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Estimating potassium nutrition of Norway spruce with needle analysis during different seasons

Kuusen neulasanalyyttinen kaliumravitsemuksen arvionti eri vuodenaikoina

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The aims of this study were 1) to get a better background for estimating limit values of potassium nutrition for Norway spruce (*Picea abies* L. Karst.) and 2) to find out if the needle potassium nutrition during dormancy could be estimated by analysing needles collected before the dormant period. Five groups of trees with different nutritional backgrounds were selected. One was on a shallow-peat (5–30 cm) mineral soil slope and four on a deep-peat site next to it. Needles were collected four times during the autumn months and twice during dormancy. The needle K concentration of a severe potassium deficiency limit indicated by the exponential accumulation of putrescine, was about 4.5 mg g^{-1}. However, trees suffered from potassium shortage already at the potassium concentrations of about 5 mg g^{-1}. The needle potassium concentrations during the autumn months from late August to early October were in very close correlation with the concentration during dormancy, $y = 0.869x - 0.208$ ($r^2 = 0.92$), where y is the potassium concentration in the winter months and x that during the autumn months.

Keywords: Deficiency, deficiency limit, mire, peatland, potassium, putrescine

Introduction

Peat soils contain only small amounts of potassium compared with the uptake by tree stands (Kaunisto & Paavilainen 1988, Laiho & Laine 1995, Kaunisto & Moilanen 1998). Although potassium circulates effectively inside trees and between the soil and trees (Helmisaari 1992), it is the nutrient whose deficiency perhaps most often leads to lethal consequences in trees on peatland sites. Therefore it is important to develop means for estimating the potassium nutrition of trees. Several studies, quite consistently, give a single value (3.5 mg g^{-1}) for the limit value of severe potassium deficiency for Scots pine (Paarlahti et al. 1971, Sarjala and Kaunisto 1993, 1996, Reinikainen et al.1998). The potassium nutrition of Norway spruce has also been discussed in some investigations, but the values of a severe deficiency limit on peatlands vary quite widely (between 4.0 and 5.4 mg g^{-1} d.m.) from one study to another (Paavilainen 1974, Kaunisto & Sarjala 1997, Reinikainen et al. 1998, Veijalainen 2001).

Kaunisto & Sarjala (1997) based the deficiency limit in Norway spruce on the accumulation of putrescine in dormant needles under K^+ deficiency, the method which they had successfully used earlier for Scots pine (Sarjala and Kaunisto 1993, 1996). The diamine putrescine is a precursor of polyamines, spermidine and spermine. The accumulation of putrescine was reported first by Richards and Coleman (1952) in the leaves of K-deficient barley plants. Since then the specific role of putrescine in maintaining the cation-anion balance in plant tissues has been established in several studies (reviewed by Flores 1991). As a result of K^+ starvation, this diamine accumulation is widespread among plant species.

So far, the foliar analyses developed for estimating the nutrition of conifer species in Finnish conditions on peatlands have been based on needle samples collected during dormancy (Paarlahti et al. 1971, Reinikainen et al.1998), the suggested time period being from the beginning of December to the end of March (Reinikainen et al. 1998). However, from a practical point of view this time is quite undesirable for needle sampling because of the short daylight time and/or the deep snow cover in these northern conditions. Only few studies have been carried out on the seasonal variation of the needle nutrient concentrations of Scots pine (Helmisaari 1990, Sarjala & Kaunisto 1996, Raitio & Merilä 1998) and even fewer for Norway spruce (Raitio & Merilä 1998) in boreal conditions. The latter one was dealing with spruce growing on mineral soil sites. It also included recommendations for sampling times. So far, no connection has been suggested for the values between the analytical data during and outside dormancy for Norway spruce growing on peatlands.

The aims of this study were 1) to get a better background for estimating the limit values of potassium nutrition for Norway spruce (*Picea abies* L.) and 2) to find out if the needle potassium nutrition during dormancy could be estimated by analysing needles collected outside the dormant period.

