Soil Biology & Biochemistry 66 (2013) 51–59

Contents lists available at SciVerse ScienceDirect

Soil Biology & Biochemistry

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

Response of soil organic layer characteristics to logging residues in three Scots pine thinning stands

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ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form
24 June 2013
Accepted 27 June 2013
Available online 11 July 2013

Keywords:
C transformations
Logging residue
N transformations
Scots pine
Tannins
Terpenes

ABSTRACT

The aim of this study was to determine how logging residues, consisting of tree tops and branches with needles, affect soil microbial processes in C and N cycling in Scots pine stands, and how these processes are related to the composition of terpenes and phenolic compounds, two major groups of plant secondary compounds. Samples were taken from the humus layer (O_{fh}) of three field experiments in Finland. The first was a single-tree experiment in a young pine stand where thinning was performed 4 years before this study and four doses of fresh logging residue were distributed on a circle around a tree, corresponding to 0, 10, 20 and 30 Mg ha^{-1} of dry matter. The other two field experiments had been thinned twice, one 29 and 4 years ago and the other 23 and 13 years ago; the treatments were whole-tree harvest, where logging residues had been harvested, and stem-only harvest, where logging residues were left on the plot. In the single-tree experiment, with increasing amount of residues, C/N ratio of organic matter decreased, C mineralization (CO_2 production) and glucose-induced respiration increased, but C and N in the microbial biomass both remained on a similar level, regardless of the amount of logging residues. Due to high variation, it was not possible to observe any statistically significant effects of logging residues on net N mineralization, but with increasing amount of residues the trend was increasing. Amount of logging residues did not affect the concentrations of total water-soluble phenolic compounds, or the concentrations of mono-, sesqui- or diterpenes in the humus layer, whereas with increasing amount of residues the concentrations of condensed tannins and triterpenes tended to increase. Amount of logging residues did not affect monoterpene concentrations in the soil atmosphere. In the two other field experiments, logging residues had little effect on soil C and N transformations or groups of organic compounds, although some significant differences were observed in the experiment sampled 4 years after harvest of logging residue. Both C and net N mineralization correlated positively with the concentrations of water-soluble low-molecular-weight phenolic compounds and sesqui-, di- and triterpenes in the humus layer. In conclusion, the response of soil characteristics in Scots pine stands to harvest of logging residue in thinning seems to depend on the amount of residues and on the time elapsed since thinning, but the response may vary on different sites. In cases where an effect was observed, however, it pointed to a stimulative effect of residues on C and N cycling processes. Terpenes and phenolic compounds, abundant in the residue, may affect soil microbial population, e.g. by providing a long-term source of carbon.

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1. Introduction

During recent years, in the Nordic countries the use of forest biomass for bioenergy has increased. In Finland the national aim is to almost double the present annual use of 7.5 million m^3 of forest chips by the year 2020 (Ilvesniemi, 2012). For these reasons, harvesting of logging residues from both clear-cuttings and thinning stands has become more common. In conventional stem-only harvest, tree branches, stem tops and needles are retained on the site, but in whole-tree harvest a large proportion of the logging residue is harvested for bioenergy production. This results in less carbon and nutrients entering the soil. In thinnings in the Nordic countries, the amount of N removed with logging residues is 60–130 kg ha^{-1} in Norway spruce (*Picea abies*) stands and 20–60 kg ha^{-1} in Scots pine (*Pinus sylvestris*) stands (Jacobson et al., 2000).

Some differences between whole-tree harvest and stem-only harvest treatments have been observed in both the tree stand and the soil. Whole-tree harvest resulted in a long-term decrease in

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0038-0717/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.soilbio.2013.06.017

tree growth in both Norway spruce stands and Scots pine stands; the decrease was larger in spruce (5 and 13% during the first and second 10-year periods, respectively) than in pine stands (4 and 8%) (Jacobson et al., 2000; Helmisaari et al., 2011). Whole-tree harvesting in thinnings also led to slight changes in soil nutrients, e.g. decreases in the amounts of exchangeable base cations (Rosenberg and Jacobson, 2004; Tamminen et al., 2012). Total N in soil was not affected which can probably be explained by the fact that the N content in logging residues is much lower than N content of the organic layer. In studies with loblolly pine in the USA, however, net N mineralization due to whole-tree-harvest over the long term (14 years) decreased (Piatek and Lee Allen, 1999). In some other more short-term studies with different tree species growing in different types of forest ecosystems a decrease in net N mineralization has also been observed (Hendrickson et al., 1985; O'Connel et al., 2004). After repeated logging-residue harvests in Norway spruce stands in Finland, as late as 10–19 years after harvest, the rates of net N and C mineralization were generally lower in whole-tree than in stem-only harvest treatment (Smolander et al., 2010). An earlier study performed 10 years after a single harvest also pointed to a decrease in mineralization of C and N due to residue removal (Smolander et al., 2008).

