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Wood ash – green energy production side product as fertilizer for vigorous forest plantations

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Abstract. Notable amounts of wood ash containing plant macro and micronutrient elements in balanced proportions are produced in Latvia. If bioenergy production source product is plant material, and facilities are operating well, then 'side product' fermentation residues or wood ashes should not contain elements in toxic concentrations. Wood ash contains P and K which are lacking in acidic organic soils and could work as fertiliser as well as a long term liming agent, besides that, all micronutrient elements necessary for physiological processes are present in wood ash. Wood ash could also be used as 'revitalization agents' – fertilisers to improve the growth of plantation forests. The aim of this research is to find and describe the positive effect of wood ash fertilisers on Norway spruce (*Picea abies*) and other economically valuable tree species. Research results show positive wood ash application effect on tree growth and vitality within the first 4 years when used for recultivation and revitalization purposes. Recycling of wood ash (0.5–3 t ha^{-1} before planting) for fertilisation of and *Picea abies* forest plantations are a sustainable and effective solution for the improvement of tree growth as well as an environmentally safe method of utilization of bioenergy production residues.

Key words: wood ash, fertiliser, regeneration, recultivation, revitalization, soil amendment, Norway spruce.

INTRODUCTION

Wood energy is continuously increasing as a renewable natural resource. Mainly wood biomass is used as burning material in heat plants. In Latvia heat plants continue to increase the amount of fuelwood burned each year (Table 1). Ash is produced as a by-product of the burning process (Fig. 1).

Table 1. Tonnes of fuelwood burned each year by Latvian companies (LEGMC)

	2012	2013	2014	2015
Pellets	21,609	23,742	15,538	45,230
Wood	497,846	641,191	753,385	907,451
Fire wood	186,747	179,472	154,764	144,795
Woodchip	690,774	978,922	1,182,330	1,305,062
Total	1,396,975	1,823,326	2,106,016	2,402,537

Wood ash is typically deposited as waste material. Given the significant amount of ash produced (Fig. 1), more rational ash disposal options should be evaluated.

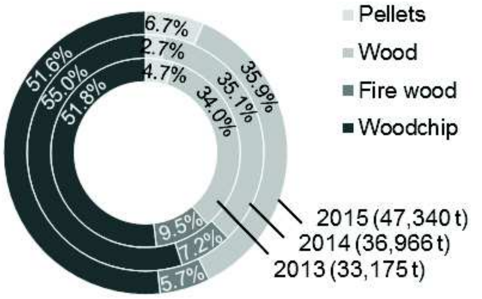


Figure 1. Ash produced in Latvia, tonnes depending on source material in 2013, 2014 and 2015 (LEGMC).

One of the obstacles for forest regeneration and recultivation is a lack of nutrients in the soil, increasing soil acidity is another typical problem in Northern Europe (EEA, 2000; Kikamägi et al., 2013). Acidity is especially problematic when recultivating cut-away peatlands (Lazdiņa et al., 2011). Ash contains bioavailable potassium, calcium, magnesium, phosphorous and other macro and micro nutrients (Augusto et al., 2008; Libiete et al., 2016). This suggests that it can be used as a fertilising substance. In previous studies, if applied on topsoil, ash has shown potential to increase tree increment by both altering pH levels of soil and increasing bioavailable nutrient amount in soil as a direct addition and by boosting biochemical soil processes (Augusto et al., 2008; Lazdiņa et al., 2011). The positive effects of ash treatment are not visible immediately but rather start to show gradually and effectiveness is long lasting in organic soils (Augusto et al., 2008; Okmanis et al., 2016; Silvan & Hytönen, 2016). Compared to mineral fertiliser ash is an environmentally friendlier alternative that also promotes circular economy and sustainability (Ingerslev et al., 2014; Huotari et al., 2015). This leads to the conclusion that wood ash should be managed as a resource instead of waste. Since ash chemical properties vary greatly depending on source material, it is safer to be used in forestry instead of agriculture.

In forestry, there are three main applications for wood ash. It can be used as soil amendment in order to improve forest regeneration, to condition recultivated lands and to revitalize both young and mature stands. Descriptive statistical data of measurements were calculated and shown in graphs and tables as a mean and standard error of mean (SE). Data following to normal distribution, to compare how significant the differences are between mean values of tree parameters after two T-test treatments. The aim of this research is to analyse wood ash utilisation options and possible use in forestry based on experience in recultivation, regeneration and revitalization in three study sites with different background and management practices.

MATERIALS AND METHODS

In this research results acquired at three different study sites in Latvia are discussed (Fig. 2). Each study site is set to represent different forestry practises and potential way of ash use. In all instances data was collected within 4 year period after ash treatment application. All tests were carried out on organic soils.

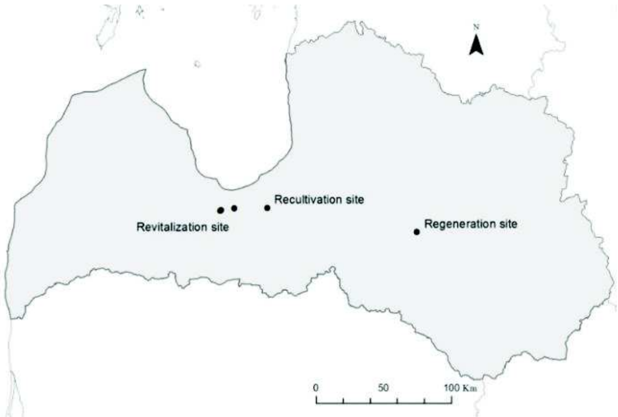


Figure 2. Study site location.

Forest regeneration

Forest regeneration with economically valuable trees species is studied in Latvia, Kalsnava parish (56°40′11″ N 25°54′36″ E). Plantation field has been established in a continuous clear-cut area, where previously stood a Norway spruce (*Picea abies*) forest of high productivity (up to 20 m^3 ha^{-1} annual increment at the age of 20), that died of unknown causes at the age of 40 years. The experiment is set as a long term study site in order to understand the requirements for the successful regeneration and management of ameliorated peatlands. The study area was then divided into multiple rectangular plots and enclosed with a fence to protect the trees from browsing. Soil chemistry originally was varying in this site (Table 3). In 2015 spring 8,207 seedlings of spruce were planted in rows of different density (2,000 trees per ha or 4,000 trees per ha). The study area consists of:

- control – only early tending or cleaning (15 plots)
- wood ash – wood ash and early tending or cleaning (9 plots)
- PK fertiliser – mineral fertiliser and early tending or cleaning (6 plots).

To evaluate the growth and survival rate of different species in this area, 1,296 birches (*Betula pendula* Roth), black alders (*Alnus glutinosa*) – each in 6 plots and 2,932 poplar (*Poplus sp*.) cuttings 20 cm length in 15 plots were also planted. Tree species were planted in rows both separately and interchangeably with spruce. Poplar plantation was restored in 2016 using planting material of the same origin but in two lengths – 20 cm long cuttings and 165 cm long cuttings (576 of each). Soil liming was carried out for poplar plantation and in nine plots wood ash was also applied.

Table 2. Soil chemistry properties in regeneration site prior treatment

	Soil pH_{CaCl_2}	Exchangeable K mg kg^{-1}	Available P mg kg^{-1}	Total P g kg^{-1}
Average ± SE	3.9 ± 0.1	55.7 ± 14.7	55.7 ± 22.2	2.3 ± 0.2
Min – Max	3.3–4.3	24.1–148.0	10.6–170.6	1.4–3.4

Data of survival rate and causes for dieback was collected for all planted species. In addition height of trees and annual growth increment for 2015 and 2016 were measured for spruce plantations in this study site. However, observation continues at this study site in order to evaluate longterm effects.

Recultivation

Recultivation possibilities of cut-away peatlands were studied in Latvia, Ķekavas parish (56°50′41″ N 24°6′30″ E), mainly focusing on use of mineral fertiliser and wood ash as soil amendment. Initially reed canary grass *Phalaris arundinacea* (RCG) was sown in this site as a short rotation energy crop. To stimulate the growth of RCG, the area was treated beforehand with wood ash applied on topsoil (10 t per ha) or PK mineral fertiliser applied on topsoil (0.5 t per ha). The control plot was left untreated.

RCG could not survive regardless of treatment type, but natural forest regeneration successfully took place instead. Self-sowing of aspen (*Populus tremula*), birch (*Betula pendula* Roth and *Betula pubescens*), spruce (*Picea abies*) and pine (*Pinus sylvestris*) occurred naturally in this study site. Data was collected in 2011 by selecting representative sampling plots in wood ash and mineral fertiliser treated areas. Self-sowing had not occurred in control plot. The trees in the plots were counted to determine the density of developing forest stands and tree height was measured.