Material and methods

Sites and treatments

The material was collected from the experimental area of Pirttineva located in southern Finland (N 61°57, E 23° 25). Five groups of trees with different nutritional backgrounds were selected for the study in order to have a wide gradient of potassium nutrition of trees (Table 1). One group was on a shallow-peat (peat depth 5–30 cm) mineral soil slope (Site A, *Vaccinium vitis idaea* type) and four groups on a deep-peat (>1.5 m) site located next to Site A, and also close to each other. The peatland site was an afforested, originally treeless low/tall sedge mire. One of the four tree groups located on peat between the mineral soil slope and a cut-off ditch at about 30–40 m distance from the slope and was unfertilised (Site E). One group (D) was located just on the other side of the cut-off ditch, only 3–6 meters from the ditch and was also unfertilised. The other two groups (B and C) were located further down (30–40 m) on the peatland side of the ditch. Groups

Table 1. Basic information on the material.

Site	Peat depth	Location	Basic fertilisation (years)	Refertilisation (years)	Sampling times (month/year)
A	Shallow peat, mineral soil	Slope	None	None	8/95; 1, 5, 8, 9, 10/96; 3/97
B	Deep peat	On peatland	1956–64	None	“
C	Deep peat	On peatland	1956–64	1976 and 1993	“
D	Deep peat	Down from cut-off ditch	1956–64	None	8/95; 5, 8, 9, 10/96; 3/97
E	Deep peat	Between slope and cut-off ditch	None	None	“

B, C and D had been fertilised with phosphorus in 1956 (71 kg ha^{-1}) and with potassium in 1962 (83 kg ha^{-1}), and Group B again with PK in 1976 (45 kg P and 83.5 K kg ha^{-1}) and again with potassium chloride (K 75 kg ha^{-1}) in 1993. The height of trees varied between 5 and 7 m.

The composition of mineral soil was sand and silt moraine; 30% passed through 0.062 mm sieve. There were only minor differences in the nitrogen concentrations of the 10 cm organic surface layer between the different groups but the variation in mineral elements was quite wide (Table 2). By far the highest aluminium, iron and phosphorus concentrations were on Site C and the lowest phosphorus and potassium concentrations on Site D.

Needle sampling and analyses

The trees were sampled once in 1995, five times in groups A, B and C and four times in groups C and D in 1996 and once in 1997 (Table 1). Two samplings were done during dormancy in winter, four times in autumn and one in spring. The current (C) and the current + one-year-old (C+1) needles were sampled from the second and third whorl from the top of five trees in each group at one time. Each tree and needle class formed a separate sample. Potassium and putrescine concentrations were analysed each time but the other nutrients (N, P, B, Zn, Cu) only once, in winter 1997. Needle nutrients were analysed with the methods routinely used in the Finnish Forest Research Institute (Halonen et al. 1983). Putrescine concentrations were analysed from the same needle samples as potassium. Putrescine was extracted from needle tissue with 5% $HClO_4$ followed by dansylation of the extract and analysed with HPLC according to Sarjala and Kaunisto (1993).

Table 2. Some total element concentrations (mg g^{-1}) in the 0–10 cm surface layer. N and P calculated per organic part of the sample.

Site	Element					Org.matter
	N	P	K	Fe	Al	%
A	22.3	1.103	0.345	3.25	2.073	73
B	22.3	0.964	0.303	4.08	1.140	94
C	25.7	1.427	0.215	16.80	1.560	93
D	22.0	0.792	0.128	2.93	1.080	97
E	21.8	1.013	0.348	4.28	1.110	92

Results and discussion

Nutrition of trees

The nutrition of trees is discussed only on the basis of the mean concentrations in different tree groups. Compared with the optimum values obtained by Reinikainen et al. (1998) and Veijalainen (2001) for spruce on Finnish peatlands, the needle nitrogen concentrations were quite low in all groups (Table 3) despite the fact that the nitrogen concentration of the top 10-cm organic layer was fairly high on all sites (Table 2). At least partly, the reason may be the exceptionally cold summer in 1996 preceding the sampling for the nutrient analyses, which was also seen in the low nitrogen concentrations of birch leaves in 1996 in that area (Sarjala and Kaunisto 2001).

