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The effect of peat nitrogen concentration and fertilization on the foliar nitrogen concentration of Scots pine (*Pinus sylvestis* L.) in three temperature sum regions

Turpeen kokonaistyppipitoisuuden ja lannoituksen vaikutus männyn neulasten typpipitoisuuteen kolmessa eri lämpösummavyöhykkeessä

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Wood production capacity on drained peatlands depends on the site type and temperature sum. Site type is closely related to the peat total nitrogen concentration. This study aims at clarifying the effect of peat nitrogen, fertilization and refertilization on the foliar nitrogen concentration of Scots pine in different temperature sum conditions (850, 950 and 1080 d.d.) on peatland sites with a wide peat nitrogen gradient (0.79–2.80% in the 0–10 cm layer). In the coldest region, regardless of the peat total nitrogen concentrations in the 0–10 cm surface peat layer and PK- fertilization or PK-refertilization (37 and 26 years earlier respectively), the needle nitrogen concentrations were mostly below the severe deficiency limit (N = 1.2%) and also the arginine concentrations revealed a nitrogen shortage (<0.5 mg g^{-1}). In the middle region the mean nitrogen concentrations in the needles were clearly higher and in the PK- fertilization and PK-refertilizations (32 and 22 years earlier respectively) surpassed the slight nitrogen deficiency limit (N = 1.3%). Also the arginine concentrations surpassed the deficiency limit (0.5 mg g^{-1}) in both fertilization treatments although the mean arginine concentrations were near or under the deficiency limit. In the warmest region 25–26 years after the spot fertilization the mean nitrogen concentration was 1.84% and the arginine concentration was 3.04 mg g^{-1} revealing a surplus of nitrogen caused by phosphorus and potassium deficiencies. The PK-fertilization given 10 years later decreased the nitrogen concentration to 1.56% and the arginine concentration to 0.58 mg g^{-1}. In the more favourable conditions the nitrogen and arginine in the needles increased when the nitrogen in the peat increased. In conclusion, tree growth in the middle and the warmest temperature sum region would respond to PK-refertilisation above a certain total peat nitrogen level but in the coldest temperature sum region tree growth would not respond to PK-refertilization in any of the studied peat total nitrogen conditions because of nitrogen deficiency.

Key words: climate, deficiency, foliar analysis, nitrogen, peat nitrogen, fertilization, temperature sum.

Introduction

Adequate drainage is a prerequisite for good forest growth on peatlands. The wood production potential of a drained peatland is determined by its site type (Lukkala 1930, Huikari 1952, Heikurainen 1959) and by the regional climate (Heikurainen 1959, Keltikangas et al. 1986). Tree growth within the same peatland site type decreases along with the decreasing temperature sum (Heikurainen 1959, Keltikangas et al. 1986, Sundström et al. 2000). This is why different climatic zones have been separated according to their post drainage productivity in Finland (Heikurainen 1959, Keltikangas et al. 1986). Tree growth decreases along with the decreasing temperature sum also in fertilized stands (Heikurainen et al. 1983, Heikurainen & Laine 1985, Sundstöm 1995), and the growth increase due to fertilization lasts a shorter period of time in low than in high temperature sum conditions (Heikurainen & Laine 1985).

The total peat nitrogen concentration (Vahtera 1956, Westman 1981) and accordingly also tree growth (Heikurainen 1959, Keltikangas et al. 1986) increase from sites with dwarf shrubs and low sedges towards sites with tall sedges and herbs. A close positive relationship between the total peat nitrogen concentration and tree growth has bee shown in several investigations (Kaunisto 1982, 1987, Kaunisto & Paavilainen 1988). Kaunisto (1982, 1987) showed that the total nitrogen concentration of the surface peat layers had a high positive correlation with the height development of young Scots pine stands in separate fertilization experiments. Similarly also peat and foliar nitrogen concentrations have a close positive correlation (Kaunisto 1982, Lauhanen & Kaunisto 1999).

It has been shown that nitrogen mineralisation decreases along with the decreasing soil temperature (Kaunisto & Norlamo 1976), and that needle nitrogen concentrations are dependent on the temperature sum of the previous summer (Kaunisto 1985). Sundström et al. (2000) suggested, using an indirect method, that tree growth is limited below the temperature sum of 950 d.d. by the inadequate microbial release of organically bound nitrogen.

On sites with high nitrogen availability mere PK-fertilization improves tree growth (Paavilainen 1979, Kaunisto 1982, Moilanen 1993) whereas on sites with low nitrogen availability fertilization with mineral nutrients increases tree growth only slightly and for a short period of time (Karsisto 1974, Paavilainen 1977, Moilanen &Issakainen 1990, Moilanen 1993). On nitrogen-poor sites even NPK- fertilization may not increase tree growth (Sundström 1995), especially so in the low temperature sum conditions (Heikurainen et al. 1983, Heikurainen & Laine 1985).

At the time of the drainage the site type and the temperature sum are good indicators in predicting the wood production capacity of a Scots pine stand (Heikurainen 1959, 1960). However, as a drained peatland site ages and the post-drainage changes in the vegetation continue, the determination of the original site type becomes difficult. Also the changes in the nitrogen concentration of peat, an increase due to decomposition process and a decrease due to the nutrient uptake by trees, make it more difficult to estimate the nitrogen status of a site and its effect on the nitrogen nutrition of trees.

The foliar nitrogen and arginine concentrations indicate nitrogen balance in Scots pines. Arginine is a normal component of the proteins and it serves as a N storage compound, buffering excess N (Ferm et. al 1990). Arginine responds to a variety of environmental and nutritional factors. Pietiläinen and Lähdesmäki (1986) showed that in unfertilized areas arginine levels increased in pine needles and PK-fertilization decreased arginine concentration. Pietiläinen et al. (1996) showed that in phosphorus, potassium and boron deficiencies the arginine concentration increases in the needles of Scots pine growing on drained peatlands. The increase in foliar phosphorus and potassium concentrations that occurs after fertilization has a close negative correlation with foliar nitrogen and arginine (Pietiläinen et al. 1996) and is followed by a strong growth reaction when the mineral nutrients promote the flux of N into growth.

This study aims at clarifying the effect of the total peat nitrogen concentration and fertilization on the foliar nitrogen concentration of Scots pine in three fertilized and refertilized peatland areas having a wide total peat nitrogen concentration gradient at the temperature sum levels of 850, 950 and 1080 d.d.

Material and methods

Three drained mires typical of central and northern central Finland representing three different temperature sum regions (850, 950 and 1080 d.d. threshold value 5 °C), and having a wide variation in peat nitrogen concentration, were chosen for this study (Table 1). The thickness of the peat layer was over one metre in all areas. Originally Pudasjärvi and Taivalkoski sites were sparsely treed where as Ilomantsi was a treeless mire. The original site types ranged from low sedge bogs (with *Sphagnum fuscum* hummocks) to herb rich fens (Huikari 1952). The sites had been drained in the middle-1960´s and early 1970´s (Table 1). The strips were halved with supplementary ditches in Pudasjärvi in 1995 (Table 1) and on the most nitrogen poor sites in Ilomantsi in 1981–82 (Kaunisto 1987, Hartman et al.2001). The ditch spacings at the time of the study were 20, 40 or 45 m. In all three areas the drainage functioned well.

