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Root biomass on an ombrotrophic pine bog and the effects of PK and NPK fertilization

Leena Finér

TIIVISTELMÄ: OHUTJUURTEN BIOMASSA LANNOITETULLA JA LANNOITTAMATTOMALLA OMBROTROFISELLA RÄMEELLÄ

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Scots pine living root biomass (Ø ≤ 10 mm) was 640 g/m^2 on the studied low-shrub pine bog before fertilization, and that of the ground vegetation almost the same. The total root necromass was 23 % of the living root biomass. The length of pine roots was 2440 m/m^2. The living root biomass and root necromass were superficial. The Ø < 1 mm pine root fraction accounted for almost 90 % of the pine root length; in contrast, over 50 % of the biomass was in the 1–10 mm thick roots. The NPK(MgB) and PK(MgB) fertilizations did not affect total living root biomass, pine root length, nor the root necromass during the three-year observation period.

Ohutjuurten (Ø ≤10 mm) biomassaa tutkittiin Pohjois-Karjalassa sijaitsevalla isovarpuisella rämeellä. Ennen lannoitusta männyn ja pintakasvillisuuden elävien ohutjuurten biomassa oli lähes yhtä suuri (640 g/m^2) ylimmässä 40 cm turvekerroksessa. Kuolleiden juurten massa oli 23 % elävien juurten massasta. Männyn ohutjuurten pituus oli 2440 m/m^2. Sekä elävien että kuolleiden juurten massa oli suurimmalta osin ylimmässä 20 cm turvekerroksessa. Alle 1 mm paksuisten juurten pituus oli lähes 90 % männyn ohutjuurten pituudesta, mutta niiden osuus biomassasta oli alle 50 %. NPK(MgB) ja PK(MgB) lannoitukset eivät vaikuttaneet merkitsevästi elävien männyn juurten kokonaisbiomassaan, pituuteen, pintakasvillisuuden juurten biomassaan ja kuolleiden juurten massaan kolmen vuoden tutkimusjaksolla.

Keywords: *Pinus sylvestris*, ground vegetation, root biomass, peatlands, fertilization.
FDC 114.4+237

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1 Introduction

On drained, ombrotrophic pine bogs the root system of Scots pine is superficial even after improved aeration (Heikurainen 1955ab, Paavilainen 1966). Although the length of pine fine (Ø < 1mm) and small (Ø 1–10 mm) roots is considerable – as much as thousands of kilometers per hectare (e.g. Heikurainen 1955ab, Paavilainen 1966, 1967a, Finér 1989, Håland and Brække 1989), their living biomass is equivalent to only a few per cent of the total biomass of the tree stand (Paavilainen 1980, Håland and Brække 1989, Finér 1989). On the other hand, a considerable proportion of the biomass of the ground vegetation is in the root system (Paavilainen 1980, Håland and Brække 1989).

Fine and small roots are short-lived and their production and mortality occur simultaneously during the growing season (e.g. Persson 1979, 1980a, Keyes and Grier 1981, Joslin and Henderson 1987, Santantonio and Santantonio 1987). Root length reaches its maximum on peat soils already in young stands (Heikurainen 1955b). The fluctuations in root biomass during the growing season are caused by e.g. the growth of above-ground compartments, soil temperature (Lyr and Hoffman 1967, Kramer & Kozlowski 1979) and the depth of the groundwater table (Heikurainen 1955b). On drained, ombrotrophic pine bogs tree growth is limited by a shortage of phosphorus, potassium, nitrogen and boron (see e.g. Meshechok 1968, Brække 1977, 1983, Paavilainen 1979). Roots also respond to fertilization on mineral (Zöttl 1964, Persson 1980b) and peat soils (Paavilainen 1967b, 1968, 1980). The relationships between root development and different ecological factors are, however, not yet fully understood.

The aim of this report is to describe the living root biomass (Ø ≤ 10 mm) and necromass distribution of Scots pine *(Pinus sylvestris)* and ground vegetation, and the effects of PK and NPK fertilization on a low-shrub pine bog. This study is a part of a Nordic project, the main objectives of which are to evaluate the amount, distribution and circulation of mineral nutrients after drainage and fertilization of ombrotrophic pine bogs in different climatic conditions.

