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Effect of drainage maintenance on the nutrient status on drained Scots pine mires

Kunnostusojituksen vaikutus rämeiden ravinnetilaan

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The effects of drainage maintenance on the nutrient contents in peat and Scots pine needles on drained pine mires were studied. The material consisted of twelve Finnish field experiments. Drainage maintenance (increasing ditching intensity; no treatment at all, mere ditch cleaning, mere complementary ditching, and both of them together) was carried out in 1982–1985. The needles were sampled in 1994–1995 and peat in 1996. There were great differences in the site types and consequently also in the peat and needle nutrient concentrations between the experiments. The needle Mn concentrations demonstrated a fairly good drainage status in all the treatments. Drainage maintenance had only minor effects on the nutrient status of peat and needles. Ditch cleaning decreased magnesium, manganese and zink amounts in the surface peat. Increasing the intensity of drainage maintenance increased the 100-needle dry mass, but decreased the needle boron concentrations. Peat and needle nitrogen concentrations increased slightly (not significantly) along with the increased intensity in drainage maintenance. The peat nutrients classified correctly 83.7% of the fertility classes for drained peatlands.

Key words: complementary ditching, ditch cleaning, forest drainage, needles, nutrients, peat, Scots pine

INTRODUCTION

The area of drained peatlands was about 4.7 million hectares in Finland according to the 8th National Forest Inventory (1989–94), while the area of drained mineral forest soils was 1.1 million hectares (Tomppo 1998). The annual stand growth was 17.7 million cubic metres on sites classified as peatlands. The growth increase due to peatland forest drainage was about 10.5 million cubic metres per year (Tomppo 1998). Deterioration of ditches, however, may hamper forest growth in the long run (Heikurainen 1980). In the 8th National Forest Inventory the need for drainage maintenance was estimated to be 1.46 million hectares within the next ten years (Tomppo 1998). Thus the positive growth trend of peatland forests depends on the activity of forest improvement operations, i.e. drainage maintenance and also in many cases forest fertilization (Kaunisto & Paavilainen 1988, Tomppo 1998).

Presently, forest drainage is almost exclusively performed as drainage maintenance on old drainage areas, and first drainage (i.e. the drainage of undrained peatlands) is not carried out at all (Tomppo 1998). The aim of drainage maintenance is to maintain the level of stand growth achieved by the first ditching. Drainage maintenance lowers the ground water table (Päivänen & Ahti 1988, Ahti & Päivänen 1997). Consequently, aeration in the root zone of trees is improved by drainage maintenance. Raitio (1982) demonstrated that needle manganese concentrations increased even to a toxic level if forest ditches did not function properly and if there were anaerobic soil conditions (see also Veijalainen 1977). On the other hand, lowering the ground water table may also lower the mean temperature in the surface peat (Hytönen & Silfverberg 1991). On the whole, however, the activity of micro-organisms in peat increases (Huikari 1953, 1954, Lähde 1969), and the enhanced microbial activity increases nutrient cycling between trees and peat soil (Karsisto 1979).

Huikari and Paarlahti (1967) stated that in addition to adequate drainage, also the nutrient stores in a peatland forest ecosystem must be sufficient to secure timber production. Paarlahti *et al.* (1971) demonstrated that the variation on the height growth of Scots pine on peatlands can be explained fairly well with models including peat and needle nutrients. Especially the peat total nitrogen concentration seems to be an essential element when estimating the potential tree growth on a site (Kaunisto 1982, 1987). Presently, the effects of drainage maintenance on the nutrient status of the substratum and trees are discussed, because nutrient leaching may increase due to drainage maintenance and simultaneously occurring thinnings. Especially the decrease in potassium stores due to tree harvesting may be critical (Kaunisto 1988, 1995, Kaunisto & Paavilainen 1988, Finér 1992). In practice nutritional aspects have a very important role in the silvicultural decision making in peatland forest ecosystems (Kaunisto 1988, 1995, see also Lauhanen *et al.* 1995). The relationships between drainage maintenance and the nutrient status of trees and peat soil have not been studied earlier.

It is often difficult to determine visually the wood productivity level in an old drainage area, since different site improvement and silvicultural measures cause drastic changes in vegetation (Sarasto 1961, Laine & Vasander 1990). Needle and peat analyses may give additional information for an objective determination of site productivity, which is essential when deciding the sensibility of drainage maintenance in a certain peatland area.

The first aim of this study was to find out if drainage maintenance affects the peat nutrient status and tree nutrition on Scots pine mires within about ten years after the drainage improvement measures. The second aim was to study the relationships between the peat and needle nutrients. The third aim was to find out how well the concentrations of the peat and needle nutrients agree with the visually determined site fertility classes according to Laine & Vasander (1990).

MATERIAL AND METHODS

Experimental sites

Twelve field experiments involving different drainage maintenance treatments were established in 1982–1985 (Fig. 1). The ditches in the Puolanka experiment, however, had been cleaned once in 1950. A detailed description of the experimental fields has been given earlier (Päivänen & Ahti 1988, Ahti & Päivänen 1997). The aim of the original experimental layout was to study the effects of the drainage maintenance treatments on stand growth and the ground water table variation on drained Scots pine mires.

The following treatments were involved: ditch cleaning, complementary ditching and a combined treatment including ditch cleaning and complementary ditching. Also a control treatment representing the first ditching was included in the experiments. An experiment included 4–22 plots. There were 1–4 control plots depending on the experiment (Table 1).

The site types varied from a poor cotton grass pine bog (TR) to a herb-rich sedge birch pine fen (RhSR) (Table 1). The experiments are located in between Leivonmäki and Taivalkoski municipalities (Fig.1). Most experiments had been fertilized with 400–500 kg ha^{-1} of the PK fertilizer in the 1960s or in the 1970s (Table 1). The finely ground rock phosphate (Frp) fertilizer had been applied at Puolanka (600 kg ha^{-1}) with 200 kg ha^{-1} of potassium chloride at Pyhäntä (350 kg ha^{-1} of Frp). Sites without thinnings or forest fertilizations within the last ten years prior to drainage maintenance were selected with only one exception, the experiment at Kuhmo, which had been fertilized with 450 kg ha^{-1} of PK in 1984. No fertilizations or thinnings were carried out during the study period, since the original aim of the experiments was to find out the effect of mere drainage maintenance on stand growth.

Data collection and analyses

The peat samples were taken in 1996. Five volumetric subsamples per each experimental plot were taken from 0–10 and 10–20 cm peat layers after cutting off the living vegetation. Four samples were taken halfway between the plot centre point and the plot corner. One sample was taken in the plot centre. On the complementary ditching plots, however, the centre point sample was taken five metres from the complementary ditch. The subsamples were pooled by layers for each experimental plot.