At Ilomantsi all the strips were ploughed with a double mould board plough that makes a shallow furrow with low peat ridges on both sides in 1970–71. The plough ridges were sown with pine seeds and spot fertilized with NPK fertilizer right away (Table 1). The sites were refertilized with various nutrient amounts and combinations in the late 1970´s or early 1980´s. The treatments selected for this study are shown in Table 1. At Ilomantsi (1080 d.d.) 18 sample plots were selected from A) unrefertilized, B) PK-refertilized and C) PK+B+Cu-refertilized plots of the experiment (Hartman et al. 2001). The peatland PK-fertilizations at Pudasjärvi and Taivalkoski were done as practical aerial fertilizations in the 1960's

Table 1. Basic information on the research sites. Site types from low sedge bogs to herb rich fens in all areas.

Taulukko 1. Koekenttien perustiedot. Suotyyppivaihtelu piensararämeestä ruohoiseen nevaan kaikilla alueilla.

Location	Temp. sum, d.d.[1)]	Total N in peat , %	Drainage year	Ditch spacing, m	Basic fertil.[2)]	Re-fertil.[3)]	Plots
Ilomantsi 62° 45' N; 31° 00' E 148 m a.s.l.	1080	0.98– 2.59	1970–71 1980–81	40 20/40 [4)]	1970-71 NPK_s	1980-81 0, P+K, P+K+B+Cu	18
Pudasjärvi 65° 23' N; 27° 40' E 190 m a.s.l.	950	1.04– 2.98	1965 1995	90 45	1968 PK_5	1978 0, PK_5	33
Taivalkoski 65° 32' N; 28° 25' E 240 m a.s.l.	850	0.70– 2.74	1962 1972	90 45	1963 P+K	1974 0, PK_2, PK_4+K_2	29

1) Threshold value 5 °C.
2) NPK_s = spot fertilization 30 g per spot of NPK fertilizer (14-8-8), 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) P+K+B+Cu = P 45 kg, K 78 kg, B 1,0 kg, Cu 8 kg ha^{-1}. $PK_{2\ and\ 5}$ = 200 and 500 kg ha^{-1} of PK fertilizer (P 18 and 45 kg and K 33 and 78 kg ha^{-1} respectively). PK_4+K_2 = 400 kg of PK fertilizer + 200 kg ha^{-1} of KCl (P 36 kg and K 66 + K 100 kg ha^{-1}).
In 2) and 3) Phosphorus given as rock phosphate and potassium as potassium chloride.
4) The strips of the most nitrogen poor sites were halved with supplementary ditches

and the refertilization experiments on the two peatlands were done in the 1970's (Table 1). At Pudasjärvi (950 d.d.) 33 plots were selected A) unrefertilized and B) PK-refertilized plots and at Taivalkoski (850 d.d.) 29 plots were selected A) unrefertilized, B) PK-refertilized and C) PK+K-refertilized for the study. In all experiments phosphorus had been given as rock phosphate and potassium as KCl. The plots for the study were selected to represent a wide gradient of the peat total nitrogen concentration both in unrefertilized and refertilized treatments in all experiments (Table 2). In the 0–10 cm surface peat layer there were great differences between the sites on the plots fertilized only once. On the northernmost site the mean peat total nitrogen content was considerably lower than in the other regions The range of the peat total nitrogen contents was wider in the 10–20 cm than in the 0–10 cm peat layer in all sites but contrary to the 0–10 cm layer the contents were slightly higher in the 850 d.d. than in the 950 d.d. region. On the refertilized plots the nitrogen range between the different sites was more even in both layers.

Table 2. Peat total nitrogen concentrations of the 0–10 cm and 10–20 cm layer in the different areas and fertilization treatments.

Taulukko 2. Turpeen kokonaistyppipitoisuus 0–10 cm:n ja 10–20 cm:n kerroksissa eri alueilla lannoituskäsittelyttäin.

	Temp. sum (d.d.)	N% Mean	N% Min.	N% Max.	n
Basic fertilization 0–10 cm layer	850	1.19	0.79	2.35	13
	950	1.55	1.12	2.16	14
	1080	1.90	1.10	2.80	6
Refertilised plots 0–10 cm layer	850	1.49	0.91	2.64	16
	950	1.59	1.04	2.98	19*
	1080	1.89	0.79	2.70	12
Basic fertilization 10–20 cm layer	850	1.93	1.02	3.11	13
	950	1.81	0.82	2.63	14
	1080	2.07	0.93	3.29	6
Refertilised plots 10–20 cm layer	850	2.08	1.18	3.26	16
	950	1.97	1.17	3.06	20
	1080	2.23	1.18	3.14	12

* One value missing – Yksi havainto puuttuu

The peat samples from Ilomantsi (1080 d.d.) were taken in October 1995 and in Pudasjärvi (950 d.d.) and Taivalkoski (850 d.d.) in October 1999. Four peat cores were taken 10 m from and parallel to the ditch from each 20 m × 20 m plot, which was marked inside an original 40 m × 45 m fertilization plot. The vegetation and undecomposed plant material on the top of the cores were discarded and the following 0–5 cm, 5–10 cm and 10–20 cm layers were separated and the four corresponding core sections of each plot were combined, put into plastic bags and stored at –21 °C. The peat N concentrations were analysed with Kjeldahl method according to the outlines given by Halonen et al. (1983).

The needles were sampled in March 1996 for Ilomantsi (1080 d.d.) and in March 2000 for Pudasjärvi (950 d.d.) and Taivalkoski (850 d.d.). The needle samples were taken from the top third of the crown of four trees per plot. The current needles and a branch from each sample tree were put into separate plastic bags and stored at –21 °C until their nutrients were analysed. The needle samples of each plot were combined and N concentrations were determined with Kjeldahl method. After dry combustion and dissolving in hydrochloric acid the potassium concentrations were determined using an atomic absorption spectrophotometer (Hitachi 100–40). The phosphorus concentrations were determined spectrophotometrically according to the outlines given by Halonen et al. (1983). The free arginine concentration in the needles was determined by the method of Sakaguchi (1951) as modified by Messioneo (1966) and Pietiläinen et al. (1996). The Figures were drawn and the Tukey´s t-tests as well as the linear regressions were calculated with the SPSS software package.

Results

Needle nitrogen

The mean nitrogen concentrations in the needles of Scots pines fertilized with PK only once were 1.10%, 1.35% and 1.84% in the temperature sum regions of 850 d.d., 950 d.d., and 1080 d.d. respectively (Fig. 1). The mean nitrogen concentrations in the needles of the Scots pines refertilized with

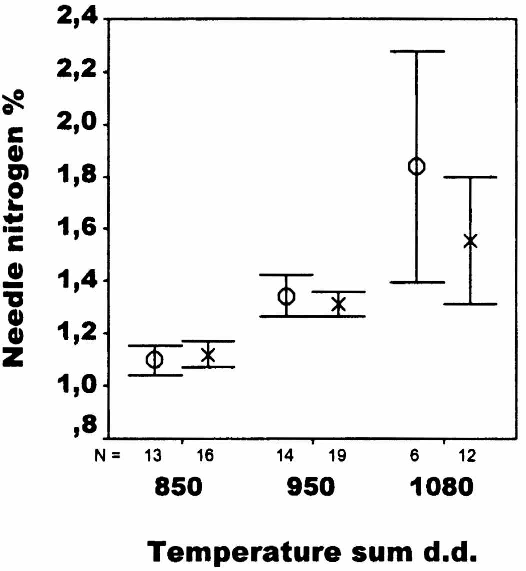

Fig. 1. The mean nitrogen concentration of the needles of PK-fertilized (O) and PK-refertilized (X) Scots pines growing on drained peatland in regions of different temperature sums. (The error bars indicate 95% confidence level and n = number of samples).

