Wood Ash Fertilisation Increases Biomass Production and Improves Nutrient Concentrations in Birches and Willows on Two Cutaway Peats

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Abstract

The effect of wood ash (0, 6, 12, and 24 t ha^{-1}) on the nutrient concentrations and biomass production in willows (*Salix viminalis* and *S. x dasyclados*) and birches (*Betula pendula* and *B. pubescens*) on two cutaway peats was studied in greenhouse conditions. In addition to ash, all treatments included fertilisation with nitrogen (150 kg N ha^{-1}). The largest amount of wood ash increased the pH from 4.0 to 7.3 for Aitoneva peat and from 5.0 to 7.5 for Piipsanneva peat. Increasing the amount of ash also significantly increased extractable phosphorus, potassium, calcium, and magnesium concentrations in peat – even the smallest dose increased concentrations manifold compared to unfertilised peats. The growth of the studied species was affected by both peat type and fertilisation treatment. Unfertilised willows and willows fertilised with nitrogen died in Aitoneva peat and grew poorly in Piipsanneva peat. Biomass production of birches in unfertilised peat was low. Nitrogen fertilisation without ash did not increase growth. The best growth was recorded with the lowest dose of ash (6 t ha^{-1}). Ash fertilisation significantly increased the foliar concentrations of phosphorus and potassium in all species studied and decreased those of calcium and magnesium. The study indicated that the original peat characteristics affect growth of seedlings even when the sites are fertilised. Wood ash proved to be a suitable fertiliser in afforestation of cutaway peatlands.

Key words: willow, birch, cutaway peatland, wood ash, fertilisation, biomass production

Introduction

The need for reducing greenhouse gas emissions is increasing the value of renewable energy obtained from forests. Wood-based fuels and recovered fuels are playing a leading role in Finland in attempts to reach national and European Union goals for increasing the use of renewable energy. The share of wood-based fuels in the total consumption of energy in Finland was 23 % in 2012 (Ylitalo 2013). In addition to using wood fuels derived from existing forests, the establishment and utilisation of woody-biomass energy plantations are gaining new interest in many countries. Short-rotation forestry involves the cultivation of rapidly growing deciduous tree species, regenerated through sprouts, using short rotation periods, intensive methods, and dense stocking. *Salix* species have been widely used in the short-rotation experiments conducted in Europe and North America (Hytönen 1996, Mola-Yudego and González-Olabarria 2010, Pučka and Lazdiņa 2013, Guidi Nissim et al. 2013, Āboliņa et al. 2014, Heinsoo and Dimitriou 2014). Also, densely planted alders, birches, and poplars may be interesting species for biomass production (Saarsalmi et al. 1992, Ferm 1993, Uri et al. 2002, Hytönen and Saarsalmi 2009, Aosaar et al. 2012, Hytönen and Aro 2012, Johansson 2013).

Short-rotation plantations are usually established on agricultural land. In peat-producing countries, peat-harvesting areas are being released from production in increasing amounts. Accordingly, continuing energy production by growing biomass for fuel with various energy crops could be an attractive after-use option. Peat cutaway areas differ considerably from agricultural soils and forested peatlands in their properties. They are characterised by usually low but variable peat thickness, low pH levels, high nitrogen concentration, and low phosphorus and potassium concentrations in the residual peat (Aro et al. 1997, Kikamägi and Ots 2010, Kikamägi et al. 2013). The large nitrogen stores in the remaining peat layer are an advantage and could reduce the need for fertilisation. However, nitrogen is bound in the organic matter in the peat and becomes available to plants via mineralisation of the organic matter. Nutritional problems may be encountered in afforesting of cutaway peatlands; consequently, the success of afforestation will depend in many cases on soil amelioration and fertilisation (Kaunisto 1983, 1987, Hytönen et al. 1995, Hytönen 1996, Aro et al. 1997, Hytönen and Kaunisto 1999, Aro and Kaunisto 2003, Huotari et al. 2008, Kikamägi and Ots 2010, Kikamägi et al. 2013).

