Soil Biology & Biochemistry 65 (2013) 39–49

Contents lists available at SciVerse ScienceDirect

Soil Biology & Biochemistry

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

An experimental study of charcoal degradation in a boreal forest

Isabella Kasin*, Mikael Ohlson [1]

Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, P.O. Box 5003, NO-1432 Ås, Norway

ARTICLE INFO

Article history:
Received 19 December 2012
Received in revised form
8 May 2013
Accepted 10 May 2013
Available online 28 May 2013

Keywords:
Pyrogenic carbon
Black carbon
Charcoal
Degradation rate
C/N ratio
Field experiment

ABSTRACT

Degradation rates of pyrogenic carbon (PyC) under natural environmental conditions are largely unknown. Here we present results from a field experiment monitoring the change in mass, C- and N concentrations of a variety of charcoal types in a Norwegian boreal forest over a period of 20 months. The charcoal types represent different feedstock tree species, production temperature regimes, and placements in the forest, i.e. above ground, in the humus layer or in contact with the mineral subsoil. The types of charcoal had different initial C concentrations mainly depending on their production temperature. Nevertheless, all types of charcoal at all placements in the forest showed an initial drop in their C concentrations, which subsequently rose back to reach near initial values in part of the charcoal types. In part of the charcoal types, N concentrations decreased throughout the experiment, exhibiting considerable variation among feedstock species, production temperature regime, and placements in the forest. C/N ratios rose especially in charcoal made from wood of Scots pine (*Pinus sylvestris* L.), and charcoal that had been stored in contact with the mineral subsoil showed the most rapid mass gain. Our results confirm the important influence of production temperature and feedstock type on the degradation of charcoal, but they also show that microbial activity and environmental conditions play significant roles in charcoal degradation and thus for the fate of pyrogenic carbon under natural conditions.

1. Introduction

Pyrogenic black carbon (PyC), the product of incomplete combustion of organic matter, has been shown to be a ubiquitous fraction of the carbon pool in soils and sediments (Schmidt and Noack, 2000) and may contribute with as much as 60% to the soil organic carbon pool (Ponomarenko and Anderson, 2001). Due to its importance in the global C cycle, its potential to act as a C sink mitigating climate warming, its adsorption of environmental pollutants, and its effects on soil biota, ecosystem function and crop yields, PyC has attracted a considerable amount of research in the last few years (Scott and Damblon, 2010; Lehmann et al., 2011; Schmidt et al., 2011; Zimmermann et al., 2012). The degradation rate of PyC is an important issue in this context, and the longevity of PyC in soils and sediments is under debate (Masiello, 2004; Czimczik and Masiello, 2007; Lehmann and Joseph, 2009; Singh et al., 2012), but how long PyC actually lasts in different types of environments is still largely unknown. Combinations of physical, chemical and biological processes interact in the degradation of PyC (Shneour, 1966; Lehmann et al., 2003; Hamer et al., 2004; Cheng et al., 2006; Preston and Schmidt, 2006; Hammes and Schmidt, 2009; Zimmerman, 2010; Zimmermann et al., 2012). The rates of these processes are significantly influenced by PyC feedstock type, pyrolysis temperature, heating rate, particle size, and environmental conditions such as e.g. soil characteristics (Williams and Besler, 1996; Fernandes et al., 2003; Brown et al., 2006; Nocentini et al., 2010; Kloss et al., 2012; Santos et al., 2012; Knicker et al., 2013). Recent studies have also emphasized that different fractions of the PyC pool have different turnover rates (Singh et al., 2012; Knicker et al., 2013), some only in the range of months (Hamer et al., 2004; Hilscher et al., 2009). This is particularly interesting as every wildfire provides unique combinations of PyC feedstocks and temperatures that will produce a wide range of different PyC forms (Schmidt and Noack, 2000; Brown et al., 2006). Some of these will degrade relatively fast, and other slow. Taken together, this calls for a better understanding of the relationships between PyC properties and degradation rates. It is, however, clear that at least part of the PyC represents an organic pool that is much more refractory in soils than most other organic pools. For example, PyC in the form of soil charcoal may be thousands of years old (Lertzman et al., 2002; Schmidt et al., 2002), because it consists mainly of recalcitrant aromatic carbon structures (Eckmeier et al., 2009).

* Corresponding author. Tel.: +47 64965800.
E-mail addresses: isabella.kasin@umb.no, isabella.kasin@gmail.com (I. Kasin), mikael.ohlson@umb.no (M. Ohlson).
[1] Tel.: +47 64965757.

