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The effect of harvesting method on the nutrient content of logging residues in the thinning of Scots pine stands on drained peatlands

Hakkuutähteiden ravinnesisältö aines- ja energiapuukorjuun jälkeen ojitettujen turvemaiden harvennusmänniköissä

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Commercial thinning is a common practice when growing even-aged stands in the Nordic countries. Thinning from below is carried out to harvest suppressed and part of the mid-sized trees that cannot successfully compete for resources and have become grown over by co-dominant and dominant trees. In five field experiments, we studied the effects of harvesting method on the nutrient amount of logging residues left at the site in thinning of Scots pine stands. Comparison was carried out between four harvesting methods representing different levels for forest-residue recovery: SOH (stem-only harvesting down to a diameter of 7 cm, SOH-E (stem-only harvesting down to a diameter of 2 cm),WTH (whole-tree harvesting including stems, tops and branches) and WTH-M (WTH and manual collection of those logging residues which were left in mechanical harvesting). In each experiment, logging residues were weighed and sampled for determination of their nutrient concentrations, and soil samples were taken from the surface peat layer (0–20 cm) for nutrient analyses. In SOH treatments, all residues and nutrients bound in the logging residues were left at the site. In WTH 28–67% and in WTH-M 4–20% of the nutrients remained at the site, with the figure depending on the experiment. The amounts of N (1%), P (1–4%), Ca (2–5%), and Mg (3–8%) bound in the logging residues in SOH were low in comparison to the corresponding amounts in the 0–20 cm peat layer. However, the amount of K in logging residues represented 10–26% and the amount of B 8–15% compared with the corresponding nutrients in peat. The amount of N, P, and K in logging residues after CTL harvesting was 39–86, 3–7, and 9–21 kg·ha^{-1}, respectively. The corresponding figures after WTH were 15–36, 1–3, and 3–9 kg ha^{-1}. We assume that WHT on peatland sites that are prone to K deficiency or already have a detected shortage may increase a risk for nutrient imbalances and growth loss in remaining tree stand.

Key words: nutrients, logging residues, thinning, whole-tree harvesting

Introduction

Most forests growing on drained peatlands in Finland are young or mid-age stands that feature abundant thinning potential and a need for improved silvicultural state. Commercial thinning is a common practice when growing even-aged stands of Scots pine, silver birch or Norway spruce especially in the Nordic countries. Thinning from below is carried out to harvest suppressed and part of the mid-sized trees that cannot successfully compete for resources and have become grown over by co-dominant and dominant trees. After thinning the retained trees have more resources available and can enhance their growth. Compared to non-thinned management, thinning does not increase the total yield but has been shown to increase economical result because of earlier harvest income from thinning, shorter rotation due to better growth, and more valuable final stocking as the proportion of saw logs is higher (e.g., Kojola 2009). In the thinnings the conventional method has been to harvest just the stemwood; logging residues have been left at the site.

The first stand thinning, however, is often problematic due to the poor trafficability of peat soils, especially during summer. Moreover, the harvesting of industrial roundwood from early thinnings is costly, owing to the small stem size and low removals.

The use of energy wood in Finland is increasing rapidly. In 2012, the consumption of forest chips originating from small-sized trees, harvesting residues, and stumps was 8.3 million m^3. Wood-based-fuels accounted for 23% of the total consumption of energy in Finland in 2012 (Ylitalo 2013), and the National Climate and Energy Strategy states that forest-chip production in Finland is to be increased to 13.5 M m^3 by 2020 (Ministry of Employment and the Economy 2010).

In forestry, small trees and logging residues have great potential as a source of bioenergy (Anttila et al. 2013). The use of wood from thinning stands must be intensified if we are to increase the proportion of wood used as an energy source further. Whole-tree harvesting (WTH) increases the efficiency of forest chip production from small-diameter trees through intensified recovery of biomass. Energy-wood harvesting has been suggested as one of the means to improve the profitability of thinning operations in peatland forests, especially in dense stands (Heikkilä 2007). WTH would be one solution, where commercial wood, tree tops, and branches are harvested at the same time. Introduction of new harvesting technologies such as whole-tree-bundling could considerably increase use of WHT in forests (Kärhä et al. 2011, Nuutinen et al. 2011).

The amount of nutrients removed from the site with harvested biomass is larger in WTH, wherein all above-ground biomass (stem and crown) is removed, than in conventional stem-only harvesting (SOH). This is because tops, branches, and foliage account for a significant proportion of the total nutrient content bound in trees (Mälkönen 1976). The increased removal of biomass and nutrients from forest sites with WTH has raised concerns about the sustainability of site productivity. SOH is considered to have little impact on site productivity because the nutrient content of the stemwood is rather low and nutrient-rich components such as foliage and twigs are left on the site (Mälkönen 1976).

According to studies carried out on upland soils, there is evidence that WTH may decrease tree growth (Jacobson et al. 1996, 2000, Helmisaari et al. 2011, Dighton et al. 2012). The high nutrient demand of a tree stand at the thinning stage may exacerbate effects of nutrient removal with WTH. The negative effects of WTH on tree growth on mineral soils have been attributed to removal of nutrients, especially nitrogen (N), in harvested tree biomass (Wall 2012). Therefore, in the studies of Jacobsen et al. (2000) and Helmisaari et al. (2011), removal of N in logging residues after WTH has been considered most likely to be the cause of the growth losses of Scots pine and Norway spruce stands on upland soils. N is the main nutrient limiting growth on upland soils in the Nordic countries (e.g., Kukkola & Saramäki 1983).

Results from upland soils cannot be directly applied in prediction of effects of WTH on organic soils. Tree stands on mires drained for forestry differ considerably from upland forests with regard to nutrition. In comparison to upland soils, N stores in the tree rooting layer of peat (0–20 cm) are considerably greater, whilst quantities of mineral nutrients such as potassium (K) are lower (Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998, Westman & Laiho 2003). From these studies it can be concluded that N and phosphorus (P) stores in peat are quite high relative to trees' demands and also in relation to the nutrient amounts bound in the tree stand. However, the availability of P due to slow mineralization may restrict stand growth on peatlands (e.g. Silfverberg & Moilanen 2008). Nutrient balance calculations have revealed that equal or even greater amounts of K and boron (B), may be bound in the mature tree stand than are found in the 20 cm surface peat layer, where most of the tree roots are located (e.g. Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998, Westman & Laiho 2003). Also, growth of trees in peatland forests is often limited by the supply of P and K (Paarlahti et al. 1971, Moilanen 1993, Silfverberg et al. 2011), and P and K deficiencies are common in Scots pine stands on drained peatlands in Finland (Moilanen et al. 2010). Because WTH in peatland forests could reduce soil K and B stores to such an extent that the risk of nutrient deficiencies and disorders on the stands increases, concerns have been raised about the negative effects of WTH on site productivity in peatland forests.

On account of lack of experimentation, very little is known about the effects of WTH on the growth and nutrition of tree stands on drained mires. The silvicultural guidelines have not recommended energy-wood harvesting for peatlands, or the harvesting of logging residues has been restricted by site type or peat thickness (Hyvän metsänhoidon suositukset 2006, Koistinen & Äijälä 2006, Hyvän metsänhoidon suositukset turvemaille 2007, Kuusinen & Ilvesniemi 2008). Nowadays, only the most fertile sites are deemed suitable for energy-wood collection and in the good practice guidelines (Äijälä et al. 2010, 2014) fertilisation with PK or ash is recommended for PtkgII and MtkgII site types (see Laine et al. 2012).

In many studies, it has been assumed that WTH completely removes the biomass of the harvested trees from the stand (e.g. Mälkönen 1976, Kaunisto 1996, Palviainen & Finér 2012). Consequently, also estimates dealing with the removal of nutrients from the sites have been based on the assumption of total removal of the harvested trees' biomass. Forestry work in Finland is predominantly (97%) mechanised and carried out by harvesters and forwarders. Mechanical felling is performed mainly by harvesters, which cut the trunks, delimb them, cut each trunk into appropriate sections, and stack the timber. WHT is also done with harvesters, often with multi-grip harvester heads. Modern harvesting technology leaves the removal of biomass in cuttings incomplete, on account of factors such as breaking of branches in the operation (e.g., Sirén et al. 2013, Hytönen & Moilanen 2014).

