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Effect of harvesting method on the amount of logging residues in the thinning of Scots pine stands

Jyrki Hytönen [a,*], Mikko Moilanen [b]

[a] Finnish Forest Research Institute, Kannus Research Unit, Silmäjärventie 2, 69100 Kannus, Finland
[b] Finnish Forest Research Institute, Oulu Research Unit, Paavo Havaksen tie 3, 90014 Oulu, Finland

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ABSTRACT

Whole-tree harvesting is an increasingly common harvesting method due to the high demand for fuel chips. In whole-tree harvesting, nutrient removal from the site is substantially higher than in cut-to-length harvesting, in which nutrient-rich branches and unmerchantable top sections of trees are left in the cutting area. There is a concern that whole-tree harvesting impairs site productivity, especially on mires drained for forestry. We employed six field experiments to study the effects of the harvesting method used on the amount of logging residues left on the site in the thinning of Scots pine (*Pinus sylvestris* L.) stands. The four harvesting treatments varied in their intensity of biomass removal from conventional stem-only harvesting (CTL), where tree tops and branches were left on the site to whole-tree harvesting (WTH) complemented by the manual collection of residues. Logging residues left on the sites were weighed and sampled to determine their moisture content. After CTL, the amount of logging residues left on the site was 7780 –15340 kg ha^{-1}(dry mass), depending on the experiment. In (WTH) the amount of logging residues left on the site was 32–66% of that of CTL. After the manual collection of residues in WTH, 4–16% of the residues still remained on the sites. The residues left at site following WTH had a larger share of small-diameter material than after CTL.

1. Introduction

Interest in the use of renewable biomass for energy production has increased rapidly during the past decade. The European Union (EU) is committed to decreasing greenhouse gas emissions by 20% compared to 1990 levels and increasing the share of renewable energy in the EU to 20% by 2020. The share of wood-based fuels on the total consumption of energy in Finland was 23% in 2012 [1]. The use of energy wood in Finland is increasing rapidly. In 2012, the consumption of forest chips originating from small-sized trees, logging residues and stumps was 8.3 million m^3. The National Climate and Energy Strategy indicates that forest chip production in Finland is to be increased to 13.5 million m^3 by 2020 [2].

In forestry, small-sized trees and logging residues have great potential as a source of extra bioenergy [3]. The usage of wood from thinning stands must be intensified to further increase the proportion of wood as an energy source. Whole-tree harvesting (WTH) increases the efficiency of forest chip

* *Corresponding author*. Tel.: +358 50 3913405.
E-mail addresses: jyrki.hytonen@metla.fi (J. Hytönen), mikko.moilanen@metla.fi (M. Moilanen).
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production from small-diameter trees through the intensified recovery of biomass. Shifting from cut-to-length (CTL) harvesting to WTH harvesting can also decrease significantly harvesting costs. In a study in second thinning of Mediterranean pine plantations in Italy this resulted in reduction of harvesting cost between 40 and 50% [4].

Finnish forests are characterised by a large proportion of young stands: about half of the forest land is covered by advanced seedling stands and young thinning stands [5]. The main aim of early thinnings besides harvesting trees mainly for raw material for pulp is to increase the production of saw and veneer logs in the stands. The current need for first thinnings in Finland has been estimated to be over 300 000 ha a^{-1} [6]. The first thinning of Scots pine (*Pinus sylvestris* L.) stands is often problematic and has often been neglected due to high procurement costs, small stem size and low removal. Energy wood harvesting has been suggested as one of the means of improving the profitability of thinning operation in peatland forests, especially in dense stands [7]. Whole-tree harvesting, where commercial wood, tree tops and branches are harvested at the same time, increases the efficiency through increased recovery. Increases in yield and logging productivity could result in a 20–40% reduction in production costs compared to stem-only harvesting [8]. The integrated harvesting of pulpwood and energy wood with new harvesting technology, e.g. the use whole-tree bundlers, could considerably increase WTH of forests [9,10].