Kuva 1. Ojitetun suon männyn neulasten typpipitoisuuksien keskiarvot PK-lannoitetuilla (O) ja PK-jatkolannoitetuilla (X) koealoilla eri lämpösummavyöhykkeillä. Jana kuvaa 95 %:n luotettavuusväliä ja n = näytteiden lukumäärä.

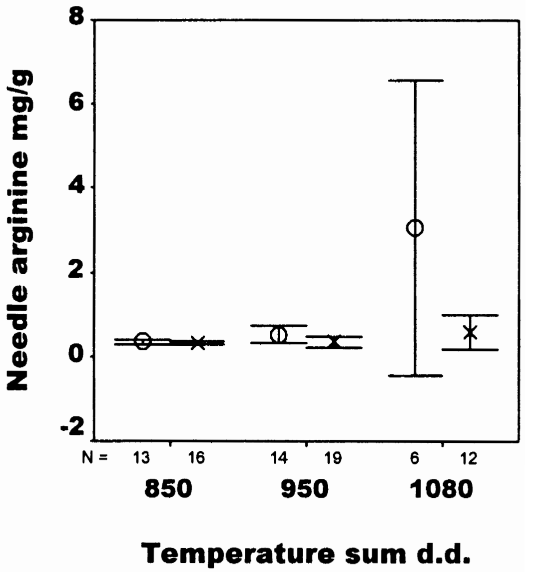

Fig. 2. The mean foliar free arginine concentration in PK fertilized (O) and PK refertilized Scots pines growing on drained peatland in regions of different temperature sums. (The error bars indicate 95% confidence level *and n* = number of samples).

Kuva 2. Ojitetun suon männyn neulasten liukoisen arginiinin pitoisuuksien keskiarvot PK-lannoitetuilla (O) ja PK-jatkolannoitetuilla (X) koealoilla eri lämpösummavyöhykkeillä. Jana kuvaa 95 %:n luotettavuusväliä ja n = näytteiden lukumäärä.

PK were 1.12% in the 850 d.d., 1.31% in the 950 d.d. and 1.56% in the 1080 d.d. region (Fig. 1). The difference in the needle nitrogen concentrations between the temperature sum regions of 850 d.d. and 950 d.d. was significant ($p = 0.026$). In the coldest region PK- fertilization or PK-refertilization (37 and 26 years earlier respectively) the needle nitrogen concentrations were below the severe deficiency limit (N = 1.2%, Fig. 1) suggested by Paarlahti et al. (1971) on average. In the middle region the mean nitrogen concentrations in the needles were clearly higher and surpassed the slight nitrogen deficiency limit (N = 1.3%, Paarlahti et al. 1971, Raitio 1981) in both treatments (fertilized 32 and 22 years earlier). In the warmest region 25–26 years after the spot fertilization the mean nitrogen concentration was above optimum (1.5–1.6%, Paarlahti et al. 1971, Kaunisto 1982). The PK-fertilization 10 years later decreased the nitrogen concentration to the optimum level.

Needle arginine

The mean free arginine concentrations in the needles of Scots pines fertilized only once were 0.35 mg g^{-1}, 0.52 mg g^{-1} and 3.04 mg g^{-1} in the temperature sum regions of 850 d.d., 950 d.d., and 1080 d.d. respectively (Fig. 2). Refertilization decreased the concentration. The mean free arginine concentrations in the needles of the Scots pines refertilized with PK were 0.33 mg g^{-1} in the 850 d.d., 0.35 mg g^{-1} in the 950 d.d. and 0.58 mg g^{-1} in the 1080 d.d. temperature sum region (Fig. 2). In the coldest region the arginine concentrations revealed a nitrogen shortage (<0.5 mg g^{-1}, Pietiläinen et al. 1996) in both PK- fertilization and PK-refertilization treatments (37 and 26 years earlier respectively). In the middle region the free arginine concentrations surpassed the deficiency limit (0.5 mg g^{-1}) in both treatments (fertilized 32 and 22 years earlier). In the warm-

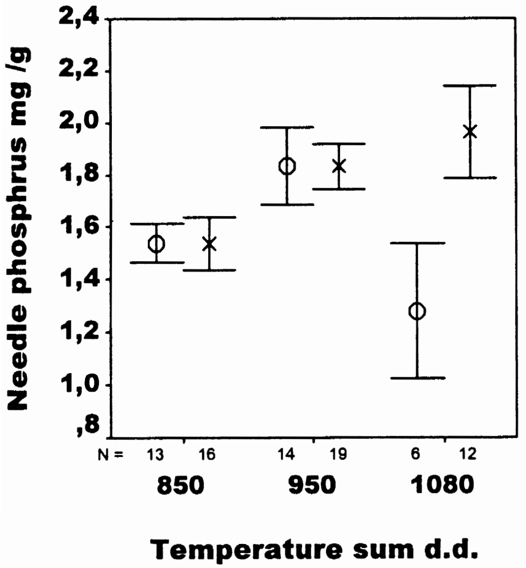

Fig. 3. The mean phosphorus concentration of the needles of PK fertilized (O) and PK-refertilized (X) Scots pines growing on drained peatland in regions of different temperature sums. (The error bars indicate 95% confidence level and n = number of samples).

Kuva 3. Ojitetun suon männyn neulasten fosforipitoisuuksien keskiarvot PK-peruslannoitetuilla (O) ja PK-jatkolannoitetuilla (X) koealoilla eri lämpösummavyöhykkeillä. Jana kuvaa 95 %:n luotettavuusväliä ja n = näytteiden lukumäärä.

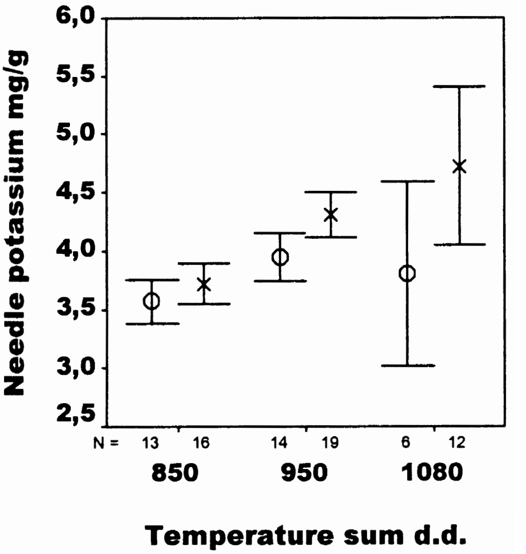

Fig. 4. The mean potassium concentration of the needles of PK fertilized (O) and PK- refertilized (X) Scots pines growing on drained mires in regions of different temperature sums. (The error bars indicate 95% confidence level and n = number of samples).

