Soil Biology & Biochemistry 42 (2010) 178–185

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

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

Amounts of carbon mineralised and leached as DOC during decomposition of Norway spruce needles and fine roots

Karna Hansson [a,*], Dan Berggren Kleja [b], Karsten Kalbitz [c], Hanna Larsson [b]

[a] Department of Ecology, Box 7044, Swedish University of Agricultural Sciences, S-75007 Uppsala, Sweden
[b] Department of Soil and Environment, Box 7001, Swedish University of Agricultural Sciences, S-75007 Uppsala, Sweden
[c] Earth Surface Science, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Nieuwe Achtergracht 166, NL-1018 WV Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 24 June 2009
Received in revised form
1 October 2009
Accepted 14 October 2009
Available online 24 October 2009

Keywords:
Dissolved organic carbon
Mineralisation
Fine roots
Needles
Litter decomposition
Norway spruce
Carbon dioxide

ABSTRACT

Changes in climate or forest management practices leading to increased litter production will most likely cause increased leaching rates of dissolved organic carbon (DOC) from the O horizon. The rhizosphere is often assumed to have a large carbon flux associated with root turnover and exudation. However, little has been done to quantify the amount of DOC originating from root litter. We studied decomposition of fine root and needle litter of Norway spruce (*Picea abies*) through a combined incubation and leaching experiment in the laboratory using five different litter types: fresh needle litter, aged needles from the litter layer, fresh and dead roots from mineral soil samples, and seven-year-old roots from a previous litterbag study. After respiration measurements, the samples were percolated with artificial throughfall water and DOC and UV absorbance were measured in the leachate. Mineralisation of dissolved organic matter in the leachate and sorption of DOC to ferrihydrite were determined as a measure of DOC ability to be stabilised by iron (hydr)oxide surfaces.

The mineralisation rate and DOC production rate of root samples were always lower than that of needle samples. However, root and needle derived dissolved organic matter (DOM) were similar in terms of aromaticity, as indicated by their specific UV absorbance, and ability to be sorbed by ferrihydrite. For seven-year-old roots, a significantly higher fraction of carbon was lost as DOC (30%) than for younger roots (20%). Furthermore, DOM from old roots bound more strongly to ferrihydrite and is mineralised at a lower rate than DOC from younger roots, suggesting that roots at late stages of decomposition, although a small fraction of total litter, significantly contribute to carbon build-up in mineral soils. The slower decomposition rate of roots compared with needles must be taken into account when modelling litter decomposition.

1. Introduction

Temperate forest ecosystems account for about 25% of the carbon stock in global terrestrial ecosystems, of which about half is stored in soil organic matter (King et al., 1997). Thus, a small change in the carbon balance of soils in these ecosystems might affect atmospheric CO_2 concentration. Compared to the processes controlling soil organic matter (SOM) turnover in the forest floor, our understanding of the chemical and microbial processes controlling turnover of SOM in mineral soil layers is poor. This is a problem when assessing the potential of forest soils to act as carbon sinks or sources since a major fraction of carbon is normally found in the mineral soil. According to an inventory of soil organic carbon (SOC) pools in boreal forest soils in Scandinavia, 70–80% of the organic carbon in the upper 100 cm is found in the mineral soil (Callesen et al., 2003). The major carbon inputs to mineral soil layers are from fine root litter and dissolved organic carbon (DOC) leached from the forest floor. Thus, the carbon pool and its dynamics in the mineral soil are determined by the input rates of root litter and retained DOC, as well as their decomposition rates.

In a recent study, fluxes of carbon into the mineral soil in the form of DOC and fine root litter were measured in three Norway spruce ecosystems situated along a climate gradient in Sweden (Kleja et al., 2008). The annual inputs of carbon as fine root (<1 mm) litter to the mineral soil (0–50 cm) ranged between 73 and 78 g m^{-2} yr^{-1}, whereas the corresponding range for DOC was 9–26 g m^{-2} yr^{-1}. Thus, root litter clearly dominates the carbon input. However, the net contribution of root litter to the steady-state carbon pool is less clear, because detailed information on the decomposition rates of root litter and DOC in the mineral soil – and their determining factors – is not yet available.

Michalzik et al. (2003) used the Dynamic DOC model (DyDOC) to estimate the contribution of DOC input and root litter to the steady-state carbon pool. According to their simulations, 73–89% of the

* Corresponding author. Tel.: +46 18 672412; fax: +46 18 672890.
E-mail address: karna.hansson@ekol.slu.se (K. Hansson).

0038-0717/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2009.10.013

mineral soil carbon originated from DOC. However, in producing this estimate they assumed that root litter behaved as needle litter in terms of carbon mineralisation and DOC production rates. Furthermore, they assumed that the quality of dissolved organic matter (DOM) produced from the two substrates was identical. These assumptions are critical and might not be valid. For example, a litterbag study by Majdi (2004) found that the mass loss of fine root litter of Norway spruce was half that of needle litter after one year of decomposition. Palviainen et al. (2004) reported similar values, with 34% mass loss of fine root litter compared with 59% mass loss of needle litter after three years of decomposition in a Norway spruce stand. However, litterbag studies provide no information on the relative losses as CO_2 and DOC. Needle litter is known to produce substantial amounts of DOC during the decomposition process (Fröberg et al., 2005). The extent to which this occurs for fine root litter is less well known. In a recent study, Uselman et al. (2007) incubated ^{14}C-labelled fine root material and leaf litter in 50-cm soil microcosm columns and measured the production of CO_2 and DOC. Their experiment showed that roots decomposed more slowly than leaf litter and that DOC made a significant contribution (~60%) to total carbon losses during the 47-day experimental period. The experimental setup did not allow for any qualitative characterisation of the DOM produced by the two substrates. The quality of DOM formed during decomposition of root litter is probably crucial for its contribution to the build-up of soil carbon stocks in mineral soil layers because the sorption of DOM to mineral surfaces such as ferrihydrate is influenced by its chemical composition. Constituents with higher molecular weight have been shown to adsorb preferentially, and fractions rich in aromatic structures such as lignin-derived hydrophobic compounds, fulvic and humic acids show stronger sorption than compounds rich in carbohydrates (Chorover and Amistadi, 2001; Kaiser, 2003). As shown by Mikutta et al. (2007), the binding mode of DOM to mineral surfaces is decisive for its bioavailability.