The peat samples were stored at – 25°C. The dry weights of the samples were determined at 105°C. The total nitrogen was analyzed by the Kjeldahl method. The other samples were extracted with HNO_3 and H_2O_2, and digested by MDS 2000 microwave oven. The total nutrient concentrations were analyzed by the ICP emission spectrometer, ARL 3580 after digestion (Halonen *et al.* 1983).

The needle samples were collected during tree dormancy in winter 1994–1995. Five trees of the dominant canopy layer in the middle of each sample plot were selected. The needle samples were taken from the topmost, south-facing whorl using a long sampling pole with a cutting device and pooled to represent each experimental plot.

The needle samples were stored at – 25°C. The nutrients were analyzed according to the normal procedures used by the Finnish Forest Research Institute (Halonen *et al.* 1983). All the samples were dried at + 70°C, and then milled. Nitrogen was analyzed by the Kjeldahl method. The other samples were dry ashed at + 550°C and extracted with HCl (0.1 M). Phosphorus (P) and boron (B) were analyzed spectrophotometrically. Potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe) and zinc (Zn) were analyzed by an atomic absorption spectrophotometer. In addition, the 100-needle dry mass of each sample was measured.

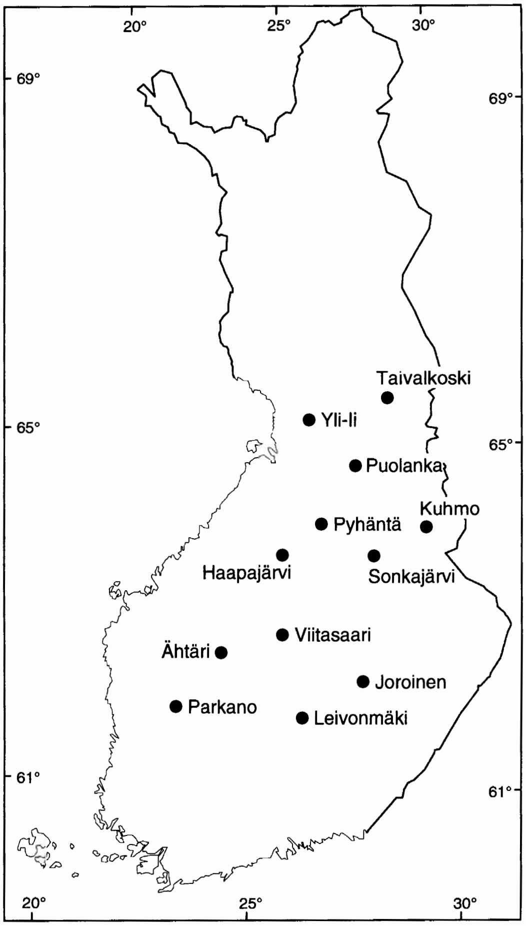


Fig. 1. Location of drainage maintenance experiments.

Kuva 1. Kunnostusojituskokeiden sijainti.

Calculations

The effect of drainage maintenance on the total nutrient concentrations was investigated for the whole dataset and for each experiment separately, since the experimental approach was assumed to provide background information for the stand growth evaluations to be published later. The deficiency and optimum needle nutrient levels defined in some earlier studies were used as reference (Paarlahti *et al.* 1971, Sarjala & Kaunisto

1993, Reinikainen *et al.* 1998).

Differences in the peat and needle nutrient concentrations caused by the drainage maintenance treatments, temperature sum or the experiments were studied by the two-way analysis of variance and covariance using the peat nitrogen concentrations or peat depth as covariates (Ranta *et al.* 1989). The effects of the drainage maintenance treatments on nutrients were also studied by the one-way analysis of variance with Tukey's test. All twelve experiments had a control versus ditch cleaning treatment, but only ten experiments (Parkano and Haapajärvi excluded) included all the four drainage maintenance treatments in the calculations. At Yli-Ii and at Puolanka the results were also calculated by the blocks because of the distance of some hundred metres between the blocks and the assumed variation in site types and stand volumes.

After checking the distribution of the variables, correlation analyses with Pearson's coefficients (Ranta et al. 1989) were carried out to find out the relationships between the needle nutrient concentrations and the peat nutrient amounts per hectare. The correlations between the peat and needle nitrogen concentrations were calculated in three temperature sum regions. In the correlation analysis, however, only the experimental plots with a complete needle and peat nutrient data (102 plots) were included. This data contained plots from all the experiments. The effects of the temperature sum, the peat nitrogen concentration and

Table 1. Some basic data on the experiments. — = missing information.

Taulukko 1. Kokeiden taustatiedot. — = puuttuva tieto.

Experiment *Koe*	Temperature sum *Lämpösumma* d.d.°C	Site type[1)] *Suotyyppi[1)]*		Peat layer *Turvekerros* m	Ditch spacing *Sarkaleveys* m	Original ditching year *Uudisojitusvuosi*	Fertilization year[2)] *Lannoitusvuosi[2)]*	Initial growing stock[3)] *Lähtöpuusto[3)]* m^3ha^{-1}	Number of plots[4)] *Koealojen määrä[4)]* 0	a	b	ab
Leivonmäki	1178	VSR	3	0.2– > 1.0	51	1955	1970	52	2	4	6	4
Joroinen	1173	IR	4	> 1.5	63	1953	1971	54	1	1	2	2
Parkano	1132	TRmu	4	0.5–1.3	67	1954	—	54	1	4	0	5
Viitasaari	1070	VSR	3	1.1– > 1.5	48	1935	1966	58	1	2	1	2
Ähtäri	1069	IR	4	0.6– > 1.5	46	1952–1953	1963	31	1	3	3	3
Sonkajärvi	1044	PsR	2	0.7– > 1.5	47	—	—	54	3	4	3	3
Haapajärvi	1044	PsR	2	0.5–0.7	43	1926	1974	61	2	1	1	0
Pyhäntä	1024	PsR	2	0.2–0.6	50	1958	1966, 1979	39	4	4	4	4
Yli-Ii I	1002	IR	4	> 1.5	35	1967	1968	19	3	3	4	4
Yli-Ii II	1002	LkR	4	> 1.5	35	1967	1968	19	2	2	2	2
Kuhmo	982	TR	4	0.6– > 1.0	45	1967	1969, 1984	21	4	4	4	4
Puolanka I	951	TRmu	4	0.8– > 1.5	44	1930	1965	43	1	3	2	1
Puolanka II	951	TRmu	4	0.7– > 1.5	44	1930	1965	21	2	2	1	2
Taivalkoski	867	RhSR	1	> 1.0	45	1966	1967	20	2	2	2	2