Revitalization

Mature Norway spruce stand was treated with wood ash and mineral fertiliser in order to revitalize the stand after spruce bud scale (*Physokermes piceae*) invasion. Study area is located in Latvia, Līvbērzes and Klīves parishes (56° 50′ 31″ N 23° 42′ 33″ E, and 56° 49′ 45″ N 23° 33′ 9″ E and 56° 49′ 25″ N 23° 32′ 27″ E). This area consists of three plots that are each further divided into 9 sub-plots (400 m^2 each) with an 11 m buffer zone between them. These 9 plots were then treated with wood ash (2.5 tonnes per ha applied on topsoil) or potassium sulphate (K_2SO_4) mineral fertiliser (145 kg per ha applied on topsoil). Control plot was left untreated.

The diameter at breast height (DBH) was measured. Height was measured for 10 trees in each sub-plot using a hypsometer. Increment core data was collected using the Pressler borer. Cores then were glued to a flat surface and grinded for better visual identification of each increment. Cores were scanned with an Epson Expression 10000 XL high resolution scanner and t measurements of increment ring width were made with WinDENDRO software (0.001 mm accuracy).

RESULTS AND DISCUSSION

In Kalsnava study site birch showed the highest survival rate of 91.74 ± 0.14% in 2015 and 88.19 ± 0.36% in 2016. Spruce survival was 59.21 ± 0.19% 30.07 ± 0.20% respectively. Black alder showed worse results – 52.16 ± 0.17% in 2015 and only 17.36 ± 0.32% of initially planted trees were left in 2016. Poplar plantation was renewed in 2016 and later on showed survival rate of 62.67 ± 0.30%, but only for 165 cm cuttings. All of 20 cm cutting poplars had dried out completely in both years (Fig. 3). Such survival rate distribution might be due to natural succession. In boreal forests of Northern Europe regeneration after natural disturbance (for example forest fires, wind falls or flooding) begins with birch, followed by spruce and later pine (Engelmark, 1993).

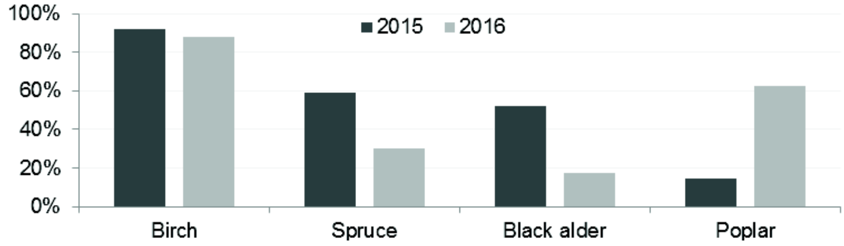


Figure 3. Survival rate of trees in year 2015 and 2016.

Later in 2015 pine (*Pinus sylvestris*) was also planted in this site. Three types of plants were selected – 960 trees from seedlings grown in mineral soil, 960 trees from seedlings grow in organic soil and 480 trees of mixed origin. Trees from organic soil seedlings showed the best survival rate (> 70%) in 2016 while others had just ~40%. The factor of soil used for seedlings is mostly neglected when regenerating a forest.

Main cause of tree death in the regeneration study site was drying out. The best vitality (62.4% healthy trees) in 2015 was achieved in with the application of mineral fertiliser. 40.3% high rate of drying out due to natural causes is present for spruces that were treated with wood ash (Fig. 4).

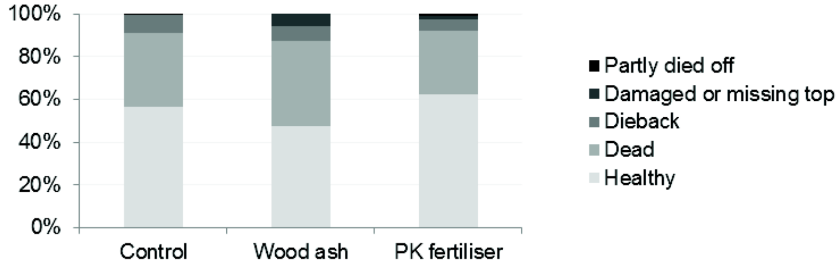


Figure 4. Vitality of 2 year old spruce in 2015 treated with wood ash or PK fertilisers and control.

In 2016 wood ash treated spruce plantations still showed the highest death rate – 63.8% of trees that were healthy in 2015 (Fig. 5).