On average, potassium concentrations were adequate or high on the mineral soil site (A) and on the refertilised peatland site (B) and also in the group between the mineral soil site and the cut-off ditch (E) but extremely low in the unrefertilised groups C and D (cf. Kaunisto & Sarjala 1997, Reinikainen et. al 1998, Veijalainen 2001). It seems that the cut-off ditch in this deep-peat site quite effectively hindered the potassium flow from the mineral soil to the peatland site located downwards from the cut-off ditch. Although this was only one case, it gives a reason for further studies on the role of cut-off ditches in drainage maintenance.

Table 3. Nutrient concentrations per dry mass and standard deviations in the 1996 needles in March 1997.

Site	N, mg g^{-1}	P, mg g^{-1}	K, mg g^{-1}	B, mg kg^{-1}
A	12.5 ± 0.1	1.4 ± 0.3	6.3 ± 2.2	16.0 ± 4.8
B	12.9 ± 0.2	2.0 ± 0.2	7.9 ± 0.5	26.0 ± 6.6
C	11.9 ± 0.1	2.1 ±0.4	2.9 ± 0.6	13.2 ± 3.4
D	11.0 ± 0.1	1.4 ± 0.3	2.6 ± 0.8	12.5 ± 5.2
E	10.7± 0.1	1.1 ± 0.2	4.6 ± 1.8	10.5 ± 2.6

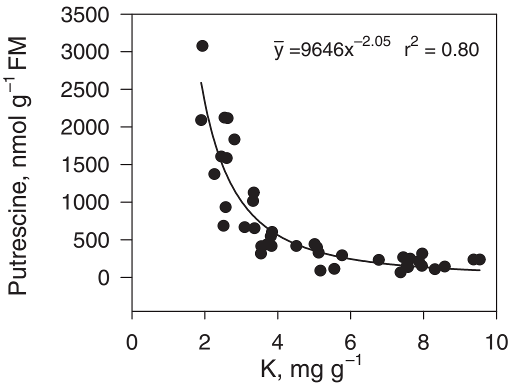

Fig. 1. Relationship between the putrescine and potassium concentrations of the current year (C) needles collected during dormancy (22.1.1996 and 7.3.1997, n = 40).

Needle phosphorus concentrations were extremely low in the tree group between the mineral soil slope and the cut-off ditch (E), and still low but clearly higher on the other side of the cut-off ditch (D), contrary to peat phosphorus concentrations (Table 2). Peat iron and aluminium concentrations were quite similar in both groups and could not explain the difference either. In the tree groups fertilised once or twice (B and C) needle phosphorus concentrations were high (Reinikainen et al. 1998, Veijalainen 2001). The boron concentrations of needles were adequate or even high (c.f., Braekke 1979, 1994, Reinikainen et al. 1998, Veijalainen 2001).

Relationships between putrescine and potassium

In this investigation putrescine accumulation was used for estimating potassium deficiency limits in the needles of Norway spruce (Figs 1 and 2). In the material including only the needles collected during winter dormancy (Fig. 1, altogether in 1996 and 1997 n = 40) a curvy linear model, $y = x^{-b}$ explained fairly well the relationship between the needle putrescine and potassium concentrations (Fig. 1). Logarithmic and linear models were used in order to estimate the change from a linear to a curvy linear relationship by adding observations one by one from high K concentrations downwards. There was a slight but not significant increase in putrescine values when going from high K concentrations down towards the needle potassium concentration of 5.0 mg g^{-1} (p linear model = 0.145, p log. model = 0.113, n = 19). Above the potassium concentration of 4.5 mg g^{-1} both the linear and logarithmic model were significant, the logarithmic one having a slightly lower p value (p lin. = 0.049 and p log. = 0.032, n = 20) indicating a slight exponential increase in putrescine at this potassium level. Above the K concentration of 3.8 mg g^{-1} p value for the linear model was 0.001 and for the logarithmic one <0.0001 indicating a high exponential increase in the accumulation of putrescine. There were no samples with a K value between 3.8 and 4.5 mg g^{-1}.