[1)] For the peatland forest site type explanations see Laine and Vasander (1990). The numbers are equal with the classification of forestry drained peatlands as follows: (1) *Vaccinium myrtillus* (Mtkg II), (2) *Vaccinium vitis-idaea* (Ptkg I), (3) *Vaccinium vitis-idaea* (Ptkg II) and (4) dwarf-shrub levels (Vatkg). — *Suotyypit Laineen ja Vasanderin (1990) mukaan. Numerot suotyypin perässä viittavat turvekankaiden ravinteisuusluokitukseen seuraavasti; (1) Mtkg II, (2) Ptkg I, (3) Ptkg II ja (4) Vatkg.*

[2)] In 1965–1967 PK contained P 7.3 % and K 12.5 %, in 1968–1975 P 10.3 % and K 12.5 % and in 1979–1984 P 9.0 % and K 17.0 %. Frp = finely ground rockphosphate contained P 13.8 % in 1965–1966. — *Vuosina 1965–1967 suometsien PK sisälsi P 7,3 % ja K 12,5 %, vuosina 1968–1975 P 10,3 % ja K 12,5 % sekä vuosina 1979–1984 P 9,0 % ja K 17,0 %. Frp = hienofosfaatti, joka vuosina 1965–1966 sisälsi P 13,8 %.*

[3)] Mean stand volume after ditch line cuttings before drainage maintenance. — *Puuston keskitilavuus ojalinjahakkuiden jälkeen ennen kunnostusojitusta.*

[4)] Explanations for treatments: 0 = control, a = ditch cleaning, b = complementary ditching, ab = combined treatment. — *Selitykset käsittelyille: 0 = kontrolli, a = ojanperkaus, b = täydennysojitus ja ab = yhdistelmäkäsittely.*

the thickness of the peat layer on the needle nitrogen concentrations were studied using the best subset regression analysis (BMDP... 90).

Discriminant analysis was applied to find out how the objectively analyzed peat and needle nutrient concentrations agreed with the visually observed site fertility classes (Laine & Vasander 1990, p. 51). The present data involved (1) *Vaccinium myrtillus* (Mtkg II), (2) *Vaccinium vitis-idaea* (Ptkg I), (3) *Vaccinium vitis-idaea* (Ptkg II) and (4) dwarf-shrub levels (Vatkg) (Table 1).

RESULTS

Peat properties

Variation between experiments

The concentrations of most nutrients in both peat layers differed significantly from one experiment to another (App. 1). However, the K concentrations (0–10 cm) did not differ statistically significantly ($p > 0.05$) within the group of ten experiments with all the drainage maintenance treatments. Neither were there any statistically significant differences in the P (10–20 cm) ($p > 0.10$) and Mn (0–10 cm) ($p > 0.05$) concentrations when all the experiments involving only the control and the ditch cleaning treatments were included (App. 1). The highest N concentrations were at Taivalkoski where also the site types were the most fertile.

The experiments differed significantly from one another also in terms of the total nutrient amounts (kg ha^{-1}, 0–20 cm) and peat densities (Table 2). The P and K amounts and the peat densities were extremely high in the Haapajärvi experiment. Five experiments (Taivalkoski, Leivonmäki, Sonkajärvi, Haapajärvi and Pyhäntä) contained quite high amounts of N, whereas the N amounts in Joroinen, Ähtäri, Kuhmo and Puolanka experiments were quite low.

Effect of drainage maintenance

All the drainage maintenance treatments increased, although not statistically significantly, the

Table 2. The mean nutrient amounts (kg ha^{-1}) in the 0–20 cm surface peat layers and peat bulk densities (kg m^{-3}, δ1 = 0–10cm, δ2 = 10–20 cm) by the experiments. Two-way analysis of variance was used. The statistical significances of the p-values are marked as follows *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, o = $p < 0,10$. Legend: 1) = with all treatments, but Haapajärvi and Parkano experiments excluded and 2) = all twelve experiments with a control and a ditch cleaning treatment.

*Taulukko 2. Turpeen ravinnemäärien keskiarvot (kg ha^{-1}, 0–20 cm) ja turpeen tiheydet (kg m^{-3}, δ1 = 0–10 cm, δ2 = 10–20cm) kokeittain. Kaksisuuntaisen varianssianalyysin p-arvojen merkitsevyydet on esitetty seuraavasti; *** = p < 0,001, ** = p< 0,01, * = p < 0,05, o = p < 0,10. Selitykset: 1) = laskennassa muut kokeet kaikilla käsittelyillä paitsi Haapajärvi ja Parkano, 2) = kaikki kokeet, mutta vain vertailu- ja perkauskäsittelyt laskennassa mukana.*

Experiment *Koe*	N	P	K	Ca	Mg	Mn	Fe	Zn	Al	δ1	δ2
Leivonmäki	5246	202	60	442	58	5	863	3	495	121	160
Joroinen	3220	143	67	450	66	5	321	4	325	83	137
Parkano	4336	234	86	351	69	4	1140	3	906	134	178
Viitasaari	4389	260	94	683	88	8	375	5	617	111	156
Ähtäri	2597	125	62	481	94	5	411	4	196	81	96
Sonkajärvi	4860	225	66	500	81	6	890	3	348	86	150
Haapajärvi	5578	568	284	403	137	9	1114	5	3219	176	422
Pyhäntä	5067	273	111	532	80	12	816	3	837	103	245
Yli-Ii I	3988	135	44	211	34	5	321	4	192	70	150
Yli-Ii II	4191	268	71	262	50	2	633	1	551	69	135
Kuhmo	2800	104	51	456	104	3	316	2	94	64	99
Puolanka I	2656	120	35	274	49	1	402	2	124	63	91
Puolanka II	2946	129	37	189	42	2	448	3	196	64	96
Taivalkoski	5377	160	51	921	116	8	1284	2	140	78	123
1)	***	***	***	***	***	***	***	***	***	***	***
2)	***	***	*	***	***	**	***	***	***	***	***

average total N amounts in the 20 cm surface peat layer and the two most effective treatments more than ditch cleaning alone (Table 3). A similar slight increase was found also in the P amounts. In neither cases, however, were the differences statistically significant. Ditch cleaning decreased significantly the amounts of Mg ($p < 0.01$), Mn ($p< 0.05$) and Zn ($p < 0.05$) when all the experiments with control and ditch cleaning plots were included (results not shown).

