Foliar Potassium Concentrations of Bilberry, Bog Bilberry and Downy Birch as Indicators of Potassium Nutrition of Scots Pine on a Drained Peatland

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Leaves of bilberry (*V. myrtillus*), bog bilberry (*V. uliginosum*) and downy birch (*B. pubescens*) were collected five times during a growing season from 18 plots in a drainage area, and needles of Scots pine (*Pinus sylvestris* L.) once during the following winter from the same plots at Parkano, southern Finland. The aim was to study the potassium nutrition of the test plants and relationships between the foliar potassium concentrations of Scots pine and of the test plants. The estimation of the potassium nutrition of test plants was based on the accumulation of putrescine in foliage. Apart from single observations, elevated putrescine concentrations were found when the potassium concentrations were <5 mg g^{-1} in bilberry, <4 mg g^{-1} in bog bilberry and <6 mg g^{-1} in downy birch, and the highest concentrations below the potassium levels of 3.0–3.5 mg g^{-1}. At the concentrations of 2–3 mg g^{-1} the accumulation increased pronouncedly in bog bilberry but less in downy birch and only slightly in bilberry. The foliar potassium concentrations in test plants correlated closely with the concentrations in pine needles. The concentrations of all species in August were quite stable at the levels of the severe and slight potassium deficiency of pine (3.5 and 4.5 mg g^{-1} respectively) indicating that August would be suitable for collecting foliage. The concentrations in bog bilberry were very close to the concentrations in pine at the severe and those in bilberry at the slight deficiency level of pine. All test plants could be used for predicting the potassium nutrition of Scots pine, but additional research is needed for the practical application of the method.

Keywords *B. pubescens*, deficiency, deficiency limit, dormancy, foliar analysis, needle analysis, peatland, *Pinus sylvestris*, potassium, putrescine, *V. myrtillus*, *V. uliginosum*
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1 Introduction

Potassium stores in the root zone of trees on drained peatlands are quite low compared with the amounts bound into tree stands in Finland (Westman 1981, Paavilainen 1980, Kaunisto and Paavilainen 1988, Finér 1989, 1991, Kaunisto and Moilanen 1998). Especially peatland forests on originally wet, sparsely forest-covered sites are susceptible to potassium deficiency. Potassium deficiency can be recognised fairly easily by visible symptoms in the needles of both Scots pine and Norway spruce. However, before any visible symptoms can be observed, trees may have suffered from potassium deficiency for several years and growth may have been retarded (Kaunisto 1992).

So far, the conventional needle nutrient analysis during winter dormancy has been used for estimating the nutrition of Scots pine in Finland (Veijalainen 1984, Reinikainen et al. 1998) because of the wide variation in needle nutrient concentrations outside the dormant period (Helmisaari 1990, Sarjala and Kaunisto 1996, Raitio and Merilä 1998, Pietiläinen et al. 2000). However, it has some disadvantages in northern conditions, such as the inconvenient time of sampling because of the snow cover, short working days and cold air temperature. Also the planning of forest management is done mainly during the unfrozen period. In this respect, the strong correlation in the needle potassium concentrations of Norway spruce (*Picea abies*) between the autumn months and the following winter found by Kaunisto and Sarjala (2002) may offer a promising alternative for needle sampling during winter dormancy. Also the possibility of using the needle analysis of the Norway spruce understorey for estimating the nutrition of a dominating Scots pine stand, as shown by Saarinen (1997), facilitates the practice of needle analysis.

Ground vegetation has been used for classifying peatland sites since the early 20th century (Cajander 1913) in Finland, and a close relationship between the site type and the tree stand growth has been shown in several investigations (e.g. Heikurainen 1959, 1960, Keltikangas et al. 1986). Since ground vegetation can be used for estimating the peatland site type and the potential of tree growth depending on the site type, one would expect a relationship to exist between the nutrient concentrations of the ground vegetation species and trees. No data has yet been published to confirm this relationship on peatlands.

Downy birch (*Betula pubescens*) and bilberry (*Vaccinium myrtillus*) are fairly common species on tall sedge and herb-rich fens and bog bilberry (*Vaccinium uliginosum*) on dwarf shrub pine bogs. The potassium concentrations of downy birch (Ferm and Markkola 1985) are considerably higher than those of pine on peat soils (Paarlahti et al. 1971) on average, and also the level of severe potassium deficiency is higher (3.5 mg g^{-1} for pine Sarjala and Kaunisto 1993 and 7–8 mg g^{-1} for birch Sarjala and Kaunisto 2002). No data has been found on the potassium concentrations of bilberry and bog bilberry growing on peat soils nor on the concentrations of the potassium deficiency of these plants. On boreal forest soils the potassium concentrations of both species seem to be closer to the values in birch than pine foliage (Johansson 1993, Karlsson 1985).

