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Jyrki Hytönen

EFFECT OF FERTILIZER APPLICATION RATE ON NUTRIENT STATUS AND BIOMASS PRODUCTION IN SHORT-ROTATION PLANTATIONS OF WILLOWS ON CUT-AWAY PEATLAND AREAS

Lannoitemäärän vaikutus lyhytkiertoviljelmien ravinnetilaan ja biomassatuotokseen suonpohjilla.

Hytönen, J. 1994: Effect of fertilizer application rate on nutrient status and biomass production in short-rotation plantations of willows on cut-away peatland areas. (Lannoitemäärän vaikutus lyhytkiertoviljelmien ravinnetilaan ja biomassatuotokseen suonpohjilla.) — Suo 45:65–77. Helsinki. ISSN 0039-5471.

The effects of N, P and K fertilizer application rates on the biomass production, soil properties and foliar nutrient status were studied in willow plantations (*Salix x dasyclados*, *Salix* 'Aquatica') established on cut-away peatland areas at Haapavesi (64°06'N, 25°36'E and Ruukki (64°27'N, 25°26'E). When the amount of one of the nutrients in NPK-fertilization was changed (N 0–200 kg/ha, P 0–60 kg/ha, K 0–80 kg/ha) the others remained unchanged (N 100, P 30, K 40 kg/ha). Three field experiments were made. Increasing phosphorus and potassium application rates increased the concentrations of corresponding soil extractable nutrients. There was a positive correlation between the fertilizer application rate and the concentrations of foliar nitrogen, phosphorus and potassium. During the first growing season, the effect of nitrogen fertilization on biomass production was modest, but during the second growing season the yield of willows increased the most when fertilized with 100–150 kg N/ha. Although phosphorus fertilization increased yields, already the smallest amounts (15 kg/ha) resulted in biomass yields as high when applying the largest phosphorus fertilizer amounts (60 kg/ha). Potassium fertilization did not increase biomass production in any of the experiments. The highest total biomass yields after three growing seasons were 28–30 t/ha. Their compositions were as follows: 44% wood, 18% bark, 17% foliage, 16% roots, and 5% stumpwood.

Key words: biomass production, cut-away peatland, fertilization, energy forestry, Salix

Jyrki Hytönen, The Finnish Forest Research Institute, Kannus Research Station, Box 44, FIN-69101 Kannus, Finland

INTRODUCTION

The short-rotation management concept includes the establishment of closely-spaced stands of fast-growing trees applying intensive cultivation practices, repeated harvesting at short cutting cycles, regeneration of subsequent crops via sprouts, and using a high degree of mechanization. Cut-away peatlands estimated to amount to 1 500–2 000 ha in 1992 (Lappalainen et al. 1992) and to increase during this decade by 1 500–3 000 ha annually (Kaunisto and Saarinen 1989, Taustatietoa... 1991, Lappalainen et al. 1992), have been considered to be suitable for short-rotation cultivation (Energiametsätoimikunnan... 1979, 1981). Cut-away peatlands are characterized by variable peat thickness, low pH and high nitrogen contents and low concentrations of phosphorus and potassium (Kaunisto 1979, 1985, Ferm and Kaunisto 1983, Lumme et al. 1984, Heikkilä 1986, Lehtonen & Tikkanen 1986, Ferm and Hytönen 1988, Kaunisto and Viinamäki 1991).

Short-rotation willows bind considerable amounts of nitrogen, phosphorus, potassium and other nutrients in their biomass (Saarsalmi 1984, Ferm 1985, Hytönen 1986). The nutrient amounts bound in a young willow stand can be of the same magnitude as those in a stand of 40-year-old birch, a stand of pole-sized Scots pine or a 100-year-old stand of Norway spruce (Mälkönen 1977, Paavilainen 1980, Saarsalmi 1984, Ferm 1985, Hytönen 1986, Finér 1989). Fertilization and soil amelioration are probably the most important factors affecting the biomass production of short-rotation plantations on cut-away peatlands (Hytönen 1982, 1986, 1987, Kaunisto 1983, Ferm and Hytönen 1988, Lumme 1989). Due to the rather high pH requirements of *S. viminalis* and *S. x dasyclados* (Ericsson and Lindsjö 1981, Ferm and Hytönen 1988) liming or ash application are necessary (Kaunisto 1983, Lehtonen and Tikkanen 1986, Lumme 1989). The survival and growth of willows on limed but unfertilized cut-away peatlands has been poor (Hytönen 1982, 1986, 1987, Kaunisto 1983, Ferm and Hytönen 1988). Fertilization has considerably increased the biomass production of willow both in field and greenhouse experiments (Hytönen 1982, 1986, Kaunisto 1983, Ferm and Hytönen 1988). The highest biomass production levels have been achieved both in greenhouse and field experiments when nitrogen as well as PK and a liming agent have been added (Hytönen 1982, Kaunisto 1983, Hytönen 1987, Ferm and Hytönen 1988).

Knowledge on the proper fertilizer application amounts in short-rotation cultivation on cut-away peatlands is still inadequate. Doubling of the NPK fertilization amounts from N 150 kg/ha, P 54–67 kg/ha and K 102–124 kg/ha increased biomass production on cut-away peatlands with nitrogen contents of 1.2–1.8%, but not on peatlands with nitrogen contents above 2.3% (Kaunisto 1983, Hytönen 1987). The aim in this investigation was to study the effects of fertilizer application rates on biomass production, soil properties and foliar nutrient concentrations of willows on cut-away peatlands.