Apart from short-rotation willows, growing of other potential biomass crops (e.g. native deciduous trees, downy birch, alders, aspen, and native willows) on cutaway peatlands is little known. However, there are indications that growing dense stands of native tree species could yield considerable amounts of biomass on cutaway peatlands (Hytönen and Kaunisto 1999, Hytönen and Saarsalmi 2009, Renou-Wilson et al. 2010). In addition to downy birch (*Betula pendula* L.), silver birch (*B. pubescens* Ehrh.), which does not grow naturally on peatlands, has been shown to thrive well on cutaway peatlands (Kaunisto 1981, Aro et al. 1997, Hytönen and Saarsalmi 2009, Hytönen and Aro 2012). Silver birch normally produces a higher yield than downy birch (e.g. Koivisto 1959, Karlsson et al. 1997, Saramäki and Hytönen 2004, Johansson 2007, Hytönen et al. 2014).

For exotic willows, annual nitrogen fertilisation even on nitrogen-rich cutaway peatlands is necessary (Hytönen 1995). Also, to ensure good survival and growth of the exotic willows, the peat pH has to be increased since the willows may even die out on acid peat in the absence of liming (Hytönen 2005). However, low pH has not had a negative effect on the growth of silver birch and downy birch (Ericsson and Lindsjö 1981, Rikala and Josefek 1990, Hytönen 2005).

Consumption of primary biomass for energy production generates increasing quantities of wood ash. In Finland, the total amount of wood ash produced annually by the forest industry is estimated to be 200,000–300,000 tonnes. Large amounts of wood ash have been produced in recent decades also in other countries, especially in Scandinavia and North America (Pitman 2006). Wood ash contains many of the essential nutrients required for plant growth – except, notably, nitrogen (N) – so may have potential as a fertiliser for cutaway peatlands where bottom peat is especially low in phosphorus (P) and potassium (K). Long-lasting positive effects of wood ash on the growth of conifers on forested peatlands have been reported from many studies (e.g. Silfverberg 1996, Silfverberg and Hotanen 1989, Moilanen et al. 2002, 2005). Since wood ash is a good liming agent (Saarela 1991) and has been found to decrease peat acidity (e.g. Silfverberg and Hotanen 1989, Hytönen and Aro 2012, Moilanen et al. 2012, Kikamägi et al. 2013, 2014, Maljanen et al. 2014), it can replace standard liming for short-rotation willows.

The main aim of the study was to determine the suitability of wood-ash fertilisation for short-rotation willows (*Salix viminalis* and *S.* × *dasyclados*) and birches (*B. pendula* and *B. pubescens*) on cutaway peats from two areas and its effect on the nutrient concentrations in foliage and peat. The hypothesis was that wood ash containing phosphorus, potassium and micronutrients would increase biomass production of these species suitable for wood energy production.

Material and methods

Experimental design

Well-humified Carex peat was collected from two peat cutaway areas, one in Kihniö (Aitoneva, 62^{o} 12' N, 23^{o} 18' E) and the other in Haapavesi (Piipsanneva, 64^{o} 06' N, 25^{o} 36' E). The species used were downy and silver birch, as seedlings, and willow (*S.* × *dasyclados*, clone P6011 and *S. viminalis*, clone S1511), as cuttings. Before planting, the birches were grown in nutrient-poor unfertilised peat to 10–15 cm height. The willow cuttings had been taken in the previous autumn and kept in cold storage. Treatments included an unfertilised control and wood-ash levels of 0, 6, 12, and 24 t ha^{-1}. Ash was mixed in the 0-10 cm peat layer before planting the seedlings. The loose wood ash came from the nearby Sievi municipal heating plant. All wood-ash treatments featured fertilisation with 150 kg N ha^{-1} as ammonium nitrate with lime in order to ensure that nitrogen did not limit growth. Thus the treatments were A0+0 (no ash, no nitrogen; unfertilised control), A0+N (no ash + nitrogen), A6+N (ash 6 t ha^{-1} + nitrogen), A12+N (ash 12 t ha^{-1} + nitrogen) and A24+N (ash 24 t ha^{-1} + nitrogen). The smallest ash dose (6 t ha^{-1}) contained 204, 714, 1470 and 276 kg ha^{-1} of P, K, Ca and Mg, respectively.

The experiment employed a randomised block design with two replications. Two seedlings or two willow cuttings (10 cm long) were planted in each pot, sized 4.8 litres. Altogether 80 seedlings were planted in the pots. Seedlings were grown in a greenhouse for 96 days, from mid-May to the end of August, in ambient lighting conditions. During the experiment, air temperature in the greenhouse varied within the range 17–24 ^{o}C. The seedlings were irrigated whenever necessary to eliminate water deficit as a limiting factor.

