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Effect of removal of logging residue on nutrient leaching and nutrient pools in the soil after clearcutting in a Norway spruce stand

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ABSTRACT

Following clearcutting applying the conventional stem-only harvesting method in a Norway spruce (*Picea abies* (L.) Karst.) stand and different levels of removal of logging residue, the nutrient fluxes from the heaps of logging residue and from the O horizon were monitored over four growing seasons and the soil nutrient pools were determined. Three levels of removal of logging residue were carried out using (i) conventional stem-only harvesting (no residues removed); (ii) residues removed; and (iii) removal of branches (foliage left on site). The heaps of logging residue were a minor source of inorganic N entering the soil in the water percolating through the heaps, but they were a significant source of organic N, P, Ca, Mg, and especially K. Nutrient fluxes from the O horizon were in general greater under the heaps of logging residue as compared to soils without overlying logging residue. The leaching of inorganic N from the O horizon under the heaps of logging residue resulted in a net loss of these compounds, while the O horizon without overlying logging residue gained N. The removal of logging residue significantly decreased the extractable K pools in the soil while it or conversely, the presence of residue heaps had no significant effect on the pools of organic matter and the pools of N, P, Ca, and Mg in the O horizon and in the 0–10 cm soil layer. The results show that the short-term effects of logging residue on nutrient dynamics in the soil can be complex and difficult to interpret in terms of site productivity as there are changes in the nutrient fluxes, which imply the opposite effects on site productivity. However, the results do indicate that, in the short-term, the removal of logging residue does not impair pools of N in the soil nor site productivity on sites where the availability of N limits productivity.

1. Introduction

In conventional forest harvesting in Finland, branches, foliage and unmerchantable stem sections (logging residue) are left on site after the stems have been cut, processed and harvested (stem-only harvesting). After clearcutting and stem-only harvesting, logging residue is left on site in heaps covering some 40–60% of the ground surface in stand dominated by Norway spruce, this percentage varying depending on the harvesting work techniques applied (Nurmi, 1994).

When logging residue is recovered after stem-only harvesting for the purpose of generating bioenergy, some 60–80% of the dry mass of the residues are removed from the site (Nurmi, 2007). Thus, the stem-only harvesting combined with the removal of logging residue is somewhat comparable to whole-tree harvesting in terms of biomass and the amounts of nutrients removed from the site. Logging residue can contribute to the pools of organic matter and pools of nutrients in the soil through leaching of dissolved organic matter and nutrients from the residues and through decomposition of logging residue leading to formation of litter and eventually soil organic matter.

Stem-only harvesting is generally considered as having little effect on the soil nutrient pools. In contrast, it has been suggested, based on simple nutrient budget calculations, that whole-tree harvesting could deplete the soil nutrient pools and impair site productivity in the long-term, particularly on infertile sites (Mälkönen, 1972; White, 1974; Carey, 1980; Tritton et al., 1987; Merino et al., 2005). However, studies have shown that whole-tree harvesting has generally no impact on the soil total nitrogen and organic carbon pools when compared to stem-only harvesting (Mattson and Swank, 1989; Olsson et al., 1996b; Piatek and Allen, 1999; Carter et al., 2002; Johnson et al., 2002; Laiho et al., 2003; Mendham et al., 2003; Belleau et al., 2006; Butnor et al., 2006; Sanchez et al., 2006). As regards other soil nutrients, the effects of whole-tree harvesting have varied depending on the nutrient in question: whole-tree harvesting has been often noted to decrease

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pools of K, Ca and Mg available to plants, but seldom to impact on the pools of P (Adams and Boyle, 1982; Carlyle, 1995; Olsson et al., 1996a; Bélanger et al., 2003; Mendham et al., 2003; Thiffault et al., 2006) or having no impact at all (Johnson and Todd, 1998; Brandtberg et al., 2000).

The nutrient concentrations in the soil solution are generally higher for a couple of years under the logging residue when compared to soils without overlying logging residue (Rosén and Lundmark-Thelin, 1987; Hendrickson et al., 1989; Stevens and Hornung, 1990; Emmett et al., 1991; Titus and Malcolm, 1992; Staaf and Olsson, 1994; Titus et al., 1997; Strahm et al., 2005). This has been attributed to the leaching of nutrients from the logging residue, increased microbial activity, increased decomposition of organic matter through enhanced temperature, and soil moisture conditions and reduced vegetation uptake. However, it has also been reported that no difference has been noted in nutrient leaching between whole-tree harvesting and stem-only harvesting (Mann et al., 1988) or that reduced leaching of soil nutrients has occurred under the logging residue (Carlyle et al., 1998).

Logging residue can be recovered after seasoning on site when the majority of the foliage has shed off the branches, which has the effect of decreasing the removals of biomass and nutrients from the site. The foliage of Norway spruce is that component in logging residue, which is the richest in nutrients, and the foliage decomposes and releases nutrients at a rate faster than the woody components (Hyvönen et al., 2000; Palviainen et al., 2004a; Palviainen et al., 2004b). The retention of foliage well distributed over the site has been proposed as a measure to mitigate the negative effects of intensive harvesting on soil fertility (Olsson et al., 2000).