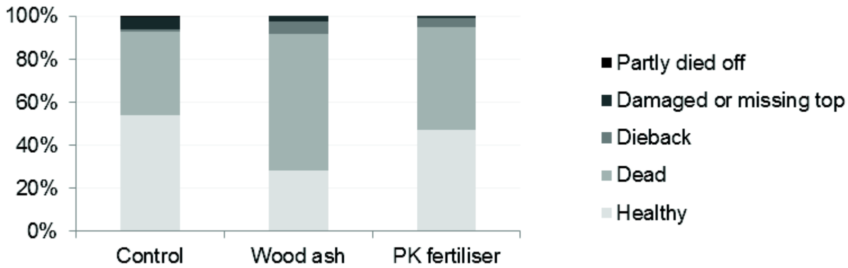


Figure 5. Vitality of 3 year old spruce in 2016 treated with wood ash or PK fertilisers and control.

Between of all treatments control had least amount of trees dying in 2016 – 39.3%. It must be taken into consideration that previous studies show some negative short term effects on tree root development if young seedlings are treated with wood ash (Gaitnieks et al., 2005; Kļaviņa et al., 2016). Therefore the acquired results might not be enough to draw conclusion of wood ash effectiveness on plant spruce plantation regeneration. Dieback was more notable in 2015 for all treatments. Control had 5.1% dieback, ash – 6.7% and fertiliser 8.7%. Damaged trees did not recover in 2016 and died off completely. In both years there are also some cases of undeveloped top.

In 2016 the shortest average spruce trees were in control plantations. In plantations treated with fertiliser spruces showed the highest average total height. Plantations treated with fertiliser showed the lowest increase in height. Ash treatment results are not significantly different from either control or fertiliser (*two-way t-test*). Control plantations had grown the most both in 2015 and 2016 (8.4 ± 0.1 cm and 8.3 ± 0.1 cm respectively). Initial planting material height was the highest in fertiliser treated plantation, but control had the lowest initial plant height (Fig. 6).

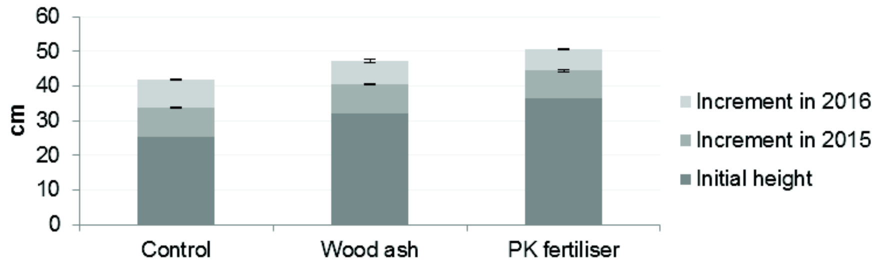


Figure 6. Average spruce height and annual growth in 2015 and 2016 treated with wood ash or PK fertiliser and control (± SE).

In order to evaluate these results more accurately, only trees of equal or similar initial planting height were compared further. In this case ash shows the highest average total height of 47.0 ± 1.0 cm followed by fertiliser 44.8 ± 0.9 cm and control 44.4 ± 0.4 cm. Control and fertiliser fields had no significant difference in height. There is also no significant difference of annual increment in 2015 between fertiliser and control or fertiliser and ash. In 2016 there is significant difference between control trees that had most average increment, and fertilised, but not between wood ash and control or wood ash and PK fertiliser treated (Figs 7 & 8).

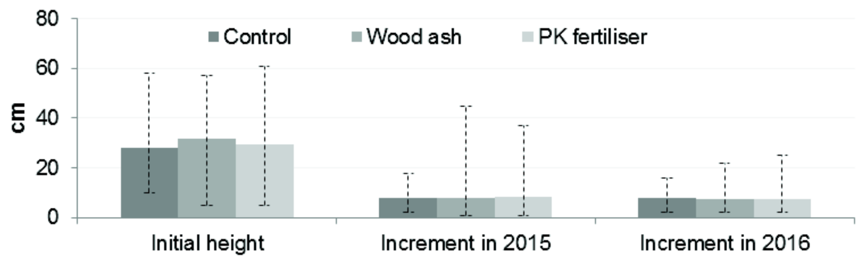


Figure 7. Average spruce initial height and annual growth in 2015 and 2016 treated with wood ash or PK fertiliser and control (data inequality showed with dashed lines).

