Effect of Repeated Fertilizer Application on the Nutrient Status and Biomass Production of *Salix ‘Aquatica’* Plantations on Cut-Away Peatland Areas

Jyrki Hytönen


The effects of repeated fertilizer treatment on biomass production and nutrient status of willow (*Salix ‘Aquatica’*) plantations established on two cut-away peatland areas in western Finland were studied over a rotation period of three years. Comparisons were made between single fertilizer applications and repeated annual fertilization.

The annually repeated fertilizer application increased the amounts of acid ammonium acetate extractable phosphorus and potassium in the soil as well as the concentrations of foliar nitrogen, phosphorus and potassium compared to single application. Depending on the fertilizer treatment and application rate, annual fertilizer application resulted in over two times higher biomass production when compared to single fertilizer application over a three-year rotation period. The effect of phosphorus fertilizer application lasted longer than that of nitrogen. The optimum fertilization regime for biomass production requires that nitrogen fertilizer should be applied annually, but the effect of phosphorus can last at least over a rotation of three years. Potassium fertilizer treatment did not increase the yield in any of the experiments during the first three years. The leafless, above-ground yield of three-year-old, annually NP-fertilized willow plantations was 9.5 t ha⁻¹ and the total biomass, including stems, leaves, and the stump, averaged 17 t ha⁻¹.

**Keywords** biomass production, fertilization, peatlands, *Salix*, fuelwood.

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1 Introduction
Short-rotation forestry management practises are under development in many countries (Coombs et al. 1990, Ledin and Alfricksson 1992, Mitchell et al. 1992). Woody biomass plantations are genetically improved, intensively cultivated, closely spaced, and consist mainly of broad-leaved species, which can be repeatedly harvested (copiced) using short cutting cycles. Mainly even-aged plantations have been used in the short-rotation experiments conducted in Finland. Cut-away peatland areas have been suggested as being suitable for intensive short-rotation cultivation. The thickness of the remaining peat layer on cut-away peatland areas varies, and it is usually well humified (Kauhisto 1986). Its total nitrogen concentration is usually quite high. The phosphorus and potassium concentrations in the peat layer are often very low. The considerably low soil pH on cut-away peatland areas (Kauhisto 1986) should be increased to 5.0–5.5 by liming or ash application (Ericsson and Lindjö 1991, Ferm and Hyltönen 1988).

Short cutting cycles entail the removal of large quantities of organic material. Small-sized trees contain high amounts of nutrient-rich bark and sapwood (Kauhisto 1983, Saarsalmi 1984, Ferm 1985, Hyltönen 1986). If foliage, too, is harvested, nutrient removal is considerably increased. This has led to concern over the maintenance of nutrient supplies.

Fertilizer application has significantly increased the survival and yield of short-rotation willow plantations on cut-away peatland areas (Hyltönen 1982, 1986, 1987, Kauhisto 1983, Ferm and Hyltönen 1988, Lumme 1989). There are indications that fertilization requirements of different peat extraction sites may vary (Ferm and Hyltönen 1988). The experiments conducted show that nitrogen is the key element, even in nitrogen-rich areas, in increasing yield (Hyltönen 1982, 1985, 1986, Kauhisto 1983, Ferm and Hyltönen 1988). In peatland forests, refertilization is recommended only after ten years have passed from the first fertilizer application (Paavilainen 1979, Jukka 1988). Spreading fertilizer in dense short-rotation plantations is technically difficult and each unnecessary management operation reduces the cost effectiveness of biomass production systems. So far, however, no results are available on whether, from the biomass production point of view, plantations should be fertilized annually, or whether fertilization could be restricted to a single application at the beginning of the rotation. We do not know whether higher fertilizer doses could compensate for renewed application using smaller amounts. In experiments conducted in Sweden, fertilization was carried out during the growing season with weekly (ideally daily) additions of complete, liquid fertilizer by means of an irrigation system (Ingestad and Ågren 1984, Christersson 1986).