Kuva 4. Ojitetun suon männyn neulasten kaliumpitoisuuksien keskiarvot PK-lannoitetuilla (O) ja PK-jatkolannoitetuilla (X) koealoilla eri lämpösummavyöhykkeillä. Jana kuvaa 95 %:n luotettavuusväliä ja n = näytteiden lukumäärä.

est region 25–26 years after the spot fertilization the mean arginine concentration was manyfold compared with the values mentioned above but the PK-fertilization 10 years later decreased the concentration near the level of arginine shortage.

Needle Phosphorus

The mean phosphorus concentrations of the needles of Scots pines fertilized only once were 1.54, 1.83 and 1.28 mg g^{-1} in the temperature sum regions of 850, 950 and 1080 d.d., respectively (Fig. 3). The difference in the phosphorus concentration between the two coldest regions was significant ($p = 0.003$). Refertilization with PK increased the phosphorus concentration of the needles from 1.28 to 1.96 mg g^{-1} (Fig. 3, $p = 0.002$) in the trees growing in the 1080 d.d. region. Refertilization had no effect on the phosphorus concentration of the needles in the other two areas (1.54 and 1.83 mg g^{-1}). According to the border values (1.39 mg g^{-1}) given by Paarlahti et al. (1971) the needle phosphorus concentration was below the deficiency level on the spot fertilized plots of the 1080 d.d. region and below the optimum level (1.70 mg g^{-1}) in both fertilization treatments in the 850 d.d. region. The needle phosphorus concentrations were at an optimum level in both fertilized and refertilized trees of the 950 d.d. region as well as on the refertilized plots of the warmest region. The phosphorus concentrations in the needles of the PK-refertilized Scots pines in the region of 850 d.d. were significantly ($p=0.001$) lower than the concentrations of the needles in the 950 d.d. region.

Needle Potassium

The mean potassium concentration in the nee-

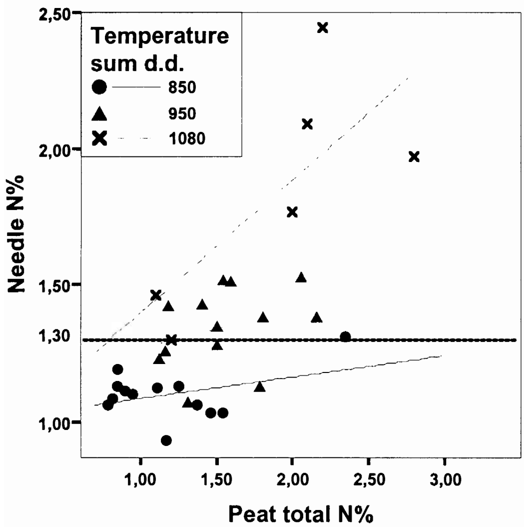

Fig. 5. Linear regression of needle nitrogen (y) and peat total nitrogen concentration (x) in fertilized Scots pines in 850 d.d. ($p = 0.204$), 950 d.d. ($p = 0.246$) and 1080 d.d. ($p = 0.083$) regions. Dotted line at needle N% = 1.30 is the nitrogen deficiency level.

Kuva 5. PK-lannoitettujen männyn neulasten (y) ja turpeen (x) 0–10 cm:n pintakerroksen kokonaistypen välinen lineaarinen riippuvuus eri lämpösummavyöhykkeillä.

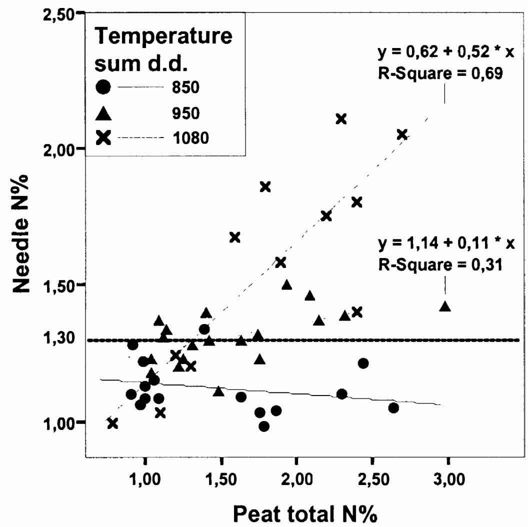

Fig. 6. Linear regression of needle nitrogen (y) and peat total nitrogen concentration (x) in refertilized Scots pines in 850 d.d. ($p = 0.351$), 950 d.d. ($p = 0.013$) and 1080 d.d. ($p = 0.001$) regions. Dotted line at needle N% = 1.30 is the nitrogen deficiency level.

Kuva 6. PK-jatkolannoitettujen männyn neulasten (y) ja turpeen (x) 0–10 cm:n pintakerroksen kokonaistypen välinen lineaarinen riippuus eri lämpösummavöyhykkeillä.

dles of Scots pines fertilized only once was 3.57 mg g^{-1} in the 850 d.d. region, 3.95 mg g^{-1} in the 950 d.d. region and 3.81 mg g^{-1} in the 1080 d.d. region (Fig. 4). Refertilization with PK increased mean potassium concentrations of the needles in all areas indicating that there may have been a potassium shortage at some stage after the first fertilization (Fig. 4). The mean potassium concentration (3.72 mg g^{-1}) was still near the severe potassium deficiency level (3.5 mg g^{-1} according to Paarlahti et al. 1971 and Sarjala & Kaunisto 1993) in the coldest region. On the other refertilized sites potassium concentrations were satisfactory 4.31 mg g^{-1} in the 950 d.d. region and 4.72 mg g^{-1} in the region of 1080 d.d. The potassium concentration of the needles in the coldest region was significantly ($p = 0.01$) lower than in the 950 d.d. region. The increases in the potassium concentration of the needles due to PK-refertilization were not significant.

Relationship between soil and needle nitrogen concentrations

On the fertilized plots the regression between the needle and peat nitrogen concentrations was not significant in the 850 d.d. region ($y = 1.01 + 0.08x$, Fig. 5). On the fertilized plots the nitrogen concentration in the needles increased with the increasing peat total nitrogen concentration in the 950 d.d. and 1080 d.d. regions (Fig. 5). In the 950 d.d. the highest nitrogen concentration of the needles was 1.53%, and the nitrogen concentrations in several needle samples were over the slight deficiency level of 1.30%. The regression between the needle and peat nitrogen concentrations was not significant in the 950 d.d. region ($y = 1.12 + 0.15x$). In the 1080 d.d. region, all needle nitrogen concentrations were above the deficiency limit. The highest nitrogen concentration was 2.44%. However, the regression between the needle and peat nitrogen concentrations was not significant (y = 0.90 + 0.49x). The nitrogen concentration in the needles of the PK fertilised stands increased when the temperature sum increased (Fig. 5).

In the refertilized plots the regression between needle and peat total nitrogen concentrations was not significant in the 850 d.d. region (y = 1.18 – 0.04x). The needle nitrogen concentration was below the nitrogen deficiency level and rather stable throughout the nitrogen gradient (Fig. 6). On the refertilized plots in the regions of the 950 d.d. and 1080 d.d. the nitrogen concentration of the needles increased with the increasing peat total nitrogen concentrations. In the 950 d.d. region the relationship between the peat total and needle nitrogen concentrations was significant and the peat nitrogen concentration was 1.45% at the deficiency level of the needles (y = 1.14+ 0.11x; r^2 = 0.31, p = 0.013). In the 1080 d.d.region the relationship was highly significant. The peat total nitrogen concentration was 1.31% when the foliar nitrogen concentration was at the deficiency level (y = 0.62 + 0.52 x; r^2=0.69; p = 0.001, Fig. 6).

