Effects of Liming on the Growth of Birch and Willow on cut-away Peat Substrates in Greenhouse

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Abstract

The effects of liming (doses 0, 6, 12, 24, 48 tonnes/ha of dolomite lime) on the growth and nutrition of birch (*Betula pendula* Roth, *Betula pubescens* Ehr.) and short-rotation willows (*Salix x dasyclados, Salix viminalis*) were studied in a greenhouse on peat obtained from two cut-away peatland areas. Peat was NPK-fertilized using either raw phosphate or superphosphate as phosphorus source. An increase in liming dose up to 48 tonnes/ha increased peat pH asymptotically from 3.5 to 6.0 and from 3.9 to 6.7 in the two peats. The substrate's pH did not affect the biomass production of silver and downy birch. Willows did not grow at all in the acidic Aitoneva peat without the substrate being limed. Willow growth was best when substrate pH was higher than 5.0. Liming decreased the foliar phosphorus and boron concentrations in birch and boron concentrations in willow. Rock phosphate and superphosphate gave almost equal results in birch growth, but willows grew significantly better when fertilized with superphosphate. Downy birch had significantly higher foliar potassium, calcium, magnesium and boron concentrations than silver birch. *Salix viminalis* had significantly higher foliar concentrations of phosphorus, potassium and boron than *S. x dasyclados.*

Key words: Cut-away peatland, liming, downy birch, silver birch, willow, *Salix*, phosphorus

Introduction

Peat cut-away areas differ considerably from forested peatland sites in regard to their soil properties. They are characterized by variation in peat thickness, low pH levels, high nitrogen concentrations, and low phosphorus and potassium concentrations (Aro *et al.* 1997). Nutritional problems may be encountered when afforesting cut-away peatlands and consequently success of afforestation will, in many cases depend on soil amelioration and fertilization (Kaunisto 1987, 1983, Valk 1986, Hytönen *et al.* 1995, Hånell *et al*. 1996, Aro *et al*. 1997, Hytönen and Kaunisto 1999, Aro and Kaunisto 2003).

Scots pine has been the main subject of study in the afforestation of cut-away peatlands, but experiments have also been conducted on the naturally use regenerated or planted closely-spaced birch and willow stands for energy wood production (Hytönen 1995, Hytönen *et al*. 1995, Aro *et al.* 1997, Gradeckas 1997, Hytönen and Kaunisto 1999, Aro and Kaunisto 2003). Generally, birch stands on peatland sites are dominated by downy birch (*Betula pubescens*). However, on cut-away peatlands silver birch (*Betula pendula*) has also been shown to regenerate naturally and thrives well (Kaunisto 1981, Aro *et al*. 1997, Hytönen *et al*. 1995, Hytönen and Kaunisto 1999).

Soil acidity is an important factor affecting soil processes and the development of plant root systems. Many plant species have been shown to have distinct requirements for the pH of their growing medium. Different willow species have different requirements regarding the substrate's pH (Lattke 1969) and thus increase in soil pH could be necessary when growing willows on cut-away peatlands (Hytönen 1996).

Liming is a technique which has long been used as a routine soil amelioration measure in agriculture. In peatland forests liming was suggested to activate soil microbial activity and increase mineralization of nitrogen and phosphorus availability. However, on nitrogen-poor peatlands liming has resulted in the decrease in mineral nitrogen due to denitrification and microbiological immobilization of mineralized nitrogen (Kaila and Soini 1957, Gardiner 1975, Kaunisto and Norlamo 1976). On nitrogen-rich sites, however, such as cut-away peatlands the peat's nitrogen concentration could be high enough to lead to the net mineralisation of nitrogen. The results, however, have shown that liming has during the first 5-10 years after the application mostly decreases tree growth in peatland forests or in peat cut-away areas (Kaunisto 1982, 1987) but later the growth can gradually improve (Meshenchok 1971). Liming affects also the availability of many nutrients to the trees. Liming can also influence the forest manager's choice of phosphorus fertilizers since the solubility of apatite widely used in fertilization of peatland forests is better in acid soils and thus liming can prevent the phosphorus fertilization effect of apatite (Salonen 1968).

The aim of the present study was to determine the soil pH requirements of silver and downy birch *(Betula pendula, Betula pubescens*) and exotic willow species used in short-rotation forestry (*Salix x dasyclados, Salix viminalis*) established on cut-away peat substrates. The effect of liming on the choice of phosphorus fertilizer was also studied.