Measurements and analyses

Two samples of the wood ash were analysed for nutrient concentrations in the laboratory (HCl extraction, atomic absorption spectrophotometry; for methods see Halonen et al. 1983) and mean nutrient concentrations were calculated (P 34 mg g^{-1}, K 119 mg g^{-1}, Ca 245 mg g^{-1}, Mg 46 mg g^{-1}, Fe 609 mg g^{-1}, Mn 16 mg g^{-1}, Zn 172 mg kg^{-1}, Cu 185 mg kg^{-1}, and B 90 mg kg^{-1}). The P and K concentrations of the ash were considerably high; however, similar concentrations have been measured from wood ash especially when birch wood has been burned (Silfverberg and Issakainen 2001, Moilanen and Issakainen 2003).

At the end of the experiment, soil samples were taken from 0-10 cm peat layer of the pots where the downy and silver birch had grown. Conductivity and pH of the substrate were determined from soil-water suspension (soil:water = 1:2.5) Nitrogen concentrations in the samples were measured by the Kjeldahl method. Acid ammonium acetate – EDTA (pH 4.64) extractable phosphorus, potassium, magnesium, and calcium concentrations were determined as outlined in Halonen et al. (1983). Phosphorus was determined photometrically and potassium, calcium and magnesium using atomic absorption spectrometry (AAS). Foliar samples were composed of all leaves of seedlings growing in the pots. Their N concentration was analysed using the Kjeldahl method. P (vanado-molybdate method) and B (azomethine-H method) (Halonen et al. 1983) concentrations were measured spectrophotometrically and K, Ca and Mg concentrations (HCl extraction) were analysed with atomic absorption photometer (Halonen et al. 1983). The sample size of willow leaves in treatment A24+N was so small that only one sample was analysed.

The height and base diameter of the seedlings were measured at the end of the 96-day growing period. Then the seedlings were cut at ground level and their leaves were separated. The dry mass of foliage and stems with branches was determined via drying to constant weight.

Statistical analyses

Differences in biomass and foliar nutrient concentrations between the treatments were tested by means of analysis of variance separately for birches and willows. In the statistical testing of willow foliar nutrient concentration treatment A24+N was excluded due to small number of analysed samples. The variance model used included as fixed factors fertilisation, peat type, tree species, their interactions (species × peat, species × fertilisation, species × peat type, species × fertilisation × peat type), and block. The variance model for soil characteristics included as fixed factors peat type, fertilisation, their interaction (fertilisation × peat type), and block. The unfertilised soils were also tested separately (peat type, block). Tukey's test was used in *post hoc* pairwise multiple comparisons. All analyses were computed using the IBM SPSS Statistics 20.0 package.

Results

Soil characteristics

The mean concentrations of soil characteristics in the two peats and different treatments are presented in Table 1. Since there were significant peat and fertilisation interactions the differences in soil characteristics between unfertilised peats were tested separately. The two unfertilised peats differed significantly from each other in their conductivity (F = 11.863, p = 0.018), pH (F = 125.00,

Table 1. Conductivity (Con.), pH, total nitrogen, acid ammonium acetate (AAc) extractable phosphorus, potassium, calcium and magnesium concentrations

Site	Fertilisation	Con. μS cm^{-1}	pH	tot N %	P AAc mg l^{-1}	K AAc mg l^{-1}	Ca AAc mg l^{-1}	Mg AAc mg l^{-1}
Aitoneva	A0+0	0.21	4.0a	1.5a	12.8a	73.8a	663a	133a
	A0+N	0.31	3.7a	1.5ab	4.5a	56.3a	581a	133a
	A6+N	0.35	5.3b	1.4ab	82.8a	867.5b	2525a	568a
	A12+N	0.80	6.8c	1.4ab	230.0b	2275.0c	7150b	1425b
	A24+N	1.33	7.3c	1.3c	285.0b	4025.0d	10050c	2050c
Piipsanneva	A0+0	0.16	5.0a	2.1a	6.8ab	65.5a	1006a	140a
	A0+N	0.24	4.7b	2.1a	0.6a	32.5a	925a	138a
	A6+N	0.38	6.5c	2.0ab	84.8bc	656.3a	4275b	758b
	A12+N	0.66	6.9c	1.9abc	127.5c	1500.0b	4850b	868b
	A24+N	1.55	7.5d	1.9bc	133.5c	3535.0c	9850c	1725c
	F_{peat}	671.9	55.3	621.3	17.7	8.7	0.0	4.3
	p_{peat}	0.000	0.000	0.000	0.000	0.000	0.966	0.048
	F_{fert}	98.2	211.3	14.0	46.3	186.3	142.6	101.8
	p_{fert}	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	$F_{peat*fert}$	1.8	6.6	0.9	6.4	2.1	5.1	4.2
	$p_{peat*fert}$	0.157	0.001	0.462	0.001	0.114	0.003	0.009

