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Logging residue harvest may decrease enzymatic activity of boreal forest soils

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ABSTRACT

Nowadays conventional stem-only harvest where logging residues are left on the site is often displaced by whole-tree harvest, in which logging residues are harvested for use as bioenergy. Logging residues consist of tree branches and tops of stems with needles. The aim of this study was to evaluate the effect of logging residue harvest on soil enzyme activities involved in C, N and P cycling, namely β-glucosidase, β-glucosaminidase, protease and acid phosphatase in relation to other soil characteristics (i.e. soil respiration, net N mineralization, microbial biomass C and N). Soil samples were taken from the humus layer of five study sites, differing in fertility, dominating tree species and time elapsed after treatment. The study sites were Norway spruce (*Picea abies*, (L.) Karst) and Scots pine (*Pinus sylvestris* L.) stands in different parts of Finland. Four of the study sites were single-tree experiments, where thinning was performed 4–5 years before this study and 3–4 different doses of logging residues (from 0 up to 37.5 Mg ha^{-1}) were distributed on a circle around a single tree in 3 replicates. The last field experiment had been thinned twice, 23 and 13 years ago; the treatments in 3 replicates were whole-tree harvest and stem-only harvest. In the whole-tree harvest *vs.* stem-only harvest experiment, activities of β-glucosidase, β-glucosaminidase, acid phosphatase were similar in both treatments. In general, in the single-tree experiment with pine, enzymes raised the activity in response to increasing amount of logging residue. The pattern was less clear for the spruce single-tree experiment, but acid phosphatase and protease activities increased with the increase in amount of logging residue. In general, other soil characteristics were less affected than enzyme activities by logging residue removal; however, in some sites logging residues seemed to increase net C and N mineralization with increasing logging residue amount. Our results suggest that retaining logging residues on the site can increase soil enzyme activities and C and N mineralization.

1. Introduction

According to Kyoto Agreement, nations must maintain emission of CO_2 on the same level as in the year 1990 (Hakkila, 2006). This aim can be partly achieved by the use of renewable bioenergy, such as bioenergy from the forest logging residues (Nurmi, 2007). It is assumed that burning of logging residues does not increase CO_2 emissions like fossil fuels in long-term (Schlamadinger et al., 1995). However, logging residue harvest may potentially affect forest productivity.

In traditional forest management only tree stems are removed (stem-only harvest, SOH). In whole-tree-harvest (WTH), most of the aboveground tree parts are removed, namely stems, branches and stem tops with needles. Logging residues are harvested in both clear-cutting and thinning stands (Rolff and Ågren, 1999). In thinning stands, whole-tree harvest has been shown to decrease forest productivity (Helmisaari et al., 2011; Kaarakka et al., 2014). Whole-tree harvest resulted in a long-term decrease in 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). Reduction of growth may be caused by a decrease in nutrient supply. Leaving logging residues on the site after thinning exposes these materials to the mineralization process, and the mineralized nutrients can be utilized by the remaining trees (Hyvönen et al., 2000).

Logging residues with needles provide rich input of nutrients to the forest ecosystem, but also provide compounds that affect soil

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properties and decomposition processes, including enzyme activities. Whole-tree harvest in Norway spruce and Scots pine stands decreased the rates of net N and C mineralization (Piatek and Allen 1999; Smolander et al., 2008, 2010, 2013) and the total C and N pools in the combined organic + mineral soil layer compared to the SOH treatment were decreased in a Norway spruce stand (Kaarakka et al., 2014). However, some sites showed little response to the logging residue harvest (e.g. Brais et al., 2002; Johnson et al., 2002; Smolander et al., 2013).

Changes in site productivity and soil decomposition processes after logging residue harvest may originate from changes in the enzyme machinery in the soil, as enzymes are the keys to making nutrients available to plants. Enzyme activities in different forest soils were widely studied before (reviewed by Caldwell, 2005 Burns et al., 2013; Baldrian, 2014). It was shown that thinning decreased the enzyme activities in comparison with undisturbed forest (Geng et al., 2012) and that wildfire mitigation strategies modify soil enzyme activity (Boerner et al., 2006). Ponder and Eivazi (2008) showed that excluding weeds from the growing forest site of oak-hickory (*Quercus*- L. – *Carya* Nutt.) reduced soil enzyme activity. However, it is not known how different amounts of logging residues affect the soil enzymatic activity. In this study we determined the influence of logging residue harvest on enzyme activities and other soil characteristics in the soil organic layer of thinned stands in a boreal forest. We hypothesize that harvest of logging residue decrease the enzyme activities and C and N mineralization. Mechanically, the decrease in enzyme activities may be caused by diminished amount of substrates due to logging residue harvest. We report the activities of: a) β-glucosidase, degrading cellulose to glucose, b) β-glucosaminidase degrading chitin to amino sugars; β-glucosaminidase (chitinase) is one of the enzymes that play a major role in N mineralization (Ekenler and Tabatabai, 2002), c) protease releasing amino acids from peptides/proteins (Nduwimana et al., 1995) and d) acid phosphatase which produces plant available phosphates (Acosta-Martinez et al., 2007). Soil samples were taken from five study sites, that differed in fertility, dominating tree species and time elapsed after treatment. In four of the experiments, different amounts of fresh logging residue were distributed on a circle around a single tree. In one experiment the treatments were whole-tree harvest and stem-only harvest. Our results for enzyme activities has never been presented earlier, however results for other soil characteristics from 2 sites (Kannonkoski and Ruokolahti) were already presented (Smolander et al., 2010, 2013).

