Effect of Drainage Intensity and Fertilization on Scots Pine Stands Growing on an Oligotrophic Tall Sedge Fen

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The effects of drainage and fertilization and their interactions on soil properties and the nutritional state of a pine stand were studied on a drained pine fen site in Central Finland (65°52' N, 26°07' E, 62 m a.s.l.). The site was drained in 1975 (ditch intervals 10 m, 20 m and 40 m) and fertilized in 1977 (control, PK and NPK fertilization). The study consisted of groundwater monitoring, decomposition tests of the peat substrate, nutrient analyses of the peat and Scots pine needles, and stand increment measurements conducted in the years 1995-1999.

When the ditch interval was reduced, it was found that the groundwater level dropped further down and the decomposition of cellulose in the surface peat layer (0 - 10 cm) was significantly accelerated. In winter, the weight loss of the cellulose samples located in the surface peat layer was clearly greater on the fertilized plots when compared to that on the control plots. A similar effect was observed regarding drainage intensity: the decomposition of cellulose was significantly faster on the strip 10 m in width than on the others. On the narrowest 10 m strips, the total nitrogen and calcium concentrations in the surface peat were significantly higher, and those of potassium significantly lower than on the 40 m strips. Fertilization increased phosphorus concentrations in the surface peat.

The unfertilized stands suffered from nitrogen, phosphorus and potassium deficiencies on the 40 m strips. The nitrogen and arginine concentrations of the pine needles increased with increasing drainage efficiency. The effect of NPK fertilization was not visible in the nitrogen concentration of the needles at the end of the study period. PK and NPK fertilization decreased the concentrations of arginine and boron of the trees growing on the narrower strips, but increased the concentrations of phosphorus of the needles on all the strips 22 years after the application. The boron concentrations of the needles decreased with decreasing strip width and were at their lowest deficiency level on the 10 m strips.

The effect of PK fertilization on stand growth and its nutritional status were visible 19 years later. Tree growth depended both on strip width and the fertilization treatment applied. A clear and significant interaction was noticed between strip width and fertilization: fertilization almost doubled tree growth on the widest 40 m strip, whereas the corresponding response on 10 m strips was fairly weak.

Key words: peatland, nitrogen, nutrients, decomposition, strip width, fertilization, stand volume

Introduction

Site type classifications for wood production on peatlands have been presented by Huikari (1952) and Heikurainen (1959). In both of these classifications, drainage is a prerequisite for profitable wood production. Pristine mires are generally unfavourable as sites for wood production from the viewpoint of the slow peat decomposition and nutrient mineralization due to their high groundwater table and anaerobic conditions. Drainage of mires lowers the groundwater table and improves the soil properties, thereby also accelerating stand productivity. The increased supply of oxygen to the root systems improves tree growth (e.g. Boggie, 1977) and also increases the bacterial biomass and further intensifies the enhanced mineralization of plant nutrients (Lähde 1966, Karsisto 1979a, 1979b, Lieffers 1988).

Wood production on drainage strips of varying widths has been discussed in several studies (Huikari and Paarlahti 1967, Meshechok 1969, Seppälä 1972, Heikurainen *et al.* 1983, Penttilä 1987, Sundström 1995). The results obtained show that stand growth has generally increased with the narrowing of ditch intervals and/or lowering of the groundwater level following drainage. Depending on the inclination and peat depth of the peatland site, ditches 0.6 – 1.1 m in depth and 30 – 40 m in width are currently applied in practical peatland forestry in Finland when carrying out remedial drainage.

Generally, drainage leads to increases in plant available nitrogen and phosphorus due to the accelerated decomposition and increased bulk density of the surface peat layer (Kaunisto and Paavilainen 1988, Laiho and Laine 1994). On the other hand, potassium, boron and zinc stores may remain equal to those in the top peat layer of undrained mires or they can significantly diminish due to leaching and absorption into the vegetation (including the tree stand) (Paavilainen 1980, Finér 1992, Laiho and Laine 1995, Sundström *et al.* 2000).

Tree growth on drained mires is often restricted by lack of phosphorus and potassium. Moreover, especially on nutrient-poor sites and in northern climatic conditions, there is often a simultaneous lack of nitrogen (Paarlahti *et al.* 1971, Kaunisto and Tukeva 1984, Veijalainen *et al.* 1984, Moilanen 1993). Also, the amounts of micronutrients - especially of boron - are low in peat, and can induce growth disturbances in trees on drained mires (Huikari 1977, Veijalainen *et al.* 1984).

Nutrient deficiencies and imbalances in pine stands growing on drained mires have been remedied by fertilization treatments. To ensure good stand growth, fertilization with NPK compound fertilizer is recommended on nitrogen-poor sites, whereas PK fertilization is recommended on nitrogen-rich sites (Paavilainen 1979). Several studies have demonstrated that nutrient application has improved tree growth on drainage areas (e.g. Paavilainen 1972, Kaunisto 1977, Kaunisto 1982, Moilanen 1993, see also Paavilainen and Päivänen, 1995). According to Paarlahti et al. (1971) and Veijalainen (1977), phosphorus, potassium and boron deficiencies can be overcome with PKB fertilization treatments. On nitrogen-poor sites in general, and in the harsh climatic conditions of northern Finland specifically, the importance of adding nitrogen to improve forest growth increases (Penttilä 1984, Moilanen 1993).