MATERIAL AND METHODS

Experimental design

Willow plantations were established on two limed (6 000 kg/ha of dolomite lime) cut-away peatlands at Haapavesi Piipsanneva (64°06', 25°36'E) and at Ruukki Paloneva (64°27'N, 25°26'E). Willows (*Salix x dasyclados* clone P6011 at Piipsanneva 1, *Salix* 'Aquatica', clone V769 at Piipsanneva 2 and at Paloneva) were planted at a density of 40 000 cuttings per hectare in the spring of 1983 and cut back to 10 cm long stumps the following autumn. All experimental fields were fertilized using 500 kg/ha of PK fertilizer for peatlands (P 44 kg/ha, K 83 kg/ha) and ammonium nitrate with lime (N 50 kg/ha) in the spring of 1983. Supplementary planting and weed control was carried out on all experimental fields, which were also fenced. The fertilization experiments were established in the spring of 1984 and the willows were cultivated for three years.

Different N, P and K fertilizer application rates were tested in three fertilization experiments. Five nitrogen (N 0, N 50, N 100, N 150, N 200 kg/ha as ammonium nitrate with lime), phosphorus (P 0, P 15, P 30, P 45, P 60 kg/ha as superphosphate) and potassium (K 0, K 20, K 40, K 60, K 80 kg/h as potassium salt) levels were used. When the amount of one of the nutrients in NPK fertilization was changed, the others remained unchanged (N 100, P 30 and K 40 kg/ha). In total, there were thirteen fertilization treatments. The sizes of the experimental plots were 56–80 m^2. The experimental design consisted of randomized blocks with three replications. Fertilization was repeated annually in the spring (1984, 1985, 1986).

Measurements

The height and diameter of the willows on the experimental plots were measured after each growing season (see Hytönen 1985, 1986, Hytönen et al. 1987). The number of living and dead stools were also recorded. The biomass of leaves, bark, wood and stumps and roots was determined annually using dry-mass equations described by Hytönen (1994).

Foliar samples from at least five randomly selected uneven sized willow sprouts were taken from each plot in 1984–1986 for nutrient analysis. Foliar N, P and K concentrations were determined from the 1984 samples. The samples taken in 1985 and 1986 were also analyzed for foliar concentrations of Ca, Mg, Fe, Mn, Zn, and Cu (Halonen and Tulkki 1983).

Soil samples (composed of five subsamples) were taken in August 1986 from the 0–10 cm top soil layer on the study plots. The samples were analyzed for their pH, acid ammonium acetate (pH 4,65) extractable phosphorus, potassium, calcium, and magnesium (mg/l, volume determined in laboratory). The average peat depth measured from five points on each plot was 150 cm at Paloneva, 60 cm at Piipsanneva 1 and 40 cm at Piipsanneva 2. The organic matter content in the peat was lowest at Piipsanneva 2 (71%), higher at Piipsanneva 2 (84%) and Paloneva (90%). The total peat nitrogen content in the organic matter was at Paloneva 3.2% and at Piipsanneva 2.3%. At Piipsanneva 1, the extractable calcium concentration of the peat averaged 971 mg/l, at Piipsanneva 2 it was 1332 mg/l and at Paloneva 735 mg/l. The corresponding figures for extractable magnesium were 255 mg/l, 422 mg/l, 200 mg/l. The average pH on the experimental sites varied between 5.2 and 5.5.

The BMDP statistical software package was used in the computation of the results and analyses of variance were calculated. The treatment means were compared using Tukey's multiple range test.

RESULTS

Soil characteristics

Soil extractable phosphorus and potassium concentrations increased the more the higher the corresponding fertilizer application rate (Fig. 1). The effect of phosphorus fertilization was statistically significant at both Piipsanneva experiments ($p < 0.001$), but not at Paloneva. Only the highest (Piipsanneva 1) or second highest (Piipsanneva 2) fertilizer application rates significantly increased the soil phosphorus concentration to a level higher than that of the control. The highest phosphorus fertilization rates increased the peat phosphorus concentration at Piipsanneva 1 by over 12 times, at Piipsanneva 2 by 17 times and at Paloneva by 25 times as high as on the NK-fertilized control plots. The increase in the soil's potassium concentration was statistically significant only at Paloneva ($p < 0.05$).

The nitrogen, phosphorus or potassium fertilizer application rates did not affect the soil's pH or soil extractable calcium and magnesium concentrations.

Foliar nutrient concentrations

Increasing the nitrogen fertilization rate increased foliar nitrogen concentrations at the Piipsanneva experiment during all three study years (Fig 2). However, at Paloneva, the nitrogen contents of the foliage during the first growing season were high regardless of the fertilization treatment; neither were the differences statistically significant during the third growing season. At Piipsanneva 1, already the lowest fertilizer application rate (50 kg/ha) increased the foliar nitrogen concentration compared to the control, whereas 100 kg/ha were required at Piipsanneva 2 for the equivalent foliar nitrogen concentration level to be achieved. Nitrogen fertilization had also a highly significant effect on the foliar N/P and P/K ratios, which increased as the amounts of applied nitrogen increased. The foliar N/P ratio of PK-fertilized willows varied between 7 and 10 while that of willows fertilized with 150 kg N/ha varied between 12 and 19.