We hypothesised that considerable amount of nutrients remain on sites after thinning with modern harvesting techniques. The aim of our study was to determine the amount of nutrients in logging residues left at the site after harvesting of various intensities, including WTH and normal harvesting (SOH). We also compared the nutrient content of the logging residues with the nutrient amounts in the soil (i.e., in trees' rooting zone). The focus was on thinning operations for mid-age stands on drained mires.

Material and methods

Study sites

The thinning experiments were set up in 2003–2010 on stands dominated by Scots pine (*Pinus sylvestris* L.) on five drained mires in Central Finland (Table 1). The mires studied were classified mostly as of the *Vaccinium vitis-idaea* II forest-site type (Vasander & Laine 2008, Laine et al. 2012). The stands were considered to be in need of thinning, according to management practices. Before the cuttings, stand mean height ranged from 11 m to 14 m (Table 1). Downy birch (*Betula pubescens* Ehrh.) appeared as a mixed tree species (0–30% of stand volume). The peat thickness varied from 56 cm to over 150 cm.

Experiment design

All five sites employed a similar experiment design, following the principles of randomised blocks. The size of the treatment plots was

0.07–0.20 ha, and there were 3–6 replicates for treatments (Table 1). The treatments studied included four intensities of forest-residue recovery, ranging from conventional stem-only harvesting to whole-tree harvesting complemented with manual collection of logging residues.

The stand harvesting was performed during winter (when the surface soil was frozen and the sites had snow on the ground) with harvesting machines, and transport with forwarders, except at Muhos, where the cutting was done using motor-manual methods. The thinning treatments were chosen such that the quantity of logging residues – and the amount of nutrients – left at the site would vary considerably. In SOH treatment, only stemwood was harvested down to the diameter of approximately 7 cm and all logging residues (needles, branches, and tree tops) were left at the site. A slightly smaller amount of logging residues was sought with a treatment wherein the tree was delimbed to the top down to the diameter of approximately 2 cm and both the stemwood and the small-diameter non-commercial top part were collected for energy. In this treatment (SOH-E), the branches with needles were left at the site. In WTH treatment, trees were harvested from the site with branches and needles (Fig. 1). The most intensive treatment was whole-tree harvesting followed by manual collection of the remaining logging residues (WTH-M).

Measurements and statistical analyses

The amount of logging residues left at the treatment plots was measured by means of systematic sampling from sub-sample plots measured during the winter snow cover period following harvesting by weighing them from 3 m^2 rectangular shaped sub-sample plots (15 on each treatment plot) (see Hytönen & Moilanen 2014). The sub-sample plots were located using systematic linear sampling and their locations were determined using measuring tape. In one experiment (Muhos), the logging residues were not measured until snow cover had melted and been weighed on five circular 10 m^2 subsample plots per treatment plot. After weighing of the logging residues, samples were taken from the weighed biomass for nutri-

Table 1. Information on the stand properties and cutting residues of the followed experiments in this study. SOH = stem-only harvesting, SOH-M = stem-only harvesting including tree top for energy, WTH = whole-tree harvesting, WTH-M = whole-tree harvesting and manual collection of residues.

Taulukko 1. Tutkimuksessa käytettyjen kenttäkokeiden puusto- ja hakkuutähdetietoja. SOH = ainespuukorjuu, SOH-E = ainespuukorjuu, jossa otettiin talteen latvuksesta tehty karsittu polttoranka, WTH = kokopuukorjuu, WTH-M = kokopuukorjuu ja koealoille jääneiden hakkuutähteiden keräys käsityönä.

