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LONG-TERM EFFECTS OF WOOD
ASH FERTILIZATION ON FOREST
PEAT SOIL AND GROWTH OF
NORWAY SPRUCE (*Picea abies*)

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Abstract		
<p>Approximately 50% of Finnish peatlands are drained for forestry and agricultural purposes. Drainage process may lead to the lack of nutrients and other needed chemicals and negatively affect the peatland environment, and for the reduction of negative impacts on soil and vegetation could be laid out so-called wood ash fertilization. The use of wood ash also reduces the amount of unrecyclable ash emissions from forestry and pulp production, decreasing the waste problem.</p> <p>This study was dedicated to the long-term effects of self-hardened wood ash application on peat soil in the catchments of two small lakes, Nimetön and Tavilampi in Evo Forest area, which were fertilized in winter of 1998. The short-term experiments (1997-2002) demonstrated that wood ash application positively affects the soil chemical structure, needle composition and growth of Norway spruce, which is the dominant tree species in both areas.</p> <p>In this study, the vegetation analyses revealed that nutrients, appeared after application of wood ash, are still positively affecting the growth of trees and thickness of spruce needles 20 years after ash treatment. The values for pH in the sampled fertilized peat were considerably higher than in control point, whereas conductivity was lower, which approves the existence of long-term fertilization effects. However, the average value for pH in soil is already in acidic range, and that phenomena can have negative consequences to the environment due to heavy metals, contained in the wood ash. In future it could be recommended to use granulated wood ash due to its lower concentrations of heavy metals in the structure.</p>		
Keywords		
soil; peat soil; peatlands; wood ash; wood ash fertilization; forestry		

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APPENDICES

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1 INTRODUCTION

In modern industry, especially during the activities of heating power plants and paper mills, one of the most acute problems is the appearance of such by-product as wood ash. In Finland, approximately 100 000 - 200 000 tons of wood ash are generated per year (Tulonen et al. 2002; Kepanen et al. 2005).

As wood ash is a material, which is valuable, cheap and rich in nutrients and trace elements, previously removed during the process of the tree harvesting, but needed for plant growth and soil productivity, it is often used as a fertilizer in peatland forestry (Pasanen et al. 2001, 9). For example, it may be practiced in previously harvested areas, which are now used for short-rotation forestry, but require soil treatment actions, such as fertilization, supplementary drainage and others (Nilsson & Lundin 1996). Along some regions, for example, in Germany, the use of wood ash is also popular for decrease of the acidity of forest soils (Meiwes 1995).

As many peatlands in Finland have been drained for forestry, agricultural use and peat extraction, the restoration of them also could be an ecological reason to use wood ash fertilization. The amount of wood ash, which is usually applied to the soil, varies from 3000 to 8000 kilograms per hectare (Tulonen et al. 2005).

However, ash application to the soil may negatively influence the surrounding ecosystem, due to heavy metals, such as Cd, Hg, Pb etc., and toxic micro-elements, possibly accumulated in the wood ash and therefore harmful to biota (Pasanen et al. 2001, 9) and groundwater.

During the period from May to October 1997 – 2002 two small, dystrophic, headwater lakes, Nimetön and Tavailampi, located in Southern Finland, Evo region were studied to evaluate effects of wood ash application on soil and water environment. Wood ash was added in the lake catchment and subcatchment areas in amount, equal approximately 6400 kilograms per hectare (Tulonen et al. 2005). Changes of the water quality, chemistry and community of plankton,

cadmium accumulation in aquatic animals, along with leaching of the ash components into soil solutions were studied over the five-year period (Tulonen et al. 2005; Tulonen et al. 2002). However, soil analyses after 5 years from initial ash treatment showed only minor effects on water or soil quality, and, although some biological changes were observed, such as increased biomass of phytoplankton and small zooplankton in nearby lakes, no accumulation of heavy metals in soil or water was revealed (Tulonen et al. 2005).

Long-term effects on the vegetation and soil environment, such as increase of growth and biomass of trees and thickness of spruce and pine tree needles, are usually the most obvious changes in vegetation caused by ash fertilization (Pihlström et al. 2000, 7).

In 2018, 20 years after the wood ash application, Lammi Biological station wanted to re-monitor and evaluate on the long-term basis the effects of wood ash, on tree growth and soil acidity. Potential re-acidification of topsoil or lower soil layers may cause changes in nutrient balance, leaking of phosphorus and heavy metals from ash-fertilized forest soils and further accumulation in the ecosystem.

The aims of the planned research were:

- a) To analyse if wood ash fertilization has affected the peatland environment on a long-term basis;
- b) To examine the remaining presence or absence of wood ash fertilizer effects in soil and trees and give possible recommendations on future research.

2 THEORETICAL BACKGROUND

Before the description of the experiments, it is essential to provide an insight into the characteristics of peatland soils in Finland to explain the need in fertilization, as well as to present the general information about wood ash as a fertilizer in forestry, its chemical structure, along with positive and possible negative impacts of ash fertilization on soil.

2.1 Finnish peatlands

Finland's first wetlands and bogs began to appear and develop more than 10000 years ago, after the Ice Age, when the ground was released from the glacier and water cover. During the numerous fertility researches, organic soils were classified as peat soils, gyttja (type of soil that mainly consists of organic matter deposited at the bottom of eutrophic lakes) soils and lake-mud soils. Nowadays, Finland can be characterized as one of the richest countries in peatland resources, as approximately one third of the land area is covered with peatlands (Figure 1), and about 53 endangered species could be found there.

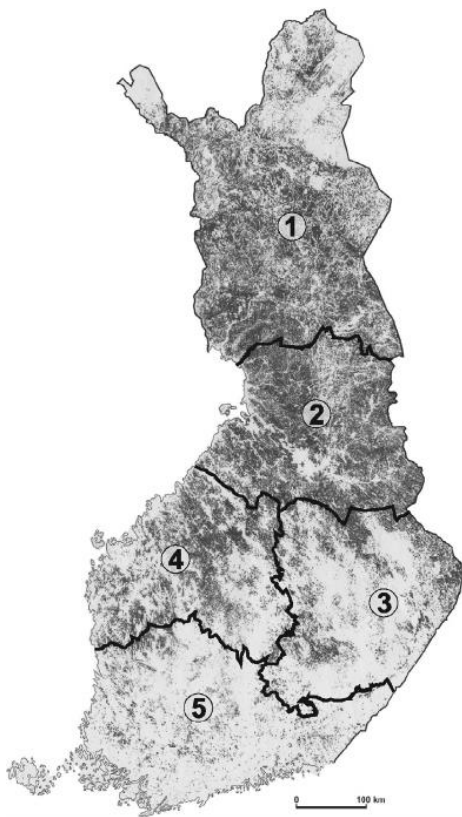


Figure 1. Location of peatlands in Finland (grey). 1 = Lapland, 2 = Northern Ostrobothnia, 3 = Eastern Finland, 4 = Western Finland, 5 = Southern Finland (Turunen 2007)

By Ruuhijärvi (1972), Finland is described as a country, economically dependent on the renewable sources. The sustainability and conservation of peatlands are significant for forest industry and agriculture, since the activities on peatland

environment have been always practiced on a larger scale than in any other country in a boreal zone.

2.1.1. Peatlands characteristics and ecology

Initially, peatlands could be defined as vegetation units, which form peat – sedentarily accumulated material consisting of dead organic matter of vegetation biomass (Joosten & Clarke 2002), so plants consequently grow on the biomass created by themselves. Peat is accumulated, when the production rate of plants is lower than decomposition, under the conditions of waterlogging and insufficient access to oxygen. Due to the lack of oxygen and the abundant water, the plants do not decompose properly, thus create a growing peat. In Finland, the conditions are favourable for the formation of peat, and the number of peatlands is constantly increasing.

According to Finnish soil classification, soils that contain over 40% of peat, are considered to be peat soils (Urvas et al. 1979).

All peatland types are generally described with humus content in about 70% of their structure (Urvas et al. 1979), but normally other properties of peat are influenced by nature of the mineral soil and bedrock, underlying or adjoining the peatland, and therefore may vary. Differences in peat structure also may appear due to cultivation or other use by human (Kurki 1982).

In overall, peat soils are more acidic, than other organic types of soils. Average values for typical Finnish peat soil usually range between 3.2 and 4.2 (Kurki 1982). The highest recorded pH value of non-fertilized peatland, as it was stated by Urvas et al. (1979), fluctuates within from 5.1 to 5.8.

Another important characteristic of peat soil is its high porosity along with low bulk density, which usually not exceeds 0.1-0.2 g/cm³. The mass of dry volume is also rather small, normally from 7 to 13 per cent of the total mass of the soil (Valmari 1982).

There are different ways to classify peatlands for agricultural and other industrial needs:

- a) Depending on the floristic affinity of the peatland, caused by differences in fertility and water conditions. This classification is used mainly in forestry purposes (Urvas et al. 1979):
 - a. Treeless peatlands;
 - b. Spruce swamps;
 - c. Pine swamps.
- b) Depending on its fertility (trophic) level, in other words, by amount of nutrients in the structure (Pyavchenko 1979):
 - a. Oligotrophic (or dystrophic) – soils, which are described with poor amount of nutrients;
 - b. Mesotrophic – soils with medium richness of nutrients;
 - c. Eutrophic – soils that are rich in nutrients.

Eutrophic and mesotrophic peatlands can be utilized for agriculture or forestry needs without special fertilization activities, but usually the acidity of peat is so high that it is impossible without additional treatment and pre-treatment (Valmari 1982).

In agriculture, peatlands are usually utilized in forms of cultivation of soil with additional mixing of sand of subsoil with peat soil for grain production, or for cultivation without additional mixing with mineral soils, mainly for grazing purposes (Baden 1972).

2.1.2. Drainage of peatlands

Despite the popularity for the agricultural activities in the past, nowadays peatlands are mainly used for forestry purposes, which usually include drainage of the area.

Drainage is practised in Finland since 17th century, along with mixing with mineral soil and burning. The purpose of the drainage process is to improve aerobic conditions while providing soil drying and warming (Sands 2001), and these processes are performed on surface and subsurface respectively.

Surface drainage is the process of extraction of excess water from the soil surface, which is completed with the help of ditching, or creation of so-called “open drains”.

Subsurface drainage is completed by removal of water from the root zone of plants, which accomplished by deep open drains or buried pipe drains (Brouwer et al. 1985).

The draining of peatlands in Finland was firstly introduced approximately in 1928, when the first forest improvement law was established (Kivinen 1982), and, since the beginning of 20th century, approximately 50% of all peatlands in Finland have been drained for forestry purposes.

The impacts of drainage activities on soil have been widely discussed by nature conservationists. The drainage process may lead to lack of nutrients and other useful substances for the biota, and, as ecology and vegetation are primarily dependent on them, cause changes in the ecosystem (Ruuhijärvi 1972). That is happening because of the decrease in the water levels, which leads to the collapse of plant structures and to the subsidence of peat surface (Minkkinen & Laine 1998). What is more, the lack of needed chemicals, such as potassium and nitrogen may also prevent the development of the next generation of tree stands and increase the possibility for trees to suffer from frost damages during the growing season (Rautjärvi et al. 2004).