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2 Material and methods

2.1 Study area

The material was collected from an experimental field in northern Karelia, (64 km SE of Joensuu 62° 14'; 29° 50' E, 81 m a.s.l.). The climatic data during 1984–1987 are presented in Table 1. The year 1987 was colder and more rainy than the other years, and the surface peat did not thaw until two weeks after the beginning of the growing season. According to Heikurainen and Pakarinen (1982), the site is a low-shrub pine bog. A detailed description of the vegetation has been presented by Finér and Brække (1991). The site was drained in 1967 with a 50 m ditch spacing, and the fluctuations in groundwater table were monitored during 1984-1987 (Table 2).

The peat layer is over one meter thick and consists of slightly decomposed (von Post, H3-H5) ombrotrophic *Sphagnum* peat with some *Carex* below 20 cm depth and remnants of wood in all layers (see Brække and Finér 1991). The Scots pine stand growing on the site is about 85 years old and naturally regenerated (Table 3).

The field experiment was established in June 1984 and fertilized during the first days of June, 1985. A 3 x 3 Latin-square design with a 1500 m^2 plot size was used. The treatments were as follows: 1) control, 2) PK(MgB), 3) NPK(MgB). The amounts of different elements applied are given in Table 4. The fertilizers were given as ammonium nitrate, raw phosphate, potassium chloride, magnesium sulphate and sodium borate.

Table 1. Length of the growing season, temperature sum and accumulated precipitation during 1984-1987. The values measured at the synoptic climatic station are given in parenthesis.

Taulukko 1. Kasvukauden pituus, lämpösumma ja sademäärä vuosina 1984–1987. Ilmatieteen laitoksen Tohmajärven säähavaintoasemalla mitatut arvot suluissa.

Year *Vuosi*	Length of growing season *Kasvukauden pituus* days – *vrk*	Temperature sum *Lämpösumma* dd°	Precipitation *Sademäärä* mm 1.6.–30.9.	 1.1.–31.12.
1984	165 (168)	1107 (1243)	238 (249)	(618)
1985	141 (169)	1097 (1129)	282 (350)	582 (755)
1986	128 (151)	1026 (1135)	240 (302)	573 (650)
1987	173 (173)	939 (967)	478 (474)	698 (749)

Table 2. Depth of the groundwater table (cm) in June-September in 1984–1987. Values are the average distance to the water table from the ground surface at three points across the plots perpendicular to the ditch direction (n=12).

Taulukko 2. Pohjaveden pinnan syvyys (cm) kesä-syyskuussa vuosina 1984–1987. Arvot ovat keskisyvyyksiä mitattuna maanpinnasta pohjavesipintaan kolmesta kaivosta, jotka oli sijoitettu tasavälein saralle kohtisuoraan ojia vastaan.

Year *Vuosi*	Treatment *Käsittely*	mean *keskiarvo*	max	min
1984	0	48	69	20
	PK	48	70	20
	NPK	48	70	20
1985	0	36	49	27
	PK	33	47	25
	NPK	34	47	27
1986	0	42	58	21
	PK	44	62	23
	NPK	44	60	23
1987	0	25	41	18
	PK	25	40	18
	NPK	25	41	18

2.2 Sampling and calculations

Root sampling was carried out twice: 12.–27.9.1984 and 18.8.–3.9.1987. Twenty square peat cores (24.7 cm^2) were systematically taken from each plot. The living moss layer was removed and the cores were divided into subsamples, starting from the surface down, as follows: 0–10, 10–20, 20–40 cm. Only every fifth subsample was taken from the deepest peat layer. The roots (Ø ≤ 10 mm) were extracted by hand from each subsample and separated into three classes: living roots of Scots pine, living roots of ground vegetation, and all dead roots. Pine roots were further divided into Ø < 1 mm and Ø = 1–10 mm fractions. The length of pine roots was measured (cm) before the roots were dried (105 °C) and weighed (0.001 g).

