Forest Ecology and Management 427 (2018) 182–189

Contents lists available at ScienceDirect

Forest Ecology and Management

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

How do logging residues of different tree species affect soil N cycling after final felling?

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ARTICLE INFO

Keywords:
Forest biomass harvesting
Logging residue piles
C cycling
N cycling
Nitrification
Tree species

ABSTRACT

The aim of this study was to compare how logging residues of Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.) and silver birch (*Betula pendula* Roth.) affect the dynamics of N and C cycling processes in forest soil after final felling. The study site was located in southeastern Finland. After clear-cutting, piles consisting of 40 kg m^{-2} of fresh logging residues of each tree species were established, together with a control plot as an additional treatment. Samples were taken from the organic layer and uppermost mineral soil at the beginning of the experiment and each spring and autumn in the two following years. Logging residues stimulated net N mineralization and net nitrification and increased both NH_4- and NO_3-N concentrations in the organic layer. Logging residues increased the soil pH, organic matter content (%) and C mineralization, whereas microbial biomass C and N decreased. No major, consistent differences were observed between the effects of the separate tree species, although there were tree-species-specific differences on the dynamics of soil processes. Logging residues of spruce, pine and birch all strongly accelerated the processes of soil N cycling soon after clear-cutting. This study provides new information for the discussion on the sustainability of logging residue distribution and harvesting in boreal forests.

1. Introduction

Both the energy demand and the political will to replace fossil fuels with renewable energy sources are driving new methods of forest use. Alternative energy sources are being developed and forest bioenergy (logging residues such as small trees, tree tops, branches, needles and even stumps) has been noted to be an important energy source to substitute fossil fuels (Ranius et al., 2018; Tamminen et al., 2014; Thiffault et al., 2015).

In traditional forestry, the distribution of logging residues on the forest floor has been relatively even. However, the harvesting of forest logging residues is current accomplished with machines, and logging residues are thus piled, leading to an uneven distribution (Rosén and Lundmark-Thelin, 1987). Both of the common harvesting methods, whole-tree harvesting (WTH) and stem-only harvesting (SOH), create slash piles on the forest floor. In WTH, all parts of the tree are removed, while in SOH, branches and tree foliage rich in nutrients are left on-site (Vanguelova et al., 2010).

In boreal forests, the harvesting of logging residues has been observed to influence soil properties (Achat et al., 2015). Nitrogen (N) has been in focus because it is tightly bound to carbon (C) cycling (Gruber and Galloway, 2008) and is a limiting nutrient for forest growth in boreal areas (Näsholm et al., 1998). Human activities, including clear-cutting as a common forest management practice in Nordic countries, can disturb the natural N cycle (Vitousek et al., 1997) and, at some sites, cause N losses from the system, since the uptake of N by plants is reduced and nitrification is enhanced (Gundersen and Rasmussen, 1990; Rósen and Lundmark-Thelin, 1987). Studies concerning the effects of logging residue removal on N cycling have mostly focused on thinning stands (e.g. Adamczyk et al., 2015; Carlyle, 1995; Dighton et al., 2012; Smolander et al., 2010; Smolander et al., 2013). Currently, however, logging residues in Finland are principally harvested from final fellings.

Some logging residue harvesting studies have been conducted at clear-cut sites. In five coniferous sites in Finland, Smolander et al. (2015) found no effect of conifer logging residues on net nitrification ten years after clear cut. However, changes in the quality of organic matter were indicated in one Scots pine experiment; especially concentrations of NH_4-N, microbial biomass N and C mineralization increased. In addition, Olsson et al. (1995) found no clear effects of harvesting practices on soil C and N content 15–16 years after clear-cutting in coniferous forests but whole-tree harvesting increased C to N ratio in the humus layer. In USA, net N mineralization decreased in a loblolly pine plantation 15 years after logging residue removal (Piatek

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https://doi.org/10.1016/j.foreco.2018.06.005
Received 3 April 2018; Received in revised form 1 June 2018; Accepted 2 June 2018

and Lee Allen, 1999). Contradictory, Blumfield and Xu (2003) noticed decreased N mineralization two years after clear-cutting in a subtropical hoop pine plantation, when residues were left on the forest floor. Very few studies have mimicked modern harvesting techniques by piling logging residues instead of evenly distributing them on the forest floor. Rosén and Lundmark-Thelin (1987) and Lindroos et al. (2016) observed increased inorganic N concentrations in soil percolation water under conifer slash piles after clear-cutting in Swedish and Finnish soils, respectively. Furthermore, Adamczyk et al. (2016) examined the effect of Norway spruce logging residue piles on N cycling five years after clear-cutting, and noted that net N mineralization and nitrification were enhanced under the piles. According to the literature, the knowledge of the immediate response of soil N cycling dynamics to logging residues, accomplished with modern harvesting technic, is very limited.

Several studies have demonstrated that tree species differ in how they affect the quality and N transformations of soil organic matter; birch species often increase soil pH and stimulate microbial activities and N cycling compared to coniferous species (Augusto et al., 2015). These impacts are partly based on differences in the composition of above-ground litter, as well as leachates entering the soil from fresh litter and as a result of decomposition (Kiikkilä et al., 2012). However, quality of litter is not fully comparable to logging residues containing fresh, green foliage and more woody material.