Characteristic	Exp. 1 Himanka	Exp. 2. Sievi	Exp. 3 Muhos	Exp. 4 Alajärvi	Exp. 5 Kinnula
Establishment (cutting) year	2003	2008	2003	2009	2010
Drainage years	1970s	1960s, 1980s	1930s, 1950s, 1977	1970s	1966, 1990s
Scots pine as percentage of stem volume	60	90	95	100	100
Mean height before thinning, m	13	11	14	12	11
Mean diameter ($d_{1.3}$) before thinning, cm	14	12	17	11	11
Stem volume before thinning, m³ ha^{-1}	265	141	160	178	130
Logging removal, m^3 ha^{-1}	150	43	70	93	55
Size of treatment plots, ha	0.15–0.2	0.16	0.07–0.09	0.12–0.19	0.1–0.18
Number of blocks (replicates)	6	4	4	3	6
Logging residues in SOH, kg ha^{-1}	15343	9942	11329	9251	7785
Logging residues in SOH-E-, % of SOH	96.7	57.5	-	77.4	-
Logging residues in WTH, % of SOH	46.4	33.5	67.0	33.6	32.3
Logging residues in WTH-M, % of SOH	16.1	12.1	-	5.1	9.6

Fig. 1. Forwarding of whole trees. Alajärvi experiment.
Kuva 1. Kokopuukorjuuta Alajärven hakkuukokeella.

ent analysis. The samples were aggregated for analysis, and one composite sample was analysed for each plot.

The peat depth was determined, and volumetric soil samples were taken from all treatment plots from the 0–20 cm peat layer with a square-shaped steel corer (size: 269 cm^3, 235 cm^3 or 484 cm^3) and composed of five, six, or 10 systematically taken sub-samples distributed uniformly over the plots, with edge areas excluded. The living vegetation and litter horizon were omitted from the samples.

The logging residue samples were analysed after digestion with HNO_3–H_2O_2 in a microwave oven for their P, K, Ca, Mg, Mn, and B concentrations with ICP spectrometry, or with AAS (P, K, Ca, Mg, Mn) following HCl digestion (for the Muhos samples). Also, total N was determined (Kjeldahl method) for all samples (Halonen et al. 1983).

The peat samples were analysed for their 0–20 cm layer nutrient amounts. Sub-samples were combined for each plot and then ground, dried (at 60 °C for 48 hours), and their pH (H_2O) was determined (Halonen et al. 1983). The bulk density of the soil samples was calculated as the ratio of dry mass (dried at 105 °C) to the volume of the sample. The ash content of the samples was estimated as loss on ignition at 550 °C for eight hours. After digestion of the soil samples with HNO_3–H_2O_2 in a microwave oven, the concentration of total P, K, Ca, and Mg was determined with ICP spectrometry. The K, Ca, and Mg concentrations of the Himanka and Muhos soil samples were analysed after HCl digestion by means of AAS. The concentration of B was determined with a spectrophotometer using the azomethine-H method and that of P by means of the vanado-molybdate method (see Halonen et al. 1983). Total N (Kjeldahl) was also determined for all samples. The amounts of nutrients at various soil depths were calculated on the basis of the oven-dry (105 °C) weight of the soil samples, using bulk densities and expressed on an area basis for the sampling depth.

Statistical analysis of the effect of harvesting treatments on the nutrient content of the logging residues left at the site was studied with analysis of variance (ANOVA) for each experiment separately. Additionally, the differences in nutrient amounts in the surface peat between sites were tested with ANOVA. Tukey's test ($p < 0.05$ significance level) was used in *post hoc* pairwise multiple comparisons between treatments or experiments. Equality of variances was tested with Levene's test. Variance-stabilising transformations were performed when needed for the amounts of nutrients in the logging residues. All analyses were computed by means of the IBM SPSS Statistics 20 package.

Results

Peat nutrient amounts

There was considerable variation in the peat nutrient amounts between sites (Table 2). The peat's ash content was highest at the Himanka and Sievi sites. These sites also showed the highest N, P, and K amounts in the 0–20 cm top peat layer. Himanka and Alajärvi had the highest Mg and B quantities. The lowest amounts of K and B were measured from the Kinnula and Muhos sites – for these nutrients, the levels were less than half of those found for the Himanka site. The mean peat depth was over 50 cm in all study areas, with the exception of Himanka, where even 20 cm peat depths were measured on some plots.

