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Nutritional diagnosis of Norway spruce stands growing on drained peatlands using foliar analysis

Ojitettujen suokuusikoiden ravinnetarpeen määritys neulasanalyysillä

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The purpose of this study was to determine critical nutrient concentration values for interpreting foliar analysis of Norway spruce stands growing on drained peatlands. During 1987–91, a total of 162 spruce needle samples from various peatland sites in Finland were taken and analysed for N, P, K, Ca, Mg, B, Cu, Fe, Mn and Zn. The mean height growth of the two preceding growing seasons was used as the growth parameter for multiple and simple regression analyses. Foliar concentrations significantly explained height growth. Simple regression analysis was used to estimate the following critical values indicating severe to moderate nutrient deficiencies for the main nutrients: N 1.15–1.30%, P 1.70–2.30 mg g^{-1} and K 5.40–6.60 mg g^{-1}. Also the following tentative critical concentrations are suggested: Cu 2.0 mg kg^{-1}, Fe 13.0 mg kg^{-1}, Mg 0.80 mg g^{-1} and Zn 16.0 mg kg^{-1}. Results for B are in accordance with previous, but unsubstantiated, critical values (6–8 mg g^{-1}).

Key words: Critical concentration, foliar analysis, nutrient deficiency, peatland forestry

INTRODUCTION

Foliar analysis, among other methods, has been used in the evaluation of nutrient status of Scots pine stands growing on drained peatlands in Finland for some 30 years (Puustjärvi 1965, Paarlahti et al. 1971). Preliminary critical foliar concentrations for Norway spruce (*Picea abies* (L.) Karst.) stands growing on peatland sites were based on limited data (Paavilainen 1975) or on values derived from stands growing on mineral soils in Central Europe (e.g. Zöttl 1990). Critical values of boron for spruce stands on mires were based on more comprehensive material (Brække 1979, Silfverberg 1980). However, critical values for most of the micro-nutrients are still lacking, and fertilization of spruce stands on peat has relied mainly upon a nutritional site type classification (Huikari 1952, Huikari and Paavilainen 1968) and preliminary results from fertilization experiments (e.g. Paavilainen 1975, Paarlahti and Paavilainen 1985). Usually this information has been adequate, but even in practical forestry more detailed nutritional information is often needed. In forest research, foliar analysis is a routine procedure in studies of nutritional diagnoses.

The aim of this study was to produce critical values for foliar element concentrations of Norway spruce growing on drained peatland and to provide more specific criteria for identifying nutrient deficiencies and the need for fertilizing deficient stands. It was hypothