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Response of soil nutrient content, organic matter characteristics and growth of pine and spruce seedlings to logging residues

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ABSTRACT

The aim of this study was to determine the effects of different amounts of logging residues on soil properties and growth of Scots pine and Norway spruce seedlings 10 years after clear-felling. The field experiments consisted of two Scots pine and four Norway spruce experiments. The treatments, on three replicate 8 m * 8 m plots in all field experiments, were whole-tree harvesting, i.e. harvesting all the above-ground biomass with no logging residue left on the site (R0), stem-only harvesting, leaving logging residues on the site (R1), and stem-only harvesting with double the amount of logging residues left on the site (R2). In the R1 treatment the amount of logging residue in the spruce stands was 39–54 Mg ha^{-1} dry mass and in the pine stands, 11–18 Mg ha^{-1} dry mass. Over all sites, logging residues had no consistent effects on seedling growth, amounts of soil carbon and nutrients or organic matter characteristics. In some spruce experiments, however, logging residues increased the average diameter, height and height growth (last three years), as well as the number of seedlings, stem volume and biomass. In pine experiments, logging residues had no effect on tree or stand characteristics. In one pine experiment the amounts of exchangeable base cations increased, and there were also changes in the quality of organic matter: the C/N ratio decreased, and NH_4–N, microbial biomass N and C mineralization increased due to residues. In the spruce experiments and the other pine experiment, the effect of logging residues on the soil properties measured was slight. Logging residues did not affect NO_3–N concentrations or rates of net nitrification, which in most soils were both negligible. Seedling height and height growth correlated strongly and positively with net N mineralization and its ratio to microbial biomass N. All in all, logging residues improved tree and stand characteristics generally in spruce stands, but the effects on soil properties and processes, if any, occurred mostly in one pine stand. This poor correspondence may point to other changes brought on by the logging residues, such as changes in physical environment or decreased competition with ground vegetation, being more important for seedling growth than nutrient status was.

1. Introduction

In Europe, forest biomass is increasingly being used as a source of energy in order to reach the targets for reductions in CO_2 emissions set by the European Union. In 2012, 8.3 million m^3 of forest chips were used in Finland, and to meet the EU targets the Finnish government has planned to increase the use to 13.5 million m^3 by 2020 (Laitila et al., 2008; Ylitalo, 2013). In practice, this means that whole-tree harvest (WTH), in which - in addition to commercial stem biomass – also logging residues: topwood, foliage and branches and eventually also stumps are removed from a site, is becoming a more common alternative to conventional stem-only harvest (SOH). At clear-fellings, in 2012 logging residues were removed from about 30% of these sites (Asikainen et al., 2014).

Logging residues from a final harvest make up only a small proportion of the total pool of organic matter and nutrients in surface soil (Tamminen et al., 2012). Leaving logging residues on the site still means a large input of fresh organic material for decomposition and nutrient release. In final cuttings of Norway spruce or Scots pine stands in Finland, the amounts of logging residues were, on average, 20–60 and 15–30 Mg ha^{-1}, respectively (Hakkila et al., 1998). Corresponding values for nitrogen were 150–300 and 75–150 kg ha^{-1} (Hakkila et al., 1998). However, annual amounts of nutrients released from logging residues are low, and in the early stages some of the nutrients may even be temporally immobilized by the soil microbial population (Fahey et al., 1991; Hyvönen et al., 2000; Palviainen et al., 2004a,b).

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Logging residues may change the physical, chemical and biological properties of soil. In thinning stands WTH, as compared to SOH, often has over the long-term – but not always – resulted in increased soil C/N ratio, decreased amounts of exchangeable base cations and decreased microbial activities in C and N cycling (Rosenberg and Jacobson, 2004; Smolander et al., 2008, 2010, 2013; Tamminen et al., 2012; Adamczyk et al., 2015). When WTH has been performed in the final felling, some long-term changes in soil properties have also occurred, such as decrease in amounts of exchangeable base cations and in net N mineralization activity; but again in some cases no significant differences between the two harvesting procedures were found (Olsson et al., 1996a,b; Piatek and Lee Allen, 1999; Brais et al., 2002; Saarsalmi et al., 2010; Kaarakka et al., 2014). In both thinning stands and clear-fellings, the effect is probably dependent on tree species, site properties and time elapsed after the harvest.

In terms of tree growth and biomass production, WTH can be considered to be negative fertilization, i.e. nutrients are removed from the site. Accordingly, in middle-aged Scots pine and, in particular, Norway spruce thinning stands, whole tree harvest led to a decrease in tree growth (Jacobson et al., 2000; Helmisaari et al., 2011; Tveite and Hanssen, 2013). WTH in clear-fellings removes considerably more nutrients than does WTH in thinnings, but the nutrient demand of young trees is small compared to that of trees at the thinning stage (Rolff and Ågren, 1999). Consequently, in both European and North American experiments during the first five-to-fifteen years after final harvest, tree growth has usually been similar in WTH and SOH, or sometimes slightly lower in WTH (Egnell and Leijon, 1999; Egnell and Valniger, 2003; Sikström, 2004; Kabzems and Haeussler, 2005; Powers et al., 2005; Saarsalmi et al., 2010; Egnell, 2011; Wall and Hytönen, 2011; Fleming et al., 2014; Morris et al., 2014). Over the longer term, when the nutrient requirements of the seedlings essentially increase and a larger portion of nutrients have already been liberated from the residues, this difference in growth may become clearer (Egnell and Valniger, 2003; Egnell, 2011). It seems likely that reductions in growth caused by WTH are related to absolute (kg ha^{-1}) amount of harvested logging residue and, in many boreal forest soils in particular, the nitrogen in this residue, but also to the ratio of nutrients in logging residue/nutrients in the surface soil (Helmisaari et al., 2011; Tamminen et al., 2012).

To better understand the changes this harvesting technique may bring about in a boreal forest ecosystem, we attempted to determine the effects of whole-tree harvest on tree growth and on soil chemical and biological properties on the same sites. Our aim was to determine how different amounts of logging residues affect soil carbon and nutrient pools, microbiological processes related to C and N cycling, and growth of Scots pine and Norway spruce seedlings 10 years after clear-felling. Our hypothesis was that intensive harvesting (WTH) would result in decreased soil exchangeable nutrient pools and microbial activities in C and N cycling; however, the effects on total C or N pools in soil, or on growth of Norway spruce and Scots pine seedlings, would be minor.

2. Material and methods

2.1. Study sites and experimental design

The material for this study consisted of two Scots pine and four Norway spruce experiments (Table 1, Fig. 1). All were naturally regenerated, mature single-species stands with no sign of non-forest usage. Soils were medium coarse or coarse and podsolized at least to some degree. The stands were cut either mechanically or manually (Exp. 743) in 2002 or 2003. The treatments were

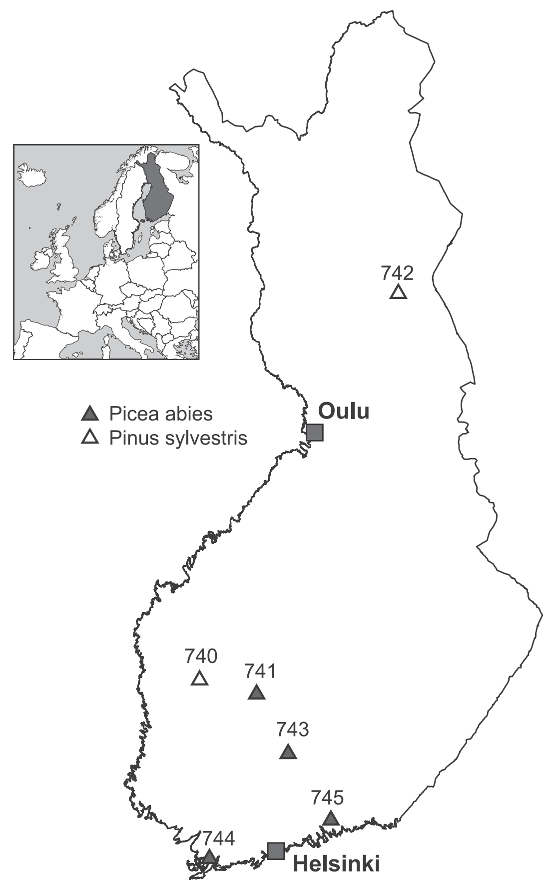

Fig. 1. Location of the experiments.

Table 1
Site and former stand characteristics.

Exp	Latitude deg min sec (WGS84)	Longitude deg min sec (WGS84)	Elevation (m)	Temp. sum (°C day)[a]	Annual precipitation (mm)[a]	Site type[b]	Former tree species	V^c (m^3 ha^{-1})	Logging residue (Mg ha^{-1})[d]
740	62 11 11	22 50 34	155	1256	594	VT	Pine	180	18
741	62 03 38	24 15 23	112	1312	618	MT	Spruce	350	54
742	66 47 33	27 59 34	180	926	544	EMT	Pine	70	11
743	61 22 01	25 06 10	110	1342	648	MT	Spruce	300	47
744	60 02 00	23 02 50	40	1545	726	MT	Spruce	250	39
745	60 36 10	26 09 49	32	1513	697	MT	Spruce	300	47

[a] Mean annual effective temperature sum (threshold + 5 °C for the study period 2003–2012).
[b] Site types (Cajander, 1949): VT, *Vaccinium vitis-idea*; MT, *V. myrtillus*; EMT, *Empetrum nigrum – V. myrtillus.*
[c] *V*, mean stem volume.
[d] Amount of logging residue in the stem-only treatment in which a single amount of logging residues have been left on the site, estimated according to Hakkila et al. (1998).