As a balanced state of nutrients and their supply in the environment is needed for successful forestry and other activities, connected with peatlands, to reduce draining negative impacts on soil, and further to increase richness and productivity of peatlands, so-called wood ash fertilization is often applied by Finnish forestry and agricultural facilities.

2.2 Characteristics of wood ash

Wood ash is mainly produced during the wood residue processes, such as burning of bark of the trees. The amount of ash is usually depending on the part of the tree, which was initially used – for example, stem wood contains the lowest amount of wood ash, bark generates higher percentage, and the largest amount is produced from needles and leaves (Saarela et al. 2005).

As it is inapplicable in the further industrial processes and cannot be incinerated, the majority of wood ash waste is therefore disposed in landfills (Demeyer et al. 2001). Nevertheless, correspondingly to the growth of costs for landfill disposal, waste taxes and fees, and, inter alia, appearance of the European Union landfill regulations, in 20th century appeared the urgent need to recycle wood ash (Nurmesniemi et al. 2012). Therefore, beginning from the 1937 year, in Finland by the Finnish Forest Research Institute were laid out experiments, which have demonstrated that fertilization of ash to the peatlands have positive results, especially on sites with nutritional disorders (Pasanen et al. 2001, 10).

As types of wood processing, along with types of wood, usually vary due to product specialization, the characteristics of ash respectively may differ, and the generalizations of the chemical structure, as well as the generalization of metal concentrations, are difficult to make (Demeyer et al. 2001). In overall, wood ash is referred according to the type of process it is produced – fly ash, airborne wooden particles from chimneys and extraction systems, and bottom ash (Pitman 2006b), and the pre-treatment type (Figure 2) - it could be granulated or pelleted by rolling of a mixture of ash and water in a drum (Nieminen et al. 2007), or “self-hardened” during the reaction with water and air (Arvidsson & Lundkvist 2003).

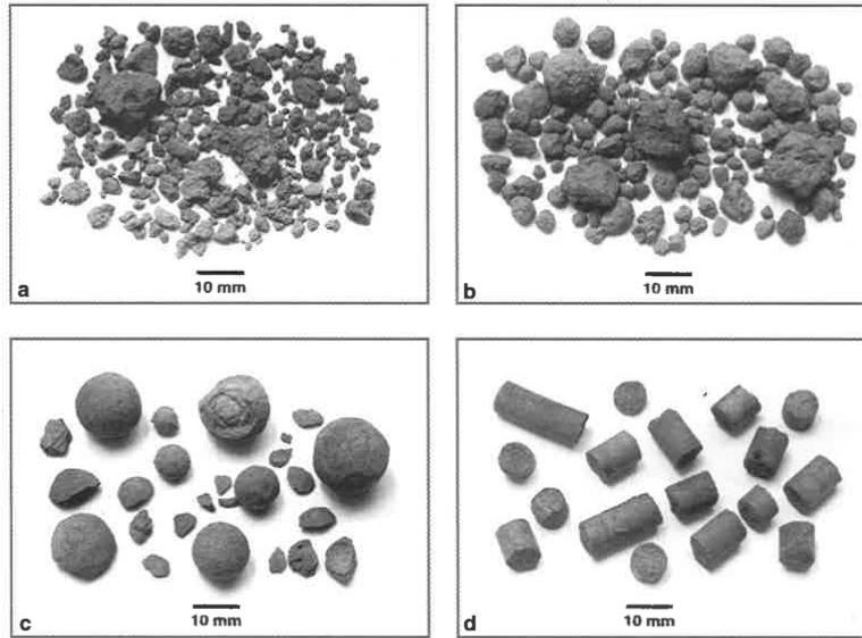


Figure 2. Wood ash with different pre-treatment types: self-hardened (a), granulated (b and c) and pelleted (d). (Ring et al. 1999, 13)

Wood ash is characterized with a high pH level, which usually varies from 12 to 13, and, consequently, with a high acid neutralizing capacity (Pasanen et al. 2001, 10). According to Pitman (2006a), calcium (Ca), phosphorus (P) and potassium (K) are usually contained in wood ash in the largest amounts (Figure 3).

	Wood residue/bark ash*		Paper mill ash [†]	Softwood ash [‡]		Hardwood ash [‡]	
	Median	Range	Median values	Stem	Bark	Stem	Bark
Ca	13.2	7.4–33.1	16.6	22.4	28.5	19	27.1
Fe	1.51	0.3–2.1	0.51	0.8	0.2	0.5	0.6
K	2.93	1.7–4.2	2.57	12.4	9.8	20.4	12.2
Mg	1.47	0.7–2.2	1.07	4.3	2.8	3.6	2.2
Mn	0.67	0.3–1.3	0.32	2.9	1.7	0.8	0.6
Na	0.24	0.2–0.5	0.1	–	–	–	–
P	0.79	0.3–1.4	0.39	2.4	2.8	4.2	3.4
S	0.56	0.4–0.7	0.02	2.3	1.2	2.1	1.1
Al	2	1.5–3.2	0.91	–	–	–	–
C	–	–	25.5	–	–	–	–
pH	12.7	11.7–13.1	12.4	–	–	–	–
N	Rarely reported <0.1%						

Figure 3. Average chemical properties of wood ash from different sources (Pitman 2006a)

The Finnish Decree on Fertilizer Products states that the ash from combustion of wood could be used as a fertiliser product in forestry, if it contains cadmium less than 25 mg/kg (Ministry of Agriculture and Forestry, 2013).

2.2.1 Wood ash characteristics as a fertilizer

Wood ash effects and usability remain popular among forest activities, and the impacts of wood ash application are widely discussed, as it affects both soil pH, nutrient and element concentrations.

a) Positive aspects

For forestry activities, wood ash main advantages are liming and effects on soil acidification, as it usually has a high content of neutralizing capacity, whereas the high amount of acidic chemicals in soil may result in raising of toxicity (Meiwes 1995) that brings negatively effects on the living organisms.

Generally, it is also known that wood ash promotes the growth of such trees as spruces and Scots pine, along with their regeneration on the site that is poor in nutrients.

Because of its lower homogeneity, when applied, wood ash also has an advantage of larger durability of fertilizing effects than other conventional fertilizers, which consequently results with long-term accumulation of nutrients in peat (Silfverberg 1996, 14). Moreover, it was concluded that the number of tree seedlings increases due to the growth of the nutrients in soil after the fertilization, in comparison with a non-fertilized area (Silfverberg 1996, 14).

Along with the growth of nutrient richness, when applied to soil, ash serves as a source of base cations, which may raise the soil pH and consequently decrease the acidity of soil (Pasanen et al. 2001, 10).

The reduction of soil acidity consequently may positively influence on the tree roots, especially in spruces, as they usually characterized as plants, which subsoil rooting is reduced in the acid soil conditions (Jentschke et al. 2001).

In Finland, as it usually contains sufficient amount of phosphorus (P) and potassium (K), wood ash is usually applied to drained peatlands to provide

mineral nutrients for trees, which could be previously removed by forestry soil activities, especially in pine trees, which are in special need of these chemicals (Nieminen et al. 2007).

According to the scientific researches on soil in 1990s, wood ash theoretically can fully replace nutrient losses from whole-tree harvesting sites (Pitman 2006b). The amount of ash, applied to the area, usually varies from 3000 and 8000 kg ha⁻¹.

As it was stated by Tulonen et al. (2002), the recommended amount of phosphorus in wood ash is from 30 to 40 kg ha⁻¹.

To summarize, positive effects of the wood ash fertilization process may be reported as a scheme (Figure 4), based on the research done by Silfverberg (1996, 15):

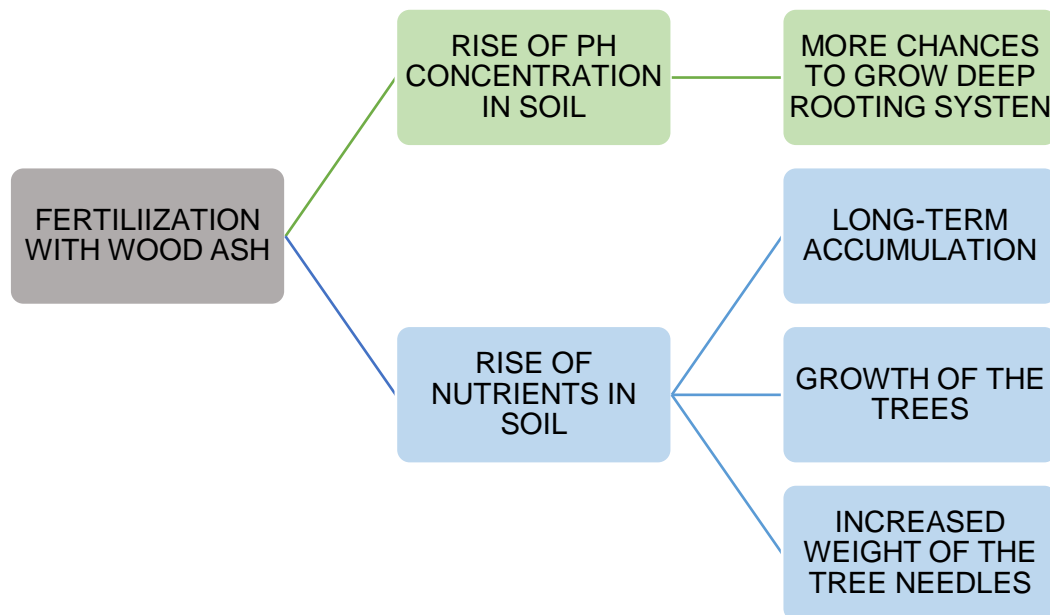


Figure 4. Summary of the positive wood ash fertilization effects

Fertilization of the peatlands by wood ash, previously drained or disturbed by other forestry and agricultural activities, normally increases the soil pH, bulk density and the amounts of nutrients to above-average levels (Hytönen 2003).

b) Negative aspects

As it was already mentioned, the use of wood ash may have some negative aspects. Application and the storage of ash in soil may result in contamination by different elements, as in the burning process heavy metals are concentrated in the wood ash (Silfverberg 1996, 20), and some of them, for example, cadmium (Cd), have caused concern for environmental risks. Concentrations of cadmium vary from 1 to 20 $\mu\text{g g}^{-1}$, and sometimes exceed the allowed levels for fertilizers. Dissolved in soil, cadmium could be taken up by plants and accumulate in the food chain (Kapanen et al. 2005), leach into recipient waters and also disturb and affect the nutrient cycling, as well as other heavy metals.

The increases in soil pH, depending on the initial wood ash structure may be long-term and influence the soil environment in prominent effects on plants and soil vertebrates, highlighting the fact that peat soils initially are more acidic than other soils (Kurki 1982). Despite their initial advantaging impacts, the changes of the pH and soil neutralizing effects may be negatively influential, as some forest species and microorganisms may be very sensitive to changes in pH due to previous long-lasting periods of adaptation to acid soil (Pasanen et al. 2001, 35).

2.2.2 Differences of wood ash from other soil fertilizers

Despite the fact of its variation in chemical compounds and the need in large amount to be applicable, wood ash fertilization is researched to be more usable and beneficial than other fertilization sources, especially in case of drained peatlands (Silfverberg 1996, 19). The examples of the comparison with other types of fertilization are provided below:

- **Forest fires**

Ash fertilization differs from forest firing - first of all, the amount of applied ash is greater than ash that appeared during the firing process; secondly, it does not provide any heating that might be destructive for soil surface and vegetation, whereas forest fires may change the area into patchy and burned (Silfverberg 1996, 19).