Phosphorus fertilization increased foliar phosphorus concentrations, although the effect

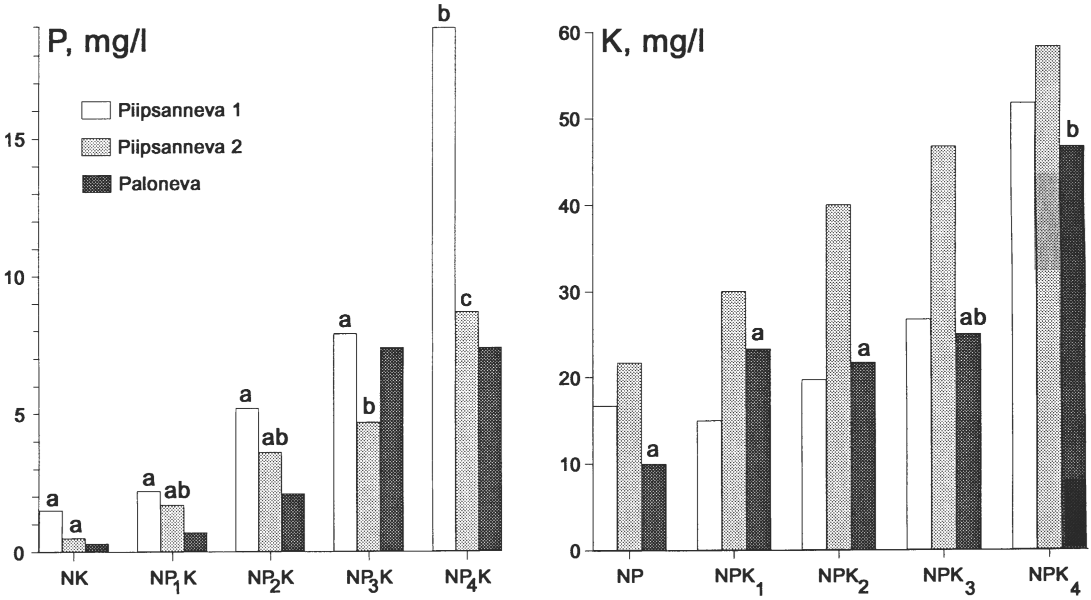


Fig. 1. Effect of fertilizer application rate on the concentration of ammonium acetate extractable phosphorus and potassium in the soil. For nutrient amounts applied, see Figure 2. Means not differing with statistical significance ($p < 0.05$) from each other are marked with the same letter.

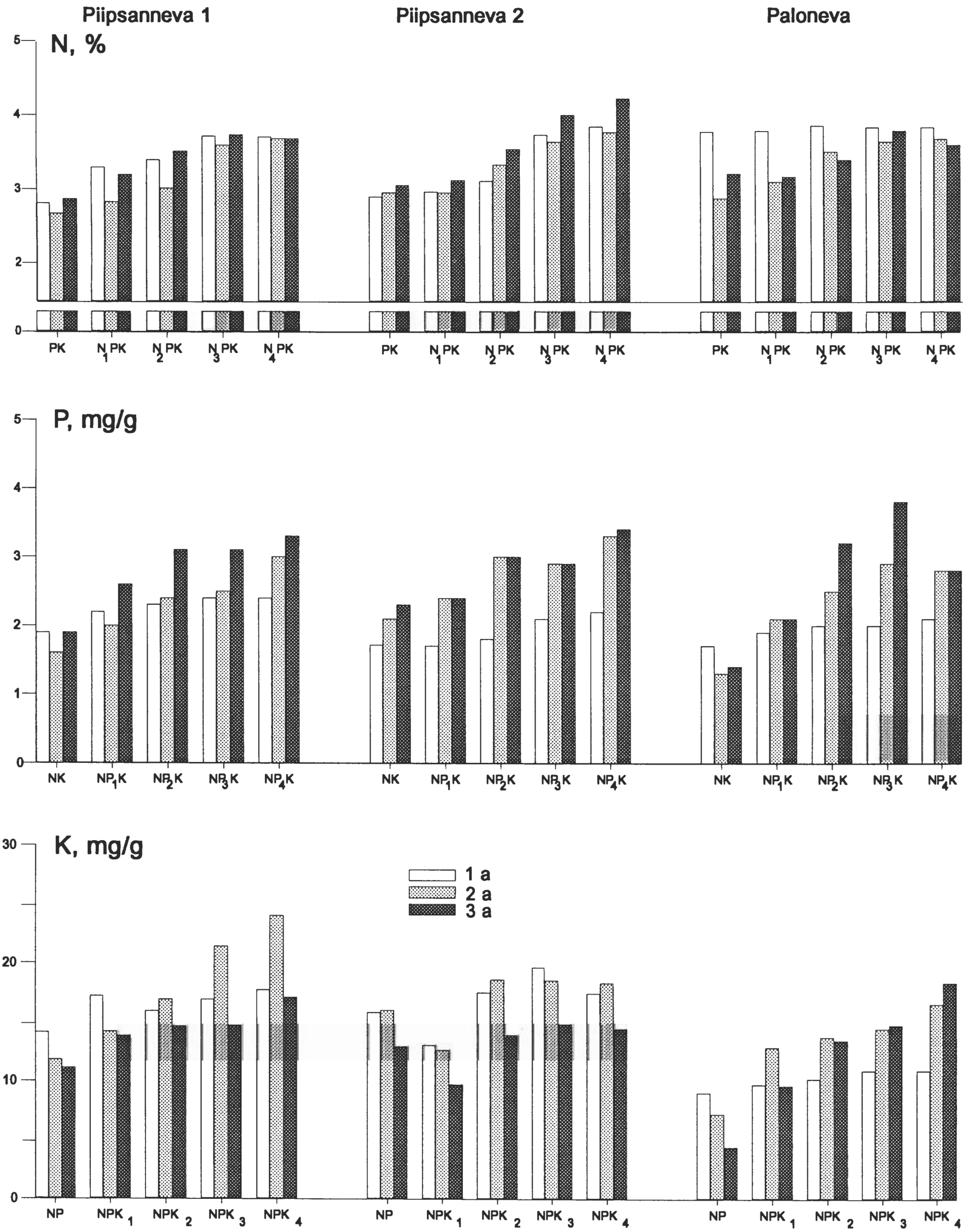
Kuva 1. Fosfori- ja kaliumlannoitemäärän vaikutus maan happamaan ammoniumasetaattiin uuttuvan fosforin ja kaliumin määrään. Keskiarvot, jotka eivät eroa toisistaan tilastollisesti merkitsevästi (p < 0,05) merkitty samalla kirjaimella.

during the first growing season was significant only at Paloneva ($p < 0.05$) (Fig 2). During the following growing seasons, the effect of phosphorus fertilization was also significant both at Piipsanneva 1 ($p < 0.001$) and Piipsanneva 2 ($p < 0.05$). At Piipsanneva 1, already 15 kg/ha phosphorus increased foliar phosphorus concentration higher than in the control, but at Piipsanneva 2 the corresponding amount was 30 kg/ha. Increasing the annual phosphorus fertilizer application rate from 45 kg/ha to 60 kg/ha did not increase the concentration of foliar phosphorus. Phosphorus fertilization decreased the foliar N/P and K/P ratios from the second growing season on.