The amount of nutrients removed from the site with harvested biomass is larger in WTH where all the above-ground biomass (stem and crown) is removed, compared to conventional stem-only harvesting using the cut-to-length method (CTL). This is because tops, branches and foliage account for a significant proportion of the total amount of nutrients bound in trees [11]. The increased removal of biomass and nutrients from forest sites with WTH has raised concern over the sustainability of site productivity. Stem-only harvesting is considered to have little impact on site productivity because the nutrient content of the stem wood is rather low and nutrient-rich components such as foliage and twigs are left on site [11].

According to studies carried out on upland soils, there is evidence that WTH may decrease tree growth [12,13]. The negative effects of WTH on tree growth of Scots pine and Norway spruce (*Picea abies* (L.) Karst) stands on mineral soils have been attributed to removal of nutrients especially nitrogen, in harvested tree biomass [14,15]. The high nutrient demand of a tree stand at the thinning stage may aggravate the effects of nutrient removal with WTH. On drained mires, due to the lack of experimentation very little is known about the effects of WTH on the growth and nutrition of tree stands, but concerns have also been raised about the negative effects of WTH on site productivity in peatland forests [17]. Compared to upland soils, N stores in the tree rooting peat layer (0–20 cm) are considerably higher whereas mineral nutrients such as potassium (K) stores are lower [18–20]. The inadequate amount of mineral nutrients and their imbalance with the abundant nitrogen are factors that limit tree growth, especially on thick-peated, initially treeless or scarcely wooded fens drained for forestry [21,22].

In many studies it has been assumed that WTH completely removes the biomass of the harvested trees from the stand [11,23,24]. Consequently, the removal of nutrients from the site has also been based on the assumption of total biomass removal of the harvested trees. Forestry work in Finland for the most part (97%) is mechanised and carried out by harvesters and forwarders [25]. Mechanical felling is mainly carried out by harvesters, which cut the trunks, de-limb them, cut each trunk into appropriately-sized sections, and stack the timber. Whole-tree harvesting is also done with harvesters, often with multi-grip harvester heads. It is probable that with modern harvesting technology the removal of biomass in cuttings is incomplete, due to the breaking of branches in the operation, for example. However, at the moment it is not known how much logging residues really are harvested or remain in the forest after WTH. Knowledge of the actual amount of logging residues and the nutrients left at the site after WTH would also be valuable for efficient risk analysis on the effects of this harvesting method on soil productivity and nutrition (see e.g. Ref. [16]).

We hypothesised that a considerable amount of logging residues remain unharvested in the site with modern techniques in thinnings of Scots pine stands, regardless of the harvesting method. The aim of this study was to determine the amount of harvesting residues left on the site following different harvesting intensities, including WTH and the normal CTL method.

2. Material and methods

2.1. Study sites

The thinning experiments were set up in 2003–2010 in Scots pine (*P. sylvestris* L.) dominated stands on five drained mires and on one upland forest site in Central Finland (Fig 1, Table 1). The studied mires were mostly classified as *Vaccinium vitis-idaea* II forest site type [26]. The mineral soil site (Alajärvi 2) represented a similar fertility level (*V. vitis-idaea* site type; [27]). The stands were considered to be in need of thinning according to management practices. Prior to the cuttings, the stand mean height was lowest at Sievi and Kinnula (11 m) and highest at Muhos (14 m). Downy birch (*Betula pubescens* Ehrh.) appeared as a mixed tree species (0–30% of stand volume).

2.2. Experimental design and treatments

All six sites had a similar experimental design following the principles of randomised blocks. The size of treatment plots was 0.07–0.20 ha with 2–6 replicates for treatments, depending on the experiment (Table 1). The plots were rectangular shaped and they were bordered on two sides with drainage ditches.

The studied treatments included different intensities of forest residue recovery, ranging from conventional stem-only harvesting using cut-to-length method (CTL) to whole-tree harvesting complemented with manual collection of logging residues (WTH-) (Table 2). The harvesting was carried out during the winter when the soil was frozen and there was snow on the ground. The cutting was performed with