Tree nutrition

Nutritional level in the experiments

There were great differences between the experiments in the needle nutrient concentrations and the 100-needle dry mass. A severe N deficiency (< 1.20%; Paarlahti *et al.* 1971, Reinikainen et al. 1998) was found in the Haapajärvi, Yli-Ii and Puolanka experiments (App. 2). In the other experiments the needle N concentrations were above the severe deficiency level.

The needle P concentrations were mostly at the optimum level of 1.6–2.2 mg g^{-1} (Reinikainen *et al.* 1998) (App. 2). The P levels were the highest at Sonkajärvi. However, the needle P concentrations were near the severe deficiency level (1.30mg g^{-1}) at Leivonmäki, Parkano and Puolanka II. At Puolanka the K concentrations were near the severe deficiency level (< 3.50 g kg^{-1}; Sarjala & Kaunisto 1993). The high P and K concentrations in the Kuhmo experiment were supposedly due to PK fertilization in 1984.

The needle B concentrations were at a sufficient level (> 10 mg kg^{-1}; Reinikainen et al. 1998) on average in all the experiments (App. 2). However, there were single plots with B concentrations below 10 mg kg^{-1} at Leivonmäki, Joroinen, Viitasaari, Yli-Ii (II block) and Puolanka (II block). The lowest boron value (6 mg kg^{-1}) was found at Puolanka II.

Effect of drainage maintenance

All the drainage maintenance treatments increased the 100-needle dry mass, and the combined treatment increased it significantly ($p < 0.05$). Complementary ditching ($p < 0.01$) and the combined treatment ($p < 0.01$) decreased needle boron concentrations (Table 4). The differences, however, were not significant between the control and ditch cleaning treatments.

The needle N concentrations rose from a slight

Table 3. The mean nutrient amounts and their standard deviations (SD) (0–20 cm, kg ha^{-1}) in peat by the all drainage maintenance treatments (key in Table 1, footnote 4) with ten experiments. One-way analysis of variance and Tukey's test were used to find out the differences between the control and the drainage treatments. The significances marked as in Table2 (notice: no significant differences were found).

Taulukko 3. Turpeen ravinnemäärien (0–20 cm, kg ha^{-1}) keskiarvot (Mean) ja -hajonnat (SD) kymmenellä kokeella, joilla kaikki kunnostusojituskäsittelyt mukana. Käsittelyjen selitykset taulukon 1 alaviitteessä 4. Yksisuuntaisella varianssianalyysilla ja Tukey'n testillä laskettiin erot kontrollin ja kunnostusojituskäsittelyjen välillä. Merkitsevyydet merkitty kuten Taulukossa 2 (Huom! merkitseviä eroja ei ollut).

Nutrient *Ravinne*	0		a		b		ab	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N	3738	1131	3973	1424	4201	1324	4116	1361
P	169	69	178	73	177	69	181	73
K	63	33	61	25	58	22	64	27
Ca	456	267	410	171	435	193	441	208
Mg	78	36	67	25	77	43	76	40
Mn	6	6	4	3	5	6	5	4
Fe	620	459	583	424	616	432	602	361
Zn	3	1	3	1	3	1	3	1
Al	351	318	321	275	334	255	339	235

deficiency level (Paarlahti *et al.* 1971, Reinikainen et al. 1998) on the controls to an adequate N level in two of the most intensive treatments. The analyses of variance, however, revealed no statistically significant difference between the nitrogen values (Table 4).

The effect of drainage maintenance on tree nutrition varied somewhat from one experiment to another (App. 2). The needle N concentrations were lower on the controls than on the treated plots on average in eight, P in seven and K concentrations in six cases, but there were only few statistically significant differences (App. 2). The combined treatment increased ($p < 0.05$) the needle P and K ($p < 0.05$) concentrations in the Kuhmo experiment compared with the control, while mere ditch cleaning increased ($p < 0.05$) needle P concentrations at Puolanka II (App 2).

The needle Mn concentrations were about 300 ppm, and they decreased slightly with the intensified drainage maintenance (Table 4).

Relationships between the peat and needle nutrients and site fertility class

The needle N, P, K and Ca concentrations correlated positively with the respective N,P,K and Ca concentrations in the upper 0–10 cm peat layer (Table 5). The needle B, Zn and Fe concentrations correlated negatively with the peat total N concentration. The needle nutrient concentrations correlated less closely with N in the 10–20 cm than in the 0–10 cm peat layer.

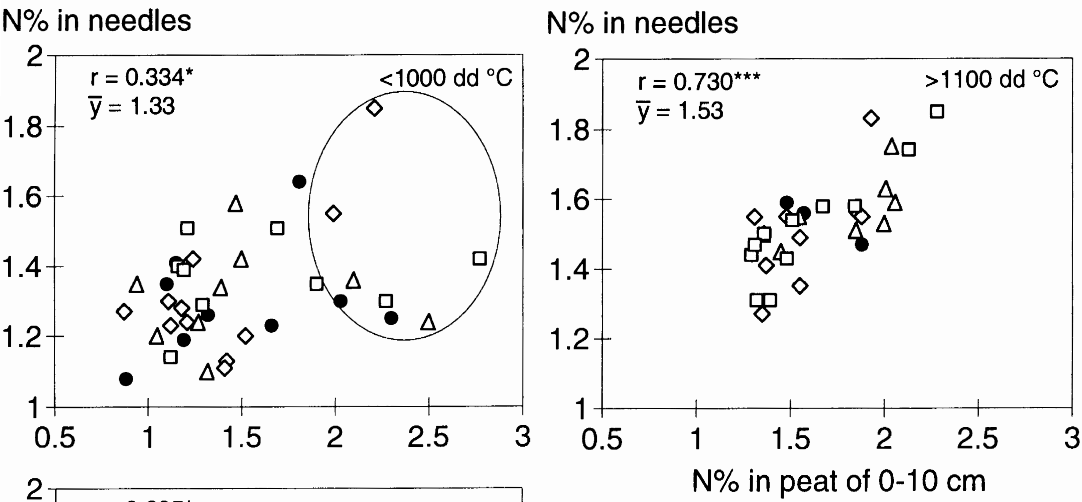
The correlation between the peat and needle N concentrations was highest in the southern part (> 1100 d.d.) and weakest in the central part (1000–1100 d.d.) of Finland (Fig. 2). According to the regression analysis both the peat total N concentration and the temperature sum were significant and therefore included in the equation explaining ($R^2 = 0.407$) the variation in the needle N concentrations (Table 6). The thickness of the peat layer did not affect significantly the needle N concentration.