- **Rock powder**

It was studied that the application of ground rock powder normally decreases the soil acidification, but it does not provide as much nutrients for plants, and, what is more, its initial amount of base chemicals that react with soil acidity is quite low (Meiwes 1995).

- **Lime**

Lime is usually applied in soil areas with high level of acidity, where in the same way could be applied wood ash. However, it was studied that in the places with low nutrient richness, wood ash is more advantaging, as it increases the level of nutrients, whereas lime does not provide such function, and therefore, ash fertilization could be more recommended (Meiwes 1995).

2.2.3 Long-term effects of wood ash application

Application of the wood ash application may result in long-lasting consequences on the environmental properties of the fertilized soil and its vegetation, therefore, the long-term studies also are of interest.

Several studies revealed that ash fertilization possibly could decrease the soil acidity even in long-term. In the research by Saarsalmi et al. (2001) on forest peat soil, the average increase of pH level by 0.6 – 1.0 units was detected in the period of 16 years.

Additionally, the growth of seedlings and fresh tree shoots was stated as a possible long-term effect in the study by Hytönen (2003), where the effects of ash fertilization were analyzed 10 years after the application. It was concluded that up to 10th year, the increase in average growth of tree seedlings in ash fertilized places was higher, than in non-fertilized areas. Overall tree stand growth also was stated as a possible long-term effect in peat fertilization researches, since wood ash contains phosphorus, which serves as a slow-soluble fertilizer (Silfverberg 1996).

3 BACKGROUND OF THE RESEARCH

To start the practical part of the research it was needed to study the environmental conditions of the research area, as well as previous research for further comparison of the long-term results with short-term, which were published in 2000 year by Pihlström et al. (2000) in Finnish language.

3.1 Description of the study area

Evo State Forest (61°14"N and 25°12"E) is a southern boreal vegetation zone with a slightly continental climate. The area of approximately 73 km² in total is mainly covered with spruces and Scots pine forests, which are the dominant species of trees in the forest cultivation practices in Finland (Rask et al. 1992).

Evo forest area (Figure 5) is a part of Natura 2000 global network, with two nature reserves and numerous conservation areas, such as shore and mire conservation areas, private conservation areas and a hiking area, protected by environmental legislation and Finnish Forestry. About half of the Evo area belongs to forestry management, 20% of the area is privately owned, whereas the rest is state-owned and governed by the forest administration Metsähallitus (Hämeen ammattikorkeakoulu 2005).

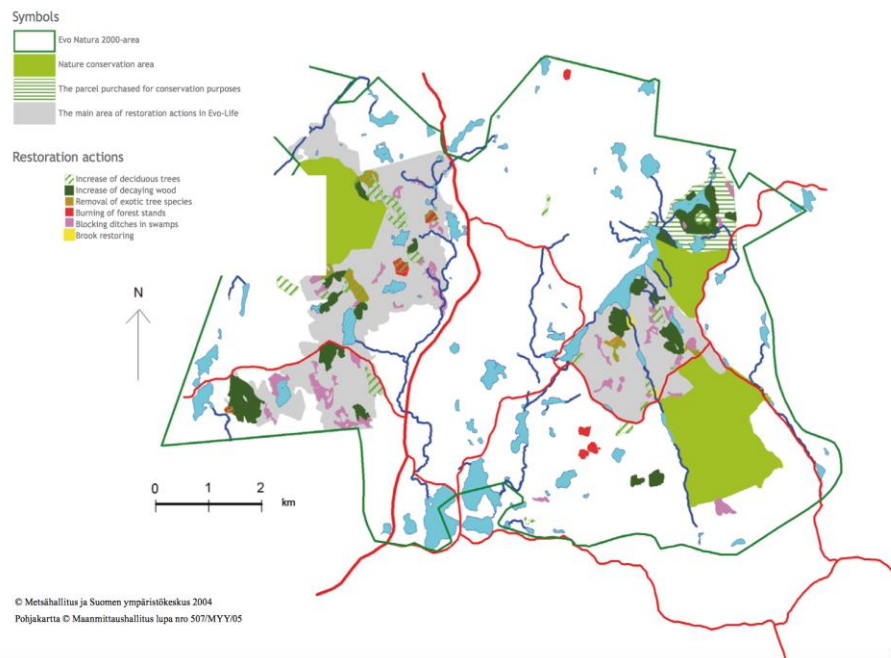


Figure 5. Map of the Evo area (Hämeen ammattikorkeakoulu 2005)

There are approximately 80 lakes in the Evo area (Figure 6), connected by brooks and small rivers, with altitude in average 125-160 meters above the sea level. These lakes compose the area of 452 hectares in total, which is approximately 6.2% of the Evo State Forest. Some of the lakes are surrounded by peatlands, which cover 20% of the total area (Rask et al. 1992).

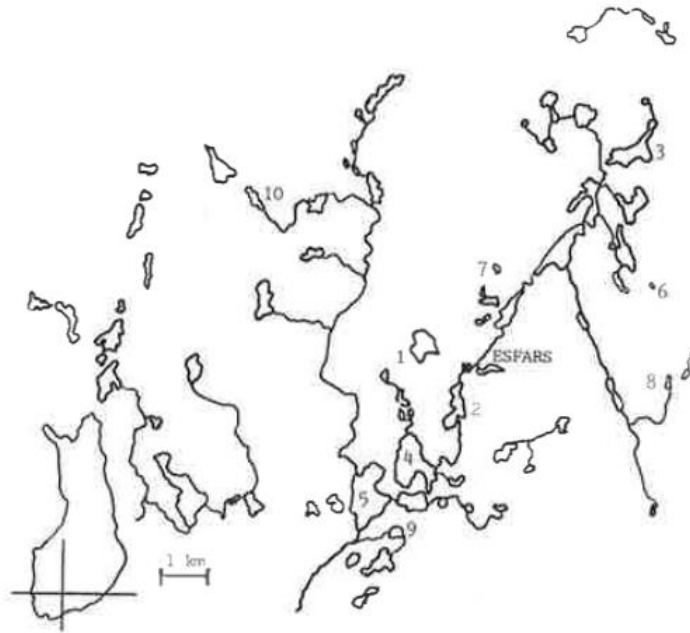


Figure 6. Map of the lakes in the Evo State Forest (Rask et al. 1992)

In overall, the lakes in Evo area are mainly described as oligotrophic and, therefore, the application of wood ash might create the risk to disturb the natural conditions, as they were also characterized as sensitive to environmental pollutants by Rask et al. (1995). Ash fertilization of surrounding land could possibly increase the leaching of nutrients and heavy metals into the lake water, and that could change the trophic status.

The studied lakes Tavilampi and Nimetön, which are adjacent to the studied peatland areas, are 0.008 km² and 0.004 km² in area respectively.

The surrounding of Nimetön lake mainly consists of mineral and peat soil types, and its flora is described mainly by deciduous (birch, aspen) and coniferous trees, such as Northern spruce. The area, surrounding Tavilampi

lake is a spruce swamp, with spruce as the main tree species respectively, characterized by peat soil (Kapanen et al. 2005).

The application of the wood ash in 1998 was funded by Metsäteho oy enterprise, and supported by such forest industries, as Stora Enso Oyj, TEKES and others. Its purpose was to investigate how the application of wood ash may improve the conditions for forestry and overall landscape (Pihlström et al. 2000) and what are potential risks for the environment.

3.2 Wood ash composition

Wood ash, which was applied to soil in winter 1998, is a self-hardened ash, which initially was a by-product from the Finnish paper mill Metsä-Botnia, Äänekoski. The ash was produced from bark of pine, spruce, birch, and aspen, as well as from small amounts of peat and bio-sludge (Kapanen et al. 2005).

The elemental composition of the wood ash is presented in the Table 1.

Table 1. The elemental composition of the studied wood ash (Tulonen et al. 2002)

Element	Concentration (g kg⁻¹)
P	6.01
K	12.08
Ca	248
Mg	10.04
Mn	4.08
S	8.04
Na	5.03
Fe	5.05
Al	11.04
Zn	1.02
Cu	0.11
Pb	0.01
Cr	0.03
Cd	0.007

The quantity of wood ash was 6400 kg ha⁻¹ (dry weight) with a medium cadmium burden 44 g ha⁻¹.

3.3 Short-term results in the studied area

Before the discussion of materials and methods, carried out in 2018 year, it is necessary to mention the short-term results of the analyses by Pihlström et al. (2000), which would be furtherly used for comparison in discussion of the long-term results.

3.3.1 Changes in soil pH

Before the ash fertilization (summer 1997), the pH value of the surface peat varied from 3.67 to 5.4. In the spring 1998 both fertilized areas, Nimetön and Tavilampi, has shown clear increase of nutrition level and decrease of acidity, as pH level varied from 5.11 to 5.4. In 1999, peat fertilized area pH level was approximately 6.12, and this result could be also described as neutral acidity. The pH of studied non-fertilized, control areas, in all years did not exceed 4.77 (Pihlström et al. 2000).

3.3.2 Changes in the weight of spruce needles

In the initial situation (1997), needles in the control areas were usually heavier, than needles in the fertilized areas. However, during the next three years, the weight of needles in the fertilized areas significantly increased, and in 1999, the needles of trees in the fertilized areas were about 40% heavier (Pihlström et al. 2000).

4 MATERIALS AND METHODS

The fieldwork experiments were aiming to study the growth of the dominant tree species, Norway spruce (*Picea abies*), and soil conditions on a long-term basis, between two previously fertilized areas in the catchments of lakes Tavilampi and Nimetön, and control non-fertilized area in the catchment of lake Nimetön

(hereinafter “control area”), respectively (Figure 7).



Figure 7. Study areas. 1 – Nimetön fertilized area, 2 – Nimetön control area, 3 – Tavilampi fertilized area

All samplings for vegetation and soil analyses were carried out in spring, from the end of April to the beginning June 2018. As dependent variables were chosen

tree shoot growth, needles thickness and basic characteristics of soil, such as water content and mineral and organic matter concentrations, acidity (based on pH level measurements), electrical conductivity and bulk density.

It is important to state that the surrounding environments of the studied areas varied even visually – both Nimetön studied areas (control and fertilized) can be characterised as peatlands surrounded by very dense and dry forest, whereas Tavilampi area is located close to the lake and may be characterised as a forest with a greater amount of sunlight, which also may have affected the vegetation growth.

4.1 Tree growth measurements

The purpose of vegetation experiments was to evaluate the possible long-term growth in nutrient level, which, consequently, might have result in the increase of the overall growth of dominant tree species, Norway spruce (*Picea abies*), in the fertilized areas, and vegetation richness. For the evaluation of spruce growth two methods were chosen, annual growth of shoots and needle weight measurements.

4.1.1 Tree shoots

In coniferous plant species (Northern spruce, Scots pine), by the distance between two adjacent boundaries of annual shoots (between two whorls on the trunk or on the branches), could be determined the length of the annual shoot, or “cohort” (Figure 8) (Muukkonen & Lehtonen 2004).

