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The effect of total peat nitrogen on the height and volume of Scots pine (*Pinus sylvestris* L.) stands in three fertilized and drained peatlands in northern Finland

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The total peat nitrogen (N) concentration is an important factor when determining stand heights and volumes in areas of poor climate conditions. This study explores the effect of peat nitrogen on the height and volume of Scots pine (*Pinus sylvestris* L.) stands in drained peatland sites in three temperature sum regions (Susivaara 909, Hepokangas 930, and Haapua 987 dd) in northern Finland. The peat nitrogen concentration ranged from 0.7% to 3.0%. In all experimental fields, the concentrations of foliar nutrients (nitrogen (N), potassium (K), phosphorus (P), and boron (B)) were analyzed. A total of 550 peat samples, 440 foliar samples, and 1687 sample trees were measured. We found nitrogen deficiencies in the foliar samples of all experimental fields. At Haapua, the stands were the highest, about 140 dm, when the peat N-concentration was at its maximum (3.0%). In the areas of Susivaara and Hepokangas, the stand heights were lower than in Haapua, about 90 dm, when N-concentrations of peat were at their maximum (2.5% and 2.8%). The stand volumes were largest at Haapua (about 190 m^3/ha, N = 3.0%). At Susivaara (80 m^3/ha, N = 2.5%) and Hepokangas (70 m^3/ha, N = 2.8%), lower stand volumes were measured. We found a strong positive relationship between peat N-concentration and stand height as well as stand volume at Hepokangas and Haapua. At Susivaara, however, this relationship was weak. The results show that the total peat nitrogen concentration strongly affects stand height and volume on drained peatlands. The information of this study can be utilized, for example, when assessing the feasibility of forest management practices, such as the profitability of ditch network maintenance and fertilizations on peatlands.

Key words: Drainage, foliar nutrient, peat nitrogen, Scots pine, stands height, stand volume.

Introduction

Drainage is a prerequisite for forest growth on peatlands (Huikari 1952, Heikurainen 1959). The wood production potential of drained peatland is determined by its site type (Huikari 1952, Heikurainen 1959) and by the regional climatic conditions (Heikurainen 1959, Kuusela 1977, Keltikangas et al. 1986, Ritari & Nivala 1993). Within the same peatland site type, tree growth decreases with a decreasing temperature sum (Keltikangas et al. 1986, Sundström et al. 2000). In fertilized stands, tree growth and the additional increment, which are due to fertilization, also decrease in conjunction with a decreasing temperature sum (Heikurainen et al. 1983, Heikurainen & Laine 1985, Sundstöm 1995).

There is a close connection between the total peat nitrogen (N) concentration and total stand growth on drained peatlands (Kaunisto 1982, 1987, Kaunisto & Paavilainen 1988, Kaunisto & Pietiläinen 2003). The wood production potential of a site type can be estimated with reference to the total peat nitrogen concentration (Pietiläinen & Kaunisto 2003). Kaunisto & Norlamo (1976) showed that nitrogen mineralization decreases with decreasing soil temperature. Considering site type productivity, Sundström (1995) suggested that tree growth is limited when the temperature sum lies below 950 d.d., which is due to an inadequate microbial release of organically bound nitrogen. Pietiläinen et al. (2005a) showed that humification decreases with a decreasing soil temperature sum, indicating slower nutrient cycling.

In the peat of fertile sites, where a low C/N-ratio exists, nitrogen is – compared to other nutrients – abundantly available for trees. In the peat areas, drained in 1960s, the nitrogen concentration was 20–30 times higher than the phosphorous concentration. However, in the needles, the nitrogen concentration was only 7–10 times higher than the phosphorous concentration (Kaunisto & Paavilainen 1988). Both phosphorus and nitrogen are organically bound in peat, and nitrogen is mineralized through the microbial degradation of the peat 20–30 times faster than phosphorous (Kaunisto & Paavilainen 1988). Humification can result in high nitrogen and low phosphorus concentrations in peat and cause phosphorus deficiencies in trees. Phosphorus deficiency as well as potassium and boron deficiencies are encountered in drained peatland stands and may limit stand growth.

As a consequence of mineral nutrient deficiencies, the nitrogen metabolism does not function normally. In addition, excess nitrogen is stored into arginine, which increases the nitrogen concentration in needles when tree growth has decreased (Pietiläinen & Lähdesmäki 1986, Kaunisto & Pietiläinen 2003). When the trees get phosphorus, potassium, or boron, for example, through PKB-fertilizers, the nitrogen concentration in the needles decreases. With the increasing nutrient concentration the metabolism is regained and the arginine stores are utilized in the accelerating growth (Kaunisto & Pietiläinen 2003). On poor sites, however, where high C/N-ratios exist, PKB-fertilizers do not increase tree growth, since the nitrogen mineralization is slow and since a continuous nitrogen deficiency limits tree growth (Kaunisto 1987).