Notes: F-values and p-values from analyses of variance. Means on each peat type that do not differ from each other according to Tukey's test at a significance level of 0.05 are marked with the same letter;
peat = peat type, fert = fertilisation treatment

$p = 0.000$), N ($F = 264.933$, $p = 0.000$), and Ca ($F = 13.256$, $p = 0.015$) concentrations. Unfertilised Piipsanneva peat had significantly higher pH, and a greater total N and extractable Ca concentration than unfertilised Aitoneva peat, while Aitoneva peat had higher conductivity. The extractable P (Aitoneva 12.8 mg l^{-1}, Piipsanneva 6.8 mg l^{-1}) and K (Aitoneva 73.8 mg l^{-1}, Piipsanneva 65.5 mg l^{-1}) concentrations did not differ significantly in the two peats.

Fertilisation treatments had a significant effect on all studied soil characteristics (Table 1). Nitrogen fertilisation on its own had only a small effect on soil characteristics; however, it decreased pH of Piipsanneva peat significantly. Addition of ash (ash + N) increased significantly soil pH and nutrient (extractable P, K, Ca, Mg) concentrations. With the use of 6 t ha^{-1} of wood ash peat pH, and K concentration increased significantly in Aitoneva peat and those of pH, Ca and Mg in Piipsanneva peat. Addition of 12 t ha^{-1} of ash increased significantly all measured soil characteristics except total nitrogen concentration. The highest ash application amount 24 t ha^{-1} increased nutrient concentrations in the peat considerably more. The highest ash dose (24 t ha^{-1}) decreased the peat total N concentration significantly.

Growth of seedlings

The two birch species did not differ from each other in their height, diameter and biomass production (Table 2). Peat type and fertilisation treatment had a significant effect on the growth of birches. Birches grew better on Aitoneva peat than on Piipsanneva one (Table 2, Figure 1). The birches grew very poorly in both cutaway peats in the absence of fertiliser application (Figure 1). Nitrogen fertilisation increased significantly only the height growth of birches. However, addition of wood ash and nitrogen increased the biomass production

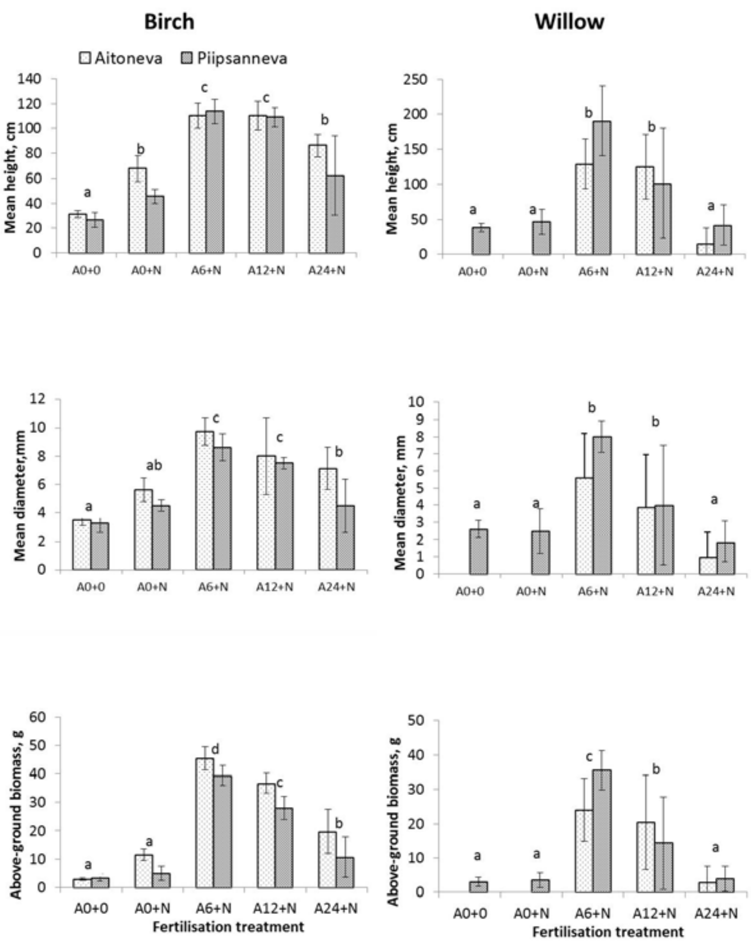

Figure 1. Height, base diameter, and above-ground biomass of the birch and willow seedlings at the end of the experiment. Fertilisation treatments that do not differ from each other according to Tukey's test at a significance level of 0.05 are marked with the same letter