0038-0717/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.soilbio.2013.05.005

Most studies on PyC degradation are based on incubation experiments under controlled laboratory conditions, e.g. (Baldock and Smernik, 2002; Gundale and DeLuca, 2006; Kuzyakov et al., 2009; Liang et al., 2010; Bergeron et al., 2013), and only few degradation experiments are done in the field under natural conditions (Hammes et al., 2008; Wardle et al., 2008). Among the small number of field experiments, only Major et al. (2010) provide basic information about the PyC feedstock and the temperature regime during the pyrolysis. However, as far as we know, no field experimental study has yet used PyC from different feedstock species and pyrolysis temperatures to test how these factors influence PyC degradation rates. Here we report results from an experiment in which we have used PyC in the form of charcoal that was produced from different tree species and temperature regimes. We did our experiment in a natural Norwegian boreal forest and the charcoal originated from the main tree species in the region (i.e. *Pinus sylvestris*, *Picea abies*, and *Betula pubescens*). There are four main reasons for why we have done our study in the boreal forest. First, 5–15 million hectares of boreal forest are burnt each year (Stocks et al., 2002) and these wildfires leave behind huge amounts of charcoal in the forest (Clark et al., 1998; Ohlson and Tryterud, 2000; Ohlson et al., 2009). Second, climate change is an important driver of wildfire activity in the boreal forest (Soja et al., 2007) and the risk of fire and area burnt is predicted to increase by at least twofold across large areas of the boreal forest by the year 2100 (Flannigan et al., 2009). Third, fresh charcoal from recent fires can play functionally important roles in the boreal forest ecosystem (Zackrisson et al., 1996; Wardle et al., 1998), and the degradation rate of charcoal in its natural environment is of wide-ranging interest. Fourth, most field experiments on PyC degradation rates are done in savannah- and steppe ecosystems (Bird et al., 1999; Hammes et al., 2008; Nguyen et al., 2008; Major et al., 2010), and there is only one study that we know of that is done in the boreal forest, i.e. Wardle et al. (2008).

Our main aim is to explore the relationships between charcoal properties, environmental conditions, and charcoal degradation rates in boreal forests. To do this, we placed different types of charcoal with known properties in various placements above and below ground in the forest and monitored change in charcoal mass and C- and N-concentration to estimate degradation rates. More specifically we hypothesised that (i) charcoal produced under high temperature is more recalcitrant than charcoal produced under low temperature; (ii) charcoal placed in the soil will change more rapidly than charcoal placed above ground due to contact with the soil community; and (iii) the change and degradation will differ between charcoal in the organic humus top-soil and charcoal in contact with mineral soil further down in the soil profile.

2. Materials and methods

2.1. Study area

The study area (60°02′N, 09°26′E) is a Scots pine (*P. sylvestris*) forest situated in the mid boreal vegetation zone (Moen, 1999) 420 m a.s.l. in the Trillemarka–Rollagsfjell Nature Reserve in south eastern Norway (Fig. 1). The climate is slightly oceanic (Moen, 1999) with an average summer temperature and precipitation (June, July and August) of 13.8 °C and 81 mm, respectively. The winters are cold (January mean: −7.5 °C) and snow-rich (climate data from the Rollag meteorological station, Norwegian Meteorological Institute (2012)). Dwarf shrubs such as e.g. *Calluna vulgaris* and *Vaccinum ulginosum* together with peat mosses (mainly *Sphagnum russowii* and *S. girgensohnii*) dominate in the forest floor vegetation, indicating moist, nutrient poor and relatively acidic soil conditions. Granites

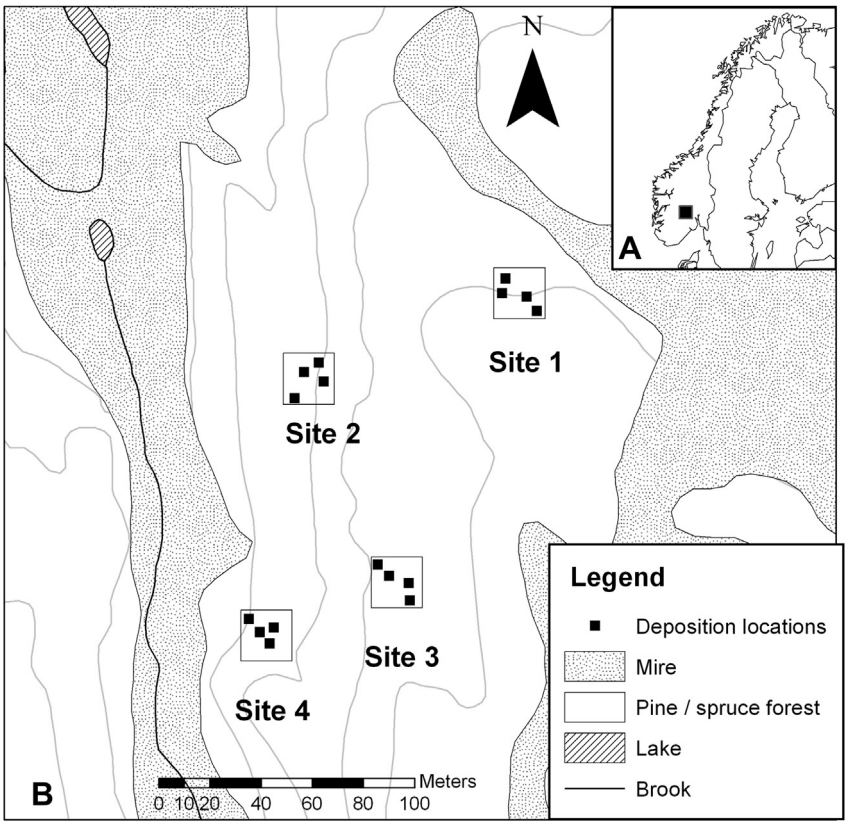

Fig. 1. Study area in south eastern Norway (A) and deposition locations within the study area (B).