Relationship between foliar free arginine and nitrogen concentrations

On the fertilized plots the free arginine concentration in the needles decreased with the decreasing temperature sum. In the 850 d.d. region the regression between free arginine and foliar nitrogen was not significant (y = 0.63 – 0.26x; Fig. 7) and the free arginine concentration was under the deficiency level (Pietiläinen & Lähdesmäki 1996). The regressions between free arginine and needle nitrogen were significant on the fertilized plots in the 950 d.d. (y = –1.46 + 1.47x; r^2 = 0.34, p = 0.029) and 1080 d.d. regions (y = –10.31 + 7.27x; r^2 = 0.83, p = 0.011). The needle nitrogen was 1.33% in the 950 d.d. region and 1.49% in the 1080 d.d. region when the free arginine was 0.5 mg g^{-1}.

On the refertilized plots in the 850 d.d. region the regression between foliar free arginine and nitrogen was not significant (y = 0.57 – 0.21x; Fig. 8). The regressions were significant in the 950 d.d. (y = –1.38 + 1.32x; r^2 = 0.27, p = 0.023) and in the 1080 d.d. regions (y = –1.47 + 1.32x; r^2 = 0.60, p = 0.003). The needle nitrogen was 1.42% in the 950 d.d. region and 1.49% in the 1080 d.d. region when the free arginine was 0.5 mg g^{-1}.

Discussion

Needle nitrogen concentrations can be quite high if there is an excess of available nitrogen with a simultaneous shortage of mineral nutrients in the needles (Paarlahti et al. 1971, Raitio 1981, Kaunisto 1982, 1987, Pietiläinen et al. 1996). In this kind of situation trees store excess nitrogen as arginine (Pietiläinen and Lähdesmäki 1986, Pietiläinen et al.1996, Lankila et al. 2000). Having a high N/C ratio (4/6) arginine is an effective nitrogen storage of amino acids in Scots pines. When mineral nutrients are added trees utilize their arginine stores, tree growth increases and needle nitrogen concentration decreases (Pietiläinen et al. 1996, see also Pietiläinen and Lähdesmäki 1986). The decrease in the needle nitrogen concentration due to PK-fertilization has been shown also in several other studies concerning Finnish peatland forests (Paarlahti et al.1971, Raitio 1981, Kaunisto 1982, 1987, Moilanen 1993).

In this investigation, the addition of mineral nutrients decreased the nitrogen and free arginine concentrations on average in the temperature sum regions of 950 d.d. and 1080 d.d. but not in the 850 d.d. region. The average needle nitrogen concentrations were above the optimum values in the spot fertilized trees of the 1080 d.d. region. Here PK-refertilization decreased nitrogen and free arginine concentrations considerably indicating that there was a reasonable surplus of nitrogen to be utilized by trees on average. The nitrogen and free arginine concentrations were above the deficiency limit on the fertilized plots also in the area of 950 d.d. on average. Here there was a slight decrease in the nitrogen and arginine concentration of the needles due to refertilization, indicating a small surplus of nitrogen. The result implies a possibility to increase tree growth by fertilizing with mineral nutrients in these temperature sum conditions. However, it does not tell if the growth increase is high enough for an eco-

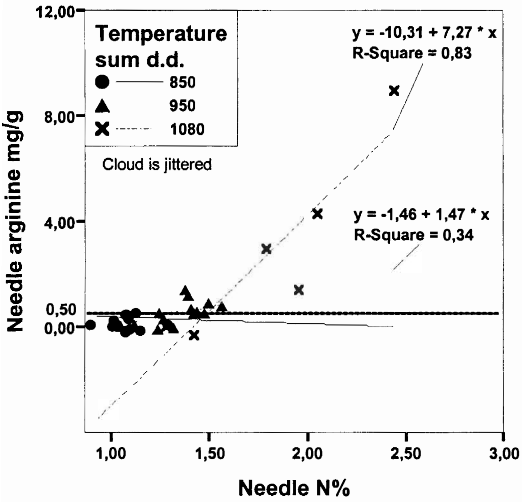

Fig. 7. Linear regression of foliar free arginine (y) and needle nitrogen concentration (x) in fertilized Scots pines in 850 d.d. ($p = 0.371$), 950 d.d. ($p = 0.029$) and 1080 d.d. ($p = 0.011$) regions. Dotted line at needle arginine = 0.5 mg g^{-1} indicates the nitrogen deficiency level.

Kuva 7. PK-lannoitettujen männyn neulasten liukoisen arginiinin (y) ja neulasten typen (x) välinen lineaarinen riippuvuus eri lämpösummavyöhykkeillä.

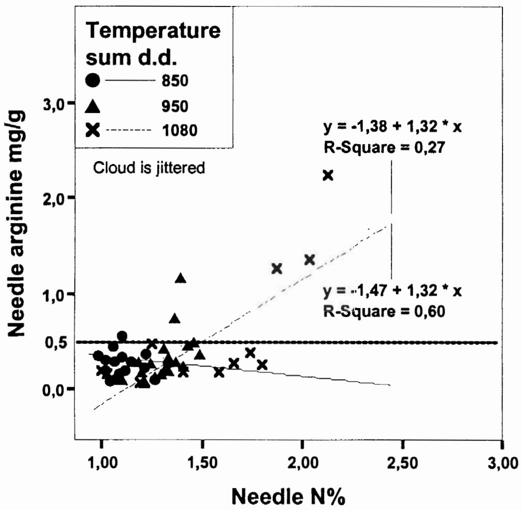

Fig. 8. Linear regression of foliar free arginine (y) and needle nitrogen concentration (x) in refertilized Scots pines in 850 d.d. ($p = 0.257$), 950 d.d. ($p = 0.023$) and 1080 d.d. ($p = 0.003$) regions. Dotted line at needle arginine = 0.5 mg g^{-1} indicates the nitrogen deficiency level.

Kuva 8. PK-jatkolannoitettujen männyn neulasten liukoisen arginiinin (y) ja neulasten typen (x) välinen lineaarinen riippuvuus eri lämpösummavyöhykkeillä.

nomically satisfactory investment.

When evaluating the effect of the peat total nitrogen concentration on the nitrogen nutrition of trees the phosphorus and potassium nutrition of trees should be satisfactory. This was the case in the refertilized stands of the 950 and 1080 d.d. regions. There was a significant positive regression between the peat total nitrogen and the needle nitrogen concentrations in both areas. The peat total nitrogen concentration in the 0–10 cm layer was 1.45% in the 950 d.d. and 1.31% in the 1080 d.d. region when the regression lines crossed the nitrogen deficiency level 1.30% in the needles. The result implies that above these peat total nitrogen concentrations trees may benefit from phosphorus and potassium fertilization. The result agrees well with the results of Kaunisto (1982). In quite similar temperature sum conditions in western Finland he found that NPK fertilization compared with PK increased tree growth below the peat total nitrogen concentration of 1.3–1.40% in the 5–10 cm peat layer.