Differences in root biomass, necromass and length between years were tested with the paired t-test. The effect of fertilization was tested with variance analysis.

Table 3. Tree stand characteristics in 1984 and 1987.
Taulukko 3. Puustotunnukset vuosina 1984 ja 1987

Treatment *Käsittely*	Stem volume o.b. *Rungon kuorellinen tilavuus* (m^3/ha) 1984	1987	Trees – *Puita*/ha 1984	1987	Volume growth o.b. *Rungon kuorellinen tilavuuskasvu* (m^3/ha/yr – m^3/ha/vuosi)
0	79.7	97.3	2333	2219	5.9
PK	78.8	97.4	2299	2178	6.2
NPK	79.4	99.1	2311	2072	6.6

Table 4. Nutrient elements applied in the different treatments, kg/ha.
Taulukko 4. Lannoituksessa käytetyt ravinnemäärät, kg/ha.

Element *Ravinne*	PK	NPK
N	–	150
P	53	53
K	100	100
Ca	135	135
Mg	25	25
S	28	28
Cl	95	95
B	2.4	2.4

3 Results

The average amount of Scots pine living root biomass was 637 g/m^2 on the plots before fertilization (Table 5), and that of the ground vegetation almost the same (Table 6). Root necromass was 23 % of the living root biomass. The variation coefficient of the living pine and ground vegetation root biomass estimate was 11 %, and that of the dead roots 32 %. There were no significant differences in root biomass between the treatments before (1984) and after (1987) fertilization. The total biomass of the ground vegetation roots on the control and PK fertilized plots decreased, and the necromass on the PK fertilized plots increased between 1984–1987 (Table 6).

The mean depth of the living root biomass was 9 cm and that of the pine root length 8 cm in 1984 (Table 7). Fertilization had no effect on the depth of pine roots. However, the average depth of the ground vegetation roots was greater on the fertilized than on the control plots. More than 60 % of the ground vegetation and over 50 % of the pine root biomass occurred in the 0–10 cm peat layer (see Fig. 1). Only 5 % of the pine and slightly more of the ground vegetation roots were growing in the deepest peat layer, 20–40 cm. The greatest amount of dead roots was separated from the surface layer. Their distribution was more even than that of the living roots. Variance analyses by peat layers did not indicate any significant fertilization response.

The fine roots (Ø < 1 mm) accounted for 45 % of the total pine root biomass in the 0–10 cm peat layer before fertilization. In the 10–20 cm peat layer the small roots (Ø = 1–

Table 5. Living fine and small root biomass (g/m^2) and root length (m/m^2) of Scots pine in 1984 and 1987. F and t-values and their significance, (standard deviation in parentheses).
Taulukko 5. Männyn elävien ohutjuurten biomassa (g/m^2) ja pituus (m/m^2) vuonna 1984 sekä t- ja F-arvot ja niiden merkitsevyys, (keskihajonta suluissa).

Treatment *Käsittely*	Size *Koko*	Biomass – *Biomassa* 1984	1987	t-value *t-arvo*	Length – *Pituus* 1984	1987	t-value *t-arvo*
0	Ø< 1 mm	263 (54)	167 (47)	–1.90	2075 (687)	1155 (193)	– 1.85
PK	–"–	276 (45)	208 (26)	–2.18	2050 (214)	1405 (129)	– 2.29
NPK	–"–	308 (21)	249 (99)	–1.01	2428 (302)	1598 (219)	–13.4***
All – *Kaikki*		282 (42)	208 (67)		2184 (457)	1386 (250)	
F-value *F-arvo*		0.52	1.31		0.54	1.77	
0	Ø 1–10 mm	325 (19)	276 (78)	–0.90	237 (56)	161 (38)	– 4.55*
PK	–"–	366 (68)	392 (22)	0.95	257 (57)	201 (34)	– 1.45
NPK	–"–	372 (69)	402 (141)	0.30	277 (12)	186 (50)	– 2.55
All – *Kaikki*		354 (54)	356 (101)		257 (44)	183 (40)	
F-value *F-arvo*		0.49	4.29		0.29	1.10	
0	Ø≤ 10 mm	588 (54)	442 (103)	–2.10	2311 (738)	1316 (191)	– 1.94
PK	–"–	641 (66)	600 (5)	–1.00	2307 (420)	1605 (160)	– 2.19
NPK	–"–	680 (89)	651 (240)	–0.18	2705 (304)	1785 (251)	–11.51***
All – *Kaikki*		637 (74)	564 (161)		2440 (493)	1569 (270)	
F-value *F-arvo*		0.73	1.41		0.04	0.11	