Although the number and also the size of the sample trees in this study were smaller than in the previous study on Norway spruce by Kaunisto and Sarjala (1997), the relationship between putrescine and potassium followed quite well the same pattern. The exponential accumulation of putrescine at the potassium levels below about 4.5 mg g^{-1} in the dormant samples is slightly higher than the K value (4.0 mg g^{-1}) given by Paavilainen (1974) to indicate a need for potassium fertilisation in older and taller spruce stands (about 15 m in height) than in this study. However, Kaunisto & Sarjala (1997) could not find any clear difference in the putrescine accumulation between the trees under and above 15 meters of height (8–15 and 15–23 m respectively). On the other hand, the severe deficiency limit of about 4.5 mg g^{-1} indicated by the putrescine accumulation in this study and in the earlier study by Kaunisto and Sarjala (1997) is somewhat lower than the value (5.4 mg g^{-1}) suggested by Veijalainen (2001). The reason for the difference may be due to a difference in the methods used for defining the limits. In this investigation and also in the earlier investigation by Kaunisto & Sarjala (1997) the severe deficiency limit was based on a biochemical reaction, the accumulation of diamine putrescine, whereas the value obtained by Veijalainen (2001) was based on the leader growth of spruce. The values given by Veijalainen (2001) and also by Reinikainen et al.

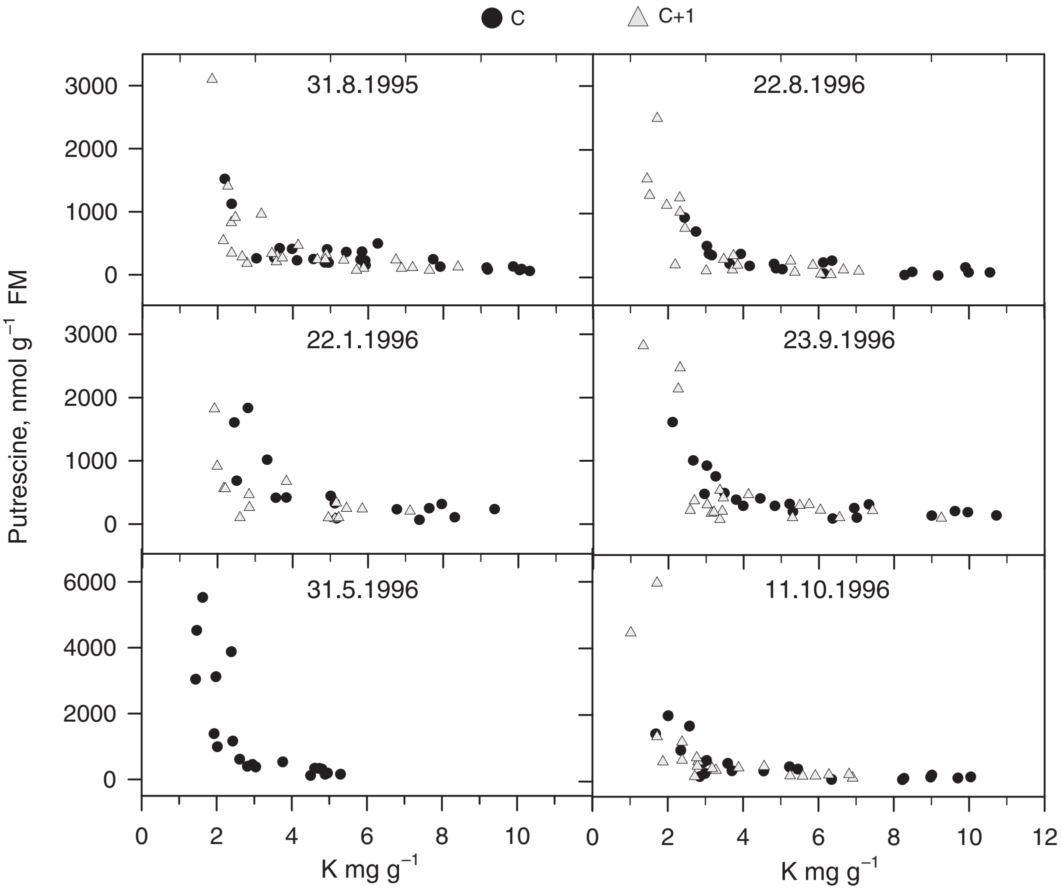

Fig. 2. Relationship between the putrescine and potassium concentrations of the current year (C) and C+1 needles in different sampling times.