The aim of this investigation was to study the effects of repeated fertilizer application on biomass production and foliar nutrient concentration of willow and the effects of fertilization on the nutrient concentrations of soil.

2 Material and Methods
Willow plantations were established on cut-away peatland areas at Haapavesi Piipsanen va (64°25'N, 25°36'E) and Ruukki Paloniva (64°27'N, 25°26'E). The experimental areas were limed (6000 kg ha⁻¹ dolomite lime) prior to planting, and fertilized with PK-fertilizer for peatlands (P 44 kg ha⁻¹, K 83 kg ha⁻¹) and ammonium nitrate with lime (N 50 kg ha⁻¹) after planting. Willow (Salix 'Aquatica', clone V769) was planted on a density of 40 000 cuttings (20 cm long) per hectare in late May–early June 1983, and the one-year old sprouts were cut back in the autumn of 1983. Supplementary planting was done later in the season in 1983, and during the following year. The fertilization experiments were established in the spring of 1984. The experimental areas were fenced and manual and mechanical weeding was done. The experimental period was three years.

The fertilization treatments consisted of NPK-fertilization at two levels (N = N 100 kg ha⁻¹, N₂ = N 200 kg ha⁻¹, P = P 30 kg ha⁻¹, P₂ = P 60 kg ha⁻¹, K = K 40 kg ha⁻¹, K₂ = K 80 kg ha⁻¹) using combinations of PK, NP, NK and NPK and N-PK, N-PK, NPK. One fertilization treatment, applied in 1984, was used as the reference and compared with repeated fertilizations applied in 1984, 1985 and 1986. Thus, the total number of treatments was fourteen. The fertilizers used were ammonium nitrate with lime, superphosphate, and potassium salt. The experimental plots were 56–80 m² in size. The experimental design consisted of randomized blocks with three replications.

Willow height and the base diameter on the experimental plots were measured after each growing season using systematic sampling. At Piipsanenva, the number of measured sprouts varied between 6169 (in 1984) and 10 945 (in 1986), while at Paloniva the corresponding figures were 4017 and 3737. The number of living and dead stools was also recorded. Annually, 26–56 sample trees were cut down in each experiment generally at the end of August. The diameter and height of the sprouts were measured and their foliage, bark and wood were separated and dried to constant weight. The dry-mass equations, of the form \( Y = a + bX \), where \( Y = \) root mass of one stool (g), \( a \) and \( b \) are constants, \( X = \) dry-mass of the sprouts of one stool (g).

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mental plots, and their sprouts, stumps (ground level to 10 cm height) and roots were separated and their dry-masses were determined after drying the material to constant weight at 105 °C. Linear dry-mass equations for the stump and root mass were calculated using the dry-mass of all sprouts on a stool as the independent variable for root mass and also the number of sprouts per stool for the stump mass (Tables 1 and 2). The number of living stools in each plot was used when converting the calculated masses to area basis.

Leaves from at least five randomly selected, uneven-sized sprouts were taken from each plot in late August or early September in 1984–1986 for nutrient analysis. Foliar N, P and K concentrations were determined from the 1984 samples, while the 1985 and 1986 samples were also examined for their foliar concentrations of Ca, Mg, Fe, Mn, Zn, and Cu (Halonen et al. 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⁻¹, volume determined in laboratory). The total nitrogen concentration (Kjeldahl), analyzed from randomly selected samples (33), in the organic matter at Paloneva was 3.2 % and at Piipsanenna 2.3 %.

The effects of repetition of fertilization, fertilization treatments and their interactions on the measured parameters was studied with analysis of variance. The treatment means were compared with Tukey’s multiple range test.

### 3 Results

#### 3.1 Soil Characteristics

The average pH at Piipsanenna was 5.7 and at Paloneva 5.2. The annual fertilization treatment reduced the soil’s pH compared with the single fertilization application. On plots fertilized three times, the pH at Piipsanenna was 0.3 pH-units (p = 0.001) less at Paloneva 0.2 pH-units (p < 0.05) lower than on plots fertilized only once.