The significance of logging residue to the dynamics of soil processes and the nutrient stage of forests is unclear. Furthermore, it is unknown how logging residues of different tree species differ in this respect. Since the utilization of forest bioenergy will continue, it is crucial to understand the spatial- and time-dependent changes in the forest. Our aim was to monitor the short-term effects of logging residues on the quality of soil organic matter and microbial processes related to C and, in particular, N cycles in boreal forest ecosystems. We compared the influence of logging residues from three tree species (Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.) and silver birch (*Betula pendula* Roth.)) for two years after final felling. These tree species are the main tree species in Finland and in the boreal forests of Fennoscandia. We hypothesized that logging residue piles of these tree species would stimulate soil processes associated with N cycling, and that the effects and dynamics would differ between the tree species.

2. Material and methods

2.1. Study site and soil sampling

The study site is located in Lapinjärvi, southeastern Finland. According to the Finnish forest site type classification, the study site is classified as Vaccinium myrtillus type, MT (Cajander, 1949). The humus type is mor and the soil type is Haplic Arenosol (IUSS Working Group WRB, 2006). The mineral soil is poorly podzolized, having somewhat separated soil horizons. The soil has developed on glaciofluvial sorted sand.

An approximately 80-year-old, spruce-dominated mixed forest was clear-cut in September 2014. The experiment (16 plots, A = 3 m^2) was established using a random block design. Four blocks, each having all four treatments (40 kg/m^2 of fresh logging residues of silver birch (*Betula pendula* Roth.), Norway spruce (*Picea abies* (L.) Karst.) and Scots Pine (*Pinus sylvestris* L.), and a control without residues), were randomized so that the tree species of the first plots in subsequent blocks were dependent, i.e. consisting of alternating tree species. Logging residues were collected from the logged trees of the same clear-cut area three days after final felling.

Soil sampling was carried out just before the treatments in 2014 (September), in 2015 (May and November) and in 2016 (May and November). Soil samples were taken from the organic layer (Ofh) each spring and autumn and from the top mineral soil (uppermost 5 cm) each autumn with a steel cylinder (d = 58 mm). The litter layer was carefully separated from the organic layer in the field. Five soil cores were taken from corners and centre of each plot and combined to form one composite sample. Samples were stored in plastic bags (+4 °C) until preparation.

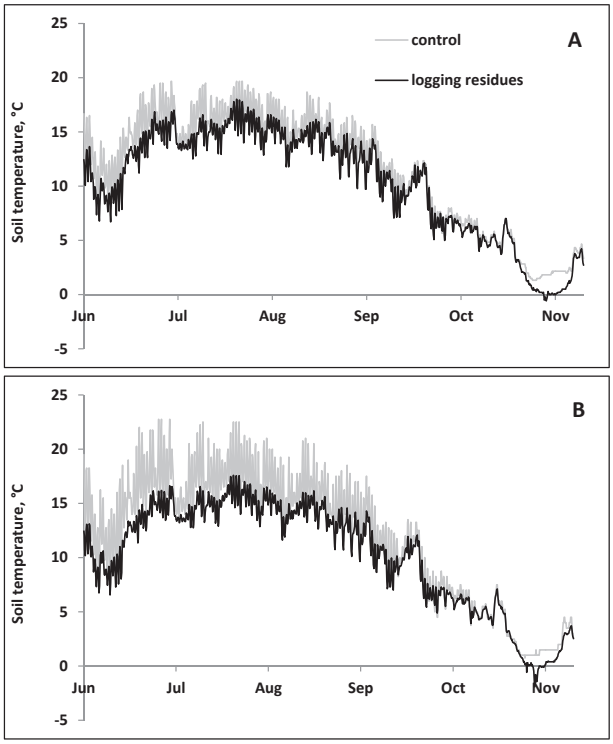

Fig. 1. Mean soil temperatures (°C) (A) on the edges of the control plots and treatment plots and (B) in the centre of the control plots and treatment plots at the study site during June–November 2016.

Soil temperature measurements from the organic layer (2 cm below ground) started on June 2016 and ended on November 2016. Data loggers (n = 32, i-Button DS1921G, Maxim Integrated Products) recorded soil temperatures every 4 h from two measurement points: the middle and outer edge of the plots.

2.2. Determination of soil characteristics

On the following day after soil sampling, fresh soil samples were homogenized by sieving (mesh size 6 mm). The dry matter content was determined by drying the samples overnight at 105 °C, and the organic matter content was determined as loss on ignition by incinerating dry samples at 550 °C for 4 h. Soil pH was measured in a soil–water suspension (15 ml/25 ml). The water-holding capacity (WHC) was measured by adding an amount of soil sample (volume 20 ml, equal to 4–8 g in the organic layer and 13–21 g in the mineral layer) to a funnel, which was then soaked in water for 2 h and drained. Total C and N were determined using an automated CHN analyser (Leco CHN-600).

2.3. Measurement of C and N transformations in an incubation experiment

Net N mineralization and net nitrification were measured in an aerobic laboratory incubation experiment as described in Smolander et al. (1995) with a few modifications. Briefly, four replicates of fresh soil samples were adjusted to constant moisture (60% WHC). Then, two replicates were stored frozen. Two other replicates were incubated for 42 d at +14 °C covered with aluminium foil and the moisture content was kept constant. After this, 40 ml 1 M KCl was added to all samples, which were shaken for 2 h and filtered. Ammonium (NH_4-N) and nitrate (NO_3-N) in the filtrates were analysed with a flow injection analyser (FIA Star 5020, Tecator). In order to determine net N mineralization,