The site fertility classes of the present study were classified better by the peat (average 83.7% correct) than by the needle nutrients (73.4%). Together, however, they classified correctly 91.3% of the site fertility classes. Peat nutrients classified correctly 100% of the *Vaccinium myrtillus* (Mtkg II) sites, 85.7% of the *Vaccinium vitis-idaea* (Ptkg I) sites, 92.3% of the *Vaccinium vitis-idaea* (Ptkg II) sites and 80.3% of the dwarf-shrub (Vatkg) sites (Fig. 3). The discriminant function containing only the peat nutrient concentrations included N1 (F = 28.1, competence 0.62), Ca2 (F= 23.4, competence 0.52), Fe1 (F = 11.6, com-

Table 4. The mean needle nutrient concentrations and the 100-needle dry mass with the standard deviations in the all drainage maintenance treatments with ten experiments. Calculations and the legend as in Table 3. Significances as in Table2.

Taulukko 4. Neulasten ravinnepitoisuuksien ja sadan neulasen kuivamassan (dry mass) keskiarvot (Mean) ja -hajonnat (SD) kunnostusojituskäsittelyittäin kymmenellä kokeella. Laskenta ja selitykset kuten Taulukossa 3. Tilastolliset merkitsevyydet kuten Taulukossa 2.

Nutrient *Ravinne*	0		a		b		ab	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N (%)	1.29	0.17	1.33	0.19	1.39	0.16	1.37	0.16
P (mg g^{-1})	1.76	0.27	1.74	0.32	1.79	0.35	1.78	0.31
K (mg g^{-1})	4.54	0.72	4.84	0.61	4.61	0.58	4.77	0.76
Ca (mg g^{-1})	2.11	0.43	2.07	0.30	1.99	0.24	1.97	0.27
Mg (mg g^{-1})	1.26	0.15	1.25	0.17	1.26	0.14	1.23	0.14
Mn (µg g^{-1})	339	128	319	111	282	91	303	102
Fe (µg g^{-1})	37	16	36	14	39	20	36	14
Zn (µg g^{-1})	43	8	43	8	43	9	41	7
B (µg g^{-1})	20	8	18	6	14**	6	15**	6
dry mass (g)	1.62	0.37	1.73	0.52	1.84	0.46	1.94*	0.45



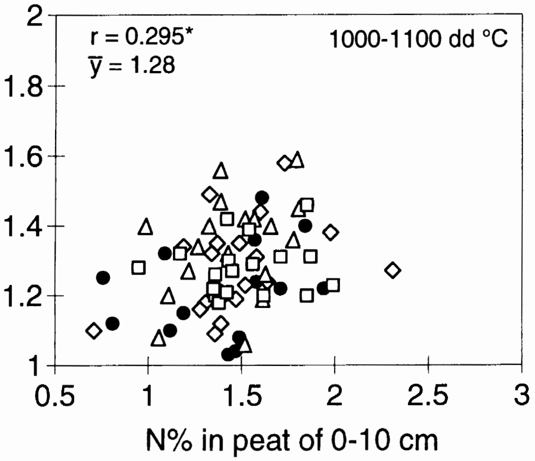


Fig. 2. The relationships between the nitrogen concentrations (%) in the 0–10 cm peat layer and the needle nitrogen concentrations (%) by different temperature sum regions (North, Central, and South Finland). Symbols: ● = control, ◊ = ditch cleaning, Δ = complementary ditching and □ = ditch cleaning plus complementary ditching. The observations of the Taivalkoski experiment are clustered with an ellipsoid.

Kuva 2. Neulasten ja turpeen (0–10 cm) typpipitoisuudet eri lämpösummavyöhykkeissä (Pohjois-Suomi, Keski-Suomi, Etelä-Suomi). Symbolit: ● = vertailu, ◊ = ojan perkaus, Δ= täydennysojitus ja □ = yhdistelmäkäsittely. Taivalkosken kokeen (runsastyppisin) havainnot erotettu muista ellipsillä.

petence 0.31), P1 (F = 11.3, competence 0.79), Mn1 (F = 7.1, competence 0.64), Mg1 (F = 5.2, competence 0.38) and Fe2 (F = 4.7, competence 0.42) (see also App. 1).

Table 5. The correlation coefficients between the needle and the peat nutrient concentrations (0–10 cm). Nitrogen concentration as percentage from the organic part of peat. Significances as in Table 2.

Taulukko 5. Neulasten ja turpeen ravinnepitoisuuksien (0–10 cm) väliset korrelaatiokertoimet. Turpeen typpipitoisuus prosentteina orgaanista ainesta kohti laskettuna. Korrelaatiokertoimien merkitsevyydet kuten Taulukossa 2.

Peat *Turve*	Needles — *Neulaset*							
	N	P	K	Ca	B	Mg	Fe	Zn
N	0.375***	– 0.028	0.044	0.010	– 0.258**	– 0.080	– 0.224*	– 0.224*
P	0.025	0.202*	0.127	0.266**	0.027	– 0.064	0.044	– 0.055
K	– 0.390***	0.404***	0.415***	0.427***	0.347***	– 0.082	0.233*	0.278**
Ca	0.202*	0.224*	0.283**	0.264**	– 0.057	– 0.249*	– 0.113	– 0.103
Mg	– 0.089	0.433***	0.475***	0.429***	0.196*	– 0.094	0.129	0.236*
Cu	0.080	0.024	0.224*	0.307**	0.385***	– 0.122	0.174°	0.154
Fe	– 0.047	– 0.023	0.167°	– 0.102	– 0.110	0.024	– 0.137	– 0.035
Zn	0.113	– 0.025	0.112	– 0.001	–0.231*	– 0.392***	– 0.222*	– 0.276**

DISCUSSION

This study involves twelve experiments, which were originally established to find out the effects of mere drainage maintenance on stand growth on drained Scots pine mires (Päivänen & Ahti 1988, Ahti & Päivänen 1997). Therefore no thinnings, normally connected with drainage maintenance, were done in the experiments. This is important to keep in mind when interpreting the results.

Drainage maintenance aims at keeping the growth of a stand at a level achieved after the first drainage. According to this study, it seems that although drainage maintenance had only minor effects on the peat and needle nutrient amounts or contents, there were indications of better nutrition of trees due to drainage maintenance for 10–14-year periods.

