Soil Biology & Biochemistry 48 (2012) 1–9

Contents lists available at SciVerse ScienceDirect

Soil Biology & Biochemistry

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

The impact of logging residue on soil GHG fluxes in a drained peatland forest

Päivi Mäkiranta [a,b,*], Raija Laiho [a], Timo Penttilä [b], Kari Minkkinen [a]

[a] Department of Forest Sciences, P.O. Box 27, FI-00014, University of Helsinki, Finland
[b] Finnish Forest Research Institute, P.O. Box 18, FI-01301 Vantaa, Finland

ARTICLE INFO

Article history:
Received 19 April 2011
Received in revised form
2 January 2012
Accepted 6 January 2012
Available online 20 January 2012

Keywords:
Drained peatland
Clearfelling
Logging residue
GHG
N_2O
Soil respiration
Heterotrophic respiration
Priming

ABSTRACT

Northern peatlands contain substantial reservoirs of carbon (C). Forestry activities endanger the C storages in some of these areas. While the initial impacts of forestry drainage on peatland greenhouse gas (GHG) balance have been studied, the impacts of other silvicultural practices, e.g. logging residue (LR) retention or removal, are not known. We measured the CH_4, N_2O and CO_2 fluxes between peat soil and atmosphere with and without decomposing LR over three (2002–2004) seasons (May–Oct) following clearfelling in a drained peatland forest, along with the mass loss of LR. Seasonal average CO_2 efflux from plots with LR (3070 g CO_2 m^{-2} $season^{-1}$) was twice as high as that from plots without LR (1447 g CO_2 m^{-2} $season^{-1}$). Less than 40% of this difference was accounted for by the decay of logging residues (530 g CO_2 m^{-2} $season^{-1}$), so the majority of the increased CO_2 efflux was caused by increased soil organic matter decomposition under the LR. Furthermore LR increased soil N_2O fluxes over 3-fold (0.70 g N_2O m^{-2} $season^{-1}$), compared to plots without LR (0.19 g N_2O m^{-2} $season^{-1}$), while no change in CH_4 emissions was observed. Our results indicate that LR retention in clearfelled peatland sites may significantly increase GHG emissions and C release from the soil organic matter C storage. This would make the harvesting of LR for biofuel more beneficial, in the form of avoided emissions. Further investigations of the sources of CO_2 under logging residues are, however, needed to confirm this finding.

1. Introduction

Northern peatlands contain substantial reservoirs of carbon (C) and nitrogen (N) in their peat soil and are therefore important in the global C and N cycles (Gorham, 1991; Khalil, 1999; Turunen et al., 2002). Accumulation of organic matter (OM) is due to high water table level and associated anoxia, which cause accumulation of partially decomposed OM as peat. In these anoxic conditions decomposition is slow and results in the formation and release of methane (CH_4) to the atmosphere. Drainage of these wet soils has been commonly used to stimulate the productivity of the peatland forest in many northern countries (Paavilainen and Päivänen, 1995). Within these countries drained peatland forests have become a large land use category, where also forest management practises are carried out with ever growing intensity (Tomppo and Hentonen, 1996). Knowledge on the effects of management practises such as clearfellings on greenhouse gas (GHG) fluxes in drained peatland forests is still very limited (Nieminen, 1998; Huttunen et al., 2003; Saari et al., 2009; Mäkiranta et al., 2010). For example, the impacts of logging residue (LR) on soil GHG effluxes are still unknown. To our knowledge the decomposition rate of LR and the effects of LR on soil CO_2, CH_4 and N_2O fluxes on peatlands have not been estimated previously. Better understanding of the effects of management practices on site GHG fluxes ensures that the most sustainable practices can be selected and the greenhouse impact of forestry activities can be minimised.

Clearfelling is a common practice used for timber harvesting worldwide. Traditional clearfelling in Finland involves cutting all trees, removing commercial stem wood and leaving logging residues on the site. Lately, the increasing demand for production of bioenergy has led to a new forest management practice, in which also LR is harvested. The greenhouse impact of LR removal and energy use is usually determined from the life cycle perspective (e.g. Savolainen et al., 1994; Kirkinen et al., 2008). In such analyses it has been commonly assumed that the decomposition of LR at a forest site is an emission source equal to that of burning the LR. Recently, it has been suggested that the decomposition rate of LR left in the site could be much smaller than anticipated earlier, resulting that LR forms a slowly decomposing C stock at the harvest site (Repo et al., 2010). This would make LR burning for energy a less favourable option. Decomposition rates of LR have, however, been little studied, and there are no empirical studies for example on the effects of climatic conditions on their decomposition rates.

* Corresponding author. Finnish Forest Research Institute, P.O. Box 18, FI-01301 Vantaa, Finland. Tel.: +358 50 3001776; fax: +358 9 19158100.
E-mail address: paivi.makiranta@metla.fi (P. Mäkiranta).

0038-0717/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2012.01.005

Table 1
Peat 0–20 cm characteristics. D_b = bulk density in Vesijako site.

D_b, kg m^{-3}	Ash, %	C, %	N, %
132	4.1	52.7	1.6

Furthermore, present studies have not considered the possible effects of LR on soil GHG effluxes.

When left on site LR alters soil moisture and temperature conditions (Roberts et al., 2005), both of which are major drivers of soil OM decomposition (Lloyd and Taylor, 1994; Davidson et al., 1998). Furthermore, LR may provide soil microbes with additional nutrients and energy in the form of fresh OM. This may increase microbial activity under the logging residue piles (Fontaine et al., 2004, 2007) and, consequently, show up as increased rate of peat decomposition. The changes in substrate supply and soil conditions may further result in a release of extra nitrogen (N) as nitrate (NO_3^-) in soil solution. In poorly aerated peat soils, especially, this fertilisation with nitrate may lead to increased N_2O effluxes through nitrification-denitrification cycles.