(1998), however, correspond fairly well with the values of a starting K deficiency both in this study and in the earlier study by Kaunisto & Sarjala (1997).

The phosphorus concentrations in the needles of Group E and also of Groups A and D were quite low. However, Kaunisto and Sarjala (1997) could not find any effect of the phosphorus concentrations on the putrescine accumulation except at very low phosphorus levels ($P<1.0$ mg g^{-1}). The nitrogen concentrations in this investigation were also low. However, the low nitrogen and phosphorus concentrations may have been only temporary due to the low temperature sum of the summer 1996. The boron concentrations were at a good or even high level (Braekke 1979, 1994). It is not likely that an imbalance between potassium and other nutrients would have caused discrepancy between the putrescine and potassium relationship. The results of this investigation and the results of the previous one by Kaunisto and Sarjala (1997) suggest that the severe potassium deficiency limit for current year spruce needles during dormancy is about 4.5 mg g^{-1} and that it is quite independent of the tree size. However, trees may begin to suffer from potassium shortage at K concentrations above 5 mg g^{-1} (Fig. 1, see also Kaunisto & Sarjala 1997).

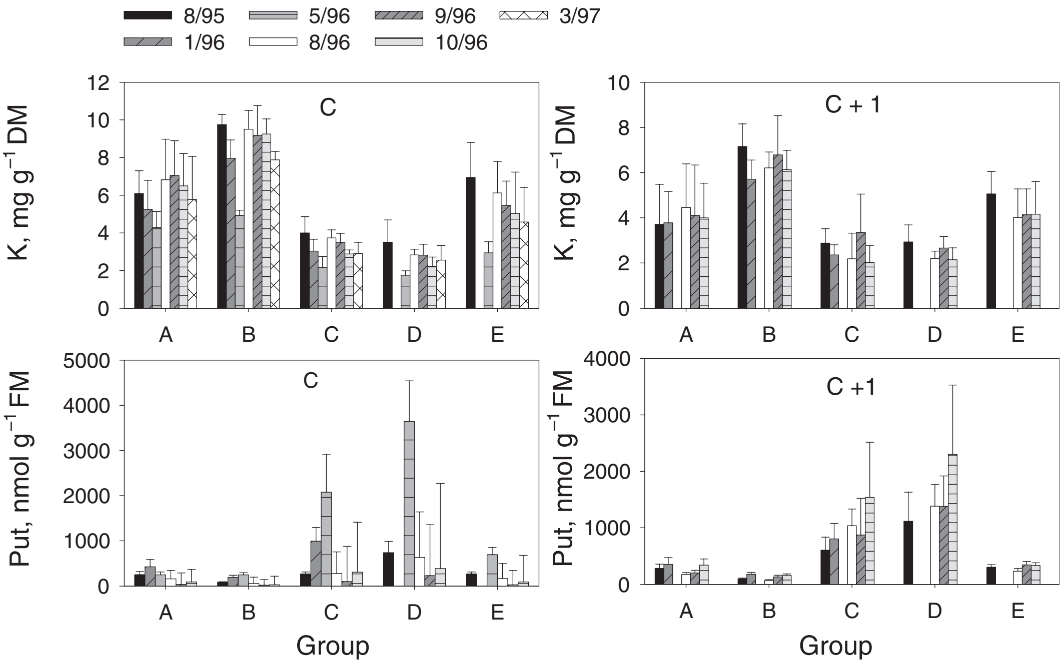

Fig. 3. Mean potassium and putrescin (put) concentrations and standard deviations in C and C+1 needles in different tree groups and sampling times (n = 5).

Needle potassium and putrescine concentrations in different sampling times

The needle potassium concentrations in the current year needles were highest in autumn and lowest in spring (Fig. 3). Differences in the potassium concentrations were quite small during the autumn months inside different groups or slightly decreasing towards October.