In the 850 d.d. region trees suffered from potassium deficiency on both fertilized and refertilized plots and also the phosphorus levels were under optimum. In spite of the low phosphorus and potassium levels on both fertilized and refertilized plots the needle nitrogen concentrations were low and indicated nitrogen deficiency regardless of the total nitrogen concentration of peat in this temperature sum region. In both treatments the needle nitrogen concentration was lower than 1.30% (except for one outlier), which was suggested by Paarlahti et al. (1971) to be the level under which trees would benefit from nitrogen fertilization. Also in the study of Lauhanen & Kaunisto (1999) the needle nitrogen concentrations were quite low in an experiment with a high peat total nitrogen concentration in an area with the temperature sum of 867 d.d., even after drainage maintenance, although the variation was very wide.

The foliar arginine concentration below 0.5 mg g^{-1} is regarded as the border value under which trees start suffering from nitrogen shortage, and the protein synthesis in the needles is retarded (Lähdesmäki & Pietiläinen 1996). In the 850 d.d. region the free arginine levels were lower than 0.5 mg g^{-1} suggesting that there were no excess nitrogen stores. The result implies that nitrogen availability rather than phosphorus and potassium controlled the nitrogen status of pines and that there was not enough nitrogen to support a PK refertilization even at the highest peat total nitrogen levels in this region.

The results agree quite well with the ones presented by Keltikangas et al. (1986) who found in a large survey concerning drained peatland forests in whole Finland that tree growth had not increased on tall sedge pine fens within about 35 years since drainage in the temperature sum region of 761–860 d.d. The results agree quite well also with the low growth increments achieved by PK and NPK fertilization in Lapland summarised by Aarnio et al. (1997) and with those presented by Kaunisto (1985). He showed that tree height growth was highly dependent on the temperature sum of the previous summer (variation from about 850 to 1150 d.d.) on pine mires.

In the 850 d.d. region the regression between the foliar free arginine and nitrogen was not significant and the arginine concentrations were less than 0.5 mg g^{-1} regardless of the foliar nitrogen concentration on both fertilized and refertilized plots. In the two warmer regions the regressions were significant in both treatments. In the 950 d.d. region the foliar nitrogen concentration was 1.33% mg g^{-1} and in the 1080 d.d. region 1.45% when the free arginine concentration was 0.5 mg g^{-1} in the fertilized trees. In the refertilized trees the foliar nitrogen concentrations were 1.42% and 1.49% respectively. This agrees with the results of Paavilainen (1979) in similar conditions. He found that NPK fertilization compared with PK fertilization increased tree growth below the foliar nitrogen concentrations of 1.45%.

Conclusions

The regression between the peat total nitrogen and the foliar nitrogen decreased as the temperature sum decreased. Regardless of the peat total nitrogen concentration both the foliar nitrogen and arginine concentration showed that there was a nitrogen deficiency in the PK-fertilized and PK-refertilized stands, when the temperature sum was 850 d.d.

On the other hand, the foliar nitrogen and arginine concentration showed a surplus of nitrogen, which could support a PK-refertilization in the higher peat nitrogen concentrations when the temperature sum was 950 d.d. and 1080 d.d.. More research is needed to confirm the range of the limit values of the surface peat obtained in this investigation.

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References

Aarnio, J., Kaunisto, S., Moilanen, M. & Veijalainen, H. 1997. Suometsien lannoitus. Julkaisussa: Mielikäinen, K. & Riikilä, M. (toim.). Kannattava puuntuotanto. Kustannusosakeyhtiö Metsälehti, pp.116–126.

Ferm, A., Hytönen, J., Lähdesmäki, P., Pietiläinen, P. & Pätilä, A. 1990. Effects of high nitrogen deposition on forests: Case studies close to fur animal farms. 1990. In: Acidification in Finland. Eds. Kauppi, P.,Anttila, P. and Kenttämies,K. Springer- Verlag. pp. 635–668.

Hånell, B. 1984. Post drainage site index of peatlands in Sweden. Reports in Forest Ecology and Forest soils: Report 50. Department of Forest Soils, Swedish University of Agricultral Sciensces, 128 pp. (in Swedish with English summary)

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis methods. Metsäntutkimuslaitoksen tiedonantoja 121: 1–28.

Hartman, M., Kaunisto, S. & Silfverberg, K. 2001. Peat properties and vegetation along different trophic levels on an afforested, fertilised mire. Turpeen ominaisuudet ja kasvillisuus metsitetyn ja lannoitetun avosuon eri trofiatasoilla. Suo 52: 57–74.

Heikurainen, L. 1959. Tutkimus metsäojitusalueiden tilasta ja puustosta. Referat: Über waldbaulich entwässerte Flächen und ihre Waldbestände in Finnland. Acta Forestalia Fennica 69: 1–279.

Heikurainen, L. 1960. Metsäojitus ja sen perusteet. WSOY. Porvoo-Helsinki 1960. 378 pp.

Heikurainen L., Laine J. & Lepola J. 1983. Fertilization and ditch spacing experiments concerned with regeneration and growing of young Scots pine stands on