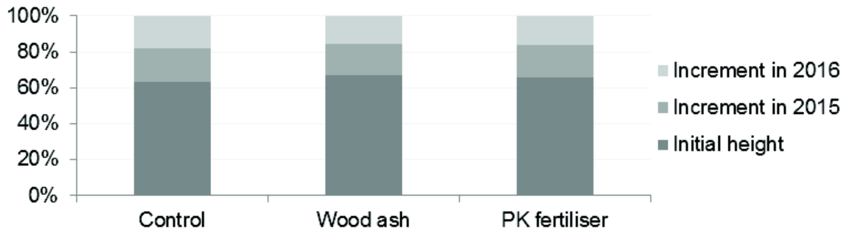


Figure 8. Initial average height and annual average growth in 2015 and 2016 from total average tree height of spruces with equal or similar initial height treated with wood ash or PK fertiliser and control.

In 2008 soil samples were taken in the natural recultivation study area after wood ash and mineral fertiliser application (prior to sowing of RCG). Upper soil horizons contain more exchangeable potassium in plots that have been treated with wood ash compared to PK fertiliser (Fig. 9). Potassium is also one of main lacking elements in peat soils (Kļaviņa et al., 2016).

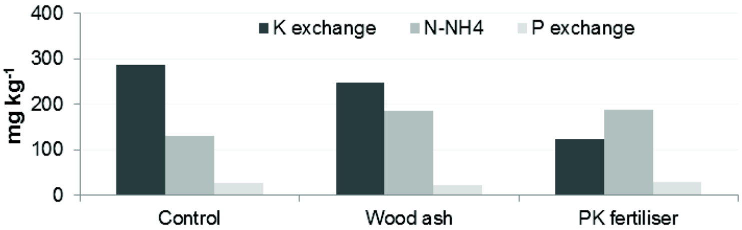


Figure 9. Available nutrients in soil in control, wood ash and mineral fertiliser treated recultivation plots in 2008.

It was concluded that self-sown forest regeneration occurs dominantly with both species of birch (*Betula pubescens* and *Betula pendula* Roth) (Fig. 10) regardless of studied treatment cases. This fits with the natural succession principles. In the control plot natural regeneration did not occur.

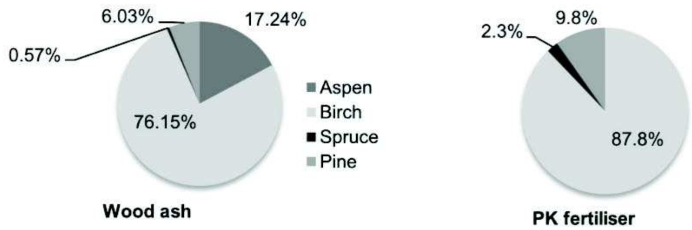


Figure 10. Tree species distribution in plantation with wood ash and mineral fertilisers application.

In mineral-fertilised area naturally regenerated aspen was not found (Table 3). However, it was present in small numbers in previous years (Table 4). This withering away might be due to soil pH value decrease or browsing. Data from 2008 shows no significant difference in soil pH_{CaCl2} for control and both treatment types (control

2.93 ± 0.07, wood ash – 2.92 ± 0.04 and PK fertilizer – 2.94 ± 0.06). Spruce is scarce in both instances despite the fact that there are mature spruces around the area that could provide seed material, spruce overall is not a common species in peatland forests (Jansons & Zālītis, 2013).

Plots with ash treatment have most naturally regenerated trees per m^2, but trees in plots with mineral fertiliser on average are taller and sturdier/thicker (Table 3). From studied tree species, pine has the strongest correlation between tree height and treatment type. Pine is 44% taller in the case of mineral fertiliser compared to ash.

Table 3. Average height and root collar of trees in wood ash and mineral fertiliser treated plots in 2008 and 2011 (± SE)

Species	2008				2011	
	Average stem diameter (mm)		Average tree height (m)		Average tree height (m)	
	wood ash	PK fertiliser	wood ash	PK fertiliser	wood ash	PK fertiliser
Birch	3.48	14.14	29.53	34.06	1.25 ± 0.04	1.53 ± 0.03
Aspen	3.60	9.48	25.89	44.42	0.66 ± 0.04	-
Pine	2.36	5.61	8.75	17.21	0.73 ± 0.08	1.31 ± 0.10
Spruce		5.01		15.75	0.30 ± 0.10	0.49 ± 0.07
Total	3.15	8.56	21.39	27.86	1.11 ± 0.03	1.49 ± 0.03

Compared to fertiliser treated plots, ash impact is less notable. However, both ash and fertiliser treatments have significant impact compared to control area that did not show any signs of natural tree ingrowing. Therefore it is valid to conclude that ash is suitable for recultivaton purposes of cut-away peatlands.