The interactions between drainage and fertilization have been examined in some studies (Huikari and Paarlahti 1967, Kaunisto 1977, Heikurainen *et al.* 1983, Sundström 1995, Lauhanen and Kaunisto 1999, Sundström *et al.* 2000). However, the results have been partly contradictory. In older studies fertilization has increased tree stand growth similarly regardless of the drainage intensity (Kaunisto 1977, Heikurainen *et al.* 1983, Sundström 1995). On the other hand, increased drainage maintenance intensity has increased peat and pine needle nitrogen concentrations but decreased the needle boron concentration (Lauhanen and Kaunisto 1999).

There is insufficient knowledge on the changes taking place in the nutrient characters of the substrate and on the nutritional development in a stand as the drainage intensity increases. The practitioners of peatland forestry need to know to what extent fertilization requirements and growth increment following fertilization depends on the efficiency of drainage on the site.

The object of this study was to investigate individual and interaction effects of drainage intensity and fertilization on the nutrient concentrations of peat substrate and on the wood production and nutrient status of Scots pine (*Pinus silvestris* L.) stands on a thick-peated drained mire. We hypothesised that the development of tree stand on drained mires depends on drainage intensity and on the nutrients applied, and that the effect of fertilization depends on the drainage intensity. Accordingly, the changes resulting from these measures should be observable both in the decomposition rate of the surface peat and in the nutrient concentrations of the tree stands.

Material and methods

Field experiment

The study was conducted in an oligotrophic tall-sedge pine fen, partly a cottongrass sedge pine fen (classification by Laine and Vasander 1990) located in Central Finland, Muhos (65°52' N, 26°07' E, 62 m a.s.l.). The pole stage Scots pine stand (mean height 3–4 m) growing on the site was of natural origin. The thickness of the peat layer was over one metre. The site was drained in 1975 applying three strip widths, which were randomized on the area: 10 m, 20 m and 40 m. The ditches were 90 cm deep.

The fertilization treatments on each strip width were carried out in 1977 and they consisted of (a) an unfertilized control, (b) PK (phosphorus-potassium) fertilization and (c) NPK (phosphorus-potassium-nitrogen) fertilization. The fertilizers used were the following: PK fertilizer for peatlands (P 10.5%, K 12.5%) at the rate of 400 kg ha^{-1} and urea (N 46 %) at the rate of 200 kg ha^{-1}. Each fertilization treatment was repeated three times on each strip width. The size of the plots was 0.16 ha.

Measurements and analyses

The data were collected in the years 1995 – 1999. Three groundwater table wells (0.9 m in depth and 21 mm in diameter) were drilled on each plot in the middle of the strip in line with the ditches. The groundwater table depth (= the distance between groundwater table and peat surface) was monitored at two-week intervals from July to September in 1995.

The relative index of microbial activity (fungi and bacteria) and decomposition rate in the surface peat was obtained as a result of the cellulose decomposition test. Pieces of cellulose (70 mm x 35 mm x 1 mm, mesh size 0.20 mm) were dried at 50°C for 48 hours, weighed and then placed in nylon-net bags into the peat at a depth of 7-8 cm (24 pieces on each plot in the centre of the strip). The sets of bags were kept buried in the peat from 9th June to 29th September in 1995 and from 29th September 1995 to 3rd June 1996. At the end of each period, the pieces of cellulose were dug up, cleaned, dried at 50°C for 48 hours and then weighed.

Four composite peat core samples per each plot were taken in September 1999. Each sample consisted of five sub-samples collected equally from different parts of the plot. The living vegetation and non-decomposed plant material at the top of the peat cores were discarded and the following 0-5 cm, 5-10 cm and 10-20 cm layers were separated and put into plastic bags and stored at –21 C°. After drying (at 70 °C for 48 hours) and weighing, the nutrient concentrations were determined. The samples were analysed for their ash content and total nutrients (P, K, Ca, B) following HCl digestion (Halonen *et al.* 1983). The concentrations of N and NH_4-N were determined using the Kjeldahl method, K and Ca concentrations by using an atomic absorption spectrophotometer (AAS-method), B concentration was determined spectrophotometrically by using the azomethine-H method, and that of P by using the vanado-molybdate method (see Halonen *et al.* 1983).

In the winter of 1999, foliar samples were taken from 8 dominant or co-dominant trees selected from the centre of the plot parallel to the ditches. The highest lateral current branch produced in the previous summer on the southern side of each sample trees pine was taken as a sample. The current intact needles from each sample tree were put into separate plastic bags and stored at -21°C to await nutrient analyses. The needle samples from each tree were analysed individually. The nitrogen concentrations of the needle samples were determined using the Kjeldahl method as outlined by Halonen *et al.* 1983. After dry combustion and dissolving in hydrochloric acid, K concentrations were determined using an atomic absorption spectrophotometer (AAS-method, Hitachi 100-40). The concentrations of B were determined using the azomethine-H method, and that of P using the vanado-molybdate method as outlined by Halonen *et al.* (1983). The free arginine concentrations in the needles were determined using the method introduced by Sakaguchi (1951) as modified by Messioneo (1966) and Pietiläinen *et al.* (1996).