Nutrients in logging residues

There was considerable site-to-site variation in the amount of nutrients left at the site. The nutrient quantity depended on the amount of harvesting removal and, accordingly, on the amount of residues left at the sites (Table 3). In all experiments, harvesting method had a significant effect on the amount of nutrients left at the site. The nutrient content in logging residues was at its highest when SOH was used and decreased with increasing harvesting intensity. Especially when WTH was complemented by manual collection of logging residue, the removal of nutrients increased considerably.

No major differences between nutrients were found in a comparison of their proportions remaining at the site in the residues. Compared to the SOH method, the SOH-E treatment method left 66–94% of the nutrients on the site and WTH left 28–67%, with the percentage depending on the experiment. After manual collection of residues following WTH, 4–20% of the nutrients

Table 2. Peat depth, soil pH, bulk density and nutrient amounts in the peat at 0–20 cm in the study experiments. Differences between sites in nutrient amounts tested with Tukey's test at $p < 0.05$ significance level. Means that do not differ from each other are marked with the same letter.

Taulukko 2. Turpeen paksuus, pH, kuivatuoretiheys ja ravinnemäärät 0–20 cm:n turvekerroksessa tutkituilla kokeilla. Keskiarvot, jotka Tukeyn testin mukaan eivät poikkea toisistaan tilastollisesti merkitsevästi (p<0,05) on merkitty samalla kirjaimella.

Experiment	Peat depth, cm	Ash content, %	pH	Bulk density, g l^{-1}	Nutrient kg ha^{-1} N	P	K	Ca	Mg	B
Himanka	64	10.1	3.7	177a	7060a	397b	127a	1239a	209a	1.0a
Sievi	56	12.1	4.0	177a	8816b	565a	110a	588bc	101b	0.6b
Muhos	>150	3.3	3.6	104c	3750c	166c	45b	383b	78b	0.3c
Alajärvi	70	4.4	3.8	129b	4168c	169c	86ab	1431a	163a	0.7b
Kinnula	124	4.4	3.7	104c	3995c	133c	60b	660c	80b	0.4c

remained at the site. The amount of N, P, and K in logging residues after SOH harvesting was 39–86, 3–7, and 9–21 kg ha^{-1}, respectively. The corresponding post-WTH figures were 15–36, 1–5, and 3–9 kg ha^{-1} (Table 3). Use of WTH decreased the amount of K from that seen with SOH by 12 kg ha^{-1} at the Himanka site, 7 kg ha^{-1} at Sievi, 14 kg ha^{-1} at Alajärvi, 6 kg ha^{-1} at Kinnula, and 4 kg ha^{-1} at Muhos.

The amounts of nutrients in the logging residues in SOH (where all residues were left at the site) were compared to the amounts of nutrients in the 0–20 cm peat layer (Table 4). The logging residues had 1% and 1–4% of the N and P amounts in the peat, respectively. Also, the Ca and Mg amounts in logging residues were low relative to those in peat (2–5%, and 3–8% respectively). However, logging residues contained considerable amounts of K and B when compared to the 0–20 cm layer of peat. The amount of K in the logging residues was 10–26% and the amount of B 8–15% of the corresponding amount in the peat.

Table 3. Amount of nutrients in the logging residues. Means denoted by the same letter do not differ from each other at $p < 0.05$, according to Tukey's test. SOH = stem-only harvesting, SOH-M = stem-only harvesting including tree top for energy, WTH = whole-tree harvesting, WTH-M = whole-tree harvesting and manual collection of residues.