We measured CO_2, N_2O and CH_4, fluxes on peat soil with and without decomposing LR, and the mass loss of LR, after clearfelling in a drained peatland forest. Our aim was to quantify both the initial post harvest C loss from LR and the effect of LR on soil GHG effluxes. We hypothesised that (1) LR would decompose faster in a southern site with higher temperature sum compared to that of a northern site, (2) LR would affect soil organic matter decomposition rate, i.e., the effect of LR on CO_2 effluxes would be different than that estimated based on the mass loss rate of LR alone (3) the flux of N_2O from plots with LR would be higher than without them and (4) LR would not affect CH_4 fluxes.

2. Materials and methods

2.1. Site and tree stand

The study site was located in a drained peatland forest in Padasjoki, Vesijako Research Forest, south-boreal Finland (61° 22′ N, 25° 07′ E). The peatland studied was originally a treed mire with an ombrotrophic centre and a minerotrophic lagg. The site was first drained by ditching in 1915 and ditch maintenance operations were carried out in 1933 and 1954. On average, the site represented oligotrophic nutrient status as indicated by the vegetation and the level of total N in surface peat (Table 1). Peat depth in the area varied from 100 to over 300 cm. The tree stand present prior to the clearfelling had evolved through seed tree cutting in 1945–1950. It consisted mostly of Scots pine (*Pinus sylvestris*; 81% of volume) with admixtures of Norway spruce (*Picea abies;* 10%) and downy birch (*Betula pubescens*; 9%). In winter 2001–2002 an area of approximately 0.5 ha was clearfelled, in the middle of the peatland.

The tree stand was measured in the autumn of 2001 prior to clearfelling. Tree species and DBH (diameter at 1.3 m height, mm) were recorded for all trees and tree height for sample trees that were selected to represent the entire range of DBH distribution, by tree species. The stem volumes and other stand parameters were then computed based on the tree volume functions by Laasasenaho (1982). Total tree stand biomass, and its distribution into stem wood (commercial and non-commercial) and stumps, branches (all including bark), foliage, and coarse roots were obtained by applying Marklund's (1988) tree-wise biomass functions, based on tree DBH and height, to the tree data. The biomass of branches, stumps and coarse roots for birch were estimated by applying the functions for pine. The tree stand biomass was dominated by stem biomass (64%) while coarse roots (16%), stumps (6%), branches (11%), and foliage (3%) each contained lesser proportions (Table 2). Above ground logging residues (branches, foliage and non-merchantable stem tops (4% of total) thus contained 18% of the total tree stand biomass (Table 2).

To test the impact of climate on LR decomposition, the LR decomposition experiment was also carried out at a more northern clearfelled site in Kivalo Research Forest (66°21′ N, 26°37′E, 180 m.asl.). The site was originally a treed minerotrophic fen. It was first drained in 1933 and is now classified as *Vaccinium myrtillus* type forest, thus showing a slightly higher nutrient status than the Vesijako site. The peat layer is thin, 30–90 cm. For a closer description of the site, see Minkkinen et al. (2007). Climatic conditions for Vesijako and Kivalo sites are given in Table 3.

2.2. Logging residue decomposition experiment

The decomposition rate of LR following clearfelling was estimated using the litter bag method. Ten sets of large mesh bags containing either one entire branch or tree top with intact needles (average dry mass of 1350 g), were buried in 10 different logging residue piles in May 2002 in both sites. The dry mass contents were determined from an extra set of sample branches and tree tops that were weighed for fresh mass in the field and oven dried until constant mass in laboratory. The average dry mass content by site, separately for branches and tree tops, was applied to estimate the initial dry mass for each sample branch or tree top. The mesh size of the nylon bags was 1 mm × 1 mm to allow small mesofauna, typical of the sites (Silvan et al., 2000), to enter the bags.

LR mass loss was measured from subsets of bags recovered approximately 0.5, 1, 2, 4 and 6 years after the beginning of the experiment (Fig. 1). The mass loss was expected to be caused mainly by microbial degradation of logging residues and consequent CO_2 efflux from microbial respiration, but to some extent also by leaching of DOC and release of small OM particles from logging residues to the soil. The remaining contents of the bags were cleaned from external materials, dried to a constant mass and weighed. Decomposition rates were expressed as dry mass loss (%) after each incubation period. Difference between Vesijako and Kivalo sites was tested using t-test.

Two types of decay functions were tested to the litter bag data. The exponential decay function (Olson, 1963), which is widely used to calculate the decomposition rate constants for litter decomposition, poorly fitted to our data. Instead, the asymptotic function (Eq. (1)), also used by Latter et al. (1998) to describe the long term course of litter decomposition, showed a better fit and was used for estimating LR decomposition over time.

Table 2
Tree stand stem volume and biomass in Vesijako site.

	Year	Stemwood volume (m^3 ha^{-1})				Biomass by component (kg m^{-2})					
		Pine	Spruce	Birch	All	Roots >1 cm	Stumps	Stems	Branches	Foliage	All
Tree stand	2001[a]	141	23	40	203	2.180	0.800	8.430	1.390	0.440	13.240
Logging residues						2.180	0.800	0.530	1.390	0.440	5.340

[a] Before clearfelling.