The results by Raitio & Merilä (1998) showed that K contents in Norway spruce needles did not fluctuate much between September and March except for a slight decrease after the end of October. When the dry weight changes in the needles were taken into account, the K concentrations per needle were surprisingly stable in southern Finland (about 20 mg needle^{-1}). In fact, the results by Raitio & Merilä (1998) showed that the K level per needle was more stable than that of most of the other nutrients (N, P, S, Ca, Mg, Mn, Cu, B, Fe, Al) throughout the study period from April 1996 to March 1997. In the present study the needle dry weight was measured only in March 1997, and the average K levels per needle were 26.6 in Group A, 24.8 in B, 12.5 in C, 10.5 in D and 19.3 mg needle^{-1} in Group E. The K levels per needle in trees with a good K status (Sites A and B) were thus slightly higher than those reported by Raitio and Merilä (1998) and about the same in trees with an adequate or low K status (group E) but clearly lower in K deficient needles.

The situation was somewhat different with the putrescine values of needles. The variation between different sampling dates was very small in the trees with good potassium nutrition but quite high in the trees with poor potassium nutrition (Fig. 3) as in Scots pine (Sarjala & Kaunisto 1996). The lowest potassium and the highest putrescine values were observed in May also in Scots pine reported by Sarjala & Kaunisto (1996).

The potassium concentrations during the autumn months, late August, September and early October, correlated linearly and very closely with the concentrations during the winter months January and early March (Fig. 4). The potassium concentrations were lower in winter than during the

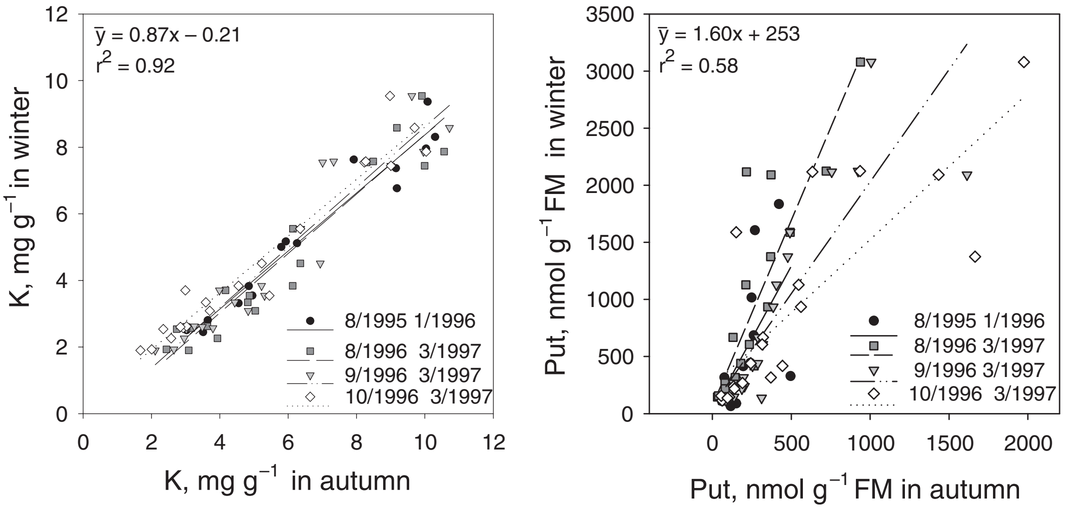

Fig. 4. Relationships of the needle potassium and putrescin (put) concentrations between the samples collected during autumn months and winter months. Equations and the degrees of determination are in Table 4.

autumn months. The linear regression lines between the autumn and winter concentrations varied only slightly. The degree of determination was over 0.90 in each equation (Table 4). The combined material gave an equation y = 0.869x – 0.208, where y is the potassium concentration in the winter months and x that during the autumn months (r^2 = 0.92).

If this result is more generally true, it would make it possible to collect needles for potassium analyses during the autumn months. From a practical point of view, this would be quite important because it would make it possible to collect needles within a longer period of time and also in better working conditions than earlier. When combined with the result by Saarinen (1997) who found that K deficiency in understorey spruces indicated deficiency also in the pine overstorey the result would be even more useful for practical forestry. More research, however, is still needed to verify the results obtained from these investigations.