The effect of potassium fertilization on the foliar potassium concentration was most pronounced at Paloneva ($p_{1a} < 0.05$, $p_{2a} < 0.001$, $p_{3a} < 0.001$), where the concentration of the peat extractable phosphorus was at its lowest (Fig. 2). At Paloneva, foliar potassium concentrations also decreased from year to year in the control (NP) treatment. At Piipsanneva 1, potassium fertilization increased foliar potassium concentrations during the second growing season ($p < 0.05$). At Piipsanneva 2, the foliar potassium concentration of willows fertilized with NP was higher than that of willows fertilized with a small amount of potassium (K 20 kg/ha).

Fig. 2. Effect of fertilizer application rate on the foliar concentrations nitrogen, phosphorus and potassium during the first (1a), second (2a) and third (3a) growing seasons. N_1 = 50 kg N/ha, N_2 = 100 kg N/ha, N_3 = 150 kg N/ha, N_4 = 200 kg N/ha. P_1 = 15 kg P/ha, P_2 = 30 kg P/ha, P_3 = 45 kg P/ha, P_4 = 60 kg P/ha. K_1 = 20 kg K/ha, K_4 = 40 kg K/ha, K_3 = 60 kg K/ha, K_4 = 80 kg K/ha. Means not differing with statistical significance ($p < 0.05$) from each other are marked with the same letter.

Kuva 2. Typpi-, fosfori ja kaliumlannoitemäärän vaikutus lehtien typpi-, fosfori- ja kaliumpitoisuuksiin ensimmäisenä (1a), toisena (2a) ja kolmantena (3a) kasvukautena. N_1 = 50 kg N/ha, N_2 = 100 kg N/ha, N_3 = 150 kg N/ha, N_4 = 200 kg N/ha. P_1 = 15 kg P/ha, $_P$ = 30 kg P/ha, P_3 = 45 kg P/ha, P_4 = 60 kg P/ha. K_1 = 20 kg K/ha, K_4 = 40 kg K/ha, K_3 = 60 kg K/ha, K_4 = 80 kg K/ha. Keskiarvot, jotka eivät eroa toisistaan tilastollisesti merkitsevästi (p < 0,05) merkitty samalla kirjaimella.


Piipsanneva 1
Piipsanneva 2
Paloneva
N, %
PK
N_1PK
N_2PK
N_3PK
N_4PK
P, mg/g
NK
NP_1K
NP_2K
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K, mg/g
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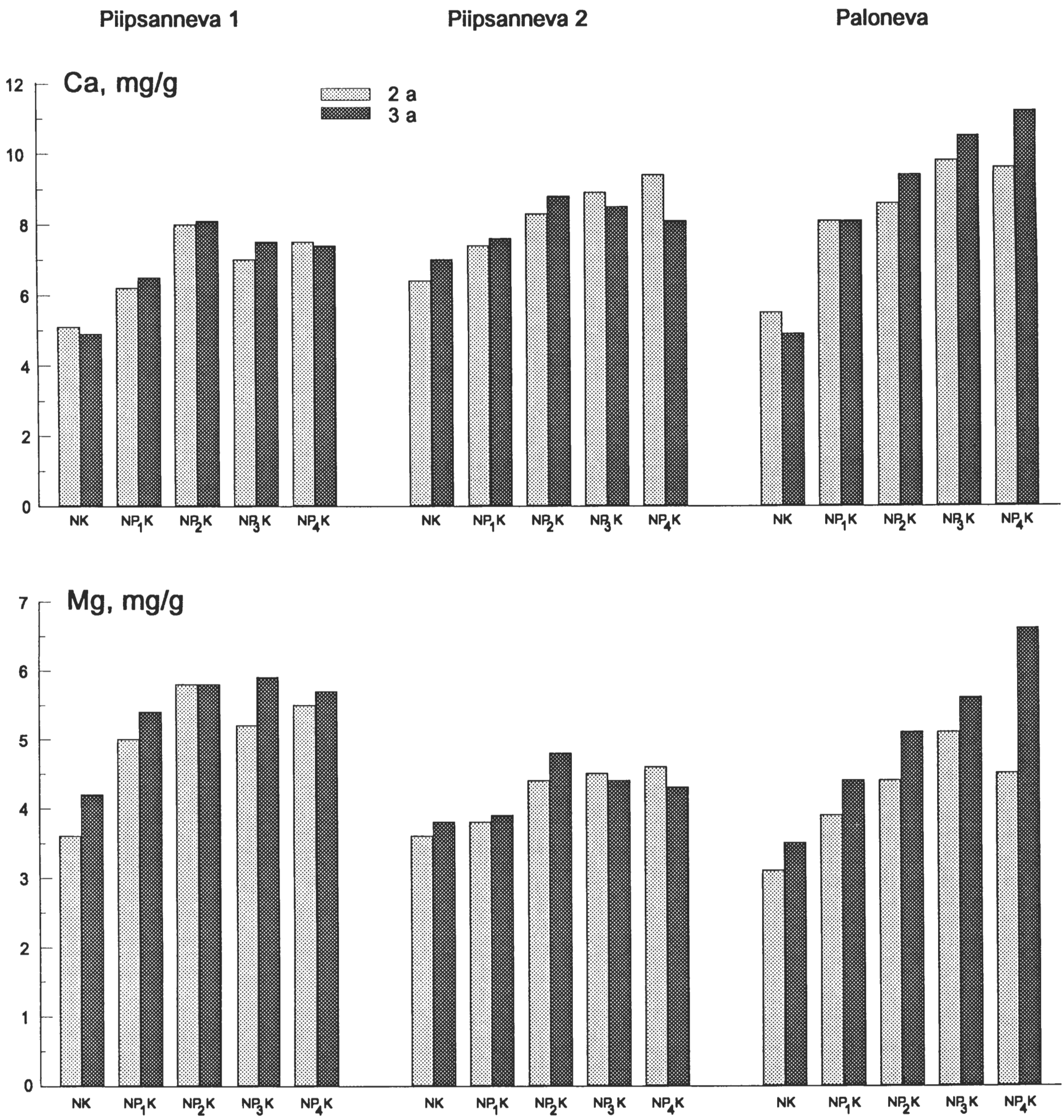