Table 2. Effect of peat type, species, fertilisation treatment and their interaction on height, diameter, and biomass of birches and willows

Species	Characteristic	*F*-value						
		F_{peat}	$F_{species}$	F_{fert}	$F_{peat*fert}$	$F_{peat*species}$	$F_{fert*species}$	$F_{peat*fert*species}$
Birch	Height	5.1*	1.5	54.6***	1.7	0.0	1.0	0.3
	Diameter	7.0*	3.3	22.8***	0.9	0.1	0.5	0.7
	Biomass	15.4**	0.1	95.7***	1.3	0.3	0.7	0.3
Willow	Height	7.1*	0.1	16.4***	0.4	1.2	0.6	0.6
	Diameter	7.0*	1.7	11.5***	0.6	0.2	0.4	0.4
	Biomass	1.9	2.4	16.7***	0.6	0.1	0.3	1.1

Stars indicate statistical significance in the analysis of variance: $p < 0.05$ = *, $p < 0.01$ = **, $p < 0.001$ = ***.
peat = peat type, fert = fertilisation treatment.

manifold compared to unfertilised seedlings (Figure 1). Increasing ash application rate from 6 t ha^{-1} to 12 t ha^{-1} did not affect height and diameter, but significantly decreased biomass production (Figure 1). Increase in ash application rate from 12 t ha^{-1} to 24 t ha^{-1} decreased significantly height, diameter and biomass of birches (Figure 1). Thus in terms of biomass best application rate proved to be the smallest one used (6 t ha^{-1}).

The willow species studied did not differ from each other significantly in their height, diameter or biomass production (Table 2). However, the willows were not able to thrive in Aitoneva peat without ash fertilisation (Figure 1). The application of wood ash was critical for the growth of willows in both cutaway peats (Figure 1). The lowest ash dose, 6 t ha^{-1}, yielded the best biomass production also for the willows. Increasing the ash dose from 6 t ha^{-1} to 12 t ha^{-1} did not affect height or diameter, but decreased significantly biomass production. Increase in ash application rate from 12 t ha^{-1} to 24 t ha^{-1} decreased significantly height, diameter and biomass of willows (Figure 1).

Foliar nutrient concentrations

Downy birch had significantly higher foliar Ca (6.1 g kg^{-1}) and Mg (3.5 g kg^{-1}) concentrations than silver birch (Ca 3.9 g kg^{-1}, Mg 2.8 g kg^{-1}) (Table 3, Figure 2). There were no differences between the birch species in their foliar N, P and K concentrations (Table 3). The only difference in the foliar concentrations between the two peats was in the Mg concentrations. The birch Mg concentrations were higher in Aitoneva peat (3.3 g kg^{-1}) than in Piipsanneva one (3.0 g kg^{-1}) (Table 2). Fertilisation had a significant effect on all studied foliar nutrient concentrations. Fertilisation with wood ash increased foliar P and K concentrations: the more the higher the ash application dose. However, at the same time ash fertilisation decreased foliar Mg concentrations (Figure 2, Table 3 and 4). Highest ash application amount (24 t ha^{-1}) decreased significantly foliar Ca concentrations of birch (Table 4). There was significant peat and fertilisation interaction in the foliar K concentrations (Table 3). Birches growing in Aitoneva (10.0 g kg^{-1}) peat had higher potassium foliar concentration than those growing in Piipsanneva (5.3 g kg^{-1}) one.

Table 4. Effect of fertilisation treatment on foliar nutrient concentrations of birch and willow

Species	Nutrient	Fertilisation treatment				
		A0+0	A0+N	A6+N	A12+N	A24+N
Birch	N	a	b	a	b	b
	P	a	a	b	c	d
	K	a	a	b	c	d
	Ca	a	a	a	a	b
	Mg	ab	a	bc	bc	c
Willow	N	a	b	b	b	
	P	a	a	b	b	
	K	a	a	b	c	
	Ca	a	ab	b	c	
	Mg	a	ab	bc	c	

Notes: Treatments that do not differ from each other according to Tukey's test at a significance level of 0.05 are marked with the same letter. In the statistical tests of willows, the treatment Ash 24+N was not included, because of small sample size.

