design

The experiment had a completely randomized block design. There were 5 replicate jars used for each combination of charcoal and soil type. As treatments, six soil types from six contrasting sites in the boreal forested zone of northern Sweden were tested together with charcoal produced from nine woody boreal plant species. These soils (Table 1), which differed greatly in fertility and plant species composition, are listed in order of decreasing total nitrogen (N), and with soils classified as according to the International Union of Soil Science World Reference Base (2014); the sites and soils are as follows: (1) early successional coastal forest dominated by alder (*Alnus incana*) on a leptosol (hereafter 'Alder' soil), (2) Under herbaceous vegetation in an open pine (*Pinus sylvestris*) forest on a gleyic podzol (hereafter 'Herbaceous' soil), (3) Under fern understorey in a closed canopy Norway spruce (*Picea abies*) forest on a podzol (hereafter 'Fern' soil), (4) Birch (*Betula pendula* and *B. pubescens*) forest on a podzol (hereafter 'Birch' soil), (5) Under ericaceous vegetation, notably crowberry (*Empetrum hermaphroditum*) in open Norway spruce forest on a podzol (hereafter 'Ericaceous' soil), and (6) Under lichen understorey in open pine forest on a podzol (hereafter 'Lichen' soil). About 50 L of each soil type were collected from the full organic horizon, in September 2011. The Herbaceous and Ericaceous soil was collected near Arvidsjaur (65°33′N, 18°36′E), the Fern, Birch and Lichen soil was collected near Vindeln (64°12′N, 19°42′E), and the Alder soil was collected in the vicinity of Umeå

Table 1
Chemical properties of the six soil types used in the incubation experiment.

	pH	NH_4^+ (mg/kg)	NO_3^- (mg/kg)	PO_4^{3-} (mg/kg)	Total C (%)	Total N (%)	Total P (mg/kg)
Alder	4.6	63.3	3.1	8.6	50.6	2.5	668
Herbaceous	5.3	22.6	2.8	4.6	44.5	2.9	596
Fern	5.5	13.6	0.8	7.7	48.3	1.8	1131
Birch	4.9	1.8	0.6	19.5	48.7	1.5	674
Ericaceous	4.4	<0.2	0.7	28.4	49.8	1.2	639
Lichen	5.4	2.1	0.4	3.3	35.3	1.1	533

NH_4^+ = ammonium; PO_4^{3-} = phosphate; total C = carbon content; total N = nitrogen content; total P = phosphorus content.

Download English Version:

https://daneshyari.com/en/article/4381837

Download Persian Version:

https://daneshyari.com/article/4381837

Daneshyari.com