Taulukko 3. Ravinteiden määrä hakkuutähteissä eri harvennuskäsittelyissä. Keskiarvot, jotka Tukeyn testin mukaan eivät poikkea merkitsevästi toisistaan on merkitty samalla kirjaimella. SOH = ainespuukorjuu, SOH-E = ainespuukorjuu, jossa otettiin talteen latvuksesta tehty karsittu polttoranka, WTH = kokopuukorjuu, WTH-M = kokopuukorjuu ja koealoille jääneiden hakkuutähteiden keräys käsityönä

Experiment	Treatment	Nutrients in logging residues, kg ha^{-1}					
		N	P	K	Ca	Mg	B
Himanka	SOH	86a	7a	21a	40a	7a	0.13a
	SOH_E	75a	6a	21a	38a	7a	0.12a
	WTH	35b	3b	9b	20b	3b	0.05b
	WTH-M	14c	1c	3c	7c	1c	0.02c
	F	37.247	41.541	49.796	25.573	47.553	50.680
	p	0.000	0.000	0.000	0.000	0.000	0.000
Sievi	SOH	43a	5a	11a	17a	5a	0.05a
	SOH-E	33a	3b	7b	13a	3b	0.03a
	WTH	21b	2c	4c	6b	2c	0.02b
	WTH-M	9c	1d	2d	3c	1c	0.01b
	F	43.435	85.543	70.574	85.026	44.678	22.926
	p	0.000	0.000	0.000	0.000	0.000	0.000
Muhos	SOH	52a	4a	12a	19a	6a	0.06a
	WTH	36a	3a	8b	12b	4a	0.03b
	F	8.221	2.666	31.215	11.933	7.584	10.444
	p	0.064	0.201	0.011	0.041	0.071	0.049
Alajärvi,	SOH	56a	7a	18a	23a	5a	0.07a
	SOH-E	39ab	4ab	12ab	16a	4ab	0.05ab
	WTH	17bc	2b	4b	8b	2bc	0.02ab
	WTH-M	3c	0b	1c	1c	0c	0.00b
	F	41.937	42.702	44.147	118.990	61.964	44.203
	p	0.000	0.000	0.000	0.000	0.000	0.000
Kinnula	SOH	39a	3a	9a	19a	4a	0.04a
	WTH	15b	1b	3b	6b	1b	0.01b
	WTH-M	4c	0c	1c	2c	0c	0.00c
	F	35.025	53.125	66.035	62.672	68.343	62.661
	p	0.000	0.000	0.000	0.000	0.000	0.000

Discussion

In this study, we measured the amount of nutrients in the residues left on-site after diverse harvesting treatments. Whole-tree harvesting was done by means of present-day harvesting techniques, with harvesters (except at Muhos). Removal of biomass was not complete. This is confirmed by results showing that the amount of logging residues left at the site after thinning in WTH was 30–65% of that found with SOH (Sirén et al. 2013, Hytönen & Moilanen 2014). After the manual collection of residues in WTH, 4–16% of the residues still remained on the study sites (Moilanen & Hytönen 2014). The residues left at the site after WTH had a larger share of small-diameter material i.e., contained more nutrients than those after SOH (Hytönen & Moilanen 2014). Accordingly, mass balance calculations assuming that all logging residues are removed from the site in WTH overestimate the nutrient removal (e.g. Mälkönen 1976, Kaunisto 1996, Palviainen & Finér 2012).

The results concerning nutrient amounts in the surface peat were comparable with those of earlier studies carried out on same kind of sites types. The amounts of N and P in the 0–20 cm peat layer were in general agreement with those reported by e.g. Laiho and Laine (1994). On three experiments K amounts (45–86 kg ha^{-1}) were quite consistent with and in two experiments somewhat higher (110–127 kg ha^{-1}) than the figures reported in earlier studies in the 0–20 cm (Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998, Sundström et al. 2000) or 0–30 cm layer (Westman & Laiho 2003). The Ca, Mg, and B amounts in the peat were of the same magnitude as in the studies of Kaunisto & Paavilainen (1988), Kaunisto & Moilanen (1998) and Sundström et al. (2000).