Table 3. Effect of peat type, species, fertilisation treatment and their interaction on foliar nutrient concentrations

Species	Nutrient	*F*-value						
		F_{peat}	$F_{species}$	F_{fert}	$F_{peat*fert}$	$F_{peat*species}$	$F_{fert*species}$	$F_{peat*fert*species}$
Birch	N	0.5	3.6	13.5***	1.9	0.0	1.7	0.6
	P	0.7	2.7	48.6***	1.0	1.1	1.8	0.3
	K	0.0	0.7	439.2***	8.3**	0.3	6.8**	1.5
	Ca	0.0	64.0***	11.6***	1.0	0.2	1.9	0.1
	Mg	6.1*	22.8***	10.7***	3.5*	0.1	4.0*	0.3
Willow	N	17.1**	50.8***	6.9**	1.0	10.1*	3.2	0.0
	P	15.1**	13.4**	11.7**	1.7	7.0*	1.5	0.0
	K	5.2*	0.7	136.6***	9.0*	0.6	1.0	1.8
	Ca	1.6	0.6	17.4***	0.1	0.1	0.8	0.0
	Mg	4.9	16.8**	20.6***	0.4	0.2	0.5	0.1

Notes: In the statistical tests of willows, the treatment Ash 24+N was not included, because of small sample size. Stars indicate statistical significance in the analyses of variance: $p < 0.05$ = *, $p < 0.01$ = **, $p < 0.001$ = ***.
peat = peat type, fert = fertilisation treatment