Nitrogen is one of the main nutrients and its deficiency symptoms in Scots pine growing on peatlands are very typical (Reinikainen et al. 1998). The nitrogen provided by fertilization is rapidly bound in the microbes (Kaunisto and Norlamo 1976, Kaunisto 1987). Scots pine is adapted to grow on soils with low nitrogen concentrations. In some cases, the soil nitrogen concentration is so high that there is a surplus of nitrogen and, thus, nitrogen fertilizations are not recommended in such Scots pine stands (Kaunisto & Paavilainen 1977, Kaunisto 1987). Already after a small amount of nitrogen fertilization, the needles can become brown and necrotic during the following winter. High nitrogen concentration, either natural (Kaunisto & Pietiläinen 2003) or caused by deposition (Ferm et al. 1990) or fertilization (Kaunisto 1987), can partially account for a decrease in cold resistance (Aronsson 1980).

High nitrogen concentrations in Scots pine needles can be reduced with PK-fertilizations (Paarlahti et al. 1971, Pietiläinen & Lähdesmäki 1986, Kaunisto & Pietiläinen 2003). The significance of nitrogen for tree growth is manifold. An abundance of nitrogen signifies high biomass productivity. However, excessive amounts of nitrogen can also cause physiological problems resulting into growth losses as the trees suffer from P and K and B deficiencies (Kaunisto & Pietiläinen 2003).

On sites with high nitrogen availability, mere PK-fertilization improves tree growth (Paavilainen 1979, Kaunisto 1982, Moilanen 1993, Pietiläinen et al. 2005b). On sites with low nitrogen availability, however, fertilization increases tree growth only slightly and for a short period of time (Moilanen & Issakainen 1990, Moilanen 1993, Pietiläinen et al. 2005b). Nonetheless, peats with low nitrogen concentration use their available nitrogen more intensively than those with high nitrogen concentration (Hobbie 1992).

Kaunisto & Pietiläinen (2003) studied the effect of the total peat nitrogen concentration on the growth of Scots pine in a temperature sum region of 1080 d.d. However, their study did not cover lower temperature sum regions. In low sedge fens and Sphagnum bogs, shortage of nitrogen becomes a growth-limiting factor, just as in higher temperature sum regions (Sundström 1995, Pietiläinen & Kaunisto 2003). Kaunisto & Pietiläinen (2003) showed that in high temperature sum regions, i.e. in those over 1000 d.d., PK-fertilization significantly increased tree growth, but only, if the peat nitrogen concentration was sufficient (N = at least 1.5%). This shows that nitrogen availability is essential for tree growth on peat. According to Aarnio et al. (1997), nitrogen fertilization is not profitable in stands growing on poor site types where the nitrogen concentration in the substrate is low. Thus, it might be reasonable to utilize only sites with naturally high nitrogen concentrations in practical peatland forestry.

An increasing elevation has a negative effect on temperature conditions and tree growth (Kuusela 1977, Ritari & Nivala 1993, Korkalainen & Laurén 2006). The mean annual temperature decreases and precipitation increases with higher elevations (Solantie 1990, Drebs et al. 2002).

The aim of this study is to examine the effect of the total peat nitrogen concentration on the height and volume of Scots pine stands growing on drained peatland sites in northern boreal conditions. We hypothesize that the amount of nitrogen in the peat is clearly in a positive correlation to the stand productions, which could be further use in more adequate allocation of forest management operations in practical forestry.

Study area

The study area includes three experimental fields in the municipalities of Posio (Susivaara), Taivalkoski (Hepokangas) and Pudasjärvi (Haapua) located at the three temperature sum regions of 909, 930, and 987 dd. in northern Finland. Each of the three experimental fields is underlain by granodiorites and gneisses of Archean basement complexes (Simonen 1960). The bedrock is covered with silt and clay sediments. The low permeability of the soil and the generally cool humid climate has induced peat growth on the gently inclining slopes within the study areas. The peat layer is over 0.3 m thick. General information as well as the site locations and their elevations are shown in Fig. 1 and Table 1 respectively.

The original site types ranged from low sedge bogs (with Sphagnum fuscum hummocks) to herb-rich fens (Huikari 1952). They were drained in the middle of the 1950s, 1960s, 1970s, and 1990s (Table 1). The main tree species was Scots pine, but also Norway spruce and pubescent birch occurred as understorey, particularly in most fertile sites. All of the stands regenerated naturally and only young stand thinning was completed in all experimental fields.