In both experimental areas, the annual fertilizer application significantly increased the soil’s acid ammonium acetate extractable phosphorus concentrations compared to single fertilization (Fig. 1). At Piipsanenna, the peat’s phosphorus concentration in the plots fertilized three times with phosphorus was 2.5 and at Paloneva 3.5 times as high as in the plots fertilized only once. The phosphorus concentration in the soil was higher on the plots fertilized with phosphorus than on the plots fertilized with NK. Similarly, a doubled phosphorus fertilizer dose (P 60 kg ha⁻¹) increased the soil’s phosphorus concentration more than a smaller dose (P 30 kg ha⁻¹) did. The effects of high single application amounts of phosphorus fertilizer (P 60 kg ha⁻¹) manifested themselves in the soil analysis results even after three growing seasons. The effect of the corresponding (P 60 kg ha⁻¹) fertilizer application, repeated annually, was greater. Increasing the nitrogen fertilizer amount from 100 kg N ha⁻¹ to 200 kg N ha⁻¹ increased the soil’s extractable phosphorus concentrations, most probably due to increased utilisation of phosphorus by willow.

The annual fertilizer application significantly increased the soil’s ammonium acetate extractable potassium concentration compared to the single fertilization; at Piipsanenna, on average, by 10 mg l⁻¹ and at Paloneva by 16 mg l⁻¹ (Fig. 1). The peat’s potassium concentration at Paloneva was lower than at Piipsanenna. The effect of high single application amounts of potassium fertilizer (K 80 kg ha⁻¹) did not manifest itself in the soil after three growing seasons.

The repeated fertilizer application did not affect the soil’s extractable calcium and magnesium concentrations. At Piipsanenna, the peat’s calcium concentration averaged 1379 mg l⁻¹ (s 135 mg l⁻¹) and at Paloneva far less, only 648 mg l⁻¹ (s 104 mg l⁻¹). Similar site-to-site differences were also observed in regard to the soil’s magnesium concentrations (Piipsanenna 459 mg l⁻¹, Paloneva 188 mg l⁻¹).

#### 3.2 Foliar Nutrient Concentrations

Compared to the single application, the annual fertilizer application significantly increased the foliar nitrogen, phosphorus and potassium concentrations of two- and three-year-old willow in both experimental areas (Table 3). The effect of the fertilizer treatment on the foliar nutrient concentrations was also significant in both experimental areas. The second and third growing season's foliar nitrogen concentrations of willow fertilized with 200 kg N ha⁻¹ of 100 kg N ha⁻¹, given as single application, did not differ. On the other hand, annual applications of 200 kg N ha⁻¹ increased the foliar nitrogen concentration compared to the effect of an annual application of 100 kg N ha⁻¹.

The foliar phosphorus and potassium concentrations were lowest when the corresponding nutrient was not applied at all, or when the nitrogen fertilizer amount was high. Thus, at Paloneva, NK-fertilizer application increased foliar nitrogen concentrations, especially during the third growing season, while the concentration of foliar phosphorus decreased. The effects of the single application with high potassium amounts manifested themselves even during the third growing season as increased foliar potassium concentrations in both experimental areas. In the case of the phosphorus fertilizer application, a corresponding increase was significant only at Paloneva. The foliar phosphorus and potassium concentrations were also high when no nitrogen was applied.

Compared to the single application, the annual fertilization at Piipsanenna decreased significantly the third growing season’s concentrations of foliar zinc from 298 to 227 mg kg⁻¹. The foliar zinc concentrations at Paloneva were two times higher than at
Table 3. Effect of fertilization on the foliar concentrations of nitrogen, phosphorus and potassium during the second and third growing seasons.

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1) Statistical significance of F-values indicated by asterisks: * p < 0.05, ** p < 0.01, *** p < 0.001.