The amount of nutrients left at the site was related to the biomass of logging residues. Our results indicate that WTH considerably increases nutrient removal in comparison to cut-to-length harvesting but still does not completely remove all nutrients. After WTH performed in winter, 28–67% of the nutrients remained at the site. Also, in a harvesting study performed in summer, large amounts of residues and nutrients were left at the site after energy-wood harvesting (Sirén et al. 2013). In the Finnish silvicultural guidelines, energy-wood harvesting is seen mostly as a suitable harvesting method for thinning stands, but some restrictions to harvesting intensity and choice of sites have been imposed (Äijälä et al. 2010, 2014). Whole-tree harvesting is not recommended for poorer site types, and on some peatland sites prone to nutrient deficiencies fertilisation with PK or ash is recommended. The current practice guidelines emphasise a need to leave 30% of the logging residues on the site to ensure sufficient nutrients remaining on the site (Äijälä et al. 2010, 2014). According to our results even commercial WTH aimed at total recovery of biomass could meet the criteria set to ensure an adequate amount of nutrients to safeguard the growth of the remaining tree stands.

Table 4. The share of nutrients in logging residues in SOH compared to the amounts of nutrients in the 0–20 cm peat layer of the study experiments.

Taulukko 4. Ravinteiden määrä ainespuukorjuun jälkeen kasvupaikalle jääneissä hakkuutähteissä verrattuna turpeen 0-20 cm:n kerroksen ravinnemääriin (%) tutkituilla kokeilla.

	Nutrients (%) in logging residues of the nutrients bound in peat					
Experiment	N	P	K	Ca	Mg	B
Himanka	1	2	16	3	4	13
Sievi	0	1	10	3	5	8
Muhos	1	3	26	5	8	15
Alajärvi	1	4	21	2	3	10
Kinnula	1	3	15	3	5	10

In contrast to mineral-soil conditions, N generally does not limit tree growth in peatland forests, since the peat contains N in large amounts, bound in the organic matter, peat. All logging residues (SOH) contained only 1% of the N stores of the peat. It is clear that total removal of N from the site in logging residues is unlikely to reduce tree growth on peatlands. Also, the release of N from woody litter is a slow process (Hyvönen et al. 2000, Laiho & Prescott 2004, Palviainen et al. 2004).

P, K, and sometimes also B are the limiting nutrients with respect to the growth of trees on drained mires (Moilanen 1993, Silfverberg & Moilanen 2008, Moilanen et al. 2010). Therefore, the main concern with peatland forests has to do with the removal of P, K, and micronutrient B in mid-rotation cuttings. In our study, the logging residues constituted only 1–4% of the stores of P found in the peat. Also, the Ca and Mg amounts in logging residues as compared to peat were low (2–5%). However, the logging residues did show considerable amounts of K and B relative to the amounts in the 0–20 cm layer of peat. Accordingly, over a whole rotation the total K removal would be relatively large in comparison with peat nutrient pools (Palviainen & Finér 2012). The logging residues in SOH contained 10–26% of the amount of K in the peat and 8–15% of the amount of B.

Compared to SOH, WTH decreased the amount of P and K left at the site in the logging residues by 1–5 kg ha^{-1} and 4–14 kg ha^{-1}, respectively. The mobilisation of K from logging residues is quite rapid. In the study of Palviainen et al. (2004), the initial K pool of the logging residues (needles, roots, and small branches) declined by 90% in three years. Since K is highly water-soluble, most of the total K in peat is in extractable form and easily leachable. Thus, on peatlands, logging residues may also be a potentially large source of nutrients entering water bodies, and increased P exports have indeed been reported after conventional SOH (Kaila et al. 2012, Asam et al. 2014).

Intensification of the utilisation of forest biomass has increased concerns about its impact on the nutritional status of forests, especially on peatland sites. According to our study, the amount of residues harvested with methods used today in practical whole-tree harvesting is considerably lower than previously assumed, which reduces the apparent risk of the negative effects of the treatment. This study points to the main concern in the removal of nutrients from peatland forests involving K and B, not N or P. We can assume that especially K is the nutrient to be considered when assessing the negative effects for stand nutrition and growth after whole tree harvesting. K deficiencies can be ameliorated by fertilisation with wood ash or commercial PK fertiliser (e.g. Moilanen 1993, Moilanen et al. 2002, Moilanen et al. 2004, Silfverberg et al. 2011, Hökkä et al. 2012). Therefore, energy-wood harvesting even from K-deficient sites could be feasible if followed by fertilisation.