Material and methods

Experiment

Well humified Carex-peat was collected from two peat cut-away areas, one located in Kihniö Aitoneva (62°12´ N, 23°18´ E) and the other in Haapavesi, Piipsanneva (64°06´N, 25°36´E). The pH and nutrient concentrations of each peat type were analyzed. The pH (water) of the Aitoneva peat was 3.5 and that of Piipsanneva peat 3.9. The corresponding figures for total nitrogen (Kjeldahl) were 1.4% and 2.1 %, for soluble phosphorus 1.7 mg l^{-1} and 1.0 mg l^{-1}, for exchangeable potassium 15 mg l^{-1} and 5 mg l^{-1}, for soluble calcium 350 mg l^{-1} and 660 mg l^{-1} and for soluble magnesium 77 mg l^{-1} and 100 mg l^{-1}, respectively.

The effects of liming (0, 6, 12, 24 and 48 tonnes of dolomite limestone), peat type (peat from Aitoneva and Piipsanneva cut–away peatland areas) and tree species (*Betula pendula* Roth., *Betula pubescens* Ehr., *Salix x dasyclados*, clone P6011, *Salix viminalis* clone S15111) and their interaction on the growth and nutrition were studied in a greenhouse. The dolomite limestone (Ca, Mg $(CO_3)_2$) had neutralizing capacity 35% of that of calcium. The experimental layout consisted of a randomized block design with two replications. All the seedlings were given basic nutrient doses of N (150 kg/ha), P (66 kg/ha), and K (125 kg/ha), and a mixture of trace elements (50 kg/ha). In order to exclude the limiting effects of poor nutrition, all treatments were NPK-fertilized. Nitrogen was administered in the form of calcium ammonium nitrate, phosphorus in the form of either superphosphate and potassium in the form of potassium sulphate.

Phosphorus fertilizer source, easily-soluble superphosphate (8.7% P, 20% Ca, 12% S, 0.2% Mg, 0.3% Na, 0.3 Fe) and poorly-soluble rock phosphate (14.8 % P, 38% Ca, 0.3% Na, 0.8% S, 0.4% Mg, 0.2% Fe) was compared using peat from Piipsanneva cut-away area and downy birch (*Betula pubescens* Ehr.) and *Salix x dasyclado*s. Rock phosphate is quarried from phosphate beds in sedimentary rocks and is almost insoluble in water. Superphosphate is a fertilizer produced by the action of concentrated sulphuric acid on ground phosphate rock. Treatment with sulfuric acid converts the ground rock phosphate to the more soluble form, a mixture of dihydrogen phosphate and hydrated calcium sulphate.

Prior to transplanting birch seedlings were germinated and raised to a height of 5-10 cm in unfertilized and poorly humified peat. The lime and fertilizers were mixed in the 1.9 litre pots into the top 10 cm layer. Two seedlings (birch) or two cuttings (willows) 10 cm in length were planted in each pot. After the first two weeks one dead silver birch seedling was replaced. The seedlings were grown for 101 days from the end of May to mid August in ambient light conditions. During this period, the seedlings were irrigated whenever necessary to eliminate water deficit as a limiting factor. Air temperature in the greenhouse varied between 17-24 °C.

Measurements and statistical analyses

At the end of the experiment all the seedlings were harvested by severing them at ground level. Leaves were separated, and the dry mass of the leaves and woody parts was determined by drying them to constant weight. At the end of the experiment, the substrate's pH (soil : water 1:2.5) was determined. All the leaves of the plants growing in the pots were collected for foliar analysis. For the nutrient analysis, microwave digestion of the ground leaves in HNO_3 + H_2O_2 solution was made (CEM MDS2000 Microwave Digestion System). Nitrogen concentration of the samples was measured by the Kjeldahl method (Halonen et al.1983) and phosphorus concentrations photometrically with vanado-molybdate method. Potassium, magnesium and calcium were determined with AAS (Varian SpectrAA-300). Boron was determined from H_3PO_4-H_2SO_4 extract photometrically with azomethine-H method.

Differences in biomass and foliar nutrient concentrations between the treatments were tested by using the analysis of variance separately for birches and willows. The variance model used included liming dose, peat type, tree species their interactions and a block. Phosphorus fertilizer types were tested separately.