In stem-only harvesting, the uneven spatial distribution of residue piles results in a patterned aggregation of nutrient pools and patterned nutrient leaching (Titus and Malcolm, 1991). However, in most previous studies on the impact of whole-tree harvesting on soil nutrient pools and nutrient dynamics when compared to stem-only harvesting, the logging residue has been spread evenly over the ground. In the present study, the spatial distribution of logging residue on the site corresponded to that done in connection with modern-day forest harvesting practices. Nutrient fluxes through the heaps of logging residue and through the O horizon were monitored over four growing seasons and the soil nutrient pools were measured after clearcutting and stem-only harvesting of a stand of Norway spruce and applying three treatments with respect to removal of logging residue. The three treatments were as follows: no removal of logging residue (conventional stem-only harvesting), removal of branches (foliage left on the site) and removal of logging residue. In treatments involving the retention of logging residue or the foliage on the site, the nutrient fluxes and pools of nutrients were expressed separately for the soil with and without overlying logging residue as well as for the total harvesting area. The aim of the present study was to examine the short-term effects of logging residue and removal of logging residue after clearcutting on nutrient leaching from the O horizon and on soil nutrient pools.

2. Material and methods

The study site is located in central Finland (61°47′N, 24°45′E). The mean annual precipitation in the area during May–October is 377 mm and the mean effective temperature sum (threshold 5 °C) is 1200 °C. The soil type is haplic Podzol (FAO, 1988) and the texture type is sandy till. The site type is moderately fertile *Myrtillus* Type (Cajander, 1926). The site covers 6 ha and carried a stand of Norway spruce (*Picea abies* (L.) Karst.) which had a timber volume of 315 m^3 ha^{-1} prior to clearcutting. The central part of the site is 1–2 m lower than the surrounding area and it was not used in the experiment due to it being paludified.

The site was clearcut and the stems were processed using a harvester in early June 1999 and the experiment was established during the following 2 weeks. The experiment was arranged in the form of incomplete randomized blocks with three treatments and three blocks (replicates). The treatments were (i) no removal of logging residue (three replicates); (ii) removal of all logging residue immediately after clearcutting in early June (three replicates); and (iii) removal of branches in August after seasoning when the majority of the foliage had fallen off (two replicates). The estimated rate of needles fallen off was 91% (Nurmi and Hillebrand, 2001). The blocks were delimited in order to include two areas with logging residue in each block. The plots were 25 m × 25 m in size in two of the blocks and 20 m × 37 m in one block. The stems and logging residue were recovered using a forwarder.

The volume of harvested timber was calculated using biomass functions according to the plot's stem distribution (Laasasenaho, 1982). The stem distribution was estimated from the stump diameter distribution. The mass of the foliage and branches of the logging residue was estimated based on their proportions in the logging residue as presented in the literature (Hakkila, 1991). The logging residue was left on site after clearcutting in heaps distributed irregularly across the site. The mean number of heaps in each plot was five. The area covered by these heaps and their height were measured for each plot using sampling points 1 m apart. The logging residue heaps covered, on average, of 18% of the plot area and the mean width, length and height of the heaps were 3.9 m, 5.2 m and 0.35 m, respectively. In the treatment involving removal of logging residues, some 14% of the residues were left on site unremoved. The mass and contents of the nutrients of the logging residue left after residue removal was measured from the circular plot 50 m^2 in size situated in the centre of the plot. In each plot, logging residue samples (dry mass of 1 kg) were collected randomly from each heap and combined into one composite sample for each plot. The logging residue sample was separated into foliage, branchwood, and stemwood, and then analyzed for total N, P, K, Ca, and Mg concentrations. The samples were dried at 60 °C to a constant weight, ground, and then digested in HCl. The total amount of organic matter and amounts of nutrients residing in the logging residue left on site after various levels of removal of logging residue are shown in Table 1. The site was planted with Norway spruce in August 2000 following mounding.

Bulk precipitation was collected from three collectors in each block using funnels 305 cm^2 in area. A funnel was mounted onto a PVC tube housing a polyethylene bag with a capacity of 5 dm^3. A polyethylene filter was inserted into the neck of the funnel. Soil leachates were collected by means of zero tension lysimeters below the heaps of logging residue and below the O horizon (L + F + H layer). The lysimeters were stainless steel trays without an edge at the front. The bottom of the trays was bent in the middle into slight V-shape. The outlet spouts discharged into 1 dm^3 polyethene bottles housed in the PVC pipe. The bottles were kept in the soil in PVC tubes 10 cm diameter buried into the soil pits. The lysimeter dimensions were 202 mm by 340 mm. The lysimeters were installed immediately below the O horizon by pushing them into the soil from the upslope side of the soil pit. In the plots with heaps of logging residue, three lysimeters were installed directly below the heaps and three lysimeters below the O horizon. The lysimeters under the heaps of logging residue were located randomly where the thickness of the heaps was around the mean thickness of the heaps. In addition, three lysimeters were also installed at random locations below the O horizon situated between the heaps of logging residue with a minimum distance of 2 m to the nearest heap. Three lysimeters were installed below