Both the N amount in peat and its concentrations in the needles increased slightly on average although not significantly along with the increasing drainage intensity, indicating an improvement in the nitrogen nutrition of trees. Also, the 100-needle dry mass increased significantly along with the intensified drainage maintenance indicating a positive effect of drainage maintenance on the tree nutrition. The decrease in the needle B concentrations with the increasing drainage intensity can be interpreted as a dilution effect due to a better availability of the main nutrients and possibly also to increased tree growth (Veijalainen 1977).

The mean needle Mn concentrations were in all the treatments under 600 mg kg^{-1}, implying that drainage was adequate in the tree stands (Veijalainen 1977, Raitio 1978, 1982, Reinikainen et al. 1998). According to the earlier investigations involving the same stands, the more intensive the drainage was, the more the ground water table had lowered (Päivänen & Ahti 1988, Ahti & Päivänen 1997). A deepening ground water level enhances microbial activity and nutrient mineralisation (see e.g. Karsisto 1979).

The site types varied from a dwarf-shrub pine bog to a herb-rich pine fen, and consequently the

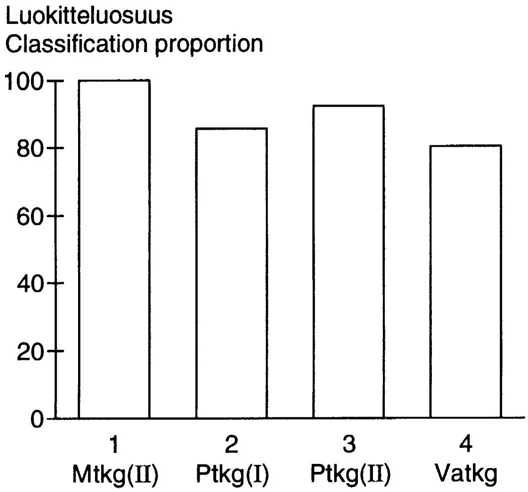


Fig. 3. The ability of peat nutrients to discriminate correctly (%) the site fertility classes of forestry drained peatlands determined according to Laine and Vasander (1990). The fertility classes (1, 2, 3, 4) are given in Table 1.

Kuva 3. Turpeen ravinteiden kyky erotella oikein (%) Laineen ja Vasanderin (1990) turvekankaiden ravinteisuustasoja. Ravinteisuustasot (1, 2, 3, 4) määritelty Taulukossa 1.

Table 6. The regression coefficients and their significances in the model explaining the nitrogen concentration of needles (N%) in the whole data. The model is N% = $\alpha + \beta 1N1 + \beta 2TS$, where N1 is the total nitrogen concentration (%) in the 0–10 cm peat layer and TS = the temperature sum. $R^2 = 0.407$, F = 31.35*** with 3.137 degrees of freedom. Significances as in Table 2.

*Taulukko 6. Neulasten typpipitoisuutta (N%) kuvaava regressiomalli koko aineistossa. Malli muotoa N% = $\alpha + \beta 1N1 + \beta 2TS$, missä N1 turpeen kokonaistyppipitoisuus (0–10 cm) ja TS = kokeen lämpösumma. Mallin R^2 = 0,407, F-arvo = 31,35*** vapausasteilla 3,137. Kertoimien merkitsevyydet kuten Taulukossa 2.*

Variable *Muuttuja*	Regression coefficient *Regressiokerroin*	Standard error *Kertoimen keskivirhe*	t value *t-arvo*	p (2 tail significance) *p (kertoimen merkitsevyys)*
Constant — *Vakio*	$\alpha = 0.107501$	0.154627	0.70	
N1	$\beta 1 = 0.191881$	0.0321861	5.96	***
TS	$\beta 2 = 0.000943145$	0.00013706	6.88	***

peat N concentrations varied from very low (0.73%) to high (2.94%) levels in the 0–10 cm layer (App. 1). Also the climatic conditions varied greatly. The average temperature sum varied from 867 to 1178 d.d.°C. Both these factors affect the N nutrition of trees. The importance of the peat total N concentration in the N nutrition of trees was fairly well seen in this study as positive and significant correlations between the needle and peat N concentrations in three temperature sum regions (see also Kaunisto 1982, 1987, Fig. 2). Despite the high peat N concentration at Taivalkoski, the needle N concentrations were mainly quite low. This may be due to the low temperature sum at Taivalkoski resulting in low N mineralisation (Kaunisto & Norlamo 1976).

The peat nutrient status explained fairly well the site fertility class groups determined for drained pine mires (Laine & Vasander 1990, see also Paarlahti *et al.* 1971, Kaunisto & Paavilainen 1988). In addition to N also the peat P, Ca, Mg, Mn, and Fe concentrations were included in the discriminant functions (see also Kaunisto & Paavilainen 1988).

The drainage maintenance treatments were not distributed equally in each experiment, which caused some limitations to the statistical analyses. There were fewer control plots than plots for each drainage maintenance treatment. This made also the comparisons of the treatments in the statistical analyses somewhat weaker. It was quite difficult to find large enough areas to randomize the sample plots in the experimental area, since the plots and especially the controls required plenty of room. The number of the plots limited statistical calculations of the nutrient analyses especially at Joroinen (n = 6), Viitasaari (n = 6), Haapajärvi (n = 4) and at Taivalkoski (n = 8) where the results may be coincidental. In addition, there was only one control plot at Parkano and Ähtäri. Different drainage maintenance treatments might have affected each other. For example, the plots treated only with complementary ditching could not be located in contact with the ditch cleaning plots. Drainage maintenance may affect also the ground water status of the untreated control plots and consequently the tree nutrition on them.

Despite these weaknesses, there were quite clear indications of the improved nutrition of trees due to the drainage maintenance treatments. It is also quite obvious that when interpreting the growth reactions of the stands in these experiments in the later studies, differences in the nutritional background should be carefully considered, because there were great nutritional and climatic differences between the experiments.

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TIIVISTELMÄ:

Kunnostusojituksen vaikutus rämeiden ravinnetilaan

Tutkimuksen tavoitteena oli selvittää kunnostusojituksen vaikutusta kasvupaikan ja puiden ravinnetilaan ojitetuissa rämemänniköissä. Tavoitteena oli tutkia myös turpeen ja neulasten ravinteiden välisiä vuorosuhteita erityisesti typen osalta eri lämpösummavyöhykkeissä. Tavoitteena oli lisäksi selvittää, miten turpeen ja neulasten ravinteet selittävät turvekankaiden kasvupaikkaluokitusta (Laine & Vasander 1990).