Results

Effects of liming on peat pH

Liming leads to an asymptotic and significant increase in soil pH in both cut-away peats (F_{lime} =

43.39, p = 0.000). Liming increased the pH from 3.5 to 6.0 in Aitoneva and from 3.9 to 6.7 in Piipsanneva peat, respectively (Figure 1). The pH values of the two peat substrates differed significantly from each other (F_{peat}=6.29, p=0.015). The more acidic peat from Aitoneva persisted in having a lower pH than the peat from Piipsanneva at all lime doses.

Effects of liming on growth and foliar nutrient concentrations

Liming and consequently pH did not affect the height growth or the biomass production of silver birch or downy birch raised on the two cut-away peat substrates studied (Table 1, Figure 2). Downy birch grew taller than silver birch in this study, but this difference was not reflected in biomass production. Peat type significantly affected the biomass production of birch (Table 1, Figure 2). Both birch species grew better in Aitoneva than in Piipsanneva peat.

Table 1. Effect of liming dose, peat type and tree species (birches: silver birch and downy birch, willows: Salix x dasyclados, S. viminalis) and their interaction on the height and biomass production and foliar nutrient concentrations of birch and willow. F-values. Asterisks indicate statistical significance * = p<0.05, ** = p< 0.01, *** = p< 0.001

Species Group	Characteristic	Source of variance Lime	Peat	Species	L*P	L*S	P*S	L*P*S
Birches	Height	0.55	1.02	11.35**	0.39	0.76	6.02*	0.71
Willows	“	13.37***	14.13**	34.25***	14.66***	0.73	0.93	2.43
Birches	Above-ground	0.76	5.67*	0.11	0.48	0.12	0.17	0.57
Willows	mass	17.36***	8.53**	0.00	13.23***	0.95	1.79	1.19
Birches	N	1.65	2.38	0.60	0.41	0.95	0.46	0.90
Willows	“	2.04	0.35	46.29***	0.64	1.29	0.05	0.50
Birches	P	6.29**	67.09***	1.37	2.59	1.07	0.10	1.87
Willows	“	0.24	42.89***	53.23***	2.34	0.52	1.81	0.51
Birches	K	3.24*	4.32	35.44***	1.36	0.97	0.35	1.63
Willows	“	3.20*	2.01	5.07*	0.13	0.50	0.70	0.04
Birches	Ca	2.07	6.91*	10.01**	0.71	2.22	0.10	0.46
Willows	“	6.81**	3.85	0.56	1.81	1.17	1.41	0.16
Birches	Mg	0.92	1.56	8.17*	0.25	2.17	2.92	1.30
Willows	“	2.98	9.42**	2.60	0.81	0.26	2.00	0.48
Birches	B	3.56*	0.09	7.17*	0.34	0.25	0.54	1.58
Willows	“	19.64***	0.02	29.26***	1.04	8.80**	4.68*	0.54

Liming and peat type significantly affected the height growth and the total above-ground biomass of both studied willow species (Table 1, Figure 2). Neither of the willow species survived in the Aitoneva peat substrate without lime application, whereas liming led to only a slight improvement in the growth of willows in the Piipsanneva peat, the smallest dose (6 tonnes/ha) being sufficient to achieve this effect (pH 4.8). In Aitoneva peat, the optimum liming amount varied between 12 to 24 tonnes/ha (pH 5.4 – 5.7).

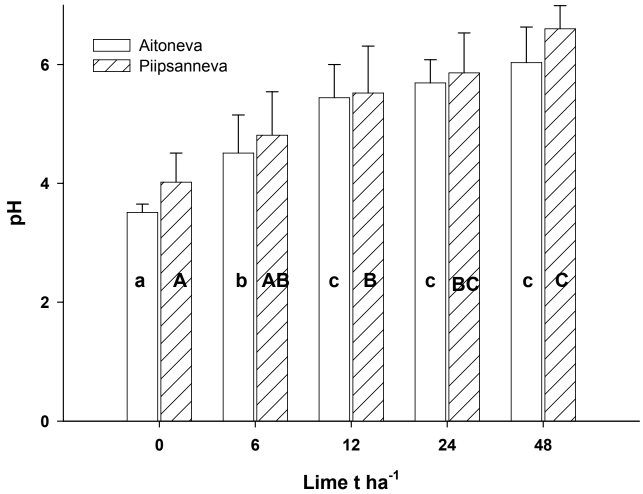

Figure 1. Effect of liming on the pH of the peat substrate from Aitoneva and Piipsanneva. Data from both experiments. The means not differing significantly from each other according to Tukey's test (p<0.05) are marked by the same letter (lower case: Aitoneva, upper case: Piipsanneva). Standard deviation marked above bars