*** p < 0.01, * p < 0.10

Table 6. Living biomass of ground vegetation roots and the necromass of all roots in 1984 and 1987 (g/m^2). F and t-values and their significance, (standard deviation in parentheses).
Taulukko 6. Pintakasvillisuuden elävien ja kaikkien kuolleiden juurten biomassa vuosina 1984 ja 1987 (g/m^2), sekä t- ja F-arvot ja niiden merkitsevyys, (keskihajonta suluissa).

Treatment *Käsittely*	Ground vegetation *Pintakasvillisuus* 1984	1987	t-value *t-arvo*	Dead *Kuolleet* 1984	1987	t-value *t-arvo*
0	653 (48)	465 (81)	–4.44**	317 (135)	342 (71)	0.50
PK	556 (47)	418 (81)	–6.86**	239 (46)	373 (13)	4.19**
NPK	689 (43)	629 (337)	–0.34	305 (89)	524 (292)	1.05
All *Kaikki*	633 (72)	504 (202)		287 (91)	413 (172)	
F-value *F-arvo*	16.24*	2.50		0.32	1.36	

** p < 0.05, * p <0.10

Table 7. Mean penetration (cm) of living root biomass, necromass and length in 1984 and 1987. F-values and their significance, (standard deviation in parentheses).
Taulukko 7. Keskimääräinen juuriston elävän ja kuolleen biomassan ja pituuden syvyysjakaantuminen (cm) vuosina 1984 ja 1987 sekä F-arvot ja niiden merkitsevyys, (keskihajonta suluissa).

	Treatment *Käsittely*	Biomass – *Biomassa* Pine *Mänty*	Ground vegetation *Pintakasvillisuus*	Dead *Kuolleet*	Pine root length *Männyn juurten pituus*
1984	0	9.3 (0.6)	7.8 (1.2)	13.8 (3.0)	8.1 (0.8)
	PK	9.5 (1.9)	10.9 (2.6)	14.2 (2.0)	8.7 (1.3)
	NPK	9.1 (1.2)	8.1 (0.8)	13.6 (3.5)	8.0 (0.5)
	All – *Kaikki*	9.3 (1.1)	8.9 (2.1)	13.8 (2.5)	8.2 0.9)
	F-value *F-arvo*	0.4	4.4	0.0	1.0
1987	0	9.2 (0.9)	6.7 (0.8)	10.1 (0.2)	7.7 (0.2)
	PK	10.7 (0.8)	8.0 (1.7)	12.6 (2.5)	9.7 (1.1)
	NPK	9.8 (0.8)	9.1 (1.7)	12.7 (1.0)	8.8 (0.9)
	All – *Kaikki*	9.9 (1.0)	8.0 (1.6)	11.8 (1.8)	8.7 (0.9)
	F-value *F-arvo*	2.4	35.5**	1.6	2.3

** $p < 0.05$

10 mm) dominated, and in the deepest layer the fine roots (Ø < 1mm).

The length of pine roots was 2440 m/m^2 in 1984 (Table 5), with no significant differences between the fertilization treatments. The pine root length decreased, especially on the NPK plots, between the surveys. The root length was more superficial than the biomass (see Table 7, Fig. 2). The fine root fraction (Ø < 1 mm) accounted for 90 % of the total root length in the 0–10 cm peat layer; in the deeper layers its proportion was smaller.

The biomass/length ratio was not affected by fertilization (Table 8), although according to the t-test the ratio of the 1–10 mm thick pine roots increased on the NPK plots. Scots pine root biomass and length per stem number and stem volume were also calculated (Table 9). They were not affected by the fertilizer treatments.