In all three experimental fields, basic fertilization was carried out with PK-fertilizers from an airplane: at Haapua in 1968, at Hepokangas in 1963, and at Susivaara in 1970. Refertilizations were carried out, for research purposes, in the form of broadcast fertilizations: at Haapua in 1978, and at Hepokangas and Susivaara in 1974. The experimental plots (strip width × 30 m to 50 m) did not have any buffer zones between the fertilization treatments. Subplots (20 m × 20 m) were established within the experimental plots. The fertilations, fertilizers, and their total amounts are shown in Table 1.

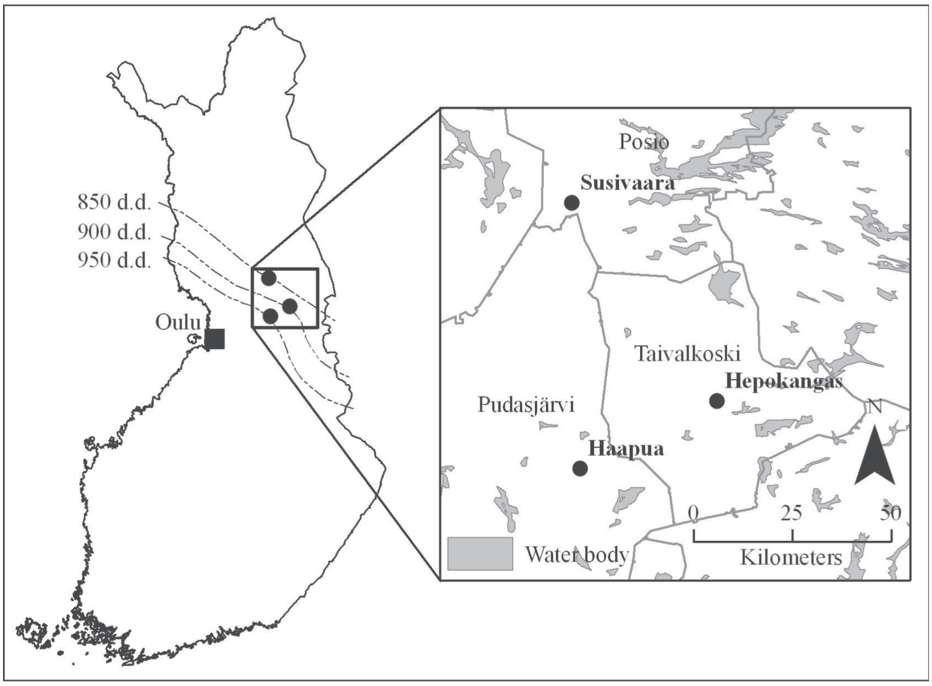

Fig. 1. Location of the experimental fields in northern Finland.

Kuva 1. Koekenttien sijainti Pohjois-Suomessa.

Table 1. Basic information on the research fields. In all areas, site types range from low sedge bogs to herb-rich fens.

Taulukko 1. Koekenttien perustiedot. Alkuperäiset kasvupaikkatyypit vaihtelevat niukkaravinteisesta lyhytkorsirämeestä ravinteikkaaseen ruohoiseen nevaan.

Experiment	Long term temp. sum[1)]	Measured temp. sum[1)]	Peat thickness, m	Drainage year	Ditch spacing, m	Basic fertilization[2)]	Re-fertilization[3)]
Haapua 65° 23' N; 27° 40' E 190 m a.s.l.	950	987	0.3–1.2	1965 1995	90 45	1968 PK_5	1978 0, PK_5
Susivaara 65° 59' N; 27° 38' E 290 m a.s.l.	850	909	0.3–1.0	1955 1969	50 25–30	1970 PK_5	1974 0, PK_2, PK_4+K_2
Hepokangas 65° 32' N; 28° 25' E 240 m a.s.l.	900	930	>1.0	1962 1972	90 45	1963 P+K	1974 0, PK_2, PK_4+K_2

1) Threshold value + 5 °C. Long term d.d. according to (Ritari & Nivala 1993). Measured d.d. average values from 2000–2005.
2) PK_5 = 500 kg ha^{-1} of PK fertilizer (P 52 kg and K 63 kg ha^{-1}), P+K (P 86 kg + K 100 kg ha^{-1}).
3) 0 = Basic fertilization. $PK_{2\ and\ 5}$ = 200 kg and 500 kg ha^{-1} of PK fertilizer (P 18 kg and 45 kg and K 33 kg and 78 kg ha^{-1} respectively). PK_4+K_2 = 400 kg ha^{-1} of PK fertilizer + 200 kg ha^{-1} of KCl (P 36 kg and K 66 kg ha^{-1} + K 100 kg ha^{-1}).
In 2) and 3) Phosphorus given as rock phosphate and potassium as potassium chloride.