Salix viminalis grew significantly taller on both peat types than *Salix x dasyclados* but they did not differ in terms of their total above-ground biomass production (Table 1). The statistically significant interaction between cut-away peat type and liming is due to *Salix viminalis* having died on the un-limed Aitoneva peat and after liming both willow species grew on Aitoneva peat better than they did on Piipsanneva peat. Thus, limed Aitoneva peat was more suitable for *Salix viminalis* growth than limed Piipsanneva peat.

Liming decreased foliar phosphorus and boron in both birch and boron and calcium concentrations in willow, but increased foliar potassium concentrations in birch and willow (Table 1, Figure 3). Both birch and willow showed foliar phosphorus concentrations that were higher on Aitoneva peat than on Piipsanneva peat. The foliar potassium, calcium, magnesium and boron concentrations of downy birch were higher than those of downy birch. *Salix viminalis* had significantly higher foliar concentrations of phosphorus, potassium and boron than *S. x dasyclados*.

Downy birch and willow grew better when fertilized with the same amount of elemental phosphorus from superphosphate than from rock phosphate but this was statistically significant only for willow (Figure 4). The effect of rock phosphate on the growth of birch was small at the highest lime amount. Foliar phosphorus concentrations of birch were highest when superphosphate was applied (Figure 5). However, phosphorus source did not affect the phosphorus concentration of willow leaves significantly. This was due to the fact that on un-limed peat substrate wil-

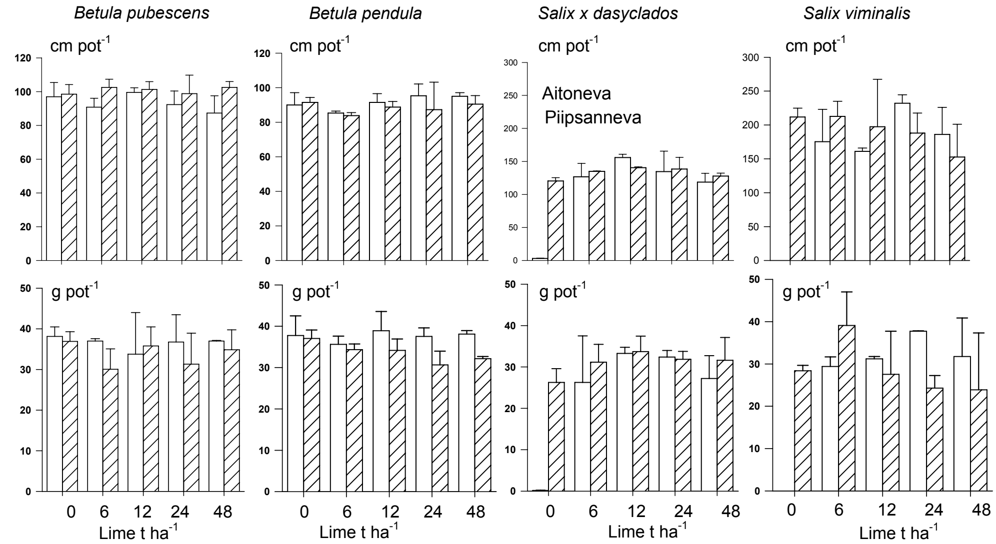

Figure 2. Effect of liming dose on the height and the above–ground biomass production of birch and willow. Standard deviation marked above bars. For pH values corresponding to liming doses see Figure 1 and for F-statistics see Table 1