nutrient poor bogs. Silva Fennica 17: 359 – 379.
Heikurainen, L. & Laine, J. 1985. Duration of the height growth response of young pine stands to NPK-fertilization on oligotrophic bogs in Finland. Silva Fennica. Vol. 19. 2: 155-167.
Huikari, O. 1952. Suotyypin määritys maa- ja metsätaloudellista käyttöarvoa silmällä pitäen. Summary: On the determination of mire site types, especially considering their drainage value for agriculture and forestry. Silva Fennica 75: 1–22.
Huikari, O. & Paarlahti, K. 1967. Results of field experiments on ecology of pine, spruce and birch. Communicationes Instituti Forestalis Fenniae. 64: 1–67.
Karsisto, K. 1974. On the duration of fertilization influence in peatland forests with special reference to the results obtained from experiments with different phosphorus fertilizers. Proc. Int. Symp. for Drainage. 2–6 Sept. 1974, Jyväskylä-Oulu, Finland, pp. 309–327.
Kaunisto, S. 1977. Ojituksen tehokkuuden ja lannoituksen vaikutus männyn viljelytaimistojen kehitykseen karuilla avosoilla. Summary: Effect of drainage intensity and fertilization on the development of pine plantations on oligotrophic treeless *Sphagnum* bogs. Folia Forestalia 317: 1–31.
Kaunisto, S. 1982. Development of pine plantations on drained bogs as affected by some peat properties, fertilization, soil preparation and liming. Seloste: Männyn istutustaimien kehityksen riippuvuus eräistä turpeen ominaisuuksista sekä lannoituksesta, muokkauksesta ja kalkituksesta ojitetuilla avosoilla. Communicationes Instituti Forestalis Fenniae 109: 1–56.
Kaunisto, S. 1985. Lannoituksen, ilman lämpösumman ja eräiden kasvualustan ominaisuuksien vaikutus mäntytaimikoiden kasvuun turvemailla. Summary: Effect of fertilization, temperature sum and some peat properties on the height growth of young pine sapling stands on peatlands. Folia Forestalia 616: 1–27.
Kaunisto, S. 1987. Effect of refertilization on the development and foliar nutrient contents of young Scots pine stands on drained mires of different nitrogen status. Seloste: Jatkolannoituksen vaikutus mäntytaimikoiden kehitykseen ja neulasten ravinnepitoisuuksiin typpitaloudeltaan erilaisilla ojitetuilla soilla. Communicationes Instituti Forestalis Fenniae 140: 1–58.
Kaunisto, S. & Norlamo, M. 1976. On nitrogen mobilization in peat. I. Effect of liming and rotavation in different incubation temperatures. Seloste: Typen mobilisaatiosta turpeessa. I. Kalkituksen ja muokkauksen vaikutus erilaisissa haudutuslämpötiloissa. Communicationes Instituti Forestalis Fenniae 88: 1–27.
Kaunisto, S. & Paavilainen, E. 1988. Nutrient stores in old drainage areas and growth of stands. Seloste: Turpeen ravinnevarat vanhoilla ojitusalueilla ja puuston kasvu. Communicationes Instituti Forestalis Fenniae 145: 1–39.
Keltikangas, M., Laine, J., Puttonen, P. & Seppälä, K. 1986. Vuosina 1930–78 metsäojitetut suot: ojitusalueiden inventoinnin tuloksia. Abstract: Peatlands drained for forestry during 1930–1978: results from field surveys of drained areas. Acta Forestalia Fennica 193: 1–94.
Lankila, J. Pietiläinen, P. annd Lähdesmäki, P. 2000. Seasonal changes in concentration of free and bound arginine in context to growth disturbances in Scots pine. Aquilo Ser. Bot. 38: 39–47.
Lauhanen, R. & Kaunisto, S. 1999. Effect of drainage maintenance on the nutrient status on drained Scots pine mires. Seloste: Kunnostusojituksen vaikutus rämeiden ravinnetilaan. Suo 50: 119–132.
Lukkala, O.J. 1930. Tutkimuksia soiden metsätaloudellisesta ojituskelpoisuudesta erityisesti kuivatuksen tehokkuutta silmälläpitäen. Referat: Untersuchungen über die waldwitschaftliche Entwässerungsfähigkeit der Moore. Communicationes Instituti Forestalis Fenniae 15: 1–278.
Messineo, L. 1966. Modification of the Sakaguchi reaction: Spectrophotometric determination of arginine in proteins with out previous hydrolysis. Arch. Biochem. Biophys. 117: 534-540.
Moilanen, M. & Issakainen, J. 1990. Suometsien PK-lannos ja typpilannoitelajit karuhkojen ojitettujen rämeiden lannoituksessa. Abstract: PK fertilizer and different types of N fertilization on infertile drained bogs. Folia Forestalia 754: 1–20.
Moilanen, M.1993. Lannoituksen vaikutus männyn ravinnetilaan ja kasvuun Pohjois-Pohjanmaan ja Kainuun ojitetuilla soilla. Summary: Effect of fertilization on the nutrient status and growth of Scots pine on drained peatlands in northern Ostrobothnia and Kainuu. Folia Forestalia 820:1–39.
Paarlahti, K., Reinikainen, A. & Veijalainen, H. 1971. Nutritional diagnosis of Scots pine by needle and peat analysis. Seloste: Maa- ja neulasanalyysi turvemaiden männiköiden ravitsemustilan määrityksessä. Communicationes Instituti Forestalis Fenniae 74: 1–58.
Paavilainen, E. 1977. Jatkolannoitus vähäravinteisilla rämeillä. Ennakkotuloksia. Abstract: Refertilization on oligotrophic pine swamps. Preliminary results. Folia Forestalia 327: 1–32.
Paavilainen, E. 1979. Metsänlannoitusopas. Kirjayhtymä. Helsinki. 112 pp.
Pietiläinen, P. & Lähdesmäki, P. 1986. Free amino acid and protein levels, and gamma-glutamyltransferase activity in Pinus sylvestris apical buds and shoots during the growing season. Scandinavian Journal of Forest Research 1: 387–395.
Pietiläinen, P., Moilanen, M. & Lähdesmäki, P. 1996. Peat inorganic nutrients and the concentration of soluble arginine in Scots pine needles. Humus 3: 4–13.
Raitio, H. 1978. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin ojitetulla, karulla avosuolla. Parkanon tutkimusaseman tiedonantoja 7: 1–9.
Raitio, H. 1981. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin ojitetulla lyhytkorsinevalla. Summary: Effect of macronu-

trient fertilization on the structure and nutrient content of pine needles on a drained short sedge bog. Folia Forestalia 456: 1–10.
Sarjala, T. & Kaunisto, S. 1993. Needle polyamine concentration and potassium nutrition in Scots pine. Tree Physiology. 13: 87–96.
Sundström, E. 1995. The impact of climate, drainage and fertilization on the survival and growth of *Pinus sylvestris* L. in afforestation of low production peatlands. Scandinavian Journal of Forest Research 10: 190–203.
Sundström, E., Magnusson, T. & Hånell, B. 2000. Nutrient conditions in drained peatlands along a north-south climatic gradient in Sweden. Forest Ecology and Management 126: 149–161.
Vahtera, E. 1955. Metsänkasvatusta varten ojitettujen soiden ravinnepitoisuuksista. Referat: Ueber die Nährstoffgehalt der fur Walderziehung entwässerten Moore. Communicationes Instituti Forestalis Fenniae 45: 1–108.
Westman, C.J. 1981. Fertility of surface peat in relation to the site type and potential stand growth. Seloste: Pintaturpeen viljavuustunnukset suhteessa kasvupaikkatyyppiin ja puuston kasvupotentiaaliin. Acta Forestalia Fennica 172: 1–77.

Tiivistelmä:

Turpeen kokonaistyppipitoisuuden ja lannoituksen vaikutus männyn neulasten typpipitoisuuteen kolmessa eri lämpösummavyöhykkeessä

Johdanto

Ojitetun suon puuntuotoskyky riippuu turpeen pintakerroksen typpipitoisuudesta (Kaunisto 1982, 1987, Kaunisto & Paavilainen 1988). Karuilla, vähätyppisillä soilla lannoitus kivennäisravinteilla voi lisätä puuston kasvua, mutta vain lyhytaikaisesti (Karsisto 1974, Paavilainen 1977). Tällaisille kohteille ei kuitenkaan suositella typpilannoitusta, koska annettu typpi sitoutuu puille käyttökelvottomaan muotoon ja vaikutus puuston kasvuun on lyhytaikainen ja heikko (Kaunisto 1977, Paavilainen 1977). Aarnio ym. (1997) osoittivat, että karujen soiden männiköiden lannoitus typpeä sisältävillä lannoitteilla ei ole kannattavaa, mutta pelkkä PK-lannoitus oli kannattava runsastyppisillä soilla.

Lämpösumman vaikutusta ojitettujen soiden männiköiden typpiravitsemukseen on tutkittu vähän. Tiedetään kuitenkin, että typen mineralisaatio pienenee, kun maan lämpötila laskee (Kaunisto & Norlamo 1976) ja että männyn neulasten typpipitoisuus korreloi positiivisesti sekä turpeen kokonaistyppipitoisuuden että ilman lämpösumman kanssa (Lauhanen & Kaunisto 1999). Tiedetään myös, että puuston kasvu pienenee samalla suotyypillä ilman lämpösumman laskiessa. (Heikurainen 1959, Keltikangas et al. 1986) ja on riippuvainen edellisen vuoden ilman lämpösummasta (Kaunisto 1985).