The Scots pine stands were measured in the autumn of 1995. The trees were counted according to their breast height diameter classes (cm). The heights (dm) and diameters at breast height (d1.3, mm) of randomly chosen 24 sample trees from each plot were measured. The height increments of the sample trees was focused on two five year periods (1967-71 and 1972-76) before the establishment of the experiment, and periods 1977-81, 1982-86, 1987-91 and 1992-95 after establishment of the experiment. The development of tree stand volume during the study periods was calculated using the equations described by Heinonen (1994).

The effects of drainage and fertilization treatments on the soil and tree stand characteristics were estimated by applying one and two-way analyses (SPSS Base 8.0, 1998). The treatment effects and the interactions between the treatments and experiments were analysed according to the following ANOVA-model:

$$y = S + F + SF + å,$$

where y is the value of response (element concentrations of peat and needles, decomposition rate and tree growth), S is the strip width, F is the fertilization treatment, and å is a random variable (error). The responses in the groundwater table depth in the summer of 1995 were tested with the GLM repeated measures procedure. The statistical significance of the differences between the treatments versus the unfertilised control was analysed using Tukey's paired t-test.

Results

Changes in substrate properties

Depending on strip width, the groundwater table depth within the experimental area varied from 30 to 53 cm in mid-July 1995 (Figure 1). The groundwater table was at its lowest underlying the 10 m strip and highest underlying the 40 m strip. Through the summer, the differences between strip widths increased. From the end of September onwards the groundwater level began to rise underlying the 40 m strips. The intensification of drainage decreased the variation in water table level. The differences between the strip widths were statistically significant. Also, fertilization appeared to influence the water table level, but its effect was distinct only in a few cases: interaction between fertilization and measure point of time was significant according to repeated measure procedure ($p < 0.05$). Analyses also revealed a significant interaction between strip width and fertilization, and between strip width and measure point of time. The fertilization effect became apparent mainly in the autumn.

During the summer of 1995, the decomposition of the pieces of cellulose sheets was not significantly

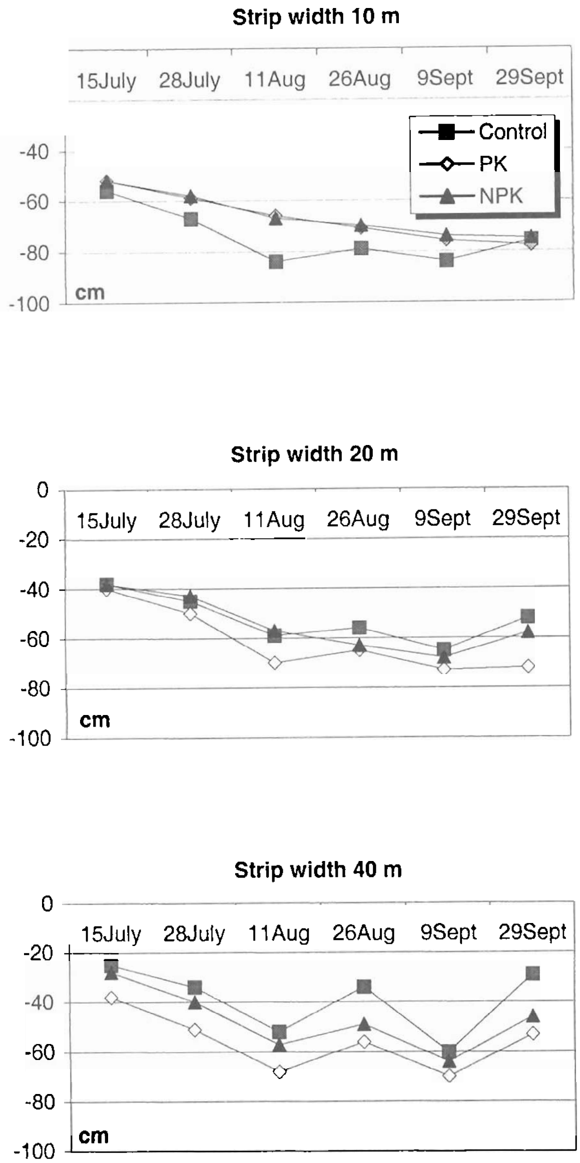


Figure 1. The groundwater table depth (cm) by strip widths and fertilization treatments in July – September 1995