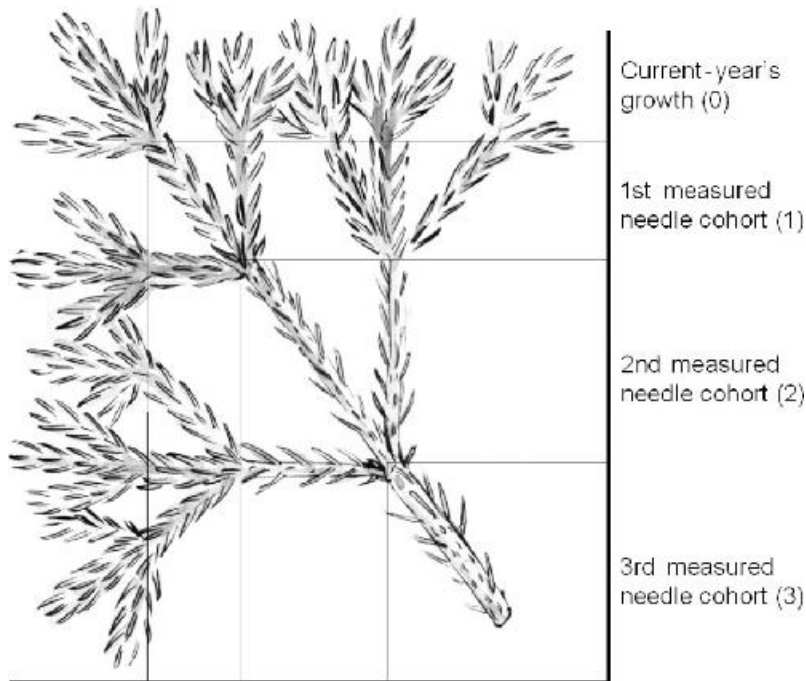


Figure 8. Schematic determination of coniferous shoot (cohort) length (Muukkonen & Lehtonen 2004)

The activity of the development and length of the annual shoot normally depends on the surrounding environment, amount of nutrients and state of soil, consequently, the measurements of tree shoot growth may indicate changes in richness of needed nutrients between fertilized and non-fertilized areas.

As vegetation studies in Tavilampi and Nimetön areas were conducted in different times – in April in Tavilampi fertilized area and in the end of May in Nimetön fertilized area, to compare the results with non-fertilized area more correctly due to possible changes in growth of control area in that period of time, tree shoots from control area were also measured twice, in April and May respectively.

For measurement of yearly growth of tree shoots on each site were randomly chosen 7 spruce trees. The measurements from latest 3 annual shoots were performed with use of standard tape measure in centimeters.

4.1.2 Weight of spruce needles

Spruce needles were collected from 7 spruce trees, which were chosen randomly in each sampling area. The same trees were measured for yearly shoot growth. From each tree were taken 100 needles (700 in total per area).

As needles from Tavilampi and Nimetön fertilized areas were collected in different times (in April and in the end of May respectively), to compare the results with non-fertilized area more correctly, samples from control area were also collected twice, in April and May.

Later, needles were dried in the temperature of 105°C for 3 days, and then weighted with analytical digital lab scale “Mettler AC100” with 0.1 mg increment. The gained results were expressed in grams.

Presumably, needles from the trees in previously fertilized areas were expected to be thicker, and, consequently, heavier than the needles from non-fertilized areas, if the prevalence in nutrients and needed chemicals remained after the fertilization 20 years before the experiment.

4.2 Soil measurements

Soil sampling for further experiments was performed at the same sites of Tavilampi fertilized area, Nimetön fertilized area and Nimetön control area, where in period between 1998-2000 samplings by Pihlström et al. (2000) were completed.

In each area, samples of soil profile from 0 to 35 cm were collected in 3 randomly chosen places. Each sample consisted of 7 cm depth – 0-7; 7-14; 14-21; 21-28 and 28-35 cm respectively. The samples of first 7 cm depth (0-7) were stated as surface layer samples, and furtherly used for dry weight and bulk density analyses. After the extraction from the study areas, soil samples were normally stored for 1-2 days in the fridge.

4.2.1 pH measurements

For measurements of differences in soil acidity between fertilized and control areas, the standard method of pH measuring was used.

All pH measurements were completed in the laboratory conditions, with use of standardly calibrated Orion model SA 720 pH-meter.

Before the pH level determination, soil was mixed with distilled water in proportion 3:5 (30 ml of soil per 50 ml of distilled water, or 15 ml of soil per 25 ml of water respectively), and then kept in room temperature for 24 hours. All pH measurements were also laid out in room temperature. In advance of the experiments, pH electrode was calibrated in pure buffer solutions of 7.0 pH and 4.0 pH respectively.

4.2.2 Conductivity measurements

In overall, electrical conductivity measurements are needed to provide data on the ability of a material – in this case, peat soil - to conduct electrical current. For soil studies, the measurements of electrical conductivity are essential, as they can predict the soil salinity, because, as it was already mentioned above, salted compound is characterized with higher conductivity.

Mainly, values of the electrical conductivity of soils vary depending on the amount of moisture held by soil particles, depending on their size and texture: for example, sandy soil is known for its low conductivity, whereas the conductivity value for clay is significantly higher (Grisso et al. 2005).

Measurements of the electrical conductivity for peat samples were performed in the laboratory, with YSI 3100 digital conductivity instrument with automatic temperature compensation, in room temperature. The samples of soil were saturated in distilled water in proportion 3:5, and the tool was kept in each sample for 60 seconds in room temperature (25 °C).

Results of the measurements were submitted in $\mu\text{S}/\text{cm}$ (micro siemens per centimetre).

4.2.3 Dry weight measurements

Surface layer of each area was additionally measured to determine the mass of water and organic matter, or soil moisture content, and losses of soil on ignition.

For calculation of soil moisture content, 15 g of surface layer of each area (first 7 centimetres of soil depth) were taken as samples, weighted and then oven-dried in ovenproof containers for 3 days in 50°C temperature.

The calculation of soil water concentration was obtained in accordance with the Equation 1.

$$WC\% = \frac{W_1 - W_2}{W_1} \cdot 100 \quad (1)$$

where	$WC\%$	water concentration	[%]
	W_1	wet soil weight	[g]
	W_2	dry soil weight	[g]

To compare the significance in differences in water concentrations between fertilized and non-fertilized area, in Excel was additionally run a t-test.

After the calculation of dry soil weight, the samples were weighted again and placed in oven for 3 hours at temperature of 450°C for calculation of losses on ignition.

Loss on ignition is expressed as a difference between moist soil and dried soil, where loss is counted as organic matter, previously contained in the sample. The principle of loss on ignition method is based on the fact that during the warming in the oven, organic matter burns off, leaving only the mineral components of the tested soil samples.

After the drying, the samples were left for cooling overnight, and then weighted.

Gained values were subtracted from the dry soil weight values, and the results express the amount of the organic matter, which was burned in the oven in 450°C temperature.

The calculation for water content in soil i.e. soil moisture were performed in identical conditions, and for each studied area were completed 3 calculations for measurement.

4.2.4 Calculations of bulk density

To reflect the soil structure profile properties in each sampling area and possible structure changes due to fertilization, it was necessary to additionally determine its bulk density, as it characterises porosity of the soil layer. The higher dry bulk density, the higher the probability of soil to have large pore space.

Initially, bulk density can be calculated as the weight of dry soil divided by the initially known soil volume of the tested sample and expressed in gram per cubic centimetre (g/cm^3).

For calculations and further comparison, 100 cm^3 of soil were extracted from the surface layer (0-7 cm depth) of each area. Further, these samples were placed in the oven for 48 hours in the constant temperature of 105°C. After the drying was completed and the samples were weighted, the bulk density was calculated.

4.3 Statistical analyses

To reveal the significance or insignificance of differences in compared samples from treated and untreated areas, it was essential to carry out several statistical analyses, which are listed below.

T-test analyses

Since the gained data values varied in all sampled areas, to assure that the fertilized and non-fertilized soils have differences, the results were additionally analyzed with a two-tailed t-test analysis method with the help of Excel data

analysis tool. These analyses were carried out to check the differences in conductivity and water content of soil samples.

Initially, the t-test is used to test the hypothesis that the means of two data groups, in this case, fertilized and non-fertilized areas, are equal. If the P-value is < 0.05 , the null hypothesis, assuming the insignificance of the difference between results, is rejected. Consequently, if the P-value is > 0.05 , it could be concluded that a difference between the results is insignificant.

ANOVA

If the gap between mean values of Nimetön fertilized and Nimetön control sites was insignificant, statistical analysis of variance (ANOVA) was planned to be performed to detect differences between treated and non-treated spruce trees.

ANOVA F-test is applied to find out the significance of the numerical results by comparing a calculated value to a critical (statistical) value. If the calculated F value is higher than the F statistical value, the null hypothesis can be rejected, therefore, could be concluded, that differences are stated as significant (Kao & Green 2008).

SPSS frequency analysis

Multiple numerical values, such as pH test results, were additionally analyzed in descriptive SPSS statistics software for comparison of the value frequency.

This test is carried out to calculate the occurrences of each respondent, in the case of the research, soil sampling places. For visualisation and summarization of the analysed data, results were expressed in a form of histogram.

5 RESULTS

5.1 Soil structure

Experiments on the soil structure showed that all tested samples were certainly peat soil, and, therefore, the overall structure of the soil, studied in experiments laid out in 1997-1999, did not change during the long-term period.

As the analyses consisted of two parts – dry weighting for measurement of water concentration, and then loss on ignition for calculation of organic matter, the results of weighting analyses are also expressed in two parts.

5.1.1 Water content

The results of the water content measurements are expressed in the table below (Table 2). In each area sample water concentration exceeded 78%.

Table 2. Water concentration of peat soil in studied catchment areas

Sampling area	Sample №	Water concentration
Nimetön fertilized area	1	81.62%
	2	84.67 %
	3	81.74 %
Tavilampi fertilized area	1	88.70 %
	2	90.57 %
	3	89.53 %
Nimetön control area	1	78.96 %
	2	80.33 %
	3	78.91 %

Average values for each studied area were also calculated, and the results for fertilized area were higher than control area – 82.67% for Nimetön fertilized area, 89.60% for Tavilampi fertilized area, whereas average concentration in Nimetön control area was 79.40%.

Based on the statistical two-tailed t-test for unequal variances (Appendix 1), differences between fertilized and non-fertilized areas in Nimetön catchment were stated as insignificant ($p > 0.05$). The difference in water concentration between Tavilampi fertilized area and Nimetön non-fertilized area could be stated as significant ($p < 0.05$).

Both fertilized areas, Nimetön and Tavilampi, were also compared, and the difference between these values, however, could be also stated as significant ($p < 0.05$).

5.1.2 Loss on ignition

For the comparison of physical soil structure between the studied areas, for each of them were calculated average concentrations out of 3 tested samples, which were expressed in graph below with a standard deviation of 1 (Figure 9). In all studied samples the water concentration in average exceeds 79 per cent, whereas mineral concentration is below 2 per cent in average.