2. Materials and methods

2.1. Study sites, experimental design and sampling

The experiments were long-term field experiments established by The Finnish Forest Research Institute. They differed in characteristics and in experimental design (Table 1). In the Ruokolahti experiment (735) logging residue was either harvested (WTH) or evenly distributed on the site (SOH) in thinnings done 23 and 13 years ago. For both treatments, there were three study plots, each 30 m × 30 m. Other experiments were single-tree experiments at spruce and pine sites, in which in thinning different amounts of fresh logging residues (from 0 to 37.5 Mg ha^{-1} of dry matter; see Table 1) were distributed evenly on a circle around individual trees (diameter 5 m). Nevertheless spruce produces more logging residues than pine in our studies for comparison purposes, we used similar amounts of logging residue for both species. Treatments were replicated three times. For a more detailed description of the Ruokolahti experiment (735) see Smolander et al. (2010) and for the Kannonkoski experiment (746) see Smolander et al. (2013); characteristics of the Jämsä experiment (416) before harvesting are given by Saarsalmi et al. (2010).

One composite sample, consisting of 20 subsamples, was collected systematically with a steel cylinder (d = 58 mm) from the humus layer (Ofh) of the circle surrounding each tree in the single-tree experiments and from each study plot in other experiment (Ruokolahti). Sampling from Ruokolahti and Kannonkoski was done in September and October 2009, and from the other experiments in September 2011. The fresh soil samples were sieved (4 mm mesh) after the plant material and roots had been removed. Soil samples were kept in plastic bags at +4 °C in cold room. The enzyme analyses were performed within a few days after sample collection. Dry weight (+105 °C, 16 h) was determined, and organic matter content was measured as loss on ignition (+550 °C, 4 h). Soil pH was measured in a soil-water suspension consisting of 15 ml soil in 25 ml ultrapure water.

Table 1
Logging residue harvest experiments.

	Salla, 406	Kiikala, 409	Jämsä, 416	Ruokolahti, 735	Kannonkoski, 746
Latitude	67°18′N	60°28′N	61°55′N	61°16′N	62°58′N
Longitude	29°14′E	23°40′E	25°02′E	28°49′E	25°15′E
Elevation (m)[a]	260	120	106	68	122
Annual mean temp. (°C)[a]	−1.0	4.8	3.9	3.9	3.2
Effective temp. sum (°C)[a]	695	1343	1308	1318	1194
Annual mean precipit. (mm)[a]	551	631	575	562	520
Tree species	Scots pine	Scots pine	N. spruce	N. spruce	Scots pine
Soil texture	Fine sand	Fine sand, coarse sand	Fine sand	Fine sand	Loamy sand
Humus type	Mor	Mor	Mor	Mor	Mor
Soil type	Podzol	Podzol	Podzol	Podzol	Podzol
Organic layer, mm	24	40	36	38	20
Organic matter content, %	85	70	75	45	63
pH	3.8	3.7	4.0	3.9	3.9
Site type[b]	EMT	CT	MT	OMT	VT–MT
Stand age during sampling, years	92	58	63	72	39
Time since thinning, growing seasons	4	5	4	23 and 13	5
Logging residue, Mg ha^{-1} dry matter	0, 12.5, 25	0, 12.5, 25, 37.5	0, 15, 30	n.d.[c]	0, 10, 20, 30

Data about Ruokolahti (735) taken from Smolander et al. (2010); data for Kannonkoski (746) from Smolander et al. (2013); data for Jämsä (416) from Saarsalmi et al. (2010); data for Kiikala (409) and Salla (406) *via* personal communication from Anna Saarsalmi (2014).

[a] Data calculated for a 30-year period before taking samples based on the dataset of the Finnish Meteorological Institute (Venäläinen et al., 2011).

[b] Site types according to Cajander (1949): EMT – *Empetrum nigrum* – *Vaccinium myrtillus*, CT – *Calluna vulgaris*, MT – *Vaccinium myrtillus*; OMT – *Oxalis acetosella*-*Vaccinium myrtillus*; VT–MT – *Vaccinium vitis-ideae* – *Vaccinium myrtillus*. Fertility order of site types: CT < EMT < VT–MT < MT < OMT.

[c] n.d. = not determined, but an estimated mean value was 16 Mg ha^{-1} dry matter of logging residue left on a site in stem-only-harvest.