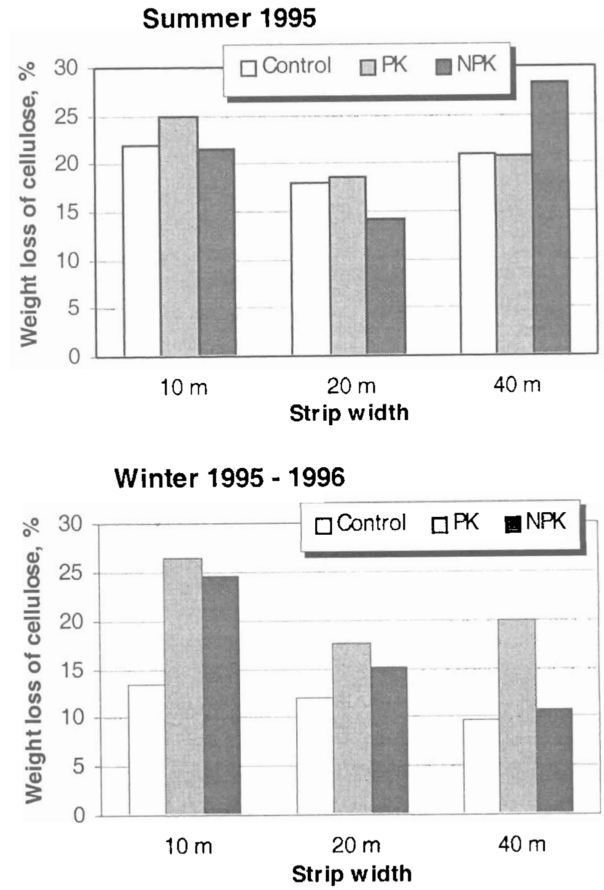


Figure 2. The decomposition rate of cellulose sheets in soil during summer time in 1995 (upper columns) and winter time in 1995-96 (under columns) by strip widths and fertilization treatments

influenced by fertilization nor drainage efficiency (Figure 2). The weight loss due to decomposition was the same order of magnitude for the pieces buried in the 10 m and 40 m strips (23%) than for those buried in the 20 m strip (17%). In the winter of 1995-1996, the decomposition of cellulose was statistically fastest in the peat of the 10 m strips. The mean weight losses were the following: 10 m strips 21%, 20 m strips 15% and 40 ms strip 13%. Weight loss was clearly greater in the peat of fertilized plots than in the peat of the control plots; the difference between the control and PK treatment was statistically significant. There were no interaction effects between fertilization treatments and strip width.

The effects of drainage and nutrient application were observed in the nutrient concentrations of the surface peat at the end of the study period. In the case of the narrowest 10 m strips, the total nitrogen and calcium concentrations in the surface peat (0 – 5 cm) were significantly higher, and potassium concentration was significantly lower than those of the 40 m strips (Table 1). Fertilization had the effect of increasing phosphorus concentrations in the peat layer 0 – 5 cm.

Nutrient status of tree stand

The highest foliar nitrogen concentrations were found in the trees growing on the unfertilized plots on 10 m strips. A decrease in the foliar nitrogen concentration with the increasing strip width was signif-

Table 1. Mean nutrient concentrations on different strip widths regardless of fertilization (left side), and on different fertilization treatments regardless of strip width (right side) in surface peat in September 1999. Underlined bold values indicate statistical difference ($p < 0.05$) compared to 10 m strip (= test between strip widths) and compared to control plot (= test between fertilization treatments).

PEAT LAYER 0 - 5 CM

	Strip width, m			Fertilization treatment		
	10	20	40	Control	PK	NPK
N_{tot}, mg g^{-1}	19	17	**15**	16	16	20
NH_4-N, µg g^{-1}	118	92	112	135	90	68
P, mg g^{-1}	0.99	0.88	0.89	0.77	**1.01**	**1.00**
K, mg g^{-1}	0.46	**0.58**	**0.58**	0.49	0.54	0.59
Ca, mg g^{-1}	3.0	2.5	**2.3**	2.4	2.6	2.8
B, mg kg^{-1}	2.5	2.4	2.5	2.5	2.0	2.3

PEAT LAYER 5 - 10 CM

	Strip width, m			Fertilization treatment		
	10	20	40	Control	PK	NPK
N_{tot}, mg g^{-1}	23	22	24	24	24	22
NH_4-N, µg g^{-1}	102	**169**	**158**	159	120	116
P, mg g^{-1}	1.07	1.18	1.21	1.08	1.14	1.17
K, mg g^{-1}	0.33	**0.39**	**0.47**	0.41	0.41	0.33
Ca, mg g^{-1}	2.1	**1.7**	**1.7**	1.8	1.9	1.9
B, mg kg^{-1}	1.7	1.8	1.7	1.6	1.8	1.9

PEAT LAYER 10 - 20 CM

	Strip width, m			Fertilization treatment		
	10	20	40	Control	PK	NPK
N_{tot}, mg g^{-1}	22	23	23	23	23	22
NH_4-N, µg g^{-1}	60	**86**	**96**	84	86	69
P, mg g^{-1}	0.85	0.80	0.92	0.81	0.91	0.86
K, mg g^{-1}	0.17	0.16	0.25	0.19	0.18	0.20
Ca, mg g^{-1}	2.3	1.8	2.1	2.4	1.9	1.8
B, mg kg^{-1}	1.6	2.5	1.4	1.7	0.9	2.8

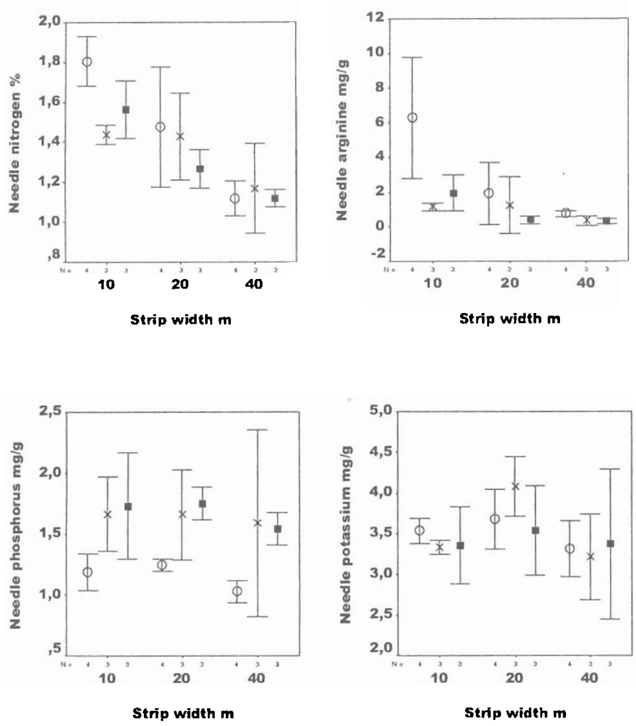
icant (Figure 3). The foliar nitrogen concentrations on the 20 m and 40 m control strips were close to the deficiency level 1.2 % (see Reinikainen *et al.* 1998). Fertilization treatments applied 22 years ago had the effect of decreasing the nitrogen concentrations of the needles; it was at its maximum on the 10 m strips. PK and NPK fertilization treatments did not differ from each other.