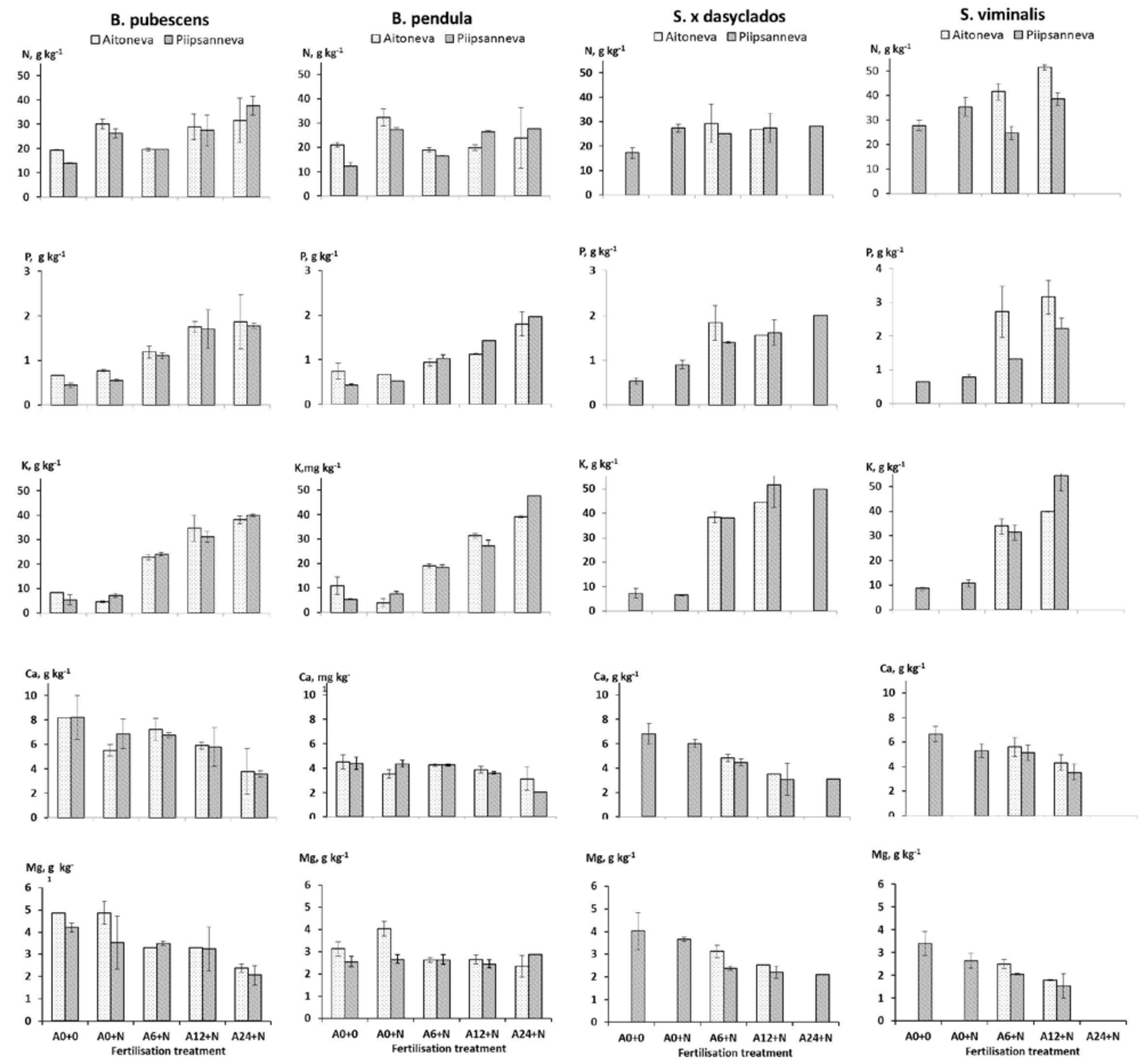

Figure 2. Foliar nutrient concentrations of the birches and willows. For willows, the treatment Ash 24+N was not included, because of small sample size

Nitrogen fertilisation (A0+N) and ash doses 12 t ha^{-1} and 24 t ha^{-1} increased foliar N concentrations of birches in comparison to unfertilised (A0+0) peat (Table 4).

S. viminalis had significantly higher foliar N (36.5 g kg^{-1}) and P (1.8 g kg^{-1}) concentrations than *S.* × *dasyclados* (N 25.6 g kg^{-1}, P 1.3 g kg^{-1}) (Table 3, Figure 2). Foliar N, P and K concentrations of willows were higher with Aitoneva peat (N 38.7 g kg^{-1}, P 2.4 g kg^{-1}, K 38.4 g kg^{-1}) than with Piipsanneva one (N 27.9 g kg^{-1}, P 1.2 g kg^{-1}, K 27.5 g kg^{-1}) (Table 3). Fertilisation with wood ash increased willow foliar N, P and K concentrations significantly compared to the unfertilised control treatment, but at the same time decreased foliar Ca and Mg concentrations (Figure 2, Tables 3 and 4). Nitrogen fertilization increased willow foliar nitrogen concentration (Table 4).

Discussion

The growth of all studied species was poor in unfertilised cutaway peat. Wood-ash application increased the biomass production of birches and willows to many times the level of unfertilised peat. Increasing the ash application amount from 6 t ha^{-1} to 12 t ha^{-1} did not increase yield and higher application amounts even decreased biomass production. However, the application amounts to be used in nature cannot be directly based on results from greenhouse studies. Recycling of wood ash could promote sustainable forestry on cutaway peatland sites and significantly reduce the waste problem that can arise when wood fuels are used for energy production. In many studies, fertilisation has not been found to increase the production of mature birch stands (Viro 1974, Oikarinen and Pyykkönen 1981, Puro 1982, Moilanen 1985). However, this study consistent with previous research on fertilisation was shown to increase growth of young birch stands (Viro 1974, Kaunisto 1987, Saarsalmi et al. 1992, Hytönen and Kaunisto 1999, Hytönen and Saarsalmi 2009, Hytönen and Aro 2012). Ash has already been shown to increase the growth of planted, naturally regenerated, or seeded birch seedlings on cutaway peatlands after four to five growing seasons (Kaunisto 1987, Huotari et al. 2009, Kikamägi et al. 2013). The effect of ash fertilisation can be quite long-lasting, and positive growth results have been measured 15–21 years from wood-ash application on birch stands (Aro and Kaunisto 1996, Hytönen and Aro 2012). From research results with pine in peatland forests, one can expect trees to show a response to ash fertilisation that is still much longer (e.g. Silfverberg and Huikari 1985, Silfverberg 1996, Moilanen et al. 2002, 2005).