Polyamines and their precursor diamine putrescine are involved in the regulation of plant growth and development (Galston and Flores 1991) and in stress adaptation of plants (Galston and Kaur-Sawhney 1990, Rajam 1997). Putrescine accumulation is a good indicator of the potassium deficiency of forest trees (Kaunisto and Sarjala 1997, Sarjala and Kaunisto 1993, 2002) and has been shown to accumulate also during the growing season (Sarjala and Kaunisto 1996).

The first aim of this study was to determine, in a drained peatland area, the foliar potassium concentrations that display a severe potassium deficiency of *Vaccinium myrtillus* L. and *Vaccinium uliginosum* L. and the understorey downy birch (*Betula pubescens* Ehrh.) by using the accumulation of putrescine as an indicator. The second aim was to evaluate the possibility of using the foliar potassium concentrations of these test species as indicators of the potassium status of Scots pine (*Pinus sylvestris* L.) trees growing in this area. The third aim was to define sampling times for the test species that would best indicate the potassium nutrition of Scots pine.

2 Material and Methods

2.1 Site and Treatments

The material was collected from a ditch spacing and fertilisation experiment drained in the middle of the 1950's using covered and open ditches at Liesineva in Parkano (61°59´N, 23°15´E; Huikari 1959, Ahti 1983, Kaunisto et al. 2002). The original peatland site types in the area consisted of meso-oligotrophic pine fens and tall sedge fens and oligotrophic low sedge pine fens and low sedge fens (classification according to Laine and Vasander 1990). Presently, the area was stocked by uneven-aged, 50–80-year-old Scots pines and downy birches either as pure pine stands or as pine dominated mixtures. The area had been partly fertilised on the belts across the ditches. The fertilisation treatments were as follows: 1) an unfertilised control, 2) fertilised only once in 1961 with all the main nutrients (NPK) or 3) fertilised three times; in 1965, 1977 and 1994 (NPK, NPK, PK respectively, Kaunisto et al. 2002). The nitrogen concentrations in the 0–10 cm surface peat layer varied between 1.67 and 2.27% (Kaunisto et al. 2002). The phosphorus concentrations were between 863 and 1281mg kg^{-1}, thus being fairly high, and the potassium concentrations between 144 and 451 mg kg^{-1} in the 0–10 cm surface peat layer. The peat layer was more than one meter thick in the whole area.

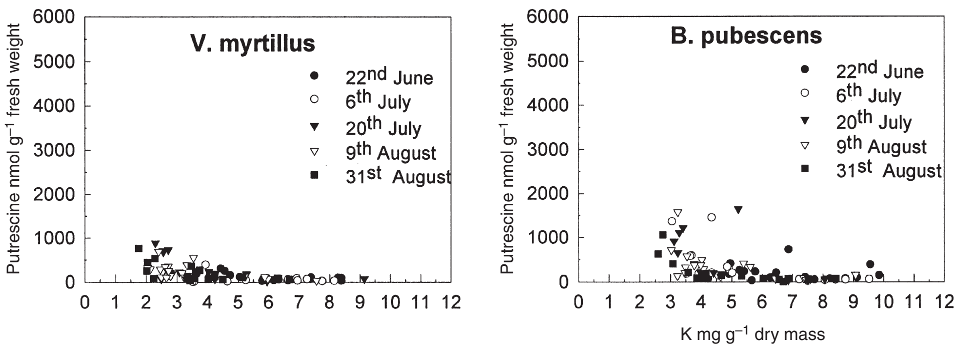
2.2 Sampling, Analyses and Calculation

All three fertilisation treatments, both ditch types and three ditch spacings (20, 40 and 60 m) were selected for this study, 18 plots altogether. The plot sizes varied between 0.05 and 0.15 ha depending on the ditch spacing. Ten subsamples of bilberry, bog bilberry and downy birch were taken from each plot and combined. Because of the uneven areal distribution of the species on the plots the samples could not be taken systematically. The foliar samples of ground vegetation and downy birch were collected on 22nd June, 6th July, 20th July, 9th August and 31st August in 1999. About 10–15-cm long pieces of stems of both berry species and branches of the upper part of downy birch trees were collected and taken into the laboratory. There the leaves were detached immediately and then stored at –80 °C for the putrescine analyses and at –20 °C for the potassium analyses. From the same experimental plots southern-side branches from the second and third whorl of five evenly distributed Scots pine trees were collected in the following winter on the 8th of March in 2000. The current year needles were detached and the needles of five trees from the same plot were combined in the laboratory and stored at –20 °C.