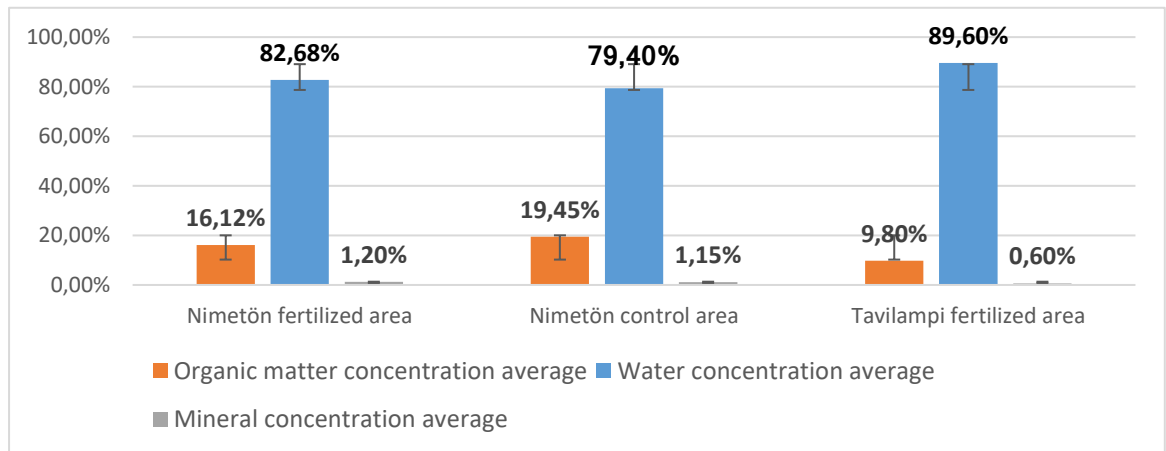


Figure 9. Mean organic matter, water and mineral content of the surface soil (0-7 cm) for each studied area

In overall, concentrations in all soil samples were distributed with a predominance of water in the soil structure – in each area the average value exceed 79% at least, which is a typical structure for peat land in lake catchments.

5.1.3 Bulk density

The results of bulk density tests additionally reaffirmed that the tested soil samples could be classified as peat, according to the low values, as none of the soil samples showed the bulk density higher than 0.114 g/cm^3 .

The average values for each area were 0.101 g/cm^3 for Nimetön control area, 0.075 g/cm^3 in Tavilampi fertilized area and 0.108 g/cm^3 for Nimetön fertilized

area. The highest values for each area were: 0.114 g/cm³ in Nimetön control area, 0.112 g/cm³ in Nimetön fertilized area and 0.091 in Tavilampi fertilized area.

Through the results-based approach it cannot be stated that there are significant differences between fertilized and non-fertilized pore structure of soil.

5.2 Chemical analyses

5.2.1 Soil pH

The measurements of pH (Appendix 2) have demonstrated the clear difference between fertilized and non-fertilized soils – the maximum value of pH in ash-fertilized areas was 5.6, whereas the pH values for the untreated area did not exceed 4.

On the graph below (Figure 10) are shown average values for each area in each sampling depth – 0-7, 7-14, 14-21, 21-28 and 28-35 cm respectively.

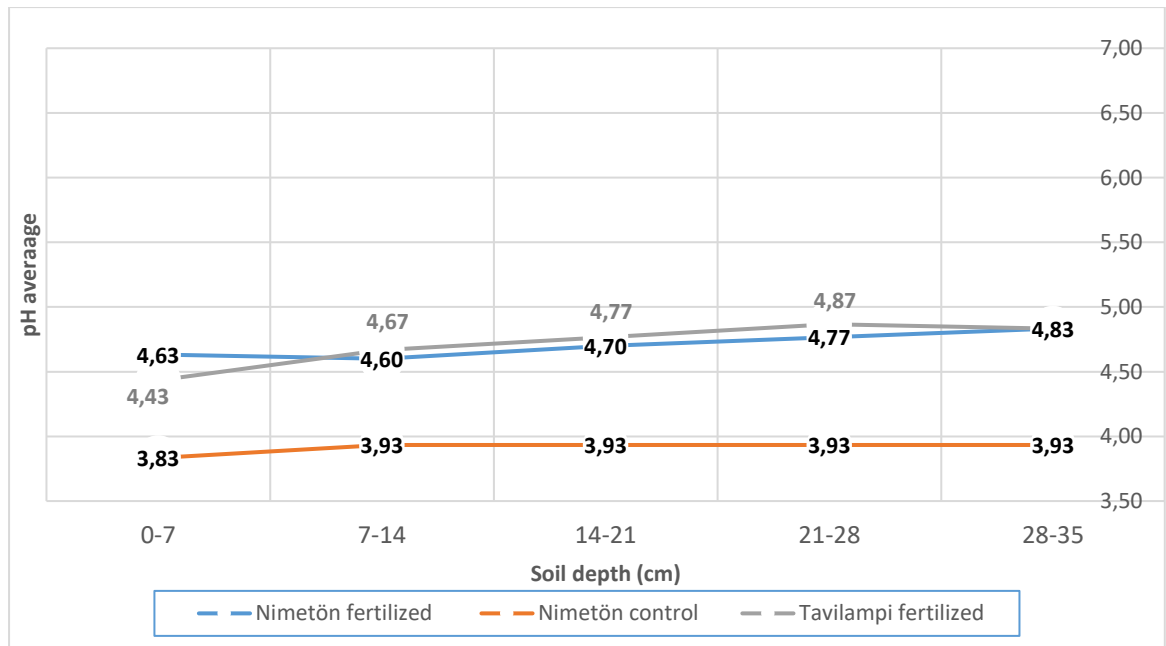


Figure 10. Average values of pH in each studied area in all sampling depths

In overall, annual mean pH value for Nimetön control area was 3.91. In fertilized area average values did not differ significantly – 4.71 for Nimetön fertilized area and 4.71 for Tavilampi fertilized area.

SPSS frequency test, carried out to all values (Figure 11), clearly demonstrated the fact that only in control area results for pH did not exceed 4, whereas pH in fertilized areas tends to be higher.

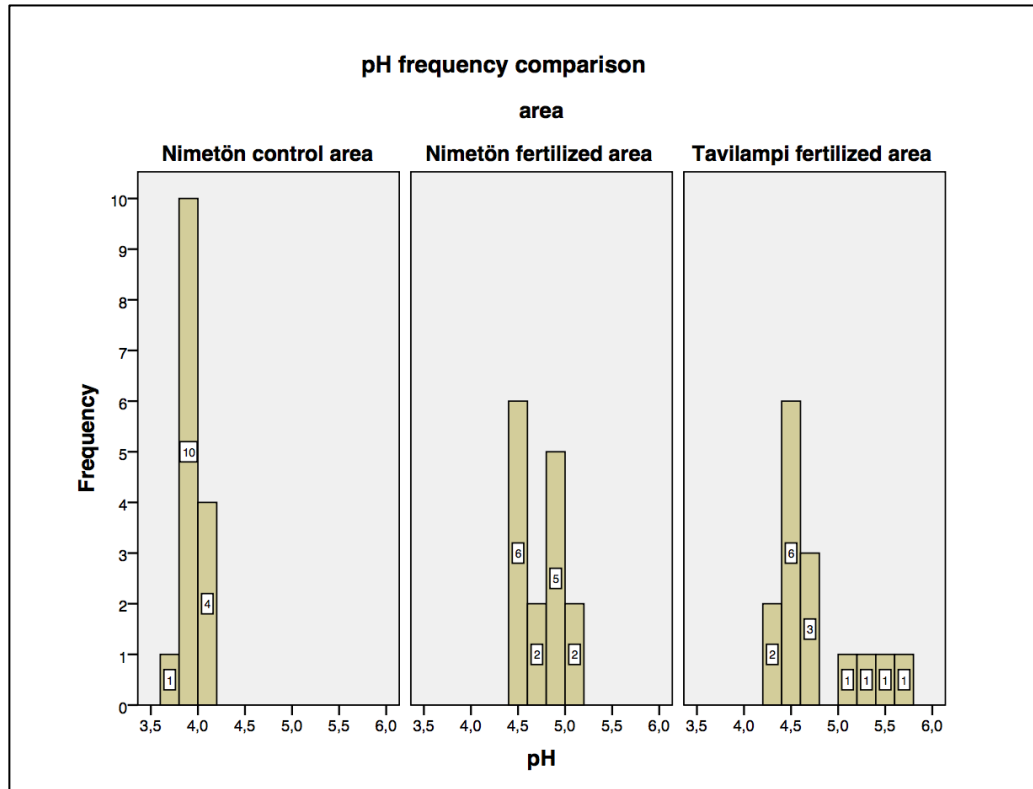


Figure 11. Comparison in frequency of pH results

Frequency analyses also showed that values for pH in the control area are more stable: 10 results out of 15 are identical, whereas in fertilized areas all results are greater than or equal to 4.3, but significantly vary from that result to 5.6 pH. That can be possibly explained by the uneven distribution of wood ash during the transformations of soil during the 20-year period after the fertilization.

5.2.2 Comparison with pH measurements of previous years

The pH analyses of first seven cm of depth (surface layer) in fertilized and non-fertilized area were also used for comparison with results of previous measurements – in 1997 (control year before fertilization), 1998 and 1999 year respectively (Figure 12; Figure 13; Figure 14).

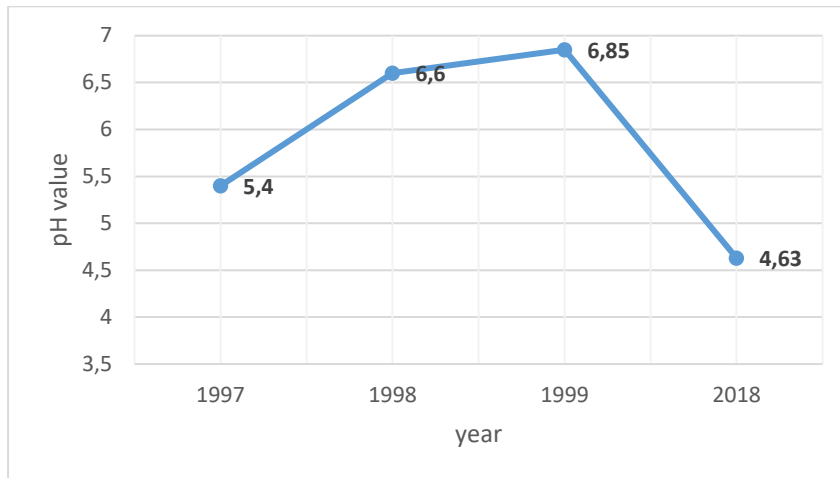


Figure 12. Comparison of pH level in surface soil (0-7 cm) for Nimetön fertilized area

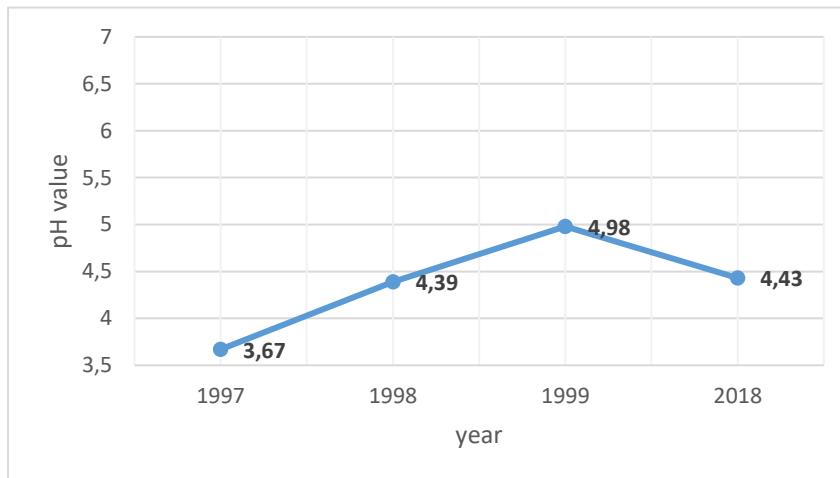


Figure 13. Comparison of pH level in surface soil (0-7 cm) for Tavilampi fertilized area