There was a wide variation in the putrescine concentration between the sampling times in autumn and in winter (Fig. 4). This reflects the role of putrescine as a metabolic compound involved in several processes including cold hardening (Kushad & Yelenosky 1987, Sarjala et al. 1997). The result means that the autumn concentrations of putrescine cannot be used for estimating putrescine or potassium values during dormancy.

Table 4. Dependence of the potassium and putrescine concentrations in winter months (y) on the concentrations in the previous autumn (x). See also Fig. 4.

x	y	potassium	r^2	putrescine	r^2
8/1995	1/1996	y = 0.87x – 0.35	0.95	y = 2.53x + 24.20	0.35
8/1996	3/1997	y = 1.03x + 1.03	0.92	y = 3.24x + 68.84	0.76
9/1996	3/1997	y = 0.90x – 0.44	0.90	y = 1.96x + 67.55	0.73
10/1996	3/1997	y = 0.85x + 0.22	0.94	y = 1.28x + 242.74	0.68
All		y = 0.87x – 0.21	0.92	y = 1.60x + 253.32	0.58

Conclusions

The needle K concentration of the severe potassium deficiency limit in Norway spruce indicated by a biochemical stress reaction, the putrescine accumulation seems to be about 4.5 mg g^{-1} and, based on this and earlier investigations, quite independent of the tree size. However, trees may suffer from potassium shortage already at potassium concentrations above 5 mg g^{-1}. It may be possible to estimate the potassium nutrition of Norway spruce on the basis of needle potassium concentrations during the autumn months from late August to early October. Cut-off ditches may hinder the flow of potassium from mineral soil sites to peatland sites.

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TIIVISTELMÄ:

Kuusen neulasanalyyttinen kaliumravitsemuksen arviointi eri vuodenaikoina

Johdanto

Kaliumin puutos aiheuttaa puissa kasvun taantumista, päärangan vaihdoksia ja johtaa akuutissa tilanteessa puukuolemiin. Kaliumin puutokseen liittyvän putreskiinin akkumuloitumisen havaitsivat ensimmäisinä Richards ja Coleman (1952) analysoimalla kaliumin puutoksesta kärsiviä ohran lehtiä. Tämän jälkeen putreskiinin spesifisestä asemasta kasvisolukkojen kationi-anioni –tasapainossa on julkaistu useita tutkimuksia (kirj. kats. Flores 1991).

Kaliumin puutos on yleisintä kasvupaikoilla, joilla puuntuotospotentiaali muutoin on hyvä, kuten saraisilla ja ruohoisilla rämeillä ja myös korvissa. Tämän vuoksi on tärkeätä kehittää keinoja, joilla puutos voitaisiin havaita mahdollisimman varhain. Neulasanalytiikkaa on käytetty jo pitkään ravinnepuutosten arvioimiseksi. Ankaran kaliumin puutoksen alaraja on voitu jo määrittää tärkeimmille puulajeille, joskin jonkin verran vaihtelua esiintyy. Neulasanalyysin käyttöä on vaikeuttanut se, että puutosrajat havupuilla on määritetty vain talvella kerätyille neulasille, jolloin neulasten keruu lumi- ja sääolosuhteiden sekä lyhyen päivän vuoksi on hankalaa ja kallista.

Tämän tutkimuksen tarkoituksena on ensisijaisesti 1) tarkentaa kuusen akuutin kaliuminpuutoksen raja-arvoa käyttämällä kaliumin puutoksen indikaattorina neulasten putreskiinipitoisuuden eksponentiaalista kohoamista kaliumpitoisuuden alentuessa ja 2) selvittää mahdollisuutta arvioida kuusen neulasten talvenaikaista kaliumpitoisuutta elo-lokakuun aikana kerättyjen neulasten kaliumpitoisuuksien avulla.