Piipanneva. The differences between the sites in their concentrations of foliar calcium, magnesium and manganese were small.

3.3 Biomass Production

The biomass production of willow fertilized two and three times was significantly (p < 0.001) higher compared with the biomass production resulting from single application (Fig. 2). The differences were statistically significant in regard to all the biomass components measured. The biomass production of willow fertilized twice with nitrogen and phosphorus was 2.0 times as high as that resulting from the single fertilizer treatment; in the case of willow fertilized three times, the corresponding factor was 2.2.

According to the results of analysis of variance, the fertilization treatments also affected biomass production significantly (Piipanneva: p < 0.001, Paloneva: second year p < 0.05, and third year p < 0.001). Best growth was recorded for willow fertilized with nitrogen and phosphorus. Repeated PK-fertilizer treatment did not increase the yield when compared to the effect of single application. However, at Paloneva, PK-fertilized willow grew much better than at Piipanneva and the effect of adding nitrogen was lower than at Piipanneva. Thus, the significance of phosphorus fertilizer application was higher at the nitrogen-rich Paloneva site than at Piipanneva. At Paloneva, PK-fertilized willows grew better than NK-fertilized willows; at Piipanneva, vice versa. At Paloneva, the single NPK fertilization treatment did not increase willow yield compared to PK fertilization. At both experimental areas, doubled doses of nitrogen, phosphorus or potassium in NPK fertilization, given as a single application, did not increase the yield when compared to lower single application rates.

Biomass production during the first growing season was low. The second growing season's leafless above-ground biomass of willow fertilized annually with nitrogen and phosphorus was 5.0 ha^{-1} at Piipanneva and 3.5 ha^{-1} at Paloneva. After three growing seasons, the leafless, above-ground biomass at Piipanneva was 9.7 t
4 Discussion

The imbalance in nutrient ratios typical of cut- 
away peatlands – high concentrations of peat 
nitrogen and low concentrations of phosphorus, 
potassium and calcium – was at its most extreme 
at Paloneva. The phosphorus and potassium fer-
tilizer treatments increased the concentrations of 
acid ammonium acetate extractable phosphorus 
and potassium in the soil the more of the corre-
sponding nutrient was applied. Since the single 
fertilization treatment using superfospha-
re and at Palonova 9.5 t ha$^{-1}$, and at both sites 
1.8 times higher when the roots and stump were 
cluded.

centrations of willows fertilized only once. How-
ever, single fertilizer amounts of phospho-
rus and potassium (storage fertilizer) were ob-
served to increase the foliar nutrient concentra-
tions even after two and three years from the 
fertilizer treatment. Only when the nitrogen fer-
tilizer treatment was repeated annually did the 
foliar nitrogen concentrations remain at high 
levels. The reaction to higher nitrogen fertilizer 
amounts (N 200 kg ha$^{-1}$) given as single applica-
tions did not correspond to that of lower (N 100 
kg ha$^{-1}$ a$^{-1}$) annual nitrogen fertilizer doses.

The leafless, above-ground yield of three-year-
old willow in this study (9.5 t ha$^{-1}$) was less than 
has been reported previously for three-year-old 
S. viminalis on cut-away peatland sites in south-
eren Finland and much less than the biomass pro-
duction of S. ‘Aquatica’ on a mineral soil field or 
landfill site in southern Finland (Ferm 1985, 

Earlier investigations have shown that although 
PK fertilization significantly increases the bio-
mass production of willow, the effect of also 
adding nitrogen is high even on nitrogen-rich cut-
away peatlands (Hyötynen 1988, 1987). The biggest 
difference between the two experimental 
areas in terms of their response to fertili-
tizer treatment was that willow growth, follow-
ing PK-fertilizer treatment, at Palonela was high-
er than at Pipsanemme. This was probably due 
to the fact that the peat’s nitrogen concentration 
at Palonela was high while the concentrations 
of phosphorus and potassium were very low. The 
high concentration of nitrogen in the peat at 
Palonela was also reflected in the fact that, at 
the end of three growing seasons, there were no 
differences in yields between single PK and NPK 
fertilization treatments. However, at Pipsannem-
na, with its lower total nitrogen concentrations, 
even the single application of NPK yielded more 
biomass than PK fertilization.