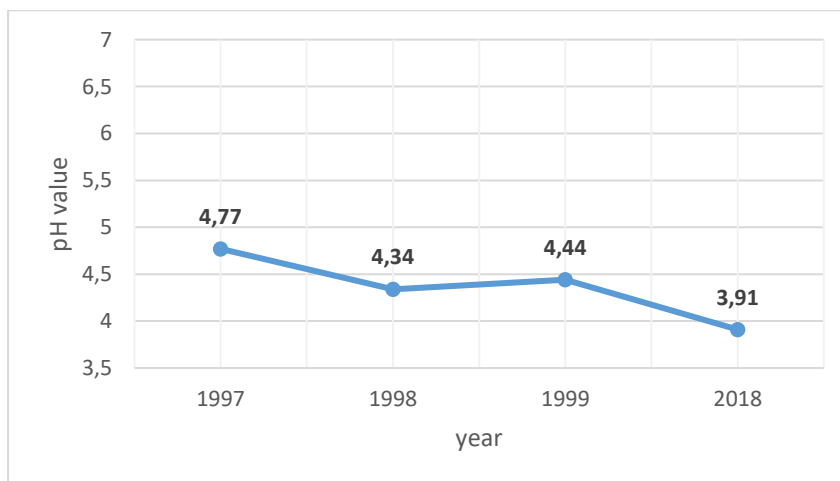


Figure 14. Comparison of pH level in surface soil (0-7cm) for Nimetön control area

Despite the fact that Nimetön fertilized area values were significantly higher than in control area, the results of the comparison with short-term results clearly show the increase of the soil acidity of the area at least in the surface area.

However, the pH level of the surface in control area, which remained not fertilized and was not used for any purposes in a long-term period, also decreased comparing to the results of previous 20 years.

5.2.3 Conductivity

Conductivity analyses of all sampled areas on all measurement depths are summarised in Appendix 3.

In overall, all studied catchments have shown not exceedingly high results. The minimal value for conductivity was found in Tavilampi fertilized area on the depth of 21-28 cm and was equal 15.2 $\mu\text{S}/\text{cm}$. The maximum value of 57 $\mu\text{S}/\text{cm}$ was found in Nimetön control area on the depth of 0-7 cm (surface layer).

For each area in each depth were calculated the average conductivity values, which are expressed on the graph below (Figure 15).

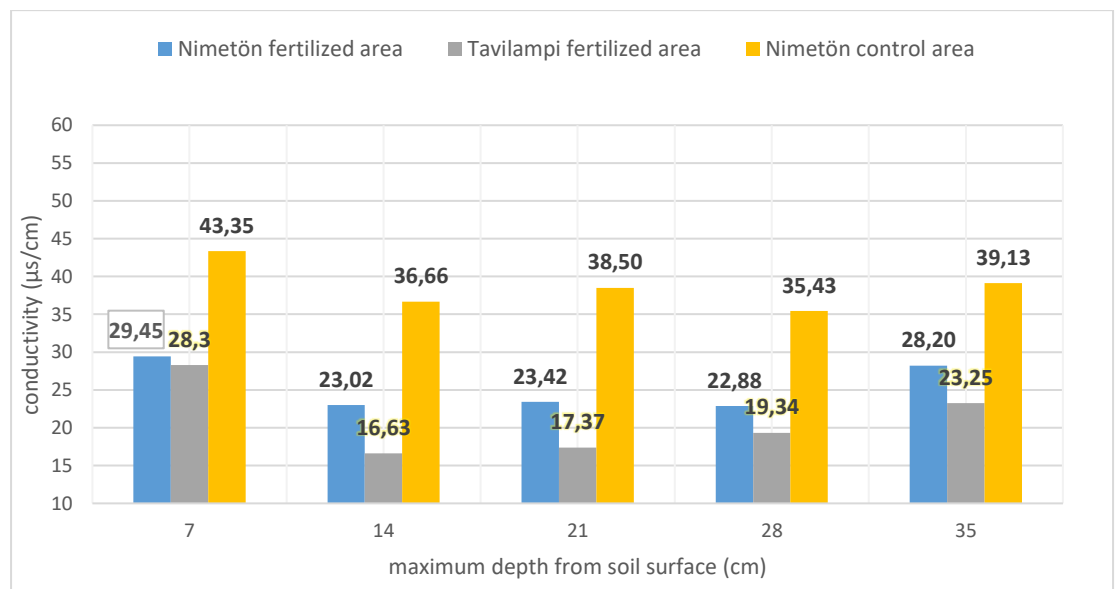


Figure 15. Average conductivity values in studied areas

For studied fertilized areas and control area a statistical t-test (Appendix 4) was performed in order to detect significant differences between control and fertilized

areas based on the overall mean values, which were 38.614 $\mu\text{S}/\text{cm}$ for Nimetön control area, 25.996 $\mu\text{S}/\text{cm}$ for Nimetön fertilized area and 21.152 $\mu\text{S}/\text{cm}$ for Tavilampi fertilized area.

The results of the comparison clearly demonstrated significance in differences between mean values: for average conductivity values in Nimetön fertilized and Nimetön non-fertilized areas the statistical difference between values is significant ($p < 0.05$). Difference in average conductivity values in Tavilampi fertilized and Nimetön non-fertilized areas could be also stated as significant ($p < 0.05$).

5.3 Tree analyses

Even though in studied areas were not performed any forestry activities on the tree stand after the fertilization, the differences in vegetation and tree structure between fertilized and control areas were clearly visible. For instance, even though Nimetön fertilized and Nimetön control area environments are basically similar – shaded peatland with spruces and birches as dominant tree species, surrounded by the ditched brook, the tree stands in non-fertilized area were visually in sharply lower condition.

5.3.1 Tree shoot length measurements

As it was already mentioned before in description of the materials and methods, in May-June 2018 were linearly measured in total 21 spruce treetops, chosen randomly, seven per studied area.

In the table (Table 3) below are presented maximal and minimal values of growth for each studied area for the last three years: 2015, 2016 and 2018 respectively.

Table 3. Minimal and maximal values of yearly growth (in cm) in each area

Year	Tavilampi		Nimetön			
			Fertilized		Control	
	maximum (cm)	minimum (cm)	maximum (cm)	minimum (cm)	maximum (cm)	minimum (cm)
2015	9.7	3.7	8	3	3.4	0.2
2016	19	3.9	5	2.5	4.4	1.6
2017	19.5	2	8	2	4.1	1

In spite of the high variation between maximum and minimum length in both fertilized areas, the minimum values for Tavilampi and Nimetön fertilized areas are averagely higher, than minimum non-fertilized area, by a rate of 71% (Tavilampi) and 63% (Nimetön) respectively. Maximum values of Tavilampi fertilized area are about 75% higher, than Nimetön non-fertilized area, as well as Nimetön fertilized area, which maximum values are higher by 44%.

In order to obtain better overall representation of tree growth differences, for all three sites were calculated average values for 2015, 2016 and 2018 years respectively, which could be seen on the graph below (Figure 16).

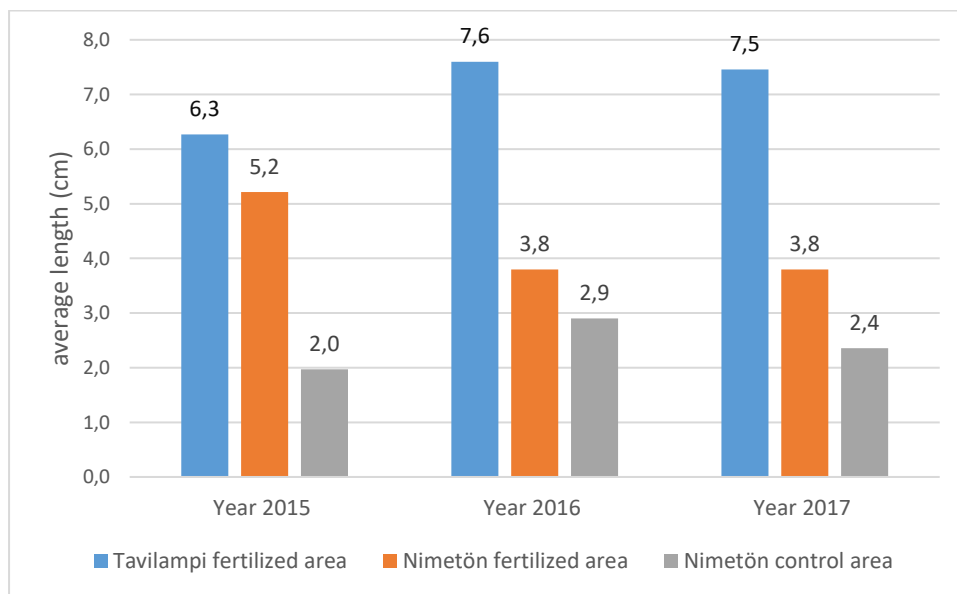


Figure 16. Average growth of spruce trees for the last 3 years in all studied areas

Length of the measured tree shoots in Tavilampi area for each year was substantially higher than in both Nimetön areas, which could be possibly explained partly by better light conditions.

5.3.2 Spruce needles weighting

As the dry weighting comparison analyses (Appendix 5) were performed separately for each of fertilized areas in different time (end of April and June 2018), the results of the measurements are presented separately and were not compared with each other.

Although the gap between mean values of Nimetön fertilized and Nimetön control sites was only 29%, according to the data, obtained after the ANOVA analyses (Table 4), the differences between needles in tested sites can be stated as significant, with the prevalence of weight in fertilized area.

Table 4. ANOVA results for Nimetön fertilized and non-fertilized area

Groups	Number of sampled trees	Average weight (g)	F	F statistical
Nimetön fertilized area	7	0.114	13.116	4.747
Nimetön control area	7	0.081		

The average results for fertilized areas were compared with the results published by Pihlström et al. (2000), including 1997 year as a “control year” without fertilization (Table 5).

Table 5. Comparison between short-term and long-term results for dry weight of needles

year	Tavilampi fertilized area (g)	Nimetön fertilized area (g)
1997	0.201	0.167
1998	0.163	0.183
1999	0.121	0.118
2018	0.31	0.114

Although in Tavilampi fertilized area the weight of needles did not increase during the short-term analyses, the average long-term result exceeds the initial value by 54%, and the latest short-term result after fertilization by 61%.

The weight of needles in Nimetön fertilized did not increase during the short-term period, and even decreased more during the gap between the experiments (1998-2018 years). The latest short-term result for Nimetön fertilized area differs with long-term average value only by 3.4%.

6 DISCUSSION AND POSSIBLE RECOMMENDATIONS

6.1 Structural changes

According to the obtained results, during the long-term period of accumulation of wood ash, significant changes in the soil structure of fertilized sites were not revealed.