The highest arginine concentrations were encountered in the unfertilized stands growing on the narrowest strips (Figure 3). A decrease in the arginine concentrations of the needles with the increasing strip width was significant. On the 40 m strips, the arginine concentrations were less than 0.5 mg/g. PK and NPK fertilization significantly decreased the foliar arginine concentrations of trees growing on the 10 m strips.

Phosphorus deficiency was observed in the needles of trees on all of the unfertilized plots regardless of strip width (Figure 3). PK and NPK fertilization significantly increased the phosphorus concentrations of the needles and phosphorus deficiencies (concentration below 1.3 mg g^{-1}, see Reinikainen *et al.* 1998) were remedied on all the strips. The potassium concentrations of pine needles on the unfertilized plots were close to the deficiency level 3.5 mg g^{-1}. PK and NPK fertilization slightly increased potassium concentrations but the concentrations were still alarmingly low. The boron concentrations in the pine needles significantly differed between the unfertilized 10 m and 40 m strips. The effect of fertilization on the boron concentrations of the needles remained minor and the boron values on plots treated with PK and NPK fertilization on the 10 m strips were at the deficiency level 5 mg kg^{-1} (Reinikainen *et al.* 1998).

Stand growth development

Growth development of the pine stand depended both on strip width and fertilization treatment (Figure 4). On the 10 m strips on the control plots the annual mean height increment, during the entire study period 1977 – 1995, was 25 cm, which was significantly higher than in the controls of the 20 and 40 m strips. PK and NPK fertilization significantly increased height



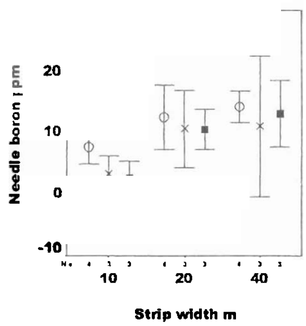


Figure 3. The nutrients (N, P, K, B) and arginine concentrations in the pine needles by strip widths and fertilization treatments in the winter of 1999
(o = Control, x = PK fertilization and ■ = NPK fertilization. The error bars indicate 95% confidence level and N = number of samples)

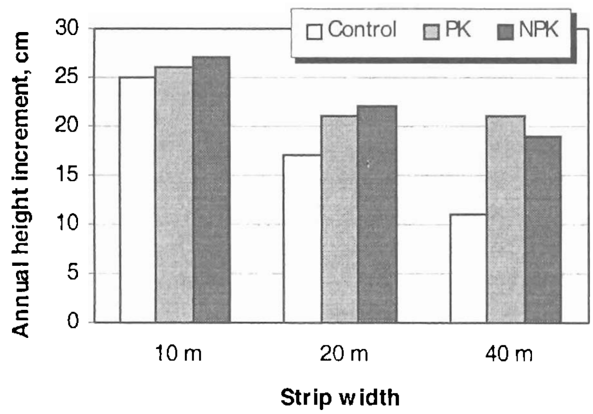


Figure 4. Annual height growth (cm) of tree stand during the years 1977 – 1995 by strip widths and fertilization treatments

increment. A clear and significant interaction effect was noticed between strip width and fertilization: fertilization almost doubled tree growth on the widest 40 m strip, whereas the corresponding response on 10 m strips was fairly weak.

Tree growth in the years 1992 - 1995 showed a similar trend as was observed for the entire period (Figure 5). The differences between the different strip widths were still significant, but the effect of the fertilization on tree growth appeared to weaken towards the end of study period, especially on 40 m strips. However, the needle weight of the pines in 1995 was still a little higher on the PK-fertilized plots than on the control plots.