The decomposition rate and DOC production of a substrate changes with time, due to changes in substrate quality during decomposition (Moore and Dalva, 2001; Don and Kalbitz, 2005). In a study of the fine root dynamics of black spruce (*Picea mariana* L.), decomposition was found to be rapid soon after the roots were identified as being dead, but decreased with time (Ruess et al., 2003). Berg (2000) suggests that the decomposition rate of plant litter at late decomposition stages is very slow and approaches zero. Different stages of decomposition should therefore be considered when estimating DOC originating from litter. To our knowledge, there is no previous study on DOC production from roots in different stages of decomposition. In the present study we focused on determining leached DOC and respired carbon for Norway spruce fine roots and needles at different stages of decomposition. Our specific objectives were (i) to investigate the extent to which the fraction of DOC lost during decomposition depended on the stage of decomposition of the substrate; (ii) to make a brief qualitative comparison of DOM leached from root and needle litter at different stages of decomposition; (iii) to determine the ability of DOM originating from root and needle litter to be sorbed by ferrihydrite; and (iv) to determine the mineralisation of DOM derived from roots and needles.

2. Materials and methods

2.1. Site description

All litter samples were taken from Asa Experimental Forest (57°08′N, 14°45′E), in southern Sweden. The site is one of three Norway spruce (*Picea abies* (L.) Karst.) stands used within the LUSTRA research programme (Berggren et al., 2004; Kleja et al., 2008). Asa is located 190–200 m above sea level in the boreonemoral vegetation zone. Mean annual air temperature is 5.5 °C and mean annual precipitation 688 mm. The duration of the growing season (temperature >5 °C) is 190 days. Field samples were collected in LUSTRA plots with a mesic moisture regime. Stand age was 44–47 years in 2007. Site productivity ranges from 10.1 to 11.3 $m^3\ ha^{-1}\ yr^{-1}$ and the field and ground vegetation is grass or no vegetation.

According to FAO. (1990) the soil is classified as a Haplic Podzol, developed on a glacial till. The texture is a stony sandy loam with a medium boulder frequency. Site productivity ranges from 10.1 to 11.3 $m^3\ ha^{-1}\ yr^{-1}$ and the field and ground vegetation is grass or no vegetation (Berggren et al., 2004).

2.2. Root and needle litter samples

Five different litter types were sampled: fresh needle litter, aged needles from litter layer, fresh roots from mineral soil, dead roots from mineral soil and seven-year-old roots from a previous litterbag study. Each litter type was a mix of several subsamples. Needle litter was collected in December 2006 and stored in the freezer. Fresh needle litter samples were obtained by shaking trees and collecting the falling needles. Green needles were excluded. Aged, slightly decomposed needles were taken from the litter (Oi) layer. The turnover time of this layer is about 5 years (Fröberg et al., 2005). Mineral soil samples (0–10 cm soil depth) were collected in October and November 2007. Roots were carefully removed from the soil, placed in deionised water and gently stirred to remove soil particles. They were carefully cleaned and sorted using forceps under 10× magnification into living and dead roots, based on visual criteria described by Vogt and Persson (1991). Grass roots were excluded. All roots used in the incubation experiment had a diameter of <2 mm. Strongly decomposed roots were obtained from a previous litterbag study. Fresh roots with a diameter < 2 mm were cut into 1–4 cm-long pieces and placed in litterbags in 1999. These litterbags were buried in the mineral soil at 10 cm depth and recovered in December 2006 and stored in the freezer. All roots used in the experiment were cut into pieces of approximately needle length, 1–2 cm. Water content in the material was determined by weighing litter samples, drying them at 105 °C for 24 h and calculating the weight loss. Total carbon and nitrogen (N) content in the dried samples were analysed by dry combustion (CN2000, LECO Corporation). Samples used in incubation were not dried.

2.3. Column incubation and measurements

Litter samples were incubated in glass columns (35 cm long with an inner diameter of 2.4 cm) using a method adapted from Sjöberg et al. (2003). Each column had a bottom plug made of silicone, containing a glass drain pipe connected to a silicone tube closed with a clip. A glass fibre filter (1.0 μm pore size, Whatman GF/B) was placed in the bottom of the column to avoid leaching of particles. The columns were filled with litter (equivalent to 1 g dry weight) mixed with 25 g quartz sand (washed with acid and heated to 600 °C to remove carbon), and a second glass fibre filter (0.7 μm pore size, Pall Corporation) was placed on top. During incubation, plastic films were placed on the opening of the column to allow gas exchange but prevent evaporation of water. Four replicates of each litter type (in total 20 columns) were incubated. Prior to each percolation, column outlets were connected by silicone tubes to vacuum chambers in which borosilicate glass bottles were placed to collect the leachate. A suction of approximately −0.2 bar was set to create unsaturated flow conditions. The chemical composition of the leaching solution resembled throughfall water at the site. The solution consisted of deionised water with addition of ions to give a concentration of Na^+: 0.066 mM, K^+: 0.054 mM, Ca^{2+}: 0.014 mM,