The prevalence of water containment in overall physical structure in Tavilampi catchment soil samples may be explained by location of the studied areas, as Tavilampi peatland catchment is quite close to the lake water surface, whereas both Nimetön tested areas are located separately from the Nimetön lake itself.

Moreover, none of the bulk density values tend to restrict root growth, as the soil with prevalence of organic matter in structure normally will have a bulk density less than 1.0 g/cm^3 (Hossain et al. 2015).

6.2 Chemical changes

The gained chemical results show that even after the long-term period, soil plots, containing applied wood ash, remained less acidic and less salted, which approves the initial hypothesis about existence long-term chemical effects of the wood ash fertilization. The exceeding of pH level in fertilized areas in comparison with non-fertilized can also be a confirmation of the theory of the long-term neutralization of acidic nature of peat soil, made by Saarsalmi et al. (2001).

Even though soil pH level in the fertilized areas 20 years after the adding wood ash remained higher than in the non-fertilized area, the average value for pH is already in acidic range (less than 5), and, as it was already stated, in control and fertilized areas the pH level is clearly regressed. This trend can be explained by the long-term natural changes in the soil environment, as well as by the overall significant increase in the seasonal temperatures of the last 40 years (Tietäväinen et al. 2010), which possibly influenced the acidity and lowered the pH level.

Another explanation of the pH regression could be the increase in forest density for the last 20 years, which caused needle fall that covered the soil surface and increasing fulvic acids in the peat.

The decrease in pH level can influence the extraction and further leaching of heavy metals in fertilized soil (Sun et al. 2001). For example, at low pH values appears the risk of growth of aluminum level, which may be toxic to the soil environment in high amounts, as well as increase in bioavailability and mobility of cadmium (Pasanen et al. 2001). Trace elements from wood ash also can be released to the soil in fertilized areas due to low pH level.

Therefore, it could be highly recommended to study the possible heavy metal accumulation in biota in the future (Huotari et al. 2015).

Due to existing possibility of accumulation of heavy metals residues from applied wood ash, could be recommended to use hard granular ash, which normally contains less heavy metals, instead of a self-granulated ash that was used in the fertilization.

It is also could be effective to apply wood ash together with lime to decrease acidification of soil (Meiwes 1995). The application of lime is highly recommended for the environments characterized with a high risk of acid toxicity, which is quite approaching to the studied areas due to decreasing pH level.

6.3 Tree growth changes

Based on the examined long-term differences in growth of Norway spruce species and needle weight between control and fertilized plots, it can be concluded that amount of nutrients, which clearly increased after the ash application, is still enough to keep balance in fertilized soil for sustainable development of trees.

Average values for tree shoot growth clearly approve the suggestion about the improvement in vegetation due to ash application and suitability of wood ash for that purpose, which approves the hypothesis made by Hytönen (2003), which proposed the possibility of increase in the nutrient level after long-term period of the fertilization, despite the fact that this research was completed only 10 years after the application of wood ash.

Needle weight analyses results also proved that nutrient status in the fertilized areas remained good, although the differences between areas with similar environments could be not that obvious.

Based on analyses of environmentally similar control area and fertilized Nimetön area, it could be stated that vegetation is also dependent on the light conditions. Recovering poor light conditions by additional silvicultural measures could increase growth of trees and may be affected due to its poorness. Therefore, it could be recommended to apply some additional events to prevent losses of light.

7 CONCLUSION

After almost 20 years after the wood ash application, the changes in the fertilized environment remained quite visible, especially when comparing of chemical characteristics of the studied fertilized and non-fertilized soil areas, as well as tree growth.

Ash fertilization positively affected the vegetation conditions, raised the amount of nutrients and pH level of soil. However, re-acidification of peat soil was also

observed, which indicates that mobility of some elements of wood ash, such as harmful cadmium, may have increased.

In overall, studied results prove the hypothesis of the existence of long-term effects of wood ash application. Thus, wood ash fertilization could be useful practice in forestry and peatland conservation activities.

REFERENCES

Arvidsson, H. and Lundkvist, H., 2003. Effects of crushed wood ash on soil chemistry in young Norway spruce stands. *Forest Ecology and Management* [online] 176, 121-132. PDF document. Available at:

<https://www.sciencedirect.com/science/article/pii/S0378112702002785>

[Accessed 14 March 2018].

Baden, W. 1972. The types of peat deposits used in present-day agriculture and the methods of their utilization. In *The Proceedings of the 4th International Peat Congress Volume 3*. Otaniemi, Finland, 7-21.

Brouwer, C., Goffeau, A. and Heibloem, M., 1985. *Irrigation Water Management: Training Manual No. 1-Introduction to Irrigation*. Food and Agriculture Organization of the United Nations, Rome, Italy. HTML document. Available at:

<http://www.fao.org/docrep/r4082e/r4082e00.htm#Contents> [Accessed 3 April

2018].

Demeyer, A., Nkana, J.V. and Verloo, M.G., 2001. Characteristics of wood ash and influence on soil properties and nutrient uptake: an overview. *Bioresource technology* [online] 77, 287-295. PDF document. Available at:

<https://www.sciencedirect.com/science/article/pii/S0960852400000432>

[Accessed 14 March 2018].

Grisso, R.D., Alley, M.M., Holshouser, D.L. and Thomason, W.E., 2005. Precision Farming Tools. Soil Electrical Conductivity. Virginia cooperative extension [online] 442-508. PDF document. Available at:

<https://pdfs.semanticscholar.org/e88b/d71059c64b1dac601981c439aa97089>

[93abf.pdf](#) [Accessed 17 May 2018].

Hytönen, J. 2003. Effects of wood, peat and coal ash fertilization on Scots pine foliar nutrient concentrations and growth on afforested former agricultural peat

soils. Silva Fennica 37, 219–234. PDF document. Available at:

<http://jukuri.luke.fi/bitstream/handle/10024/532559/wood.pdf?sequence=1>

[Accessed 17 May 2018].

Jentschke, G., Drexhage, M., Fritz, H.W., Fritz, E., Schella, B., Lee, D.H., Gruber, F., Heimann, J., Kuhr, M., Schmidt, J. and Schmidt, S., 2001. Does soil acidity reduce subsoil rooting in Norway spruce (*Picea abies*). Plant and Soil 237, 91-108. PDF document. Available at:

<https://link.springer.com/content/pdf/10.1023%2FA%3A1013305712465.pdf>

[Accessed 17 April 2018].

Joosten, H. and Clarke, D., 2002. Wise use of mires and peatlands. International Mire Conservation Group and International Peat Society 304. PDF document.

Available at: <http://www.gret->

[perg.ulaval.ca/fileadmin/fichiers/fichiersGRET/pdf/Doc_generale/WUMP Wise Use of Mires and Peatlands book.pdf](http://www.gret-perg.ulaval.ca/fileadmin/fichiers/fichiersGRET/pdf/Doc_generale/WUMP_Wise_Use_of_Mires_and_Peatlands_book.pdf) [Accessed 22 March 2018].

Hämeen ammattikorkeakoulu (HAMK), 2005. Evo Forest - Awareness-raising and Protection of Southern Finland Forest Biotopes 1.5.2002–30.9.2005. PDF

document. Available at: <http://www3.hamk.fi/Evo->

[Life/pdf_tiedostot/Evo Life eng.pdf](http://www3.hamk.fi/Evo-Life/pdf_tiedostot/Evo_Life_eng.pdf) [Accessed 10 April 2018].

Hossain, M.F., Chen, W. and Zhang, Y., 2015. Bulk density of mineral and organic soils in the Canada's arctic and sub-arctic. Information processing in agriculture 2, 183-190. HTML document. Available at:

<https://www.sciencedirect.com/science/article/pii/S2214317315300093>

[Accessed 12 June 2018].

Kao, L.S. and Green, C.E., 2008. Analysis of variance: is there a difference in means and what does it mean? Journal of Surgical Research, 144(1), pp.158-170. PDF document. Available at:

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2405942/pdf/nihms46206.pdf>

[Accessed 3 October 2018].

Kepanen, A., Lodenius, M., Tulisalo, E. and Hartikainen, H., 2005. Effects of different wood ashes on the solubility of cadmium in two boreal forest soils. *Boreal environment research* [online] 10, 135-143. PDF document. Available at: <http://www.borenv.net/BER/pdfs/ber10/ber10-135.pdf> [Accessed 28 February 2018].

Kivinen, E. 1982. Introduction. In *Peatlands and their utilization in Finland*, Finnish peatland society, Finnish national committee of the international peat society. Espoo: Suomen Graafinen Group Oy, 7-8.

Kurki, M. Main chemical characteristics of peat soils. In *Peatlands and their utilization in Finland*, Finnish peatland society, Finnish national committee of the international peat society. Espoo: Suomen Graafinen Group Oy, 37-41.

Meiwes, K.J. 1995. Application of lime and wood ash to decrease acidification of forest soils. *Water, Air and Soil Pollution* 85, 143-152.

Ministry of Agriculture and Forestry, 2013. Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011, amendments up to 7/2013 included). PDF document. Available at: https://mmm.fi/documents/1410837/2061117/MMMa_24_2011_lannoitevalmistasetus_EN.pdf/c49d5007-0b00-431e-b5ca-53ecdf236c3a/MMMa_24_2011_lannoitevalmistasetus_EN.pdf.pdf [Accessed 19 October 2018].

Minkkinen, K. and Laine, J., 1998. Effect of forest drainage on the peat bulk density of pine mires in Finland. *Canadian Journal of Forest Research* 28, 178-186. PDF document. Available at: <http://www.nrcresearchpress.com/doi/pdf/10.1139/x97-206> [Accessed 26 March 2018].

Muukkonen, P. and Lehtonen, A., 2004. Needle and branch biomass turnover rates of Norway spruce (*Picea abies*). *Canadian Journal of Forest Research* 34, 2517-2527. PDF document. Available at:

<http://www.nrcresearchpress.com/doi/pdf/10.1139/x04-133> [Accessed 24 May 2018].

Nieminen, M., Piirainen, S. and Moilanen, M., 2007. Release of mineral nutrients and heavy metals from wood and peat ash fertilizers: Field studies in Finnish forest soils. *Scandinavian Journal of Forest Research* [online] 20, 146-153. PDF document. Available at:

<https://www.tandfonline.com/doi/pdf/10.1080/02827580510008293?needAccess=true> [Accessed 14 March 2018].

Nilsson, T and Lundin, L. 1996. Effects of drainage and wood ash fertilization on water chemistry at a cutover peatland. *Hydrobiologia* 335, 3-18.

Nurmesniemi, H., Mankinen, K., Pöykiö, R. and Dahl, O., 2012. Forest fertilizer properties of the bottom ash and fly ash from a large-sized (115 MW) industrial power plant incinerating wood-based biomass residues. *Journal of the University of Chemical Technology & Metallurgy* 47, 43-52. PDF document. Available at:

http://dl.uctm.edu/journal/node/j2012-1/4-Finland_43-52.pdf [Accessed 14 March 2018].

Pasanen, J., Louekari, K. and Malm, J., 2001. Cadmium in wood ash used as fertilizer in forestry. Helsinki: Ministry of Agriculture and Forestry Publications 5/2001.