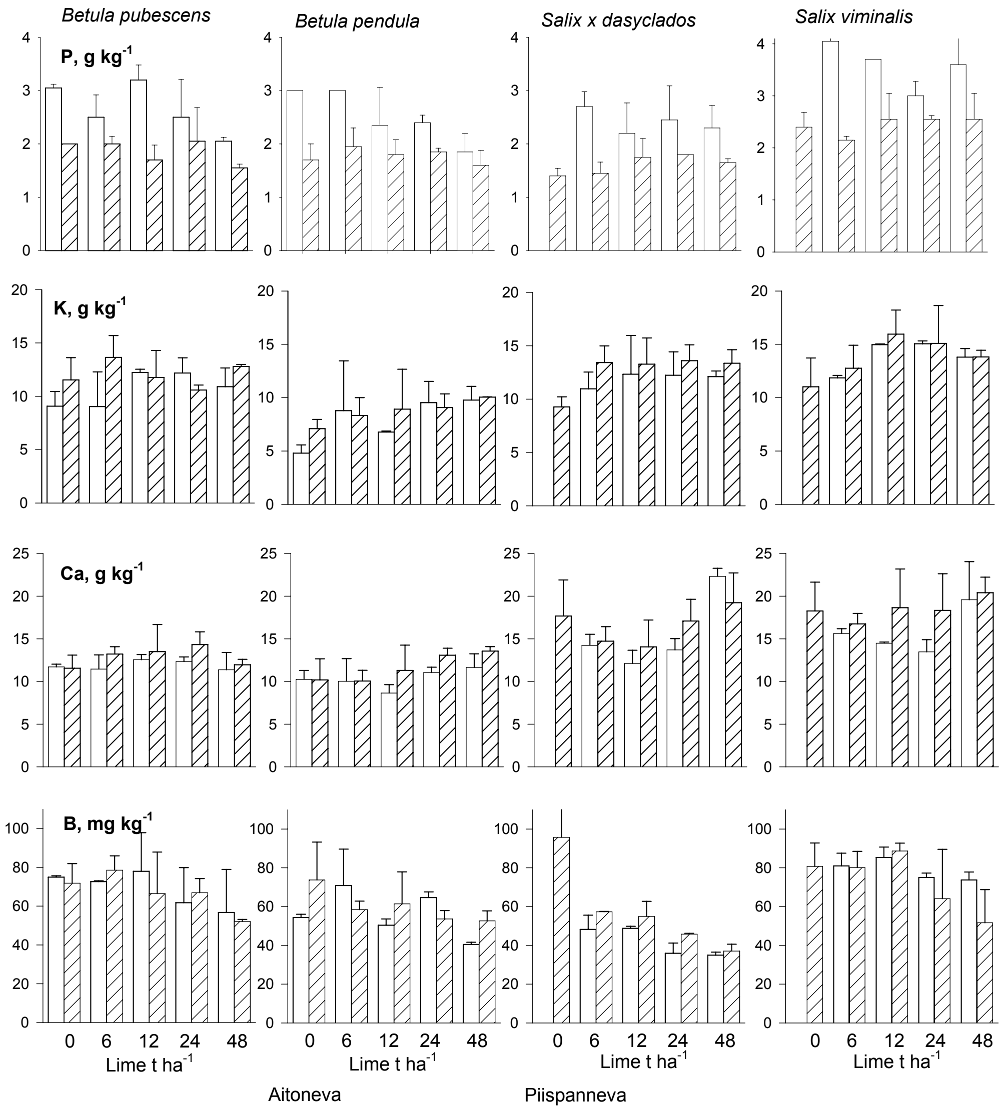

Figure 3. Effect of liming on foliar phosphorus, potassium, calcium and boron concentration in birch and willow. For pH values corresponding to liming doses see Figure 1 and for F-statistics see Table 1. Standard deviation marked above bars

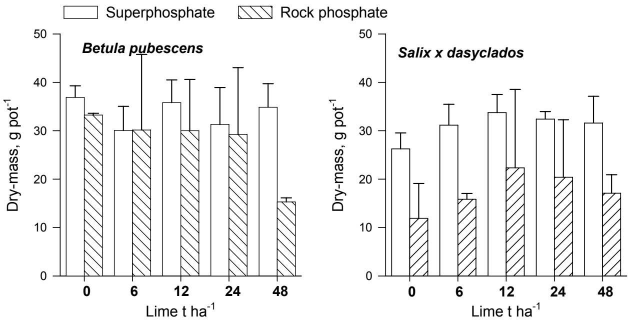

Figure 4. Effect of liming and phosphorus source on the above-ground biomass production of downy birch and *Salix x dasyclados* on peat substrate from Piipsanneva. Standard deviation above the bars. F phosphorus source: *B. pubescens* 3.61, p=0.090, *S. x. dasyclados* 21.82, p=0.001