In revitalization study area pH_{CaCl2} of soil was similar in all plots and treatment types, but phosphorus content (determined using aqua regia) and exchangeable potassium differs between plots, showing higher concentration of phosphorous when fertiliser is applied (except for plot 1) (Table 4, Fig. 12.)

Table 4. Soil pH in control, wood ash and PK fertilizer treated revitalization plots (± SE)

Treatmet	Plot 1			Plot 2			Plot 3		
	Control	Wood ash	PK fertiliser	Control	Wood ash	PK fertiliser	Control	Wood ash	PK fertiliser
pH_{CaCl2}	4.32 ± 0.37	4.40 ± 0.31	4.39 ± 0.31	4.60 ± 0.40	4.53 ± 0.34	4.56 ± 0.33	3.60 ± 0.37	3.62 ± 0.40	3.84 ± 037

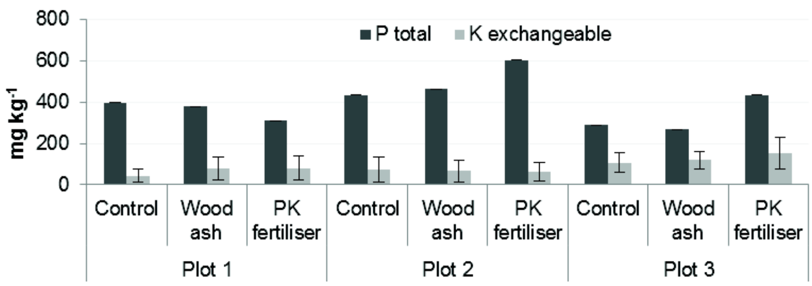
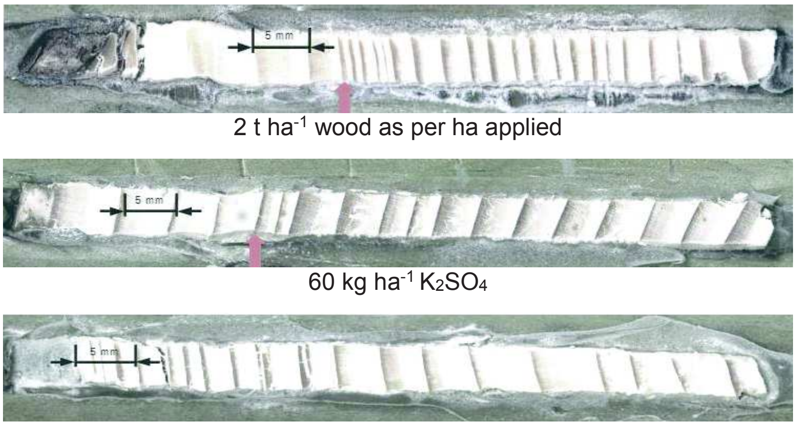


Figure 11. Soil total phosphorous and exchangeable potassium content in control, wood ash and PK fertilizer treated revitalization plots (± SE).

Both mineral fertiliser and wood ash showed significant increase in radial increment of spruce in first year and next years after application. Positive effect of wood ash continued in the following four years of observation (Fig. 12). This supports long term effects of ash treatment noted in other studies (Saarsalmi et al., 2014; Jansons et al., 2016).



2 t ha^{-1} wood as per ha applied

60 kg ha^{-1} K_2SO_4

Control

Figure 12. Spruce increment and revitalization four years after wood ash application.

CONCLUSIONS

1. Wood ash application improves revitalization of mature Norway spruce stands and aids recultivation in drained organic soils.
2. Wood ash treatment for regeneration purposes in this study showed similar results as fertiliser treatment and untreated plots.
3. Wood ash or mineral fertiliser application aids natural recultivation by selfsowing of trees. In this case, the forest regenerates according to succession principles.
4. Birch shows higher survival and self-sowing rate compared to other tree species in the case of both recultivation and regeneration.
5. Positive effects of wood ash is already evident within first 1–2 years after application when used for revitalizing and recultivation.

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