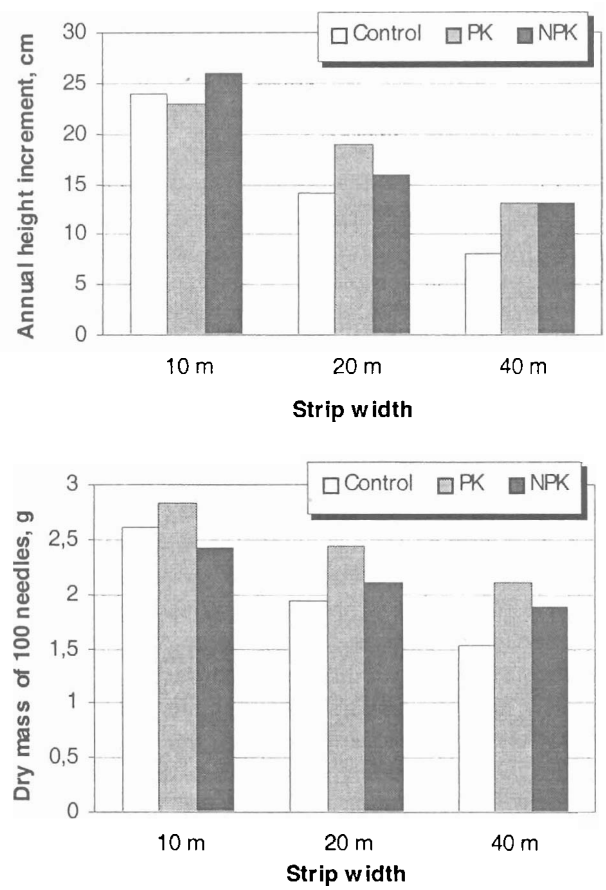


Figure 5. Annual height growth (cm) of tree stand during the years 1992 – 1995 and dry mass (g per 100 needles) of needles in 1995

In 1995, the total volume of the tree stand varied between 17 $m^3 ha^{-1}$ and 68 $m^3 ha^{-1}$, depending on the fertilizer treatment and the strip width. When the area taken up by the ditches was taken into consideration, the mean stand volume of the unfertilized plots located on the 10 m and 20 m strips was 37 and 40 $m^3 ha^{-1}$ and on the 40 m strips it was 20 $m^3 ha^{-1}$ (Figure 6). On

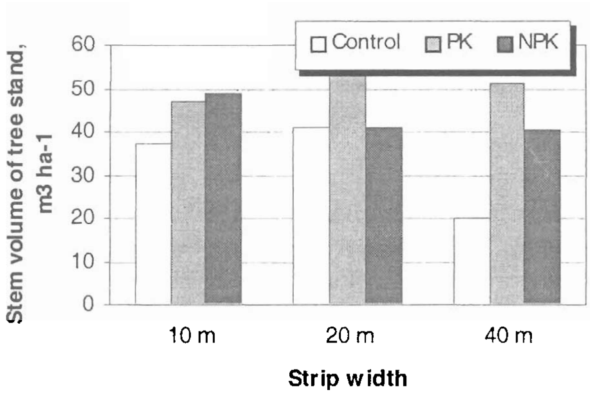


Figure 6. Stem volume (m^3 ha^{-1}) of tree stand by strip widths and fertilization treatments in 1995

the fertilized plots, stand volume varied from 40 m^3 ha^{-1} to 53 m^3 ha^{-1}. On the PK-fertilized plots, the stand volume was significantly higher than on the unfertilized plots. The interaction between strip width and fertilization was significant; overall, the fertilization effect was detected only on the 40 m strips.

Discussion

In this study, ditch spacing proved to be an important variable in determining drainage efficiency: the depth of the groundwater table level was at its lowest underlying the narrow strips. Also, the fluctuation of the groundwater level during the summer was at its minimum underlying the narrowest strips. This complies with the results of previous studies (e.g. Huikari *et al.* 1966). The objective of drainage is to lower the groundwater table to a depth of at least 35 – 55 cm, depending on the site and peat type, in order to ensure sufficient aeration and favourable conditions for the root systems of trees (Paavilainen and Päivänen 1995). This precondition was fulfilled in this study during the latter part of the growing season in plots representing all strip widths. It should also be borne in mind that the groundwater wells were situated in the middle of the strips where the groundwater table level is at its highest. The conclusion is that the tree stand did not suffer from excess water during the study period.

Height increment and stem volume increment were both promoted along with drainage efficiency as strip width decreased from 40 m to 10 m. The long-term and short-term growth patterns were similar. The results obtained were consistent with previous research results on the effect of strip width on stand development: as drainage becomes more intense, stand development speeds up (Huikari and Paarlahti 1967, Meshechok 1969, Seppälä 1972, Heikurainen *et al.* 1983, Penttilä 1987, Lauhanen and Ahti 2001). According to the results obtained by Huikari and Paarlahti (1967), the effects of drainage along with that of fertilization on height development were at their maximum when the groundwater level dropped from 10 cm to 50- 70 cm (see also Karsisto 1979a). Seppälä (1972) discovered that by increasing strip width from 20 m to 60 m had the effect of reducing stand growth and volume. Heikurainen et al. (1983) found that after drainage the height development of pine stands on nutrient-poor bogs was so much the faster the narrower the strips were (the treatments were 10 m, 20 m and 30 m). The enhanced growth conditions of trees growing on narrow strips were a consequence of the lower water table.

The nitrogen concentration of the surface peat increased with decreasing ditch spacing and was highest on the narrowest strip as was observed by Lauhanen and Kaunisto (1999). The effect of fertilization was evident in the nutrient status of surface peat even 22 years after the application. However, the effect was restricted mostly to the 0 – 5 cm peat layer and it was confined to phosphorus. Similar results have been observed also earlier: in the study by Sundström et al. (2000) more than half of the added phosphorus and 10 – 20 % of potassium were detected in the surface peat layer 22 years after the fertilization treatment.