Fig 3. Effect of phosphorus fertilizer application rate on the foliar calcium and magnesium concentrations. For nutrient amounts applied, see Figure 2.

Kuva 3. Fosforilannoitemäärän vaikutus lehtien kalsium- ja magnesiumpitoisuuksiin. Selitykset kuvassa 2.

The effect of different fertilizer application rates on other foliar nutrient concentrations was modest. Phosphorus fertilization increased foliar calcium and magnesium concentrations (Fig 3) and at Paloneva it significantly ($p < 0.001$) decreased the foliar copper concentrations. The site-to-site differences in foliar iron, manganese, zinc and copper concentrations were considerable (Fig 4).

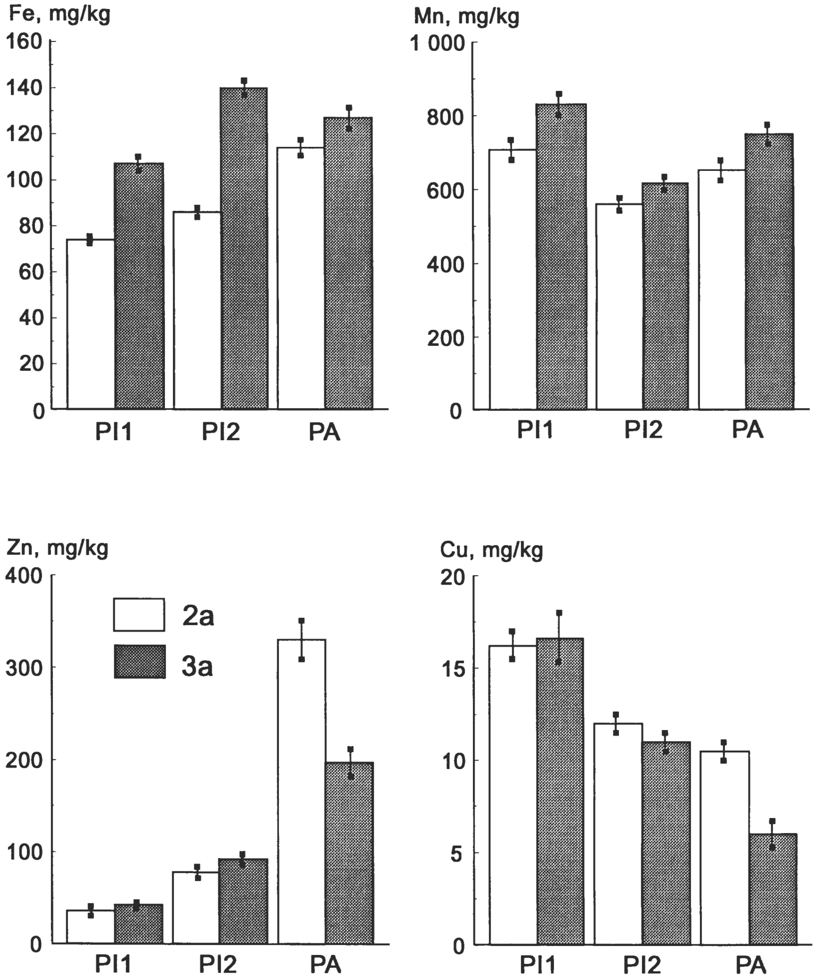

Fig 4. Foliar iron, manganese, zinc and copper concentrations (mg/kg) in the experimental areas. PI1 = Piipsanneva 1, PI2 = Piipsanneva 2, PA = Paloneva. Age of willows 2 (2a) and 3 (3a) years, ±SE marked with line on top of each bar.

Kuva 4. Pajujen lehtien rauta-, mangaani-, sinkki- ja kuparipitoisuudet koealueilla. PI1 = Piipsanneva 1, PI2 = Piipsanneva 2, PA = Paloneva. Pajujen ikä 2 (2a) ja kolme (3a) vuotta. Keskiarvon keskivirhe merkitty janalla pylväiden päälle.

Survival

The survival of willows at the end of the experiments was considerably high (Fig 5). The higher rates of nitrogen fertilizer slightly decreased survival; only at Piipsanneva 2, however, was this decrease significant ($p < 0.05$). At Paloneva, survival decreased with increasing phosphorus fertilizer application rates.