Material and methods

All sample trees were measured and all foliar and peat samples were collected within the subplots. In September 1999 (Haapua and Hepokangas) and in 2003 (Susivaara), five peat core samples per subplot were taken from the even soil surface; altogether 550 samples. The sample plots within each experimental field covered a wide and relatively even total peat nitrogen concentration gradient, determined by vegetation and peat samples. The living vegetation and non-decomposed plant material at the top of the peat cores were discarded. Then, the 0–5 cm and 5–10 cm surface layers were separated, put into plastic bags, and stored at –21 °C to await the analyses of their nutrient concentrations. For this purpose, the 0–5 cm and 5–10 cm cores were halved, and the halves of the two layers were combined and mixed to obtain peat samples of the 0–10 cm surface layer. These samples were then dried at 70 °C for 48 hours.

At Haapua and Hepokangas, the foliar sampling was done in 2000 and at Susivaara in 2004. The foliar samples were taken from the top third of the crowns of four trees per subplot. A total of 440 sample trees were chosen for the study. From each plot, four branches with their current needles were put into separate paper bags and stored at –21 ºC, until their nutrients were analysed. The analyses were made from a combined sample of the needles. After dry combustion and dissolving in hydrochloric acid, the potassium concentrations were verified by means of an atomic absorption spectrophotometer (Hitachi 100-40). The phosphorus and boron concentrations were determined spectrophotometrically. Both foliar and peat nitrogen concentrations were determined with the Kjeldahl method (Halonen et al. 1983).

The mean nutrient concentrations in the Scots pine needles are presented in Table 2. The foliar N-, K-, and B-concentrations were highest at Haapua, and the highest amount of P was at Hepokangas. The lowest N-, P- and K-concentrations were found at Susivaara, and the lowest amount of B-concentration was at Hepokangas.

At Haapua and Hepokangas, the Scots pine stands were measured in the autumn of 1999 and those at Susivaara in the autumn of 2004, each within circular sample plots with a radius of 7 meters. The ages and diameters at breast height ($d^{1.3}$) and the total height of the sample trees were measured, and 5–32 sample trees were selected from each plot to represent the $d_{1.3}$ classes (a total of 1687 sample trees). Their stand volumes were calculated by using the equations described by Heinonen (1994). The average stand heights were calculated with reference to the sample trees.

In 2005, we measured the temperatures of each experimental field at a depth of 7 cm in the peat and at a height of 2 m in the air, using Hobo loggers (Fig. 2). In each experimental field, the air temperature accumulated from the middle of April to the middle of November, and the peat temperature from the middle of May to the end of November. There were only minor differences between the air temperatures of the studied experimental fields. Regarding the peat, however, some differences occur in spring and late autumn. A soil temperature of +10 °C is required for opti-

Table 2. Scots pine foliar nutrients within the experimental fields.
Taulukko 2. Männyn neulasten ravinnepitoisuudet koekentillä.

Experiment		N mg g^{-1}	P mg g^{-1}	K mg g^{-1}	B µg g^{-1}
Haapua	av.	12.80	1.87	4.75	20.97
	SD	0.10	0.26	0.44	6.11
Susivaara	av.	11.80	1.74	4.03	12.74
	SD	0.13	0.23	0.50	8.78
Hepokangas	av.	12.00	1.90	4.60	12.50
	SD	0.09	0.26	0.34	2.03

N = nitrogen concentration, P = phosphorus concentration, K = potassium concentration, B = boron concentration. av = average value, SD = standard deviation.

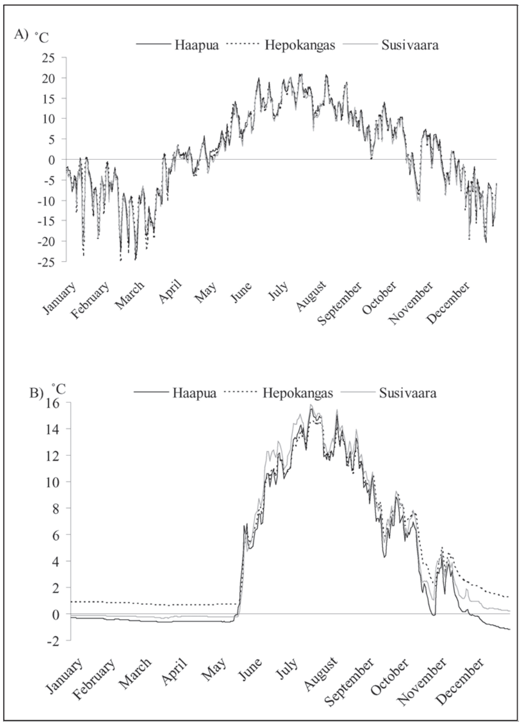

Fig. 2. Air (A) and peat (B) temperatures in 2005 at Haapua, Susivaara, and Hepokangas.

Kuva 2. Ilman (A) ja turpeen (B) lämpötilat vuonna 2005 Haapuan, Susivaaran ja Hepokankaan koekentillä.

mal nitrogen uptake for Scots pine (Pietiläinen & Lähdesmäki 1998). In all experimental fields, this temperature was reached in June.

According to Ritari & Nivala (1993), the long-term temperature sums in the experimental fields were lower than those measured in 2000–2005. The difference at Haapua was 37 d.d., at Susivaara 59 d.d., and at Hepokangas 30 d.d. (Table 1).

Finally, we applied regression analysis to explain the Scots pine stand height and volume as a function of the total peat nitrogen concentration.

Results

The average stand ages, measured from breast height, ranged from 43 years at Haapua to 40 years at Susivaara and 46 years at Hepokangas. The total peat nitrogen concentration ranged from 0.7% to 3.0%. The greatest variation in the range of peat N-concentration occurred at Hepokangas. The results showed that the maximum heights and volumes of the Scots pine stands were in areas where the peat nitrogen concentration was highest.

The highest mean peat nitrogen concentration (1.76%) was measured at Susivaara and the lowest (1.31%) at Hepokangas. However, the highest mean Scots pine stand height (111 dm) and volume (103.5 m^3/ha) was found at Haapua, where the mean nitrogen concentration was 1.57%. The mean values and standard deviations of peat nitrogen, of the Scots pine heights, and of their volumes as well as the stand ages and total stand volumes are shown in Table 3.

Table 3. Peat nitrogen concentration (0–10 cm surface peat) and Scots pine stand height, volume, age, and total stand volumes in the experimental fields.

Taulukko 3. Turpeen typpipitoisuus (0–10 cm kerros) sekä männiköiden pituus, tilavuus ja ikä sekä kokonaispuuston tilavuus koekentillä.

Experiment	n_1	n_2	Peat N (%) mean ± SD	Scots pine H (dm) mean ± SD	Scots pine V (m^3/ha) mean ± SD	Total V (m^3/ha) mean ± SD	Scots pine stand age (years)
Haapua	33	522	1.57 ± 0.44	111±19	103.5 ± 40.0	108.9 ± 44.5	43
Susivaara	40	426	1.76 ± 0.26	90±16	70.3 ± 20.7	78.5 ± 19.5	40
Hepokangas	37	739	1.31 ± 0.54	74±18	39.9 ± 18.2	46.2 ± 26.2	46

n_1 = number of experimental plots, n_2 = number of sample trees, N = nitrogen concentration, H = stand height, V = stand volume, SD = Standard deviation.

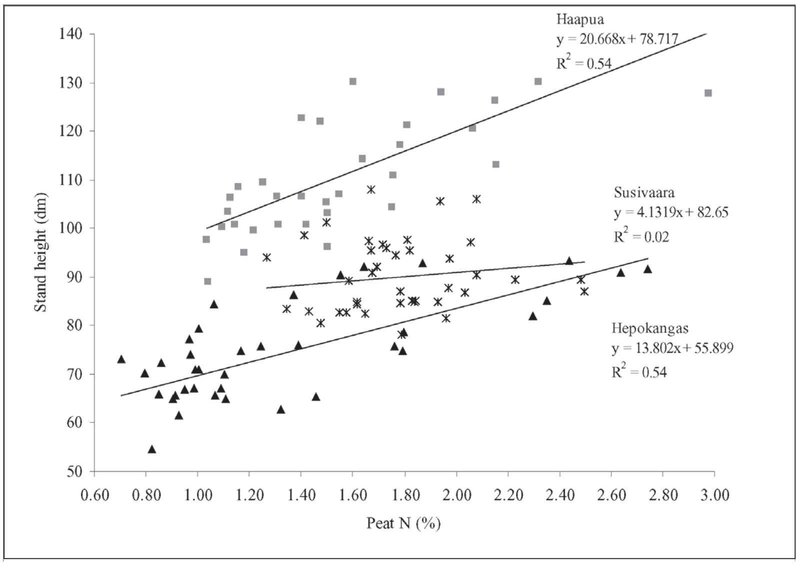

Fig. 3. Relationships between peat nitrogen concentration and average Scots pine stand height by sample plots.