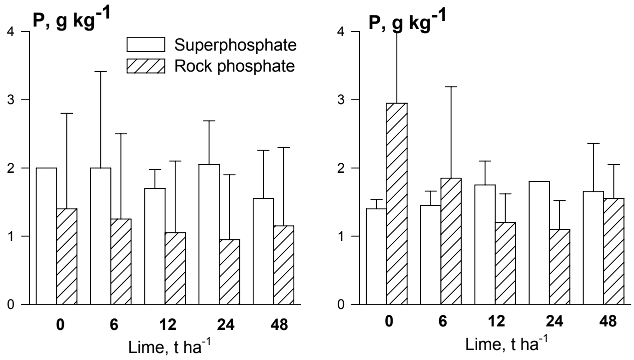

Figure 5. Effect of liming and phosphorus source on the foliar phosphorus concentration of downy birch and *Salix x dasyclados* on peat substrate from Piipsanneva cut-away peatland area. Standard deviation marked above bars. F phosphorus source: *B. pubescens* 10.50, p= 0.010, *S. x. dasyclados* 0.27, p=0.614.

lows fertilized with rock phosphate had quite high phosphorus concentrations. Superphosphate decreased significantly, probably due to dilution effect, the birch foliar nitrogen concentrations. Willow foliar calcium concentrations were significantly higher when rock phosphate was used than with superphosphate.

Discussion

In this study dolomite lime application increased the pH of well-humified Carex peat asymptotically with increasing application amounts. The highest lime dose (48 tonnes/ha) increased the soil pH by 2.5 pH units. Liming did not affect the growth of birches. They grew equally well on un-limed (pH 3.9 for Aitoneva peat) and on limed peat (up to pH 6.0-6.7) and thus no optimum pH range was found for the biomass production of birch. In agreement with the present study on well humified *Carex* peat, Ericsson and Lindsjö (1981) and Rikala and Josefek (1990) have shown on poorly humified *Sphagnum* peat in their greenhouse studies that neither height nor dry mass production of birch (*Betula pendula*) seedlings depend on the substrate's pH (range 3.8 – 7.0). Birches are known to be indifferent to the soil pH over a wide range and to be less sensitive to pH than most of the other species studied (Ingestad 1979). Longer term field studies have shown that liming has in some cases increased but mostly decreased the height growth of birches (Kaunisto 1973, 1981, 1987).

For willow survival and growth, increase in the pH was necessary with Aitoneva peat as substrate. Both of the studied willow species (*Salix viminalis* and *Salix x dasyclados*) died when grown on fertilized Aitoneva peat without liming. In the greenhouse study conducted by Ericsson and Lindsjö (1981), the root development of *Salix viminalis* grown in poorly humified peat was completely inhibited within the pH range of 3.8 – 4.3. The optimum pH for good development of willow root systems varies by species. The roots of *Salix pentandr*a L. and *Salix cinerea* L. have been observed to develop almost as well in a hydroponic culture with pH 3.5 as with pH 5.0 (Lattke 1969). With Aitoneva peat, the optimum pH for *Salix viminalis* and *S. x dasyclados* growth was 5.4 – 5.7 while for Piipsanneva peat it was 4.8 – 5.5. This corresponds well with the results of an earlier investigation showing that *S. viminalis* L., *S.* 'Aquatica', *S x dasyclados* require rather high substrate pH levels (5.0 - 6.0) (Ericsson and Lindsjö 1981). Also the greenhouse experiment conducted by Kaunisto (1983) showed that the effect of liming on the growth of willows was generally positive, albeit minor. To reach this optimum pH range, the liming amounts applied with Aitoneva peat were greater that those for Piipsanneva peat. In this study, a slight decline in growth was noted with the maximum lime doses at pH 6.0 – 6.6.