Biomass production

Although nitrogen fertilization increased biomass production already during the first growing season, the differences between the treatments were not statistically significant (Fig. 6). During the second growing season, biomass production at Piipsanneva was significantly higher than in the control with the nitrogen fertilizer application rates higher than 50 kg/ha. However, amounts exceeding 100 kg/ha no longer increased the biomass production. At Paloneva, only the 150 kg/ha application rate resulted in higher biomass production than the control. During the third growing season at Piipsanneva, fertilizer application rates of 100 kg/ha or more did not differ from each other in terms of the biomass produced; the total biomasses in these treatments varied within the range of 23.4–28.4 t/ha. Increasing the nitrogen fertilizer application rate from 50 to 100–200 kg/ha at Paloneva had no statistically significant effect on biomass production during the third growing season.

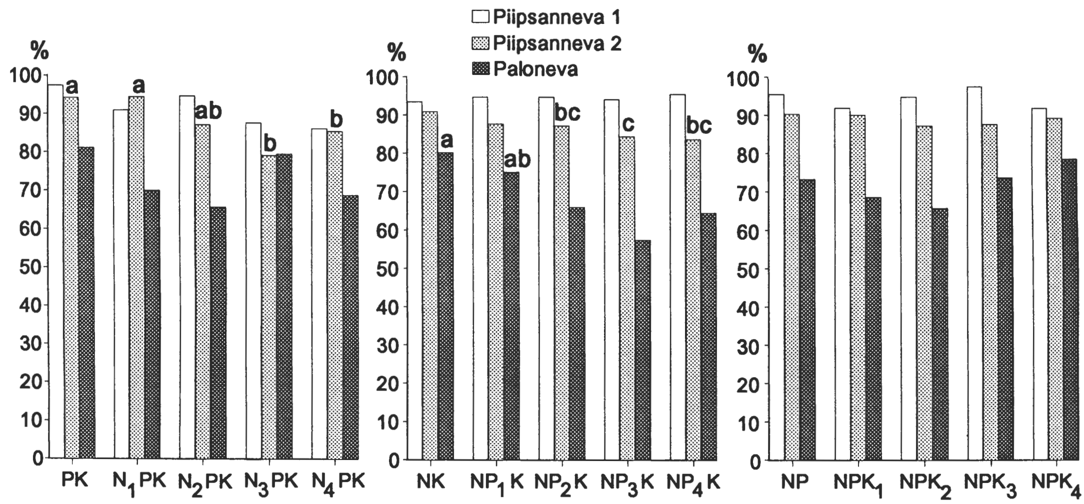

Fig. 5. Effect of fertilizer application rate on the survival of willows at the end of the third growing season. Means not differing with statistical significance ($p < 0.05$) from each other are marked with the same letter. For nutrient amounts applied, see Figure 2.

Kuva 5. Lannoitemäärän vaikutus pajujen elävyyteen kolmannen kasvukauden lopussa. Keskiarvot, jotka eivät eroa toisistaan tilastollisesti merkitsevästi (p < 0,05) merkitty samalla kirjaimella. Selitykset kuvassa 2.

Compared with NK fertilization, phosphorus fertilization enhanced biomass production, but the differences between different phosphorus fertilizer application rates were not statistically significant. Already 15 kg P/ha given annually resulted in as good a yield as the higher amounts of 60 kg P/ha. Compared to NP fertilization, potassium fertilization did not increase biomass production during any of the study years.

The first year's biomass production was low, 1.0–4.0 t/ha (Fig. 6). The composition of the total biomass produced by one-year-old, NPK-fertilized *S. x dasyclados*, 3.2 t/ha, was as follows: 23% wood, 20% bark, 22% foliage, 22% roots and 13% stumpwood. The annual increment during the following years increased manyfold. The mean annual leafless biomass production of NPK-fertilized *S. x dasyclados* (3.0–6.3 t/ha/a) was higher than that of *S.* 'Aquatica' (2.6–4.7 t/ha/a). The maximum total production of 30.6 t/ha/3a was composed of 44% wood, 18% bark, 17% foliage, 16% roots and 5% stumpwood.

DISCUSSION

Increasing phosphorus and potassium application rates increased the corresponding concentrations of acid ammonium acetate extractable nutrients in the soil. However, even after three annual PK fertilizer applications, the ammonium acetate extractable phosphorus and potassium concentrations in the peat were rather low compared to Finnish tilled soils (Kurki 1982). The imbalance of nutrient ratios, typical for cut-away peatlands – high contents of peat nitrogen but low concentrations of phosphorus and potassium – was at its most extreme at Paloneva (Kaunisto 1979, 1985, Lehtonen & Tikkanen 1986, Ferm and Hytönen 1988, Kaunisto and Viinamäki 1991). At Paloneva, the peat's nitrogen content was exceptionally high (see also Hytönen 1986, 1987, Ferm and Hytönen 1988). Willow growth was probably not limited by the peat's low pH values (Ericsson and Lindsjö 1981, Ferm and Hytönen 1988).

The willows in this study responded readily to the fertilizer application treatments. Fertilizer application can be used to adjust foliar nitrogen, phosphorus and potassium concentrations and also foliar nutrient ratios (also Kaunisto 1983, Hytönen 1985). The results of this and earlier studies suggest that increases in nitrogen fertilizer application rates have less effect on foliar nitrogen concentrations on nitrogen-rich sites than they do on nitrogen-poor sites (Kaunisto 1983, Hytönen 1987).