Kuva 3. Turpeen typpipitoisuuden ja männiköiden keskipituuden välinen vuorosuhde kolmella tutkitulla koekentällä.

Scots pine height and peat nitrogen concentration

In all experimental fields, the stand height increased with increasing peat nitrogen concentration (Fig. 3). At Haapua and Hepokangas, the relationship between peat nitrogen and stand height was strongest. At Haapua, the stand was highest (about 140 dm) when the peat nitrogen concentration rose up to 3.0%. The linear relationship between nitrogen concentration and stand height was strong: y = 20.668x + 78.717 (R^2 = 0.54). At Hepokangas, the stand height was about 90 dm when the N concentration was highest (2.8%), and the linear relationship was also strong: y = 13.802x + 55.899 (R^2 = 0.54). At Susivaara, the stand height was also about 90 dm at the highest level of N concentration (2.5%), but there was no linear relationship: y = 4.1319x + 82.65 (R^2 = 0.02).

Scots pine volume and peat nitrogen concentration

The same tendency as in stand heights was observed in the Scots pine stand volumes (Fig. 4). At Haapua and Hepokangas, the relationship between peat nitrogen and stand volume was strongest. At Haapua, the largest stand volumes (about 190 m^3/ha) occurred when the peat nitrogen concentration (3.0%) was at its highest. The linear relationship between the nitrogen concentration and volume was strong: y = 63.086x + 4.5342 (R^2 = 0.47). At Hepokangas, the stand volume was 70 m^3/ha when the N concentration was highest (2.8%), and the linear relationship was also strong: y = 22.503x + 10.514 (R^2 = 0.44). At Susivaara, the stand volume was 80 m^3/ha, when the N concentration was highest (2.5%), but there was no linear relationship: y = 15.845x + 43.776 (R^2 = 0.05).

Discussion and conclusions

Nitrogen, phosphorus, potassium, and boron deficiencies are frequently encountered in drained peatland forest stands (Paavilainen 1979, Kaunisto 1982, Moilanen 1993, Kaunisto & Pietiläinen 2003). In peatlands, the threshold value for foliar nitrogen deficiency is 13.0 mg g^{-1}, for phosphorus 1.4 mg g^{-1}, for potassium 3.5 mg g^{-1} (Paarlahti et al.1971), and for boron 7 ug g^{-1} (Reinikainen et al. 1998). In all three experimental fields, the mean nitrogen concentration was below the deficiency border value. The average foliar phosphorus, potassium, and boron concentrations were above the deficiency level in all three experimental fields (Table 2). Considering the nitrogen concentrations in the needles, it

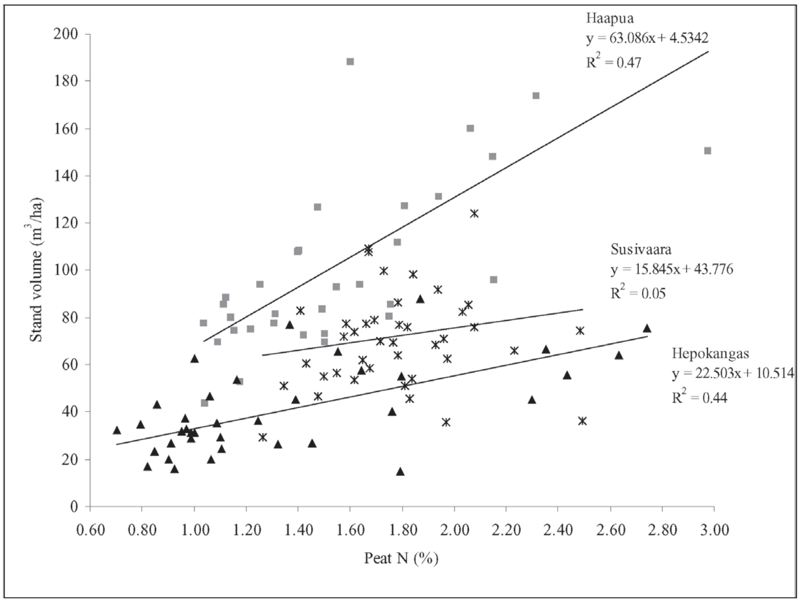

Fig. 4. Relationships between peat nitrogen concentration and average Scots pine stand volume by sample plots.