Metsäntutkimuslaitoksen suontutkimusosasto perusti tutkimuksen kunnostusojituskokeet vuosina 1982–1985 (Päivänen & Ahti 1988, Ahti & Päivänen 1997). Eteläisin koe sijaitsi Leivonmäellä (N 61°45´) ja pohjoisin Taivalkoskella (N 65°45´) (Taulukko 1, Kuva 1). Koejärjestelyn tavoitteena oli tutkia miten kunnostusojittamaton vertailukäsittely, ojan perkaus, täydennysojitus sekä perkauksen ja täydennysojituksen yhdistelmä (kunnostusojituksen tehokkuus kasvaa tässä järjestyksessä) vaikuttavat puuston kasvuun ja suon pohjavesipinnan tasoon. Koeruutujen määrä vaihteli 4–22 kappaleeseen koetta kohti. Kohteita ei ollut hakattu tai lannoitettu kymmeneen vuoteen ennen kunnostusojitusta. Neulas- ja turvenäytteitä ei otettu kokeiden perustamisen yhteydessä, vaan vasta kun perustamisesta oli kokeesta riippuen kulunut 10–14 vuotta. Turve- ja neulasanalyysit tehtiin Metsäntutkimuslaitoksen tavanomaisin menetelmin (Halonen et al. 1983).

Sekä turpeen että neulasten ravinnepitoisuuksissa ja -määrissä ilmeni selvää kokeittaista vaihtelua (Taulukko 2, Liite 1, Liite 2). Kunnostusojitus vaikutti jonkin verran turpeen (0–20 cm) ja neulasten ravinnepitoisuuksiin. Pelkkä ojanperkaus alensi pintaturpeen Mg-, Mn- ja Zn-määriä kontrolliin verrattuna koko aineistossa (tuloksia ei taulukoitu). Sekä turpeen että neulasten N-pitoisuudet kohosivat suuntaa antavasti kunnostusojituksen tehokkuuden kasvaessa kontrollista yhdistelmäkäsittelyyn. Samalla neulasten B-pitoisuus aleni merkitsevästi, mikä vahvisti käsitystä ns. ohentumisilmiöstä (Paarlahti et al. 1971, Veijalainen 1977) (Taulukko 4, Liite 2). Myös kustakin näytteestä määritetty sadan neulasen kuivamassa kasvoi merkitsevästi kunnostusojituksen tehokkuuden kasvaessa (Taulukko 4). Neulasten keskimääräinen Mn-pitoisuus osoitti kohteiden olevan keskimäärin kohtuullisessa kuivatuksellisessa tilassa (Taulukko 4, Veijalainen 1977, Raitio 1978, 1982).

Turpeen kokonaistyppipitoisuuden ja neulasten typpipitoisuuden välinen riippuvuus oli selvintä, kun lämpösumma ylitti 1100 d.d.°C (Kuva 2). Erotteluanalyysin perusteella turpeen ravinteet luokittelivat oikein 83,7% kasvupaikoista, kun Laineen ja Vasanderin (1990) turvekangasluokitusta käytettiin kasvupaikan ravinteisuuden kuvaajana (Kuva 3). Osin tätä taustaa vasten tulokset antavat hyödyllistä taustatietoa kunnostusojituksen kasvu- ja tuotosvaikutusten myöhempään analysointiin.

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Appendix 1. Peat nutrient concentrations by the experiments. The upper values are means and the lower ones standard deviations. N (%) in the organic proportion of peat, P, K, Ca, Mg and Fe concentrations given as mg g^{-1}, and the other nutrients given as mg kg^{-1} of the total dry weight. Legend: N1, P1, ... = 0–10 cm peat layer and N2, P2, ... = 10–20 cm peat layer. The names of the experiments in Table 2. The two-way analysis of variance 1) with all treatments, but Haapajärvi and Parkano experiments excluded and 2) all twelve experiments with the control and the ditch cleaning treatment. The significances of the p values as follows: *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ° = $p < 0.10$.

*Liite 1. Turpeen kokeittaiset ravinnepitoisuudet. Ylärivissä keskiarvot ja alarivissä -hajonnat. N (%) orgaanista ainetta kohti, P, K, Ca, Mg ja Fe (mg g^{-1}), sekä muut (mg kg^{-1}) näytteen kuivamassaa kohti. Selitykset; kokeiden nimet Taulukossa 2, N1, P2, ... = 0–10 cm:n ja N2, P2,... = 10–20 cm:n turvekerroksessa. Kaksisuuntaisen varianssianalyysin 1) laskennassa muut kokeet kaikilla käsittelyillä paitsi Haapajärvi ja Parkano sekä 2) kaikki kokeet, mutta vain vertailu– ja perkauskäsittelyt laskennassa mukana. p-arvojen merkitsevyydet seuraavasti; *** = $p < 0{,}001$, ** = $p < 0{,}01$, * = $p < 0{,}05$, ° = $p < 0{,}10$.*