Pihlström, M., Rummukainen, P., Mäkinen A. 2000. Tuhkalannoitusprojektin kasvillisuus- ja maaperätutkimukset Evolla 1997-1999. *Metsätehon raportti* 89.

Pitman, R.M. 2006a. Wood ash use in forestry – a review of the environmental impacts. *Forestry: An International Journal of Forest Research* 79, 563-588.

HTML document. Available at: <https://academic.oup.com/forestry/article-abstract/79/5/563/558716> [Accessed 14 March 2018].

Pitman, R.M. 2006b. Wood ash use in forestry—a review of the environmental impacts. PDF document. Available at:

[https://forums.forestry.gov.uk/pdf/Use_of_ash_in_forestry.pdf/\\$FILE/Use_of_ash_in_forestry.pdf](https://forums.forestry.gov.uk/pdf/Use_of_ash_in_forestry.pdf/$FILE/Use_of_ash_in_forestry.pdf) [Accessed 26 March 2018].

Pyavchenko, N.I. 1979. On types of peat and their diagnostics. In Kivinen E., Heikurainen L. and Pakarinen, P. (eds) Classification of peat and peatlands Proceedings of the International Symposium held in Hyytiälä, Finland, September 17-21, 1979. Helsinki: International Peat Society, 190-193.

Rask, M., Arvola, L., Salonen, K. and Ruuhijärvi, J. 1992. Limnological studies on the lakes in Evo area - a historical perspective. *Aqua Fennica* 22, 185-192.

Rautjärvi, H., Kaunisto, S. & Tolonen T. 2004. The effect of repeated fertilizations on volume growth and needle nutrient concentrations of Scots pine (*Pinus sylvestris* L.) on a drained pine mire. *SUO (Mires and peat)* 55, 21-32.

Ring, E., Nohrstedt, H.O., Jansson, G. and Loevgren, L., 1999. Ash fertilization in a clear cut and in a Scots pine stand in central Sweden. Effects on soil-water and soil chemistry coupled to laboratory leachings of six ash products (No. SKOGFORSK-R--2-1999). Forestry Research Institute of Sweden.

Ruuhijärvi, R. 1972. Multiple-use of Peatlands in Finland with Special Reference to Their Conservation. In The Proceedings of the 4th International Peat Congress Volume 1. Otaniemi, Finland, 191-202.

Saarela, K.E., Harju, L., Lill, J.O., Heselius, S.J., Rajander, J. and Lindroos, A. 2005. Quantitative elemental analysis of dry-ashed bark and wood samples of birch, spruce and pine from south-western Finland using PIXE. PDF document. Available at: <http://www.doria.fi/bitstream/handle/10024/36055/SaarelaKE.pdf> [Accessed 22 March 2018].

Saarsalmi, A., Mälkönen, E. & Piirainen, S. 2001. Effects of wood ash fertilization on forest soil chemical properties. *Silva Fennica* 35: 355–368. PDF document.

Available at:

<http://jukuri.luke.fi/bitstream/handle/10024/532535/AnnaS.pdf?sequence=1>

[Accessed 22 May 2018].

Sands, G. 2001. Soil water concepts. *Environmental Science and Technology* 24. PDF document. Available at:

<https://www.extension.umn.edu/agriculture/water/science/soil-water-concepts/docs/soil-water-concepts.pdf> [Accessed 22 March 2018].

Silfverberg, K. 1996. Nutrient status and development of tree stands and vegetation on ash-fertilized drained peatlands in Finland, D.Sc.thesis. University of Helsinki, Faculty of Science. The Finnish Forest Research Institute, Research Papers 558.

Sun, B., Zhao, F.J., Lombi, E. and McGrath, S.P. 2001. Leaching of heavy metals from contaminated soils using EDTA. *Environmental pollution* 113, 111-120. PDF document. Available at: [https://doi.org/10.1016/S0269-7491\(00\)00176-7](https://doi.org/10.1016/S0269-7491(00)00176-7)

[Accessed 11 June 2018].

Tietäväinen, H., Tuomenvirta, H. and Venäläinen, A., 2010. Annual and seasonal mean temperatures in Finland during the last 160 years based on gridded temperature data. *International Journal of Climatology* 30, 2247-2256. PDF document. Available at:

<https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/joc.2046> [Accessed 26 June 2018].

Tulonen, T., Arvola, L. and Ollila, S. 2002. Limnological effects of wood ash application to the subcatchments of boreal, humic lakes. *Journal of environmental quality*, 31, 946-953. PDF document. Available at:

<https://dl.sciencesocieties.org/publications/jeq/articles/31/3/946> [Accessed 28 February 2018].

Tulonen, T., Arvola, L., Pihlström, M. and Rask, M. 2005. Chemical and biological response in small humic lakes after catchment treatment with wood ash. *Verhandlungen des Internationalen Verein Limnologie* 29, 531-534.

Turunen, J., 2008. Development of Finnish peatland area and carbon storage 1950-2000. *Boreal environment research* 13. PDF document. Available at: <http://www.borenv.net/BER/pdfs/ber13/ber13-319.pdf> [Accessed 16 April 2018].

Urvas, L., Sillanpää, M. and Ervio, R., 1979. The chemical properties of major peat types in Finland. In Kivinen E., Heikurainen L. and Pakarinen, P. (eds) *Classification of peat and peatlands Proceedings of the International Symposium held in Hyytiälä, Finland, September 17-21, 1979*. Helsinki: International Peat Society, 184-189.

Valmari, A., 1982. In *Peatlands and their utilization in Finland*, Finnish peatland society, Finnish national committee of the international peat society. Espoo: Suomen Graafinen Group Oy, 42-52.

APPENDICES

Appendix 1

Statistical two-tailed t-test for all studied areas water content

	<i>Nimetön fertilized area</i>	<i>Nimetön control area</i>
Mean value	82.67%	79.4%
t Statistical value	2.975	
t Critical two-tail value	3.182	
p value	0.059	p > 0.05

	<i>Tavilampi fertilized area</i>	<i>Nimetön control area</i>
Mean value	89.6%	79.4%
t Stat value	14.304	
t Critical two-tail value	2.776	
p value	0.0001	p < 0.05

	<i>Tavilampi fertilized area</i>	<i>Nimetön fertilized area</i>
Mean value	89.6%	82.67%
t Stat value	6.098	
t Critical two-tail value	3.182	
p value	0.009	p < 0.05

Recordings of the pH measurement results for each studied area

Area	pH
Nimetön fertilized area	4,5
Nimetön fertilized area	4,4
Nimetön fertilized area	4,5
Nimetön fertilized area	4,5
Nimetön fertilized area	4,6
Nimetön fertilized area	4,9
Nimetön fertilized area	4,9
Nimetön fertilized area	4,9
Nimetön fertilized area	5
Nimetön fertilized area	5,1
Nimetön fertilized area	4,5
Nimetön fertilized area	4,5
Nimetön fertilized area	4,7
Nimetön fertilized area	4,8
Nimetön fertilized area	4,8
Nimetön control area	3,7
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	4
Nimetön control area	4
Nimetön control area	4
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	3,9
Nimetön control area	4
Tavilampi fertilized area	4,5
Tavilampi fertilized area	5
Tavilampi fertilized area	5,3
Tavilampi fertilized area	5,6

Tavilampi fertilized area	5,5
Tavilampi fertilized area	4,5
Tavilampi fertilized area	4,4
Tavilampi fertilized area	4,5
Tavilampi fertilized area	4,6
Tavilampi fertilized area	4,7
Tavilampi fertilized area	4,3
Tavilampi fertilized area	4,6
Tavilampi fertilized area	4,5
Tavilampi fertilized area	4,4
Tavilampi fertilized area	4,3

Recordings of the conductivity measurement results for each studied area

Area	conductivity ($\mu\text{S/cm}$)
Nimetön fertilized area	34,1
Nimetön fertilized area	30,9
Nimetön fertilized area	23,7
Nimetön fertilized area	26,93
Nimetön fertilized area	24,1
Nimetön fertilized area	23,74
Nimetön fertilized area	21,84
Nimetön fertilized area	22,3
Nimetön fertilized area	21,42
Nimetön fertilized area	20,81
Nimetön fertilized area	30,5
Nimetön fertilized area	25,35
Nimetön fertilized area	24,27
Nimetön fertilized area	20,28
Nimetön fertilized area	39,7
Nimetön control area	57
Nimetön control area	36,96
Nimetön control area	39,65
Nimetön control area	37,92
Nimetön control area	27,09
Nimetön control area	35,58
Nimetön control area	35,03
Nimetön control area	36,6
Nimetön control area	30,8
Nimetön control area	47,9
Nimetön control area	37,47
Nimetön control area	37,98
Nimetön control area	39,26
Nimetön control area	37,57
Nimetön control area	42,4
Tavilampi fertilized area	25,6
Tavilampi fertilized area	15,31
Tavilampi fertilized area	17,04
Tavilampi fertilized area	17,21
Tavilampi fertilized area	21,6
Tavilampi fertilized area	23,8
Tavilampi fertilized area	20,5
Tavilampi fertilized area	18,05

Tavilampi fertilized area	15,2
Tavilampi fertilized area	19,66
Tavilampi fertilized area	35,5
Tavilampi fertilized area	16,7
Tavilampi fertilized area	17,03
Tavilampi fertilized area	25,6
Tavilampi fertilized area	28,48

Statistical two-tailed t-test for all studied areas conductivity values

	<i>Nimetön control area</i>	<i>Nimetön fertilized area</i>
Mean value ($\mu\text{S/cm}$)	38.614	25.996
t Stat	5.529	
t Critical two-tail	2.052	
p value	0.00000737	p < 0.05

	<i>Tavilampi fertilized area</i>	<i>Nimetön control area</i>
Mean value ($\mu\text{S/cm}$)	21.152	38.614
t Stat	7.549	
t Critical two-tail	2.052	
p value	0.00000004	p < 0.05

Recordings of the needle weighting for all studied areas

area	wet weight (g)	dry weight (g)	month of collection
Tavilampi fertilized area	0,7	0,33	April
Tavilampi fertilized area	0,56	0,25	April
Tavilampi fertilized area	0,97	0,47	April
Tavilampi fertilized area	0,71	0,33	April
Tavilampi fertilized area	0,53	0,27	April
Tavilampi fertilized area	0,63	0,29	April
Tavilampi fertilized area	0,44	0,21	April
Nimetön control area	0,21	0,09	April
Nimetön control area	0,17	0,08	April
Nimetön control area	0,27	0,11	April
Nimetön control area	0,28	0,12	April
Nimetön control area	0,23	0,10	April
Nimetön control area	0,37	0,16	April
Nimetön control area	0,66	0,28	April
Nimetön fertilized area	0,29	0,14	June
Nimetön fertilized area	0,23	0,12	June
Nimetön fertilized area	0,25	0,12	June
Nimetön fertilized area	0,24	0,1	June
Nimetön fertilized area	0,27	0,12	June
Nimetön fertilized area	0,34	0,09	June
Nimetön fertilized area	0,24	0,11	June
Nimetön control area	0,23	0,1	June
Nimetön control area	0,15	0,07	June
Nimetön control area	0,22	0,08	June
Nimetön control area	0,19	0,08	June
Nimetön control area	0,15	0,06	June
Nimetön control area	0,27	0,11	June
Nimetön control area	0,18	0,07	June