Table 8. Scots pine living root biomass in g per root length (m) of the two root size classes. F and t-values and their significance.
Taulukko 8. Männyn elävien ohutjuurten biomassa (g) pituusyksikköä (m) kohti eri kokoluokissa sekä t- ja F-arvot ja niiden merkitsevyys.

Treatment *Käsittely*	Size *Koko*	1984	1987	t-value *t-arvo*
0	Ø<1 mm	0.13	0.14	0.56
PK	–"–	0.13	0.14	1.70
NPK	–"–	0.12	0.15	0.85
F-value *F-arvo*		0.39	0.47	
0	1–10 mm	1.37	1.70	0.76
PK	–"–	1.44	1.98	1.68
NPK	–"–	1.34	2.13	6.64**
F-value *F-arvo*		0.07	7.14	

** $p<0.05$

Table 9. Scots pine living root biomass and length per stem and stem volume (m^3 o.b.) in different root size classes in 1984 and 1987. F and t-values and their significance.
Taulukko 9. Männyn elävien ohutjuurten biomassa ja pituus puuta ja puuston tilavuusyksikköä kohti eri kokoluokissa 1984 ja 1987 sekä t- ja F-arvot ja niiden merkitsevyys.

Treatment *Käsittely*	Size class *Koko*	kg/tree – *puu* 1984	kg/tree – *puu* 1987	t-value *t-arvo*	kg/m^3 1984	kg/m^3 1987	t-value *t-arvo*	km/tree – *puu* 1984	km/tree – *puu* 1987	*t-value t-arvo*	*km/m^3* 1984	*km/m^3* 1987	*t-value*
0	Ø<1 mm	1.1	0.8	1.64	33	17	2.63	9.0	5.2	1.70	260	119	2.32
PK	–"–	1.2	1.0	1.72	35	21	3.51*	8.9	6.5	1.96	260	144	3.31*
NPK	–"–	1.3	1.2	0.51	36	25	2.06	10.5	7.8	15.50***	306	161	8.47**
F-value – *F-arvo*		1.14	1.79		0.34	1.55		1.21	2.87		0.33	1.86	
0	1–10 mm	1.4	1.2	0.58	41	28	1.98	1.0	0.73	3.85*	30	17	5.73*
PK	–"–	1.6	1.8	–1.61	46	40	1.60	1.0	0.93	1.04	33	21	2.48
NPK	–"–	1.6	2.0	–0.72	47	41	0.67	1.2	0.90	1.92	35	19	3.34*
F-value – *F-arvo*		1.37	5.60		0.32	4.40		0.79	1.36		0.21	1.59	
0	Ø≤10 mm	2.5	2.0	1.60	74	45	3.37*	10	5.9	1.80	290	135	–2.44
PK	–"–	2.8	2.8	0.03	81	61	3.39*	10	7.5	1.84	293	165	3.21*
NPK	–"–	2.9	3.1	–0.27	86	66	1.79	12	8.7	–13.82**	341	180	7.57**
F-value – *F-arvo*		3.41	3.32		0.48	3.05		1.16	2.61		0.30	1.73	