Foliage for nutrient analyses was dried at 60 °C and the dry weight determined after drying at 105° for 24 hours. Potassium analyses were performed with a flame atomic spectrophotometer (Varian AA-30) with the methods routinely used in the Finnish Forest Research Institute from ashed (at 550 °C) samples (Halonen et al. 1983). Polyamines were extracted from the leaf tissue with 5% $HClO_4$ followed by dansylation of the extract and analysed with HPLC according to Sarjala and Kaunisto (1993). Regression and correlation analyses were used when explaining the relationships between the potassium concentrations of bilberry, bog bilberry and downy birch foliage and Scots pine needles.

3 Results

By selecting samples from the unfertilised controls and from the treatments having a different fertilisation background it was possible to get a very wide range of potassium concentrations in the foliage of all test species (about 2–9 mg g^{-1}, Fig. 1). Free putrescine accumulated in low potassium concentrations in the leaves of all test species (Fig. 1). Apart from some single observations, elevated putrescine concentrations were found when the foliar potassium concentration was <5 mg g^{-1} in bilberry, <4 mg g^{-1} in bog bilberry and <6 mg in downy birch. Seasonal variation in putrescine concentrations was quite independent of the sampling time above the potassium concentrations of 4 mg g^{-1} but the accumulation of free putrescine in low potassium concentrations was more pronounced in all species in July and August than in June (Fig. 1). The accumulation of free putrescine occurred at



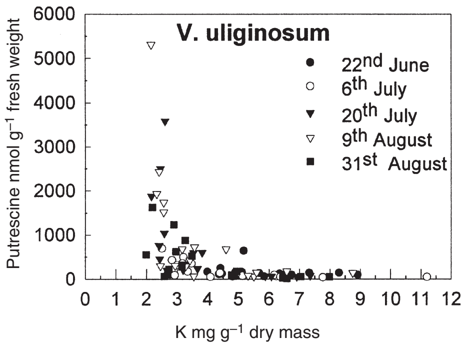


Fig. 1. Relationship between the putrescine accumulation and potassium concentrations of *V. myrtillus*, *V. uliginosum* and *B. pubescens* at different sampling dates in 1999.

Table 1. Correlation coefficients (r) between potassium concentrations in Scots pine needles collected during dormancy (8th March 2000) and in leaves of *V. myrtillus*, *V. uliginosum* and *B. pubescens* collected during the growing season in 1999, and potassium concentrations of these species (mg g^{-1}), which correspond to the potassium concentrations of severe and slight deficiency limit for *Pinus sylvestris*. (K 3.5 and 4.5 mg g^{-1} respectively). n = 18, *** p< 0.001, ** p<0.01.

Sampling time	*V. myrtillus*			*V. uliginosum*			*B. pubescens*		
	r	K 3.5	K 4.5	r	K 3.5	K 4.5	r	K 3.5	K 4.5
22nd June	0.845***	5.59	7.10	0.784***	5.33	6.62	0.833***	6.20	7.90
6th July	0.803***	4.59	6.39	0.756***	4.03	6.01	0.828***	4.76	6.83
20th July	0.831***	3.45	5.25	0.820***	3.29	5.01	0.902***	4.57	6.36
9th August	0.671**	3.04	4.30	0.794***	3.31	5.00	0.757***	4.35	6.03
31st August	0.781***	3.20	4.48	0.846***	3.51	5.36	0.878***	4.26	6.05

lower potassium levels in the leaves of bilberry and bog bilberry than in downy birch (about 2–3 and 2.5–3.5 mg g^{-1} respectively, Fig. 1). In the foliar samples of downy birch and bilberry HPLC analyses revealed also peaks corresponding with 1,3-diaminopropane.