Logging residues contain large amounts of many plant secondary compounds (Obst, 1998), and whole-tree harvest leads to decreased input of these compounds to soil compared to stem-only harvest. Two major groups of compounds are terpenes and phenolic compounds, in particular tannins. There is, for example, much resin, a mixture of both mono- and higher terpenes, in the residue. In short-term laboratory experiments it has been shown that exposure of soils to several monoterpenes or tannins may inhibit soil N transformations, at least net N mineralization and nitrification; in some cases a decrease in the amount of microbial biomass N has also been reported (reviews by Kraus et al., 2003; Smolander et al., 2012). There are also indications that both secretory resin and certain higher terpenes alone affect soil N transformations at least in short-term (Lenoir et al., 1999; Uusitalo et al., 2008; Adamczyk et al., 2011). In Norway spruce stands, harvest of logging residue caused a long-term decrease in the concentrations of sesqui- and diterpenes (Smolander et al., 2010) and in total water-soluble phenolic compounds and condensed tannins in the humus layer (Smolander et al., 2008). The results of Huang et al. (2011) from *Pinus radiata* plantations suggested that over the long term, with increased residue return the amount of stable soil C increased. All these results point to long-term effects of whole-tree harvest on soil organic matter composition which can lead to changes in C and N cycling.

The effects of logging residue removal on soil may depend on tree species. The biomass of logging residues in the first thinning was 9 Mg ha^{-1} in pine stands and 16 Mg ha^{-1} in spruce stands, and the corresponding values for amount of N were 40 and 90 kg ha^{-1} (Tamminen et al., 2012). In the first thinning in southern Finland the composition of crown mass of pine was the following: needles 27%, bark 19%, wood 33% (all in living branches), and dead branches 21% (Hakkila, 1991). Corresponding values for spruce were 39, 21, 33 and 7%. In general the share of needles, the most nutrient-rich material, in logging residues is estimated to be 20–30% for pine and 35–40% for spruce (Hakkila, 1971). Thus differences in both biomass and composition of logging residues are the reasons for the fact that in pine stands the removal of nutrients is not as large as in spruce stands. However, pine stands are often growing on less-fertile sites. With both tree species, logging residues give a great sudden pulse of organic matter to soil as compared to stand annual mean above-ground litterfall: In southern Finland 1.72 Mg ha^{-1} for pine and 2.80 Mg ha^{-1} for spruce, corresponding values for needle litterfall 0.97 and 1.72 Mg ha^{-1}, respectively (Starr et al., 2005; Saarsalmi et al., 2007). Moreover, in the residue the branches are green (Hakkila, 1971) on the contrary to the senescent material dominant in litter.

The aim of this study was to investigate how logging residues affect microbial processes related to C and N cycling in the humus layer of Scots pine stands, and how the effects on these processes are related to changes in the input of terpenes and phenolic compounds. We studied three long-term field experiments. In one of these experiments, four different amounts of fresh logging residues were distributed on a circle around individual trees four years before this study. In one experiment there were plots where, on thinnings done 23 and 13 years ago, logging residues were either left on the site or removed. In one experiment, on thinnings done 29 and 4 years before this study, a treatment with an extra amount of logging residues was also included.

2. Materials and methods

2.1. Study sites

The experiments were established in pure Scots pine (*Pinus sylvestris* L.) stands growing on relatively unfertile sites in central and southern Finland (Table 1). All soils were coarse and podsolized, having a mor layer on top of the mineral soil.

The Kannonkoski study site (746) had been thinned in 2004, and four doses (0, 40, 80 and 120 kg) of fresh logging residues were distributed evenly on a circle around individual trees ($A = 19.6$ m^2) corresponding to 0, 10, 20 and 30 Mg ha^{-1} of dry matter, respectively. Treatments were replicated three times. The organic layer was sampled four years after the treatment.

The Rautavaara study site (726) had been thinned twice, in 1979 and in 2004. The treatments were whole-tree harvest where logging residues had been removed (WTH; no residues), stem-only harvest where logging residues were left on the plot (SOH) and stem-only harvest where additional residues were brought from adjacent whole-tree harvest plots (SOH2). Logging residues were evenly distributed on the SOH and SOH2 plots. For all treatments, there were three study plots, each 30 m × 30 m. The amount of dry logging residue was estimated to be, on average, 5.3 and 8.2 Mg ha^{-1} in SOH and SOH2 treatments, respectively (Hakkila, 1991). The organic layer was sampled 4 years after the second thinning.

The Savitaipale study site (734) had been thinned twice, in 1985 and in 1995. The treatments were whole-tree harvest (WTH) and stem-only harvest (SOH), described above. For both treatments, there were three study plots, each 30 m × 30 m. Amount of dry

Table 1
Description of field experiments.

Experiment	Latitude	Longitude	Effective temperature sum (°C)[a]	Soil teanic layer, cm	Organic layer, cm	Site index H100, m	Stand age, a	Time since 1st thinning, a	Time since 2nd thinning, a
Kannonkoski (746)	62°58′	25°15′	1190	Loamy sand	2.0	24	38	4	–
Rautavaara (726)	63°40′	28°33′	1070	Loamy sand	2.7	27	53	29	4
Savitaipale (734)	61°13′	27°30′	1380	Sandy loam	3.9	28	57	23	13

[a] Mean effective temperature sum calculated for a 30-year period (1979–2008) based on the dataset of the Finnish Meteorological Institute (Venäläinen et al., 2011).

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