Aineisto ja menetelmät

Aineisto kerättiin viidestä ravinnetaloudeltaan ja lannoitushistorialtaan erilaisesta, mutta lähellä toisiaan sijaitsevasta kohteesta Kurun Pirttinevalta. Yksi (kohde A) oli ohutturpeinen (5–30 cm) kivennäismaarinne (Taulukko 1). Muut olivat tähän rajoittuvalla paksuturpeisella (>1,5m) suolla. Kohde E sijaitsi em. rinteen ja niskaojan välissä, kohde D välittömästi niskaojan alapuolella ja kohteet B ja C 30–40 m:n päässä niskaojasta. Kohteet B, C ja D oli lannoitettu fosforilla vuonna 1956 (71 kg ha^{-1}) ja kaliumilla vuonna 1962 (83 kg ha^{-1}), sekä kohde B uudelleen PK:lla vuonna 1976 (45 kg P and 83.5 K kg ha^{-1}) ja edelleen kalisuolalla (K 75 kg ha^{-1}) vuonna 1993. Puiden pituus oli 5–7 m. Kasvupaikkkojen orgaanisen pintaosan typpipitoisuudet olivat varsin samanlaisia eri kohteissa ja verraten korkeita. Kivennäismaakohteella sekä niskaojan yläpuolisella kohteella (A ja E) turpeen kaliumpitoisuudet olivat korkeimmat ja niskaojan alapuolisella kohteella (D) matalimmat. Fosfori- ja rautapitoisuudet olivat korkeimmat kohteella C ja matalimmat niskaojan alapuolisella kohteella D. Jokaisesta kohteesta valittiin 5 puuta, joista kerättiin saman ja edellisen kasvukauden neulasia 6–7 kertaa, kaksi kertaa talvella ja muut kerrat talvilevon ulkopuolisena aikana vuosina 1965–97 (Taulukko 1). Näytteet analysoitiin puukohtaisesti. Neulasnäytteistä analysoitiin putreskiini- ja kaliumpitoisuudet joka kerta sekä yhdestä talvinäytteestä lisäksi typpi, fosfori ja boori.

Tulokset ja päätelmät

Neulasten kaliumpitoisuudet olivat keskimäärin lähellä akuutin puutoksen rajaa niskaojan yläpuolisissa kuusissa, mutta osoittivat erittäin vakavaa puutostilaa niskaojan alapuolisissa kuusissa (Taulukko 3), mikä näyttäisi viittaavan siihen, että niskaoja on estänyt kaliumin kulkeutumista suolle. Neulasten fosforipitoisuudet sen sijaan olivat korkeammat niskaojan ala- kuin yläpuolella. Turpeen fosforipitoisuus oli kuitenkin korkeampi niskaojan ylä- kuin alapuolella ja toisaalta rauta- ja alumiinipitoisuudet olivat samaa suuruusluokkaa, joten puiden erilainen P-ravitsemustila ei selittyne näillä turpeen ominaisuuksilla.

Putreskiinia alkoi lisääntyä neulasten kaliumpitoisuuden arvoilla n. 5 mg kg^{-1} ja lisääntyminen muuttui eksponentiaaliseksi noin K-pitoisuuden 4,5 mg kg^{-1} kohdalla tai vähän sen yläpuolella osoittaen samalla akuutin kaliuminpuutoksen rajan kuusen neulasissa (Kuva 1). Tulos tukee aikaisemmin samalla menetelmällä saatua tulosta (Kaunisto & Sarjala 1997).

Talvilevon aikana kerättyjen neulasten kaliumpitoisuudet olivat erittäin kiinteässä vuorosuhteessa syyskuukausina elokuun loppupuolesta lokakuun alkupäiviin kerättyjen neulasten kaliumpitoisuuksien kanssa (Kuva 4). Kaliumpitoisuuksien välistä yhteyttä kuvasi suora, jonka yhtälö oli $y = 0{,}869\ x - 0{,}208$, jossa y on kaliumpitoisuus talvella ja x kaliumpitoisuus syksyllä. Yhtälön selitysaste, r^2, oli 0,92. Tuloksen mukaan kuusen neulasnäytteet kaliumanalyysiä varten voitaisiin kerätä jo elokuun loppupuolen ja lokakuun alkupuolen välisenä aikana. Lisää tutkimuksia kuitenkin tarvitaan tuloksen varmistamiseksi.

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