Käytännön metsätaloudelle on tärkeää kehittää menetelmiä, joilla voidaan tunnistaa ne kasvupaikat, joilla typen saatavuus riittää ylläpitämään kannattavaa puuntuotantoa. Tätä tietoa tarvitaan erityisesti silloin, kun tehdään kunnostusojitus- ja lannoituspäätöksiä.

Tässä tutkimuksessa pyritään selvittämään maa- ja neulasanalyysin avulla männyn typpiravitsemusta eri lämpösummavyöhykkeissä sijaitsevilla soilla, joilla on laaja sisäinen pintaturpeen typpipitoisuuden vaihtelu. Aihetta käsitellään sekä peruslannoituksen että jatkolannoituksen näkökulmasta. Tutkimuksessa tarkastellaan myös turpeen typpipitoisuuden merkitystä PK-lannoituksen tulokseen vaikuttavana tekijänä eri lämpösummavyöhykkeissä.

Aineisto

Tutkimukseen valittiin kolme paksuturpeista ojitettua suota kolmesta eri lämpösummavyöhykkeestä (850 d.d. Taivalkoskella, 950 d.d. Pudasjärvellä ja 1080 d.d. Ilomantsissa, kynnysarvo 5 °C, taulukko 1). Kaikilla alueilla aineistossa oli sekä kertaalleen että kahteen kertaan lannoitettuja koealoja. Pudasjärven ja Taivalkosken kohteet olivat alunperin vähäpuustoisia rämeitä ja Ilomantsin kohde avosuota. Trofiataso vaihteli rahkamättäisestä piensarasaisuustasosta ruohoisuuteen. Jokaisella koekentällä pyrittiin saamaan mahdollisimman suuri turpeen typpipitoisuuden vaihteluväli. Tämä onnistuikin verraten hyvin, mutta pohjoisimmalla koekentällä pintaturpeen (0–10 cm) kokonaistyppipitoisuus kertaalleen lannoitetuilla koealoilla oli keskimäärin selvästi alempi kuin muilla (taulukko 2). Sen sijaan 10–20 cm:n typpipitoisuus oli keskimäärin korkeampi kuin keskimmäisellä koekentällä. Ojitukset ja lannoituskäsittelyt on esitetty taulukossa 1. Ilomantsin, koekentältä valittiin tutkimukseen käsittelyt A) laikkulannoitus metsityksen yhteydessä, B) A ja PK-jatkolannoitus ja C) A ja PK+B+Cu-jatkolannoitus. Pudasjärven koekentältä valittiin tutkimukseen käsittelyt A) peruslannoitus ja B) A ja PK- jatkolannoitus ja Taivalkosken koekentältä A) peruslannoitus, B) A ja PK-jatkolannoitus ja C) A ja PK+K-jatkolannoitus. Kaikissa kokeissa fosfori annettiin raakafosfaattina ja kalium kaliumkloridina (kalisuolana). Turve- ja neulasnäytteet otettiin kaikissa kokeissa samalla tavoin. Ilomantsin turpeet otettiin lokakuussa 1995, Pudasjärven ja Taivalkosken turpeet lokakuussa 1999. Kultakin koealalta otettiin neljä osanäytettä. Elävä kasvillisuus- ja maatumaton pintakerros poistettiin näytteistä ja osanäytteet yhdistettiin kerroksitttain (0–5, 5–10 ja 10–20 cm) ja säilytettiin muovipusseissa –21 °C:ssa.

Neulasnäytteet kerättiin Ilomantsin kokeelta maaliskuussa 1996 sekä Pudasjärven ja Taivalkosken kokeilta maaliskuussa 2000. Neulasnäytteet otettiin männyn latvuksen etelänpuoleisesta ylimmästä kolmanneksesta. Turve- ja neulasnäytteet analysoitiin Muhoksen tutkimusasemalla Metsäntutkimuslaitoksen käyttämillä rutiinimenetelmillä.

Tulokset

Jatkolannoitetuilla koealoilla neulasten typpi-, arginiini, fosfori- ja kaliumpitoisuudet alenivat lämpösumman alenemisen myötä (kuvat 1– 4). Neulasten fosforipitoisuus oli tyydyttävä tai hyvä, mutta kaliumpitoisuus oli kylmimmän lämpösummavyöhykkeen (850 d.d.) koealoilla lähellä ankaran puutoksen rajaa (3,5 mg g^{-1}) sekä perus- että jatkolannoitetuilla koealoilla. Lämpimimmän lämpösummavyöhykkeen (1080 d.d.) koealoilla jatkolannoitus korjasi laikkulannoituksen jälkeen ilmenneet fosforin ja kaliumin puutokset (kuvat 3 ja 4). Kylmimmässä lämpösummavyöhykkeessä männyn neulasissa oli ankara typen puutos (N = 1,2 %) riippumatta turpeen kokonaistyppipitoisuudesta, joka jatkolannoitetuissa koejäsenissä oli 0–10 cm:n turvekerroksessa korkeimmillaan 2,64 % ja 10–20 cm:n kerroksessa 3,10 % (taulukko 2, kuvat 5 ja 6). Neulasten arginiinipitoisuudet olivat kylmimmässä lämpösummavyöhykkeessä kaikilla koealoilla, turpeen ja neulasten typpipitoisuudesta riippumatta, alle 0,5 mg g^{-1} (kuvat 7 ja 8), jonka alapuolella valkuaisainesynteesi hidastuu (Pietiläinen & Lähdesmäki 1996). Tällä vyöhykkeellä jatkolannoitus ei todennäköisesti lisäisi puuston kasvua perus- tai jatkolannoituksen jälkeen korkeimmissakaan tällä kasvupaikalla tavatuissa turpeen typpipitoisuuksisssa, vaikka peruslannoituksesta olisi kulunut jo 32 ja jatkolannoituksesta 26 vuotta.

Keskimmäisessä vyöhykkeessä neulasten typpipitoisuus ylitti lievän puutosrajan (N = 1,30 %) jatkolannoitetuilla koealoilla, kun turpeen typpipitoisuus oli yli 1,45 % (kuva 6). Lämpimimmässä vyöhykkeessä vastaavasti neulasten typpipitoisuus ylitti jatkolannoitetuilla koealoilla puutosrajan, kun turpeen typpipitoisuus oli 1,31 %, ja neulasten typpipitoisuus kohosi jyrkästi turpeen typpipitoisuuden lisääntyessä. Tulokset viittaavat siihen, että PK-jatkolannoituksella voitaisiin lisätä puuston kasvua edellämainittuja korkeammissa turpeen typpipitoisuuksissa 950 d.d:n ja 1080 d.d:n lämpösumma-alueilla ja että viimemainitulla kasvu lisääntyisi varsin voimakkaasti turpeen typpipitoisuuden funktiona.

Päätelmät

Tulosten mukaan kasvupaikan kykyä tyydyttää puiden typen tarve eri lämpösummavyöhykkeissä voidaan arvioida turpeen kokonaistyppipitoisuuden avulla. Tulokset osoittavat lisäksi, että puut saattavat kärsiä typen puutoksesta varsin runsastyppisilläkin rämeillä, jos ilman lämpösumma on 850 d.d. tai sitä pienempi. Edelleen näyttää siltä, että PK-lannoituksella tai PK-jatkolannoituksella ei tällaisissa olosuhteissa voida saada aikaan sanottavaa puuston kasvun lisäystä.

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