Liming significantly decreased the birch and willow foliar boron concentrations. The boron uptake of plants is affected by the soil pH, and the amounts of calcium and magnesium. Elevation in pH caused by liming can negatively affect the boron uptake of trees (Lehto and Mälkönen 1994) and increase boron fixation by the soils (Saarela 1985) and absorption to the forest mor layer (Lehto 1995). Liming has also been found to decrease foliar boron concentrations of Scots pine on both peat and mineral soil substrates (Kaunisto 1982, Lehto and Mälkönen 1994). Boron deficiencies resulting in growth defects caused by leader diebacks have been especially common in trees growing on limed abandoned fields (Hytönen and Ekola 1993). Liming also decreased the phosphorus concentration of birch seedlings indicating that calcium could decrease phosphorus uptake of birches.

Site-specific differences in foliar nutrient concentrations were also noted. Especially soil-inherent phosphorus concentration was reflected in foliar concentration even though the peat substrates were NPK-fertilized. The foliar phosphorus concentrations were significantly higher in the case of Aitoneva peat; it contained almost twice as much inherent soluble phosphorus as did Piipsanneva peat. However, similar differences in soil potassium concentrations were not reflected in the foliar potassium concentrations.

This study showed that the phosphorus fertilizer source was of little importance for birch growth in greenhouse. Also field experiments with rock phosphate and superphosphate have influenced the growth of Scots pine to a similar extent (Silfverberg and Hartman 1999), even though superphosphate has given the strongest initial response (Paarlahti and Karsisto 1968). No statistically significant interaction between phosphorus source and liming dose was found in this study. For willows, the use of fast soluble superphosphate was necessary in order to maximize the biomass production. This is in agreement with the results from field experiment on cut-away peatlands in which willows fertilized with the same amount of phosphorus as superphosphate produced over three times more biomass compared to fertilization with rock phosphate (Hytönen 1986). On limed peatland sites, slowly-soluble phosphorus fertilizers have failed to increase the amount of extractable phosphorus in the substrate and to ensure the availability of phosphorus for willows (Kaunisto 1983, Hytönen 1986, Yli-Halla and Lumme 1987). Kaunisto (1983) has demonstrated that when liming amounts of cut-away peatlands increased from 6 to 12 t/ha the soluble phosphorus amounts in the soil decreased even though at the same time the phosphorus fertilizer application as rock phosphate was doubled.

While there were no differences in the biomass production of birches the two birch species studied differed from one another in their foliar potassium, calcium, magnesium and boron concentrations. They were higher in downy birch than in silver birch. In agreement with the results of this experiment also in a field study in which silver and downy birches were compared it was found that downy birch had higher foliar calcium, manganese, iron, aluminium and boron concentrations than silver birch (Saramäki and Hytönen 2004). Also Koricheva and Haukioja (1995) found that leaves of downy birch contained significantly more manganese and iron than those of silver birch along a pollution gradient. According to foliar analyses *Salix viminalis* seems to be nutritionally more demanding species than *S. x dasyclados*.

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ВЛИЯНИЕ ИЗВЕСТКОВАНИЯ НА РОСТ БЕРЕЗЫ И ИВЫ НА БОЛОТНОМ ДОННОМ ТОРФЕ ДВУХ ВИДОВ В ТЕПЛИЧНЫХ УСЛОВИЯХ

Й. Хитёнен

Резюме

Исследование влияния известкования (0, 6, 12, 24, 48 тонн доломитной извести) на рост и обмен веществ берез (*Betula pendula* Roth, *Betula pubescens* Ehr.) и ив (*Salix x dasyclados, Salix viminalis*) было проведено в тепличных условиях на болотном донном торфе двух видов. В торф ввели удобрения NPK, с использованием в качестве источника фосфора сырого фосфата или суперфосфата. Увеличение количества извести вплоть до 48 тонн на гектар асимптотически увеличивало значение pH торфа. Значение pH субстрата не влияло на рост по высоте березы бородавчатой и березы пушистой, как и на производство у них биомассы. Ивы же вовсе не росли на кислом торфе (pH 3,5) без известкования. Лучше всего ивы росли при значении pH субстрата выше 5,0. Известкование уменьшило содержание фосфора и бора в листьях березы, а также содержание бора в листьях ив. Рост берез был почти одинаков при внесении сырого фосфата или суперфосфата, но ивы росли значительно лучше при удобрении их суперфосфатом. Содержание калия, кальция, магния и бора в листьях березы пушистой было выше, чем у березы бородавчатой.

Ключевые слова: березы, ивы*, Salix*, извести, фосфора, болотный донный торф