Exp *Koe*	N1	N2	P1	P2	K1	K2	Ca1	Ca2	Mg1	Mg2	Mn1	Mn2	Fe1	Fe2	Zn1	Zn2	Al1	Al2
Le	1.97	2.04	0.83	0.64	0.33	0.11	1.60	1.54	0.26	0.17	28	11	3.4	2.8	21	6	1239	2020
	0.25	0.27	0.10	0.14	0.05	0.03	0.21	0.31	0.03	0.05	7	7	0.9	0.7	4	2	183	812
Jo	1.42	1.57	0.70	0.62	0.41	0.24	2.42	1.82	0.38	0.25	39	11	1.5	1.4	34	12	1040	1736
	0.09	0.07	0.05	0.06	0.07	0.04	0.26	0.17	0.08	0.03	12	2	0.2	0.3	2	2	96	194
Par	1.53	1.48	0.86	0.67	0.42	0.17	1.17	1.11	0.27	0.19	16	9	3.8	8.6	15	5	2272	3271
	0.13	0.10	0.28	0.17	0.15	0.10	0.31	0.14	0.06	0.05	15	5	0.6	5.1	3	1	864	1462
Vii	1.60	1.79	1.17	0.84	0.56	0.21	0.56	1.89	0.42	0.27	55	11	1.8	1.1	30	11	1626	2781
	0.13	0.06	0.51	0.07	0.07	0.05	0.07	0.52	0.02	0.04	9	9	0.4	0.3	4	6	330	440
Äh	1.24	1.72	0.65	0.71	0.54	0.20	2.86	2.57	0.69	0.41	44	15	2.8	1.9	28	14	1189	1027
	0.28	0.65	0.12	0.20	0.42	0.07	0.32	0.36	0.66	0.03	37	6	2.0	0.5	5	7	1950	328
Son	1.85	2.29	1.05	0.89	0.44	0.18	2.63	1.89	0.43	0.30	53	13	5.1	3.0	23	7	1003	1749
	0.31	0.33	0.26	0.13	0.09	0.04	0.56	0.46	0.08	0.08	39	9	3.7	1.8	5	3	310	514
Haa	1.65	1.69	1.31	1.20	0.46	0.38	1.39	0.52	0.25	0.24	15	13	2.3	1.9	16	6	4234	7174
	0.14	0.24	0.46	0.69	0.05	0.23	0.56	0.28	0.07	0.22	5	11	0.6	1.1	5	2	1219	3154
Py	1.74	2.10	1.19	0.79	0.51	0.26	2.82	1.27	0.33	0.21	41	29	3.5	2.1	19	5	1805	2814
	0.18	0.20	0.68	0.27	0.11	0.07	1.83	0.24	0.06	0.03	18	23	0.8	0.4	4	1	737	667
YI	1.33	2.09	0.61	0.62	0.39	0.11	1.45	0.74	0.30	0.09	20	4	2.1	1.4	19	5	507	1046
	0.15	0.14	0.06	0.05	0.08	0.01	0.25	0.11	0.07	0.02	8	1	0.3	0.3	4	1	91	170
YII	1.52	2.46	1.10	1.44	0.50	0.27	1.83	1.03	0.36	0.19	15	6	4.1	2.6	13	3	1255	3444
	0.09	0.15	0.13	0.18	0.04	0.06	0.39	0.17	0.05	0.03	3	1	0.8	0.5	1	1	189	378
Ku	1.32	2.00	0.70	0.59	0.50	0.20	3.42	2.43	0.67	0.63	38	8	1.7	2.0	20	8	508	611
	0.32	0.38	0.19	0.08	0.08	0.04	2.41	0.48	0.13	0.14	29	3	0.4	0.5	5	5	85	136
PuI	1.33	2.01	0.74	0.78	0.38	0.12	2.01	1.62	0.40	0.26	14	6	2.9	2.4	17	6	535	987
	0.15	0.33	0.04	0.13	0.11	0.04	0.45	0.48	0.1	0.09	5	1	0.3	0.3	4	5	74	170
PuII	1.42	2.19	0.74	0.84	0.39	0.14	1.34	1.11	0.35	0.21	12	9	3.5	2.4	22	14	813	1453
	0.25	0.38	0.12	0.15	0.11	0.09	0.24	0.26	0.09	0.09	3	5	1.1	1.1	8	6	406	551
Ta	2.43	3.06	0.96	0.58	0.49	0.11	3.93	5.03	0.62	0.57	65	21	8.5	4.8	16	5	622	726
	0.29	0.30	0.11	0.05	0.07	0.03	1.58	1.01	0.13	0.14	84	20	5.1	2.1	2	1	211	199
1)	***	***	***	**	°	***	***	***	***	***	***	***	***	***	***	***	**	***
2)	***	***	**		*	**	***	***	***	***	°	**	**	**	***	***	***	***
	N1	N2	P1	P2	K1	K2	Ca1	Ca2	Mg1	Mg2	Mn1	Mn2	Fe1	Fe2	Zn1	Zn2	Al1	Al2

Appendix 2. The mean needle N (%), P (mg g^{-1}), K (mg g^{-1}) and B (µg g^{-1}) concentrations by the experiments and treatments. The names of the experiments in the Table 2. Legend: 0 = no treatment, a = ditch cleaning, b = complementary ditching, ab = ditch cleaning and simultaneous complementary ditching, and – = missing treatment. One-way analysis of variance and Tukey's test were used. The significant differences in concentrations between the control and the drainage treatments are marked as follows; *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ° = $p < 0.10$.

*Liite 2. Neulasten keskimääräiset typpi- (%), fosfori- (mg g^{-1}), kalium- (mg g^{-1}) ja booripitoisuudet(µg g^{-1}) kokeittain ja käsittelyittäin. Kokeiden nimet Taulukossa 2. Selitykset: 0 = vertailu, a = ojanperkaus, b = täydennysojitus, ab = yhdistelmäkäsittely ja – = puuttuva käsittely. Käsittelykeskiarvojen tilastollinen poikkeama vertailusta laskettiin yksisuuntaisella varianssianalyysilla ja Tukey'n testillä seuraavin merkitsevyyksin; *** = p < 0,001, ** = p < 0,01, * = p < 0,05, ° = p < 0,10.*

Exp *Koe*	N				P				K				B			
	0	a	b	ab	0	a	b	ab	0	a	b	ab	0	a	b	ab
Le	1.53	1.57	1.59	1.68	1.56	1.29	1.37	1.47	5.03	4.83	4.21	4.17	9	10	10	9
Jo	1.54	1.55	1.48	1.46	1.70	1.53	1.78	1.76	4.84	4.77	4.67	4.68	13	11	9	14
Par	1.56	1.43	–	1.43	1.65	1.40	–	1.34	4.93	4.28	–	4.21	18	17	–	12
Vii	1.48	1.32	1.40	1.41	1.59	1.50	1.75	1.84	4.51	4.80	4.84	5.25	11	13	13	9
Äh	1.32	1.31	1.46	1.30	1.44	1.56	1.72	1.65	3.99	5.02	4.21	4.47	14	17	11	13
Son	1.27	1.28	1.34	1.38	2.06	2.18	2.24	2.16	5.50	5.54	5.59	5.68	19	16	18	17
Haa	1.16	1.44	1.19	–	1.68	1.72	1.72	–	4.85	5.04	5.13	–	21	16	16	–
Py	1.27	1.34	1.46	1.29	1.80	1.81	1.85	1.91	4.87	5.20	4.53	5.15	28	26	26	25
Y I	1.10	1.15	1.15	1.24°	1.57	1.60	1.59	1.60	4.10	4.38	4.66	4.75°	17	20	14	16
Y II	1.06	1.22	1.37	1.21	1.67	2.03	2.37	2.69	4.25	3.86	4.53	4.09	19	14	12	8
Ku	1.27	1.31	1.33	1.44	1.86	1.94	2.10	2.50*	4.61	5.12	5.13	5.81*	30	26	19**	18**
Pu I	1.19	1.20	1.17	1.14	2.12	1.84	1.81	1.61	4.58	4.54	4.46	3.43	21	15	14	15
Pu II	1.45	1.17	1.58	1.34	1.28	1.55*	1.27	1.40	3.14	4.22	3.14	3.74	16	21	6	9
Ta	1.27	1.70°	1.30	1.36	2.14	1.87	1.90	1.57	4.28	4.74	4.69	4.23	15	14	10*	10*