Compared with the amounts given in fertilization, the willow stands in this study bound considerably small amounts of nitrogen, phosphorus and potassium in their biomass (Saarsalmi 1984, Ferm 1985, Hytönen 1986). During the first growing season, biomass production was low and nitrogen fertilization did not increase it significantly. Thus fertilization using the lowest nitrogen rates, or with no nitrogen being applied during the establishment phase, could be appropriate. This is in good agreement with Swedish recommendations for practical energy forestry cultivation with willows. According to these recommendations, nitrogen fertilization is usually not needed during the first growing season or it is needed in only small amounts (30–60 kg N/ha) (Sennerby-Forsse and Johansson 1989, Ledin and Sennerby-Forsse 1992). During the following years, increases in annual nitrogen fertilizer application rates over 100 kg/ha did not lead to considerable increases in yields. This is also in agreement with the Swedish recommendations for nitrogen fertilization (60–80 kg N/ha) (Sennerby-Forsse and Johansson 1989). On the nitrogen-rich site, the effect of increasing nitrogen fertilizer amount was less pronounced than on the site containing less nitrogen. Similarly, yields produced by mere PK fertilization were higher at the nitrogen-rich, and phosphorus and potassium-poor Paloneva than at Piipsanneva. These results suggest that although nitrogen fertilization is necessary, the need for nitrogen fertilization on nitrogen-rich sites is lower than on nitrogen-poor sites (Hytönen 1987).

Increasing the annual phosphorus fertilizer application rate over 15 kg/ha did not increase yields on any of the sites. Similarly, in the Swedish instructions for practical energy forestry, annual phosphorus fertilization amounts of 15–40 kg/ha are recommended after the planting year, depending on soil type (Sennerby-Forsse and Johansson 1989). Although the remaining peat on cut-away peatlands has a low potassium concentration, potassium fertilization did not increase the yield of willow. The reason for this could be in the basic potassium fertilization prior to the establishment of the experiments. However, potassium fertilization does increase potassium concentrations in the soil and the foliage.

Low biomass production during the first growing season and considerable increase in growth during the following years have been observed in many studies (Hytönen 1982, 1985, 1987, 1988, Lumme et al. 1984, Lehtonen and Tikkanen 1986, Nilsson et al. 1987). Increasing the rotation causes more biomass to be allocated to above-ground parts. The mean annual leafless biomass production of NPK-fertilized *S. x dasyclados* was higher than that of *S.* 'Aquatica'. The leafless biomass yield of three-years-old willow in southern Finland have been much higher (Ferm 1985, Hytönen 1988). Early summer frosts caused some damage, especially to *S.* 'Aquatica', which is frequently susceptible to winter damage in the study area (Lumme et al. 1984, Lumme and Törmälä 1987, Hytönen 1982, 1986) and probably also decreased biomass production (Ericsson et al. 1983, Christersson et al. 1984, Lumme et al. 1984, Hytönen 1986).

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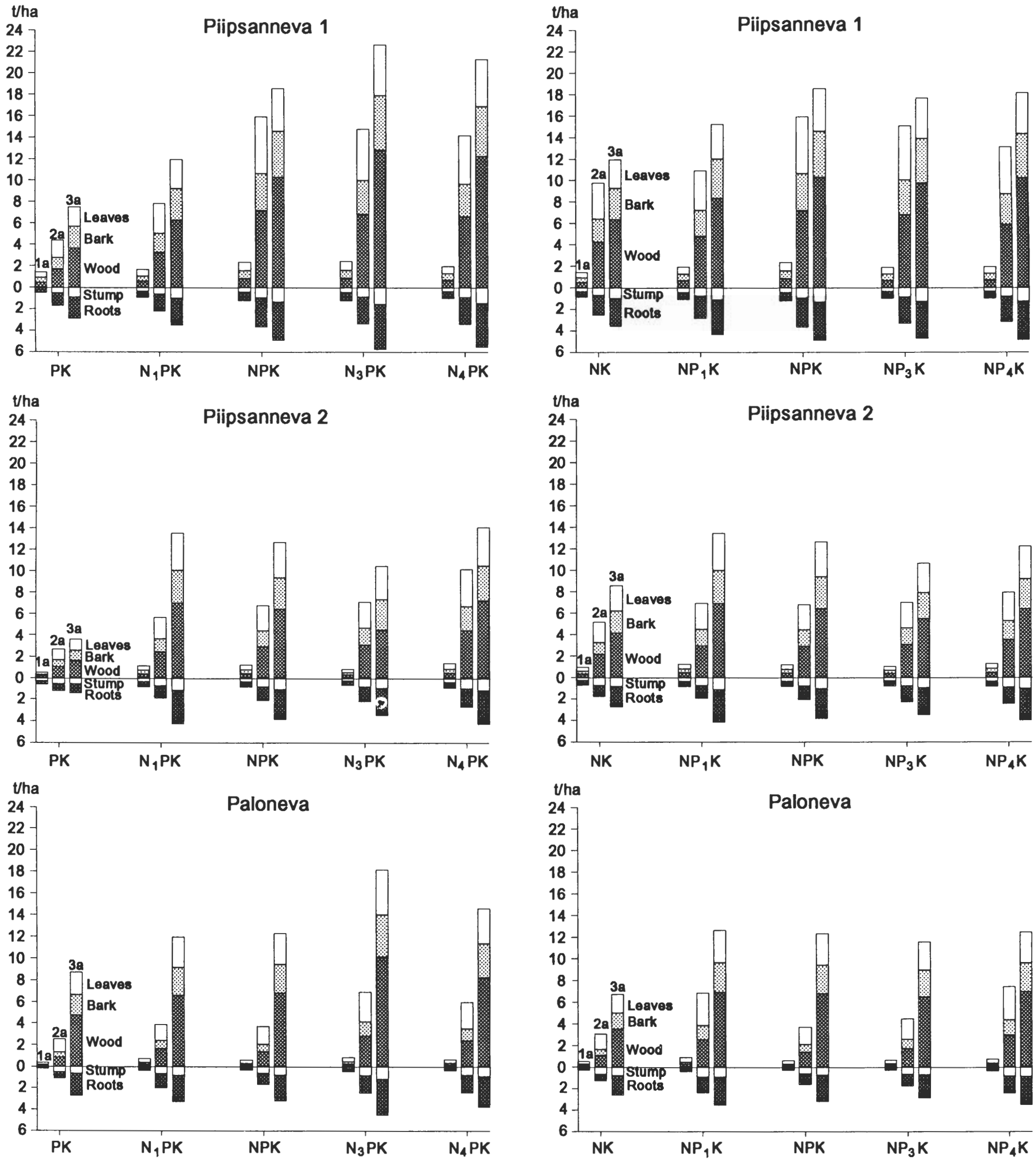
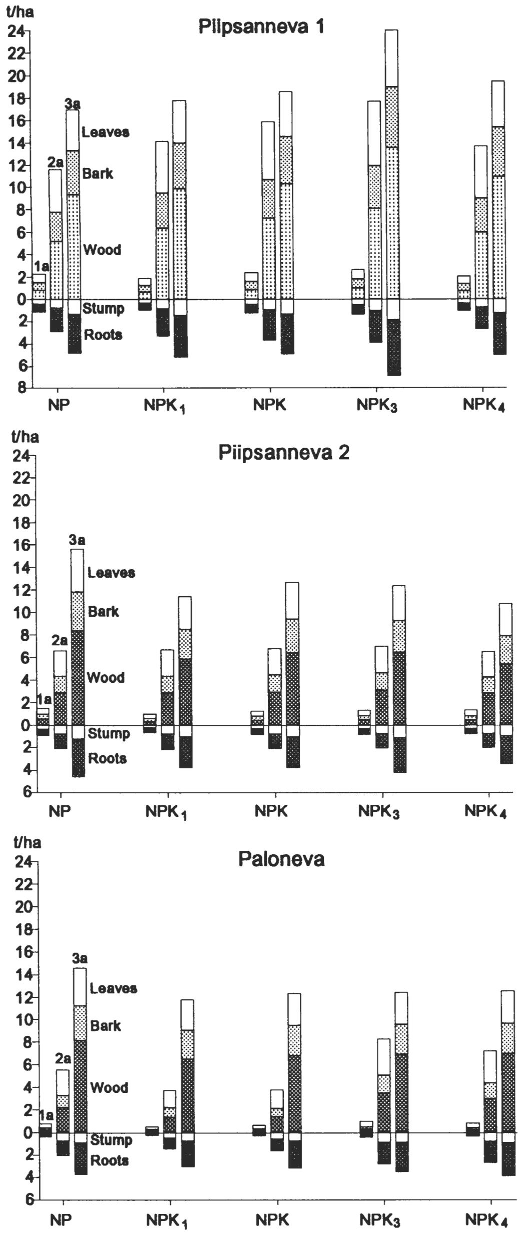