There were strong positive correlations between the foliar potassium concentrations of bilberry, bog bilberry and downy birch analysed during the growing season and the Scots pine needles analysed during dormancy at all sampling times (Table 1). However, the regression equations between the foliar potassium concentrations of the test plants and Scots pine calculated on the basis of the data collected in June and early July differed greatly from the ones calculated on the data collected in August (Fig. 2). The equations between bilberry and Scots pine were quite similar at both sampling times in August but slightly more ambiguous between downy birch and

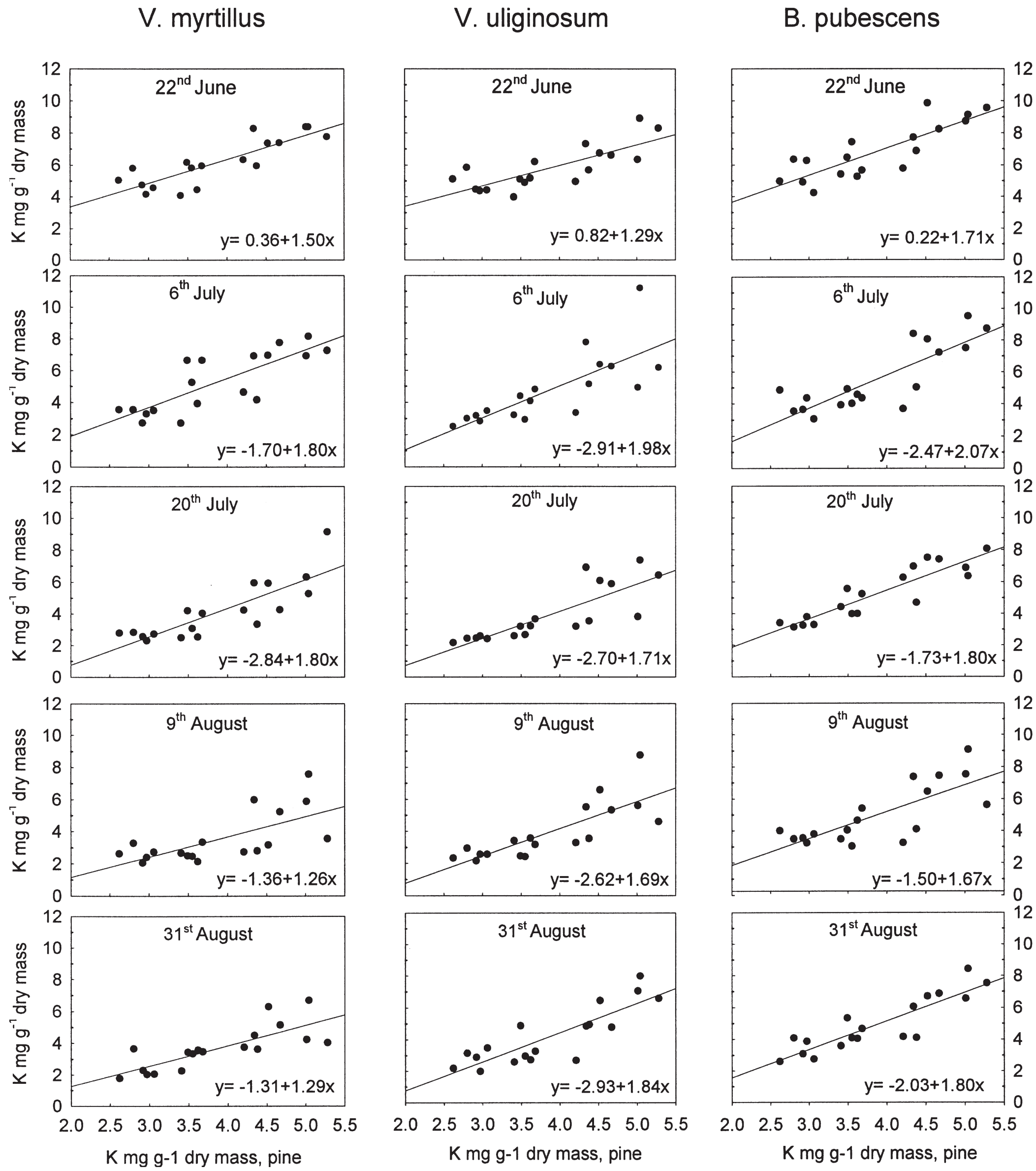


Fig. 2. Linear regressions between the foliar potassium concentrations of *V. myrtillus*, *V. uliginosum* and *B. pubescens* collected during the growing season in 1999 and the concentrations of Scots pine (*Pinus sylvestris*) needles collected during dormancy in winter 2000.

Scots pine. The equations between bog bilberry and Scots pine were fairly similar in the samples collected in both late July and August.