Kuva 4. Turpeen typpipitoisuuden ja männiköiden tilavuuden välinen vuorosuhde kolmella tutkitulla koekentällä.

would be reasonable to assume that nitrogen affects stand height and volume in different temperature sum regions.

The peat nitrogen concentrations in the study areas were comparable to those of the average values found on drained peatlands in northern Finland (Westman 1981). The study showed that the total peat nitrogen concentration has a strong effect on Scots pine height (Fig. 3) and volume (Fig. 4) as the temperature sum decreases. At Susivaara, where the d.d. was lowest when compared to other experimental fields (Table 1), there was no relationship between the total peat nitrogen concentration and stand height and volume. Kaunisto & Pietiläinen (2003) reported that the peat nitrogen concentration has a significant effect on tree growth in high temperature sum (1080 d.d.) conditions. In our study, the stand height and volume at Haapua and Hepokangas strongly increased with increasing peat nitrogen concentration. At Susivaara, however, they increased only slightly. The results are coherent with those of Sundström et al. (2000), who observed that tree growth was restricted in temperature sum regions below 950 d.d.

The measured air temperatures were higher than the long-term averages presented by Ritari & Nivala (1993) (Table 1). At Haapua, the temperature sum of 950 d.d. was yet adequate for normal stand heights and volumes, which was comparable to the results of Moilanen (1993). At Hepokangas and Susivaara the temperature sums (900 d.d. and 850 d.d.) as well as the stand heights and volumes were lower. However, stand heights and volumes at Susivaara (290 m a.s.l.) were higher when compared to Hepokangas (240 m a.s.l.). At Susivaara, the smaller range of the total peat nitrogen concentration may have affected the slopes of the stand height and volume curves (Figs. 3 and 4). More favorable local climate conditions and the higher nitrogen concentration in the peat may have increased the stand heights and volumes at Susivaara when compared to Hepokangas (Table 3).

The stand ages were nearly the same and only the young stand thinning were included in all experimental fields. Thus, we can assume that these did not explain the differences in the stand heights and volumes of this study.

In previous studies, Huikari (1952) and Heikurainen (1959) showed that the site type, i.e. its fertility, determined the wood production potential of drained peatland. Heikurainen (1959), Kuusela (1977), Keltikangas et al. (1986), and Ritari & Nivala (1993) showed that regional climatic conditions affect the growth of trees on drained peatland. Furthermore, Keltikangas et al. (1986) and Sundström et al. (2000) showed that tree growth within the same peatland site type decreases with a decreasing temperature sum. The findings of this study support the previous results. We found that, especially in the lowest temperature sum (850 d.d.) region (at Susivaara), stand heights and volumes were lower when compared to the region of 950 d.d. (at Haapua). In the lower temperature sum regions, nutritional aspects and the higher elevation of the site substantially affected the Scots pine heights and volumes.

The elevations of the areas of this study (190–290 m a.s.l.) are all at high risk to snow damages (Hyvän metsänhoidon suositukset 2006). The risk is higher in Scots pine stands, because of their asymmetric and broad crowns (Autio & Colpaert 2005). Our study areas included many trees that suffered from snow load damages, and therefore, these trees were not used as sample trees. The snow damages were more frequent in fertile sites where the trees had a branchy crown.

Information considering the relation between peat N-concentration, temperature sum, and stand height and volume is usable, for example, when assessing forest management practices, such as the profitability of ditch network maintenance, fertilizations, and stand regeneration of drained peatlands in low temperature sum regions as well as in sites in higher temperature sum regions that are poor in nitrogen (Moilanen 1993). In general, stand growth decreases with increasing latitudes (Sundström et al. 2000, Korkalainen & Laurén 2006). In future, it would be important to clarify the productivity limits for cost-effective stand growth in peatlands of higher latitudes and lower temperature sum regions.