Wood ash proved to be a good source of phosphorus and potassium for both birch and willow seedlings, significantly increasing foliar concentrations of these nutrients. Similar results have been shown in a field study in Estonia (Kikamägi et al. 2011). Mere nitrogen fertilisation increased foliar N concentration of birches. For birch, foliar K concentrations of seedlings grown in unfertilised peat and in peat fertilised with nitrogen was at the deficiency level (6–7 g kg^{-1}, Sarjala and Kaunisto 2002), but ash fertilisation increased K concentrations and eliminated deficiencies. The effect of wood ash on nutrition of birch can be long-lasting. Wood ash has been reported to increase foliar P, K, and B concentrations 15 years from application (Aro and Kaunisto 1996) and concentration of P for even 21 years (Hytönen and Aro 2012). In this study ash decreased the foliar Ca and Mg concentrations of both willows and birches. In the study of Huotari et al. (2011), wood ash (8 t ha^{-1}) did not affect foliar Ca concentrations but increased birch Mg concentration significantly after five growing seasons, and in the study of Kikamägi et al. (2011) ash increased foliar Ca concentrations but did not affect Mg concentrations. The two birch species differed from each other in their Ca and Mg concentrations, with downy birch having higher concentrations than silver birch, as reported earlier in some studies (Saramäki and Hytönen 2004, Hytönen 2005, Hytönen et al. 2014). *S. viminalis* was a more demanding species than S. × *dasyclados*, which was reflected in this study by higher foliar N and P concentrations.

The more it was used, the more ash increased the soil pH. The good liming effect of wood ash was evident from the increase in soil pH by 1.3–1.5 pH units after 6 t ha^{-1} application of ash and by 2.5–3.3 pH units after fertilisation with 24 t ha^{-1} of ash. Similar peat pH responses to wood ash have been reported for 1–3 years from wood ash application on cutaway peats (Kaunisto 1983, Huotari et al. 2011, Kikamägi and Ots 2010, Kikamägi et al. 2013, 2014). Even 10 years from application of 5 t ha^{-1} of wood ash, topsoil pH was 0.9 pH units higher in a cutaway peatland area in Finland (Hytönen and Aro 2012). For willow survival and growth, a pH increase was necessary with Aitoneva peat as substrate. Both of the willow species studied died when grown in Aitoneva peat without fertilisation or with only nitrogen fertilisation, emphasising the significance of soil pH for energy-willow cultivation. Earlier investigations have shown that willows in bioenergy-plantation require rather high substrate pH levels (5.0–6.0) (Ericsson and Lindsjö 1981, Hytönen 2005). For reaching this optimal pH range, the wood-ash dose of 6 t ha^{-1} was adequate. However, birches do not need an increase in pH for good growth (Ericsson and Lindsjö 1981, Rikala and Josefek 1991, Hytönen 2005), and liming has, while in some cases increasing mostly decreased the growth of birches (Kaunisto 1979, 1981, 1987).

The two unfertilized cutaway peats differed from each other in their chemical characteristics: Piipsanneva peat had higher pH, total N, and acid ammonium acetate extractable Ca concentrations than Aitoneva peat. However, the growth of birches was better in Aitoneva than in Piipsanneva peat. Cutaway peatlands have low P and K concentration in the residual peat (Aro et al. 1997, Kikamägi et al. 2013). Thus, the higher P (Aitoneva 12.8 mg l^{-1}, Piipsanneva 6.8 mg l^{-1}) and K concentrations in the unfertilised Aitoneva peat, even though differences between peat types were not significant, may have reflected in the growth results. Ash fertilisation increased soil extractable P, K, Ca, and Mg concentrations in both cutaway peats studied with increasing application amounts. Similar high increases in extractable P, K, Ca, and Mg concentrations have been reported in field studies from cutaway peats one to three years from application (Kikamägi et al. 2013, 2014). The effect of ash on soil nutrient stores seems to be long-lasting; for example, Hytönen and Aro (2012) reported increases in amounts of extractable nutrients (P, K, Ca, Mg, and B) especially in the top peat layer even 10 years after application of 5 t ha^{-1} of wood ash. Probably on account of increases in mineral matter in the soil with ash application, the largest amount of ash reduced the soil total nitrogen concentrations, as shown earlier by Kikamägi et al. (2013, 2014) on cutaway peatlands in Estonia.

Conclusions

Large areas of peat-production fields will become available for other uses. Cutaway peatlands often have high nitrogen content in the remaining bottom peat while concentrations of mineral nutrients are low. Wood ash proved to be a good source of P and K for both birch and willow seedlings, also significantly increasing their growth. The growth of all species was poor on unfertilised peat. Ash also increases soil pH, a prerequisite for energy-willow cultivation on peatlands. The usability of ash on cutaway peatlands is enhanced by the technical ease of spreading ash in treeless and level areas. Variations in inherent nutrient status between cutaway peats can be expected to be of importance for afforestation or short-rotation cultivation.

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