Fig. 6. Effect of fertilizer application rate on the dry-mass yield of willows. Age of willows from one to three years. For nutrient amounts applied, see Figure 2.

Kuva 6. Lannoitemäärän vaikutus pajujen biomassatuotokseen. Pajujen ikä yhdestä kolmeen vuoteen. Selitykset kuvassa 2.



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TIIVISTELMÄ:

LANNOITEMÄÄRÄN VAIKUTUS LYHYTKIERTOVILJELMIEN RAVINNETILAAN JA BIOMASSATUOTOKSEEN SUONPOHJILLA

Kolmessa kenttäkokeessa tutkittiin Haapaveden Piipsannevan (64°06', 25°36'E) ja Ruukin Palonevan (64°27'N, 25°26'E) kalkituilla turvetuotannosta vapautuneilla suonpohjilla typpi-, fosfori-, ja kaliumlannoitemäärän vaikutusta vanne- (*Salix x dasyclados*) ja vesipajuviljelmien (*Salix 'Aquatica'*) tuotokseen kolmen vuoden aikana. Lannosmäärän muuttuessa yhden ravinteen osalta kahden muun ravinteen määrät olivat keskimmäisellä tasolla (N 100, P 30 ja K 40 kg/ha). Kokeilta määritettiin maan happamaan ammoniumasetaattiin uuttuvien ravinteiden pitoisuudet, pajujen lehtien ravinnepitoisuudet ja lehtien, kuoren, puuaineen, kannon sekä juurien kuivamassa.

Fosfori- ja kaliumlannoitemäärien lisääminen kohotti vastaavien ravinteiden pitoisuutta turpeessa ja pajujen lehdissä sitä enemmän mitä enemmän ravinteita annettiin. Typpilannoitemäärän kasvu lisäsi pajujen lehtien typpitoisuutta.

Typpilannoituksen vaikutus ensimmäisenä kasvukautena oli vähäinen. Seuraavina vuosina pajujen kokonaistuotos oli korkein typpilannoitusmäärillä 100–150 kg/ha. Tulosten mukaan typpilannoitemäärä runsastyppisillä suonpohjilla voisi olla pienempi kuin vähätyppisillä suonpohjilla. Vaikka fosforilannoitus lisäsi pajujen kasvua, niin pienimmällä lannoitusmäärällä (15 kg P/ha) tuotos oli samantasoinen kuin suurimmalla lannoitusmäärällä (60 kg/ha). Kaliumlannoitus ei vaikuttanut pajujen tuotokseen ensimmäisenä kolmena kasvukautena. Toisen ja kolmannen kasvukauden vuotuinen tuotos oli moninkertainen ensimmäiseen kasvukauteen verrattuna. Suurimmillaan pajujen kokonaismassa oli kolmen vuoden iässä 28–30 t/ha. Tästä oli 44% puuta, 18% kuorta, 17% lehtiä, 16% juuria ja 5% kantoa. Vannepaju kasvoi paremmin kuin vesipaju. Talvivauriot, erityisesti vesipajulla, saattoivat alentaa pajujen biomassatuotosta.

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