The concentrations of potassium in bilberry, bog bilberry and downy birch foliage corresponding with both the acute and slight potassium deficiency level of Scots pine (K 3.5 and 4.5 mg g^{-1} respectively, Paarlahti et al. 1971, Sarjala and Kaunisto 1993) were calculated on the basis of the regression equations in Fig. 2. The results show that the potassium concentrations of bilberry, bog bilberry and downy birch at these Scots pine potassium levels varied greatly in June and in early July (Table 1). However, the concentrations in bog bilberry and downy birch were fairly stable in the leaves collected in late July or in August and also in the leaves of bilberry collected in August. The concentrations of bog bilberry in August and late July were about the same or slightly lower (3.29–3.51 mg g^{-1}) than the concentrations of pine needles at the acute deficiency level and slightly over (5.00–5.36 mg g^{-1}) the values of pine at the slight deficiency limit. The concentrations of bilberry in August were lower (3.03–3.20 mg g^{-1}) than those of pine needles at the acute deficiency level and at about the same level (4.30–4.48 mg g^{-1}) as the values of pine at the slight deficiency level. The concentrations of downy birch in August and late July were clearly higher (4.26–4.57 and 6.03–6.36 mg g^{-1} respectively) than those of pine at both given limit values.

4 Discussion

The material was collected from a drained peatland area known to have quite low amounts of natural potassium in peat. However, different fertilization treatments made it possible to study the potassium nutrition of different species in a wide range of foliar potassium concentrations.

Bilberry, bog bilberry and downy birch showed an increase in putrescine accumulation at low foliar potassium levels indicating potassium deficiency, but the greatest accumulation was at a slightly lower level in berry species (K 2.0–3.0 mg g^{-1}) than in downy birch (K 2.5–3.5 mg g^{-1}). The deficiency limit for bilberry in this study seems to be quite similar to the lowest foliar potassium levels (2.5 mg g^{-1}) found by Sheppard (1990) for Canadian blueberry (*V. angustifolium*). In the earlier investigation of Sarjala and Kaunisto (2002), where the downy birch trees represented the dominant crown layer, putrescine accumulated at considerably higher (K 6–8 mg g^{-1}) foliar potassium levels. In the work of Reinikainen (1967) downy birch leaves displayed chlorosis at the potassium concentration of 3.9 mg g^{-1}. Also Ingestad (1973) showed that potassium requirement of bilberry was lower than that of downy birch. It seems that bilberry and bog bilberry are more tolerant of low potassium levels than downy birch. On the other hand, putrescine accumulation at low foliar potassium concentrations in bog bilberry was manifold, compared with the other species. In addition to putrescine, the accumulation of another diamine, 1,3-diaminopropane, was observed under potassium deficiency in downy birch by Sarjala and Kaunisto (2002). Now this diamine was also found in bilberry. If the synthesis of 1,3-diaminopropane is involved in stress response under potassium deficiency, it may partly explain the lower levels of the other diamine putrescine in downy birch and bilberry in comparison with bog bilberry in which only putrescine was accumulated. There are no earlier published results on potassium deficiency values for bilberry and bog bilberry.

The foliar potassium concentrations of bilberry, bog bilberry and downy birch collected from late June to late August correlated closely with the potassium concentration in Scots pine needles collected during dormancy. However, the regression equations on the concentrations between bilberry and pine and between downy birch and pine were close to each other only in August and between bog bilberry and pine in late July and August. Similarly, the potassium concentrations which correspond to the potassium concentrations of the severe and slight deficiency limit in Scots pine (K 3.5 and 4.5 mg g^{-1} Paarlahti et al. 1971, Sarjala and Kaunisto 1993) were for bilberry and downy birch more stable in August and for bog bilberry in late July and August than at the earlier sampling times. The result implies that the best sampling time would be late July and August for bog bilberry and August for bilberry and downy birch. The result for downy birch agrees with the one received in an earlier study (Sarjala and Kaunisto 2002). We have not found any published investigations concerning the other two test species.

The foliar potassium concentrations of bog bilberry at its acute deficiency level were considerably lower than those of Scots pine (Sarjala and Kaunisto 1993). However, it was interesting to find out that in late July and August the foliar potassium concentrations of bog bilberry were very close to those of pine at the severe deficiency level of pine. Also at the slight potassium deficiency of pine the concentrations in bog bilberry were about the same as the incipient putrescine accumulation found in pine (K 5.2 mg g^{-1}, Sarjala and Kaunisto 1993). This implies that the foliar potassium concentrations of bog bilberry in late July and August could possibly be used quite directly to estimate the potassium nutrition of pine. The potassium concentrations of bilberry were quite close to the concentrations in pine needles at slight potassium deficiency.

In conclusion the present study shows that the potassium concentrations of bilberry, bog bilberry and downy birch leaves collected in August quite well explained the variation in the potassium concentration of Scots pine needles on that particular drained peatland site, and that the foliar analyses of these plants may be used for estimating the potassium nutrition of Scots pine. However, additional research is needed for the practical applications of the method.

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