In this study, the pines had suffered from phosphorus and potassium deficiencies prior to the fertilization treatment (for deficiency limits see Reinikainen *et al.* 1998). Fertilization treatments increased tree growth most of all on the widest 40 m strips. On the narrower strips, the nitrogen nutrition was adequate and the effect of the additions of the main nutrients (PK) were fairly modest. The result is similar to that obtained by Penttilä (1987). In his study fertilization increased stand growth on 30 m and 50 m strips and decreased it on narrower strips.

The effect of nitrogen application with phosphorus and potassium (NPK treatment) could not be detected in the height growth of tree stand 18 years after the fertilization. Several studies have shown that the duration of nitrogen fertilization effect on tree growth is relatively short - less than ten years - especially on nitrogen-rich sites (Kaunisto 1977, Paavilainen 1977, Moilanen 1993).

Studies conducted by Kaunisto 1977, Heikurainen *et al.* (1983) and Sundström (1995) showed that NPK fertilization increased tree stand growth equally on plots representing all the strip widths - the data were collected from nutrient-poor and nitrogen-deficient drained mires, where nitrogen probably limited tree growth also in the efficiently drained areas. In this study, the site type in question was relatively rich in nitrogen. The results of needle analysis enable one to conclude that the availability of nitrogen for the trees had improved essentially as a result of efficient drainage and that this resulted in maximal height increment reaction, which masked part of the PK-fertilization reaction. Moreover, on the 10 m strips, all the sample trees were located by the sides of ditches where the nitrogen mobilization is high (Lähdesmäki and Piispanen 1983).

On fertilized 40 m strip plots - where the increased tree growth was most conspicuous - the groundwater table was lower than on the corresponding unfertilized plots. Presumably the tree stand's increased volume due to fertilization has resulted in greater interception and transpiration, which had then lowered the groundwater table. This possibility has been discussed also in previous studies (Heikurainen and Päivänen 1970, Päivänen 1982, Laine 1986).

Karsisto (1979a), among others, presented results on cellulose decomposition activity and the increase in microbial activity as drainage efficiency increases. In this study, the phenomenon was encountered only during the winter, from October to May, when the drop in the weight of cellulose on average was so much greater narrower the strip in question.

Fertilization had a somewhat confusing impact on the decomposition of cellulose: the treatments appeared to increase the decomposition rate during the winter whereas in summer the differences in the decomposition rate were very small. The effect of NPK and ash fertilization on cellulose decomposition - indicating microbe biomass and basal respiration activity – has been observed also in other studies (Karsisto 1979a, 1979b, Paavilainen 1980). In the results obtained by Brække and Finér (1990), fertilization improved cellulose decomposition in the surface peat of a low-shrub pine bog both in summer and in winter.

Despite the high nitrogen concentrations in the peat, nitrogen deficiency affected the needles of trees forming the unfertilized stands in the middle of the 40 m strips and the nitrogen concentrations increased with increasing drainage efficiency. The mean nitrogen concentrations of the control stands were sufficient on the narrower (10 and 20 m) strips. The results are in agreement with the results presented by Lauhanen and Kaunisto (1999): as drainage maintenance intensity increased the foliar nitrogen content was higher.

According to Paarlahti et al. (1971), PK-fertilization decreases the foliar nitrogen concentrations of pines growing on drained mires. In this study, this proved to be the case in stands growing on 10 m strips. The foliar nitrogen concentrations in the fertilized stands on the 10 and 20 m strips were well over the deficiency level (1.30 %). In this study, the addition of nitrogen had no effect on the foliar nitrogen concentrations.

Foliar nitrogen concentrations can be quite high if there is an excess of available nitrogen with a simultaneous shortage of mineral nutrients in peat and needles (Paarlahti *et al.* 1971, Kaunisto 1982, 1987, Pietiläinen *et al.* 1996) as was the case in this study on the 10 m strips. In such a situation, trees store excess nitrogen as arginine (Pietiläinen and Lähdesmäki 1986, Pietiläinen *et al.* 1996). If mineral nutrients are added, trees utilize their arginine stores, tree growth increases, and foliar nitrogen concentrations decrease (Pietiläinen *et al.* 1996). The decrease in foliar nitrogen concentration due to PK and NPK fertilization has been demonstrated in several other studies, too, focusing on peatland forests in Finland (Paarlahti *et al.* 1971, Kaunisto 1982, 1987, Moilanen 1993). In this study, PK and NPK fertilization decreased the arginine concentrations of the needles on all strip widths. These concentrations were extremely low in the stands on the 40 m strips, indicating nitrogen deficiency in these stands.

Regardless of strip width, the phosphorus concentrations were below the deficiency level (1.4 mg g^{-1}) in the needles of trees growing on the control plots. Both PK and NPK fertilizations increased the phosphorus concentrations of the needles and eliminated the phosphorus deficiencies, thereby serving to indicate that the effect of the applied phosphorus still continued. Hartman et al. (2001) showed that the effect of broadcast fertilization can last for 25 - 30 years (see also Kaunisto 1989).