** $p<0.05$, * $p<0.10$

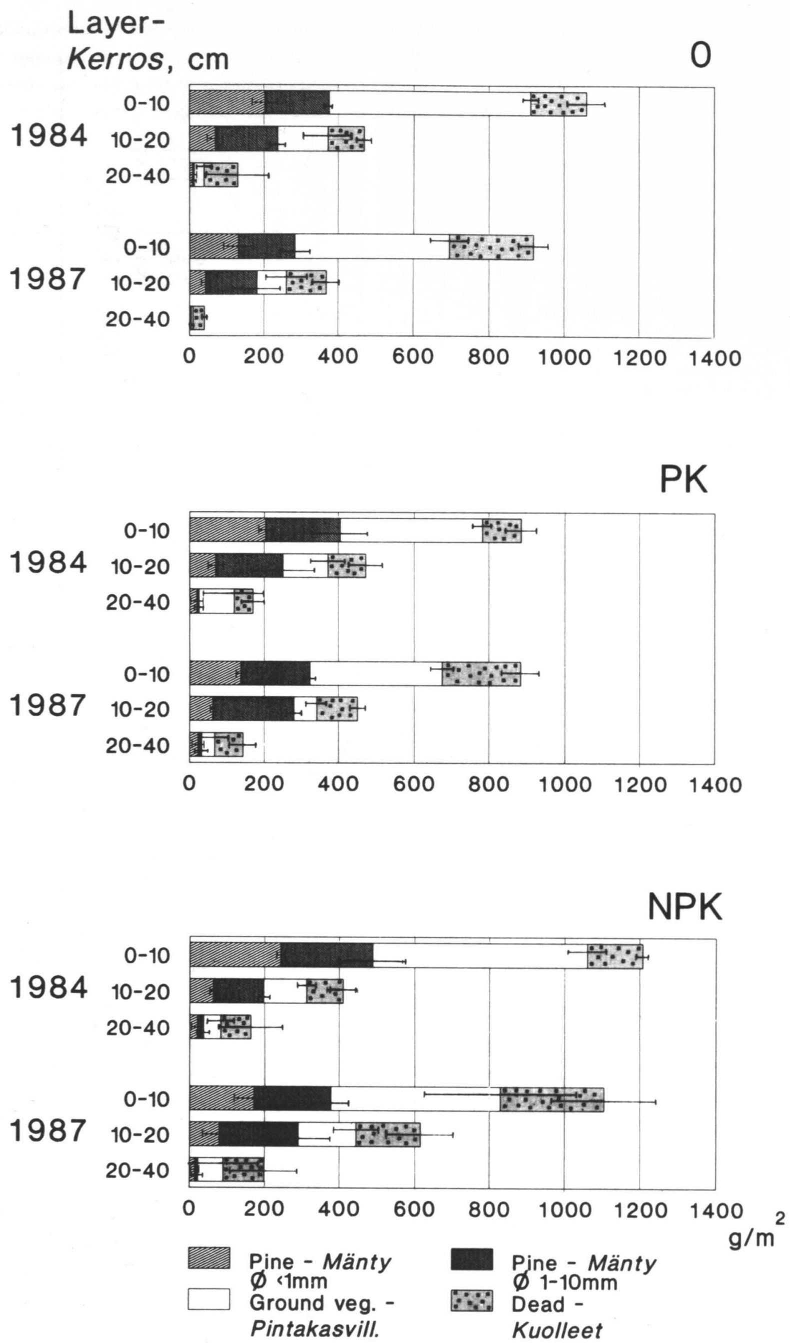

Figure 1. Living root (Ø ≤10 mm) biomass and root necromass in different peat layers in 1984 and 1987 on the control, PK and NPK fertilized plots. Standard deviation indicated by lines in the columns.

Kuva 1. Elävien ja kuolleiden juurten (Ø ≤ 10 mm) biomassa eri turvekerroksissa vuosina 1984 ja 1987 lannoittamattomilla, PK- ja NPK-lannoitetuilla koealoilla. Keskihajonta esitetty janoin.