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Tiivistelmä:

Turpeen typpipitoisuuden vaikutus männyn (*Pinus sylvestris* L.) pituuteen ja tilavuuteen kolmella lannoitetulla ojitusalueella Pohjois-Suomessa

Kasvupaikan puuntuotoskykyyn ojitetuilla turvemailla vaikuttavat kasvupaikan ominaisuuksien lisäksi alueelliset ilmasto-olosuhteet, koska pohjoiseen ja merenpinnan tasoa korkeammalle siirryttäessä lämpösumma laskee ja ravinteiden mineralisaatio turpeessa hidastuu. Typen huono saatavuus rajoittaa karuilla turvemailla männyn kasvua Pohjois-Suomen ilmasto-oloissa, mikä näkyy mm. neulasten alhaisina typpipitoisuuksina. Männyn kasvu turvemailla vähenee laskevan lämpösumman funktiona — sama pätee myös lannoitetuissa metsiköissä. Lisäksi lannoituksen puunkasvun lisäämiseen tähtäävä vaikutus on lyhyempi alhaisilla lämpösumma-alueilla. Puut tosin hyödyntävät viileissä ilmasto-oloissa maaperän typpeä suhteellisesti tehokkaammin kuin lämpimämmissä oloissa. Lämpösummaa 950 d.d. pidetään tasona, jonka alapuolelle mentäessä typen puute rajoittaa metsänkasvua turvemailla.

Tämän tutkimuksen tarkoituksena oli selvittää onko turpeen kokonaistypen ja männyn (*Pinus sylvestris* L.) pituuden ja tilavuuden välillä riippuvuutta kolmella korkeusasemaltaan ja kasvukauden tehoisan lämpösumman suhteen toisistaan poikkeavalla metsäojitusalueella. Tutkimukseen valittiin kolme Metsäntutkimuslaitoksen seurannassa 1970-luvulta saakka ollutta koekenttää Metsähallituksen mailta Pohjois-Suomesta: Posion Susivaara (290 m m.p.y.; 850 d.d.), Taivalkosken Hepokangas (240 m m.p.y.; 900 d.d.) ja Pudasjärven Haapua (190 m m.p.y.; 950 d.d.) (Kuva 1, Taulukko 1).

Tutkimuksessa mukana olevien koealojen koot olivat 30 m × 50 m. Näiden sisään perustettiin pienemmät koealat, joiden koko oli 20 m × 20 m, joista noudettiin turvenäytteet vuosina 1999 (Haapua ja Hepokangas) ja 2003 (Susivaara). Neulasnäytteet haettiin vuonna 2000 (Haapua ja Hepokangas) ja 2004 (Susivaara). Neulasnäytteistä mitattiin ravinteet; typpi, fosfori, kalium ja boori (Taulukko 2), koska haluttiin selvittää mahdolliset ravinnepuutokset tutkimusmetsiköissä. Koepuutunnukset mitattiin vuosina 1999 (Haapua ja Hepokangas) ja 2004 (Susivaara). Näytemäärät olivat 550 turvenäytettä, 440 neulasnäytettä ja 1687 koepuuta. Turvenäytteistä (0–10 cm pintakerros) mitattiin typpipitoisuus ja koepuista rinnankorkeusikä- ja läpimitta sekä pituus. Tutkimusmetsiköiden pituuksien ja tilavuuksien riippuvuutta turpeen kokonaistyppipitoisuuteen tutkittiin regressioanalyysillä (Kuvat 3 ja 4).

Turpeen typpipitoisuus vaihteli yksittäisten koealojen välillä 0,7 %–3,0 % turpeen kuivamassasta. Neulasten typpipitoisuus oli alle puutosrajan. Sen sijaan muut ravinteet ylittivät selvästi puutosrajan. Tulokset osoittivat, että typpipitoisuudella on merkittävä vaikutus mäntymetsiköiden keskipituuksiin ja tilavuuksiin. Pituudet ja tilavuudet lisääntyivät turpeen typpipitoisuuden funktiona erityisesti Haapuassa ja Hepokankaalla. Sen sijaan Susivaarassa lisäys ei ollut merkittävää. Haapuassa saavutettiin parhaimmat keskipituudet ja tilavuudet (111 dm ja 103,5 m^3/ha), kun taas Susivaara (90 dm ja 70,3 m^3/ha) ja Hepokangas (74 dm ja 39,9 m^3/ha) jäivät pienemmäksi (Taulukko 3). Haapuan suurimmat pituudet ja tilavuudet selittyvät sen alhaisella korkeusasemalla ja suurimmalla lämpösummalla verrattuna Hepokankaaseen ja Susivaaraan. Susivaarassa pituudet ja tilavuudet oli suurempia kuin Hepokankaalla, vaikka Susivaara sijaitsee ilmastollisesti epäsuotuisemmassa paikassa. Erot johtuvat Susivaaran keskimääräisesti korkeammasta typpipitoisuudesta (1,76 %) verrattuna Hepokankaaseen (1,31 %) (Taulukko 3).

Tutkimuksen tuloksia voidaan hyödyntää muun muassa arvioitaessa turvemaiden metsälannoituksen kannattavuutta Pohjois-Suomen alhaisilla lämpösumma-alueilla.

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