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Tiivistelmä: Hakkuutähteiden ravinnesisältö aines- ja energiapuukorjuun jälkeen ojitettujen turvemaiden harvennusmänniköissä

Energiapuun hakkuut ja käyttö ovat kasvaneet voimakkaasti viime vuosien aikana. Energiapuuta ei ole juurikaan korjattu turvemailta, vaikka suometsissä voisi olla tähän soveltuvia kohteita. Integroitu energia- ja ainespuunkorjuu voisi parantaa suometsien harvennushakkuiden taloutta. Tutkimme viidessä ojitetussa turvemaamännikössä erilaisten harvennushakkuutapojen vaikutusta metsikköön jäävien hakkuutähteiden ravinnemääriin ja vertasimme hakkuutähteiden ravinnemääriä turpeen ravinnemääriin. Tutkitut metsiköt kasvoivat pääosin puolukkaturvekankaan (Ptkg II) kasvupaikoilla Keski-Suomessa, Pohjanmaalla ja Pohjois-Pohjanmaalla. Ennen hakkuuta puuston keskipituus oli 11–14 m (taulukko 1). Hieskoivua esiintyi metsiköissä sekapuuna (0–30 % kokonaistilavuudesta). Harvennukset tehtiin talviaikana ja hakkuupoistuma oli kohteesta riippuen 43–150 m^3 ha^{-1}. Ainespuukorjuussa (SOH) kaikki hakkuutähteet jätettiin metsään. Kun ainespuukorjuussa otettiin talteen latvuksesta tehty karsittu polttoranka, jäi hakkuutähteitä hieman vähemmän (SOH-E). Kokopuukorjuussa (WTH) kasvupaikalta poistettiin puut latvuksineen. Lisäksi täydensimme kokopuukorjuuta keräämällä koealoilta niille jääneitä hakkuutähteitä (WTH-M) käsityönä. Kukin käsittely toistettiin 3-6 kertaa pinta-alaltaan 0,07–0,20 ha kokoisilla koealoilla.

Koealoille jääneiden hakkuutähteiden massa punnittiin (systemaattinen otanta) ja niistä otettiin näytteet kosteuden ja ravinnepitoisuuksien määrittämiseksi. Lisäksi otettiin tilavuustarkat näytteet turpeesta 0–20 cm:n kerroksesta ja määritettiin turvenäytteiden ravinnepitoisuudet (taulukko 2).

Hakkuutähteitä ja niihin sitoutuneita ravinteita jäi kasvupaikalle eniten ainespuukorjuun jälkeen (taulukko 3). Kuitenkin myös käytännön kokopuukorjuussa kasvupaikalle jäi hakkuutähteitä ja niiden ravinnesisältö oli 28–67 % ainespuuhakkuuseen verrattuna. Kun kokopuukorjuuta täydennettiin keräämällä hakkuutähteitä käsin, niin senkin jälkeen metsikköön jääneissä hakkuutähteissä ravinteita oli 4–20 % ainespuukorjuuseen verrattuna.

Ainespuukorjuun jälkeen hakkuutähteissä kasvupaikalle jääneen typen, fosforin, kalsiumin ja magnesiumin määrä oli pieni verrattuna turpeen 0–20 cm:n ravinnemääriin (N 1 %, P 1–4 %, Ca 2–5 % ja Mg 3–8 %) (taulukko 4). Sen sijaan kaliumia ja booria oli ainespuukorjuun hakkuutähteissä huomattavasti enemmän suhteessa turpeen ravinnemääriin (K 10–26 %, B 8–15 %). Kokopuukorjuun jälkeen kasvupaikalle jäi kokeesta riippuen 4–14 kg ha^{-1} vähemmän kaliumia kuin ainespuuhakkuun jälkeen. Hakkuutähteen korjuun vaikutuksia puuston kasvuun ja ravinnetilaan seurataan jatkotutkimuksissa.

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