In this study, the repetition of PK fertilization 
did not increase the yield of willow. However, 
when maximizing the yield, it is extremely im-
portant to apply nitrogen fertilizer annually. The 
importance of annual nitrogen fertilizer applica-
tion was underscored by the observation that the 
growth reaction induced by a single application 
of nitrogen, amounting to 200 kg ha$^{-1}$, did not 
correspond to that induced by an annual fertiliza-
er application of 100 kg ha$^{-1}$ of nitrogen. Com-
pared with the amounts given in fertilization, S. ‘Aquatica’ in this study probably bound consid-
erably small amounts of nitrogen, phosphorus 
and potassium in its biomass (Saarasmaa 1984, 
Ferm 1985, Hyötynen 1986). Especially during 
the first year fertilization with lower nitrogen 
fertilizer amounts should most proba-
ably have been appropriate. Part of the nitrogen 
could have been leached and part may have been 
bound to the organic matter in soil. Nitrogen 
fertilization amounts similar to those used in this 
study have increased the growth of pine on 
peatlands for five to eight years (Paavilainen 

Ideally, small amounts of nutrients, applied in 
the correct proportions, should be made availa-
able to the plants daily in order that maximum 
growth might be maintained (Ingstad and Ågren 
1984, Christersson 1986, 1987). Production phys-
ology studies conducted in Sweden are based 
on Ingstad’s nutrient status studies and theories 
(Ingstad 1987). Accordingly, nutrients are added 
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Biomass Production and Nutrient Uptake of Short-Rotation Plantations

Jyrki Hytönen, Anna Saarasmäki & Pekka Rossi

The biomass production and nutrient uptake of silver birch (Betula pendula), downy birch (B. pubescens), grey alder (Alnus incana), native willows (Salix triandra and S. phylicifolia) and exotic willows S. × dasyclados and S. × 'Aquatifica' growing on a clay mineral soil field (Sukeva) and on two cut-away peatland areas (Piipansanneva, Valkeanov) were investigated.

Biomass production of downy birch was greater than that of silver birch, and the biomass production of the native willows greater than that of the exotic ones. The performance of S. phylicifolia was the best of the studied willow species. Exotic willows were susceptible to frost damage and their winter hardiness was poor. The production of all species was lower on the clay mineral soil field than on the cut-away peatland areas. Fertilization of birches and alder – or the double dose given to the willows – increased biomass production. After 6 growing seasons the leafless biomass production of fertilized silver birch at Piipansanneva was 21 t ha⁻¹, of downy birch 25 t ha⁻¹ (at Valkeanov 34 t ha⁻¹) and of grey alder 24 t ha⁻¹, and after five growing seasons the leafless biomass production of S. triandra was 31 t ha⁻¹, of S. phylicifolia 38 t ha⁻¹ and of S. × dasyclados 16 t ha⁻¹.

6-year-old stands of silver birch bound more nutrients per unit biomass than downy birch stands. Grey alder bound more nitrogen, carbon and copper but less manganese and zinc per unit biomass than silver birch and downy birch. On the field more phosphorus was bound in grey alder per unit biomass compared to downy birch. The willows had more potassium per unit biomass than the other tree species, and the exotic willow species more nitrogen than the native ones. Less nitrogen, potassium and magnesium were bound per unit biomass of S. phylicifolia compared to the other tree species.

Keywords: biomass production, nutrient uptake, Betula pendula, B. pubescens, Alnus incana, Salix triandra, S. phylicifolia, S. × dasyclados, S. × 'Aquatifica'.

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