Paarlahti et al. (1971), Sarjala and Kaunisto (1993 and 1996) determined the potassium deficiency level as being at 3.5 mg g^{-1}. In this study, the potassium concentrations were low on plots representing all strip widths. Evidently the effect of the added potassium had ceased in 22 years: earlier investigations have shown that the effect of potassium fertilization with potassium chloride on tree growth or nutrient status lasts for about 15 – 20 years (Kaunisto 1989, 1992). The high N/K ratio of the needles also indicated decreasing potassium contents. Several factors can affect foliar potassium concentrations. In this study, the most likely reason for the decrease in the potassium concentrations of the foliage was simply its scarcity in the substrate, which is characteristic of this kind of thick-peated fens (Kaunisto and Paavilainen 1988).

The applied fertilizers did not contain boron. The boron concentrations of the needles were effected by the interaction of drainage intensity and fertilization. On 10 m strips, the boron concentrations in the needles of the fertilized trees diminished close to the deficiency level of 7 mg kg^{-1}. The N/B ratio of the needles increased as drainage efficiency increased. Lauhanen and Kaunisto (1999) also observed low boron concentrations on drainage maintenance areas.

It appears to be inevitable that pine stands on the 10 m strips will run into boron deficiencies. In cases where stands have suffered from severe boron deficiency alone or accompanied by concurrent potassium deficiency, frequent apical dieback has been observed in pine stands (Huikari 1977, Reinikainen *et al.* 1998). To avoid such situations, boron containing peatland fertilizers should be used.

Conclusions

The results show that in Northern Central Finland the narrowing of strip width of thick-peated tall-sedge fen drainage areas improves the nitrogen status in the stands, but it also causes potential problems with respect to sufficiency of mineral nutrients. On more efficiently drained shoulders and narrow strips (10-20 m), powerful nitrogen mineralization and improved tree growth deplete potassium and boron stores and enhances PKB fertilization requirement as the nutrient stores are depleted. As the fertilization effects are most beneficial on the presently recommended 40 m strips, the narrowing of the strips from 40 m is not justified even when fertilization treatments are considered: as the drainage intensity increases the cost of drainage as well as the wood production area lost in the ditches increases. If thick-peated areas are drained intensely applying narrow strips, boron-containing PK or NPK fertilizers must be used to prevent the occurrence of potassium and boron deficiencies.

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ВЛИЯНИЕ ИНТЕНСИВНОСТИ ОСУШЕНИЯ И УДОБРЕНИЙ НА СОСНЯКИ, ПРОИЗРАСТАЮЩИЕ НА ОЛИГОТРОФНОМ БОЛОТЕ

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Резюме

Целью исследования было выяснение роста и содержания питательных веществ у сосны в зависимости от осушения и добавления питательных веществ на олиготрофном болоте. Гипотеза заключалась в том, что увеличение интенсивности осушения ускоряет как процесс минерализации питательных веществ торфа, так и рост древостоя.

Объект исследования осушен в 1975 г. (ширина осушенных полос 10 м, 20 м и 40 м). В 1977 году внесены удобрения (без удобрений, обработка PK, обработка NPK). В 1995-1999 годах замерены и проанализированы параметры древостоя и местопроизрастания.

Осушение и удобрение положительно влияли на гидроструктуру торфа и параметры, характеризующие его питательность, а также на содержание питательных веществ в древостое и его рост. На узких полосах 10 и 20 м в летний период уровень грунтовых вод падал, распад целлюлозы происходил быстрее, чем на широких полосах 40 м. Удобрения ускорили распад целлюлозы в верхнем слое торфа в зимний период. В течение зимы 1995-1996 г. потери в массе целлюлозных брикетов в поверхностном слое торфа составили соответственно 21 % на 10-метровых полосах, 15 % на 20-метровых и 13 % на 40-метровых полосах. На 10-метровых полосах величины концентрации общего азота, аммиачного азота, и содержания фосфора были наибольшими, но значения калия и бора были значительно ниже, чем на 40-метровых полосах. Внесение удобрений привело к повышению содержания фосфора и калия в торфе и к уменьшению концентрации аммиачного азота. Неудобренные сосны на широких полосах страдали от недостатка азота, фосфора и калия (пределы дефицита: N = 12 мг/г, P = 1,4 мг/г, K = 3,5 мг/г). Значения содержания азота и аргинина в хвое росли по мере увеличения интенсивности дренажа. Обработка удобрениями повышает концентрацию фосфора и калия в хвое на всех полосах и - к снижает концентрации бора и аргинина на узких полосах. По мере сужения полосы параметры содержания бора явно уменьшались. Уменьшение ширины полосы приводит к улучшению состояния насыщенности азотом сосняка на олиготрофных болотах с толстым слоем торфа. Возможна проблема получения азота и других питательных веществ: с улучшением роста и увеличением биомассы древостой связывает значительную часть запасов содержащихся в торфе минеральных веществ (P, K, B) и, таким образом, увеличивает необходимость использования удобрений по мере истечения запасов вышеупомянутых питательных веществ. Влияние удобрений наиболее выражено на широко используемых в настоящее время полосах шириной 40 м.

Сужение полосы необосновано, поскольку возрастают расходы по дренажу и увеличивается выпадающая из древопроизводства площадь, необходимая для создания дренажных каналов. При выполнении дренажа с узкими полосами на участке с толстым слоем торфа, в качестве удобрения следует применять борсодержащее PK-удобрение с целью предотвращения возникновения состояния питательного истощения.

Ключевые слова: торфяная почва, болото, питательные вещества, разлагающее воздействие торфа, ширина полосы, внесение удобрений, рост древостоя, грунтовые воды.