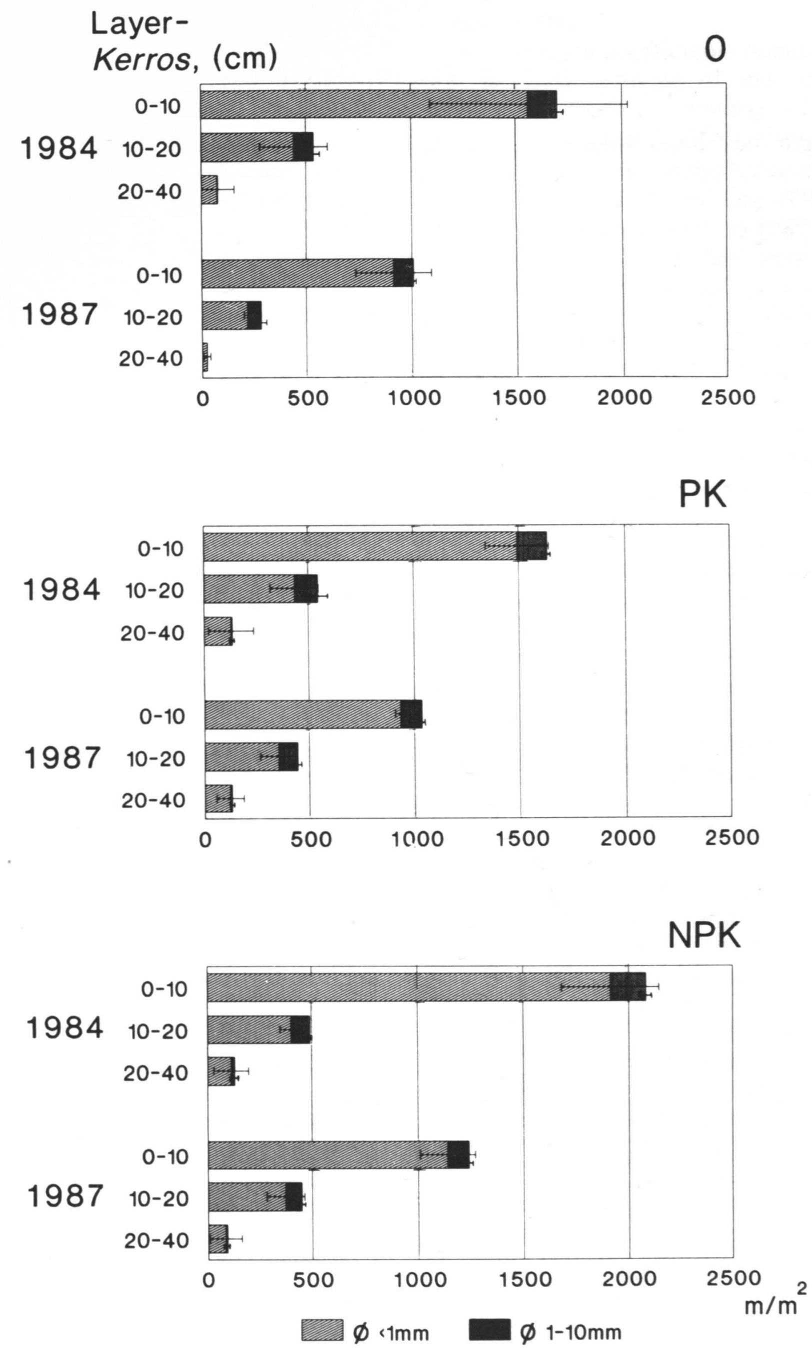

Figure 2. Scots pine root length (Ø ≤ 10 mm) in different peat layers in 1984 and 1987 on the control, PK and NPK fertilized plots. Standard deviation indicated by lines in the columns.

Kuva 2. Männyn juurten (Ø ≤ 10 mm) pituus eri turvekerroksissa vuosina 1984 ja 1987 lannoittamattomilla, PK- ja NPK-lannoitetuilla koealoilla. Keskihajonta esitetty janoin.

4 Discussion

Root length has been studied in Finland (Heikurainen 1955ab, Paavilainen 1966, Finér 1989) and in Norway (Håland and Brække 1989) on pine bogs with almost the same site type and tree stand characteristics as in this study. The root length in proportion to stem volume and tree number was lower on virgin sites studied by Heikurainen (1955b) and Håland and Brække (1989), and almost equal to those reported by Heikurainen (1955b), Paavilainen (1966) and Finér (1989) from drained sites. The pine root biomass was larger than that on the Norwegian site (Håland and Brække 1989), and almost the same as on the Finnish pine bog studied by Finér (1989). These observations are in accordance with results showing that root amount increases after improved drainage (Heikurainen 1955b, Paavilainen 1966).

The root biomass of the ground vegetation was almost equal to those reported by Paavilainen (1980) from a drained low-shrub pine bog in Finland, and Håland and Brække (1989) from a virgin bog in Norway. The proportion of ground vegetation roots compared to pine roots was clearly smaller than on the Norwegian site. After drainage the above-ground biomass of pine increases, whereas the ground vegetation, which is dominated by dwarf shrubs may gradually decrease (Brække 1988). This is probably also true for root biomass.

In general, pine produces a superficial root system on pine bogs (e.g. Heikurainen 1955ab, Paavilainen 1966, 1967, Finér 1989, Håland and Brække 1989). Although the roots penetrate to deeper peat layers after drainage, the change in the depth distribution is not great (Heikurainen 1955b, Paavilainen 1966). The root system on the Norwegian site (Håland and Brække 1989) had a similar distribution pattern to that on the studied site. The nutrient conditions were probably more favourable for the roots near the surface, where the decomposition activity was the highest (see Brække and Finér 1990). The higher temperatures and better aeration in the surface also promote the formation of a superficial root system. The pine roots were thicker in the 10–20 cm peat layer than in the surface layer. This has also been observed on some other sites (Heikurainen 1955b, Håland and Brække 1989), but not on all (Finér 1989).

The ground vegetation root system was more superficial on the studied site than on the pine bog studied by Håland and Brække (1989). The species composition may explain this phenomenon (see Finér and Brække 1991). The roots of *Eriophorum vaginatum*, which was more dominant on the Norwegian site, penetrate to deeper peat layers than those of bog dwarf shrubs. Scots pine and the ground vegetation had equally deep root systems (compare Paavilainen 1968, Håland and Brække 1989).

No reports on the root necromass of pine bogs were found in the literature. Separating dead roots from peat is a more subjective procedure than that for living roots, and their mass is underestimated by this method. The annual fine root turnover has been estimated to be almost equal to the average, living, fine root biomass in cold temperate and boreal coniferous forests (Vogt et al. 1986). If the same relationship also prevailed on the study site, the root necromass was very low compared to the living root biomass. This may be an indication of a high rate of decomposition of the root litter. The root necromass was more evenly distributed in the different peat layers than the living biomass. This is probably explained by the differences in the decomposition between the peat layers (see Brække and Finér 1990) or a higher mortality rate close to the water table.

The results did not show that fertilization would have had any significant effect on the total root biomass or length (cf. Paavilainen 1980). According to Zöttl (1964, ref. Lyr and Hoffman 1967), the increased increment of stemwood given by fertilization in vigourously growing stands is associated with unstimulated or only slightly increased root systems. On the other hand, in stands with a poor nutrient status, additional growth of the above-ground compartments requires an enlargement of the root systems. Although the studied site was an oligotrophic low-shrub pine bog, the trees were growing

vigourously (Table 3). On oligotrophic pine bogs PK and NPK fertilizations have increased the root biomass and root length of pine seedlings and ground vegetation (Paavilainen 1967b, 1968). The site in this study was at the developmental stage where the amount of roots has already reached its maximum (Heikurainen 1955b). The root zone may have been fully occupied, with little room for root enlargement. In previous studies an increase in fine root biomass has also been observed later, 5–8 years after fertilization (see Paavilainen 1967b, 1968).

Axelsson and Axelsson (1986) found that the ratio of roots to total biomass fell during the 12-year period following fertilization of a Scots pine stand. In this study the amount of fine and small roots per stem volume did not change within the three-year study period. The depth of the ground vegetation root system was greater on the fertilized than on the unfertilized plots in 1987. This may be due to improved nutrition in the deeper layers, or to changes in the species composition after fertilization (see Finér and Brække 1991).

The variation coefficients obtained for the total biomass estimate of the site can be regarded as small for material of this type (Brække and Håland 1990). However, the small effects of fertilization may have been obscured by the variation between the treatments. Possible responses in root dynamics were not revealed by the method used (see Persson 1980b).

The results indicate that the pine root length and ground vegetation root biomass decreased and the necromass increased between the surveys on both the control and fertilized plots. The root system probably suffered from poor aeration in 1987, when the groundwater table remained for most of the time in the studied peat layer (Table 2). The surface peat did not thaw until two weeks after the beginning of the growing season in 1987. Low temperatures may have prevented elongation and increased the mortality of roots (Kramer and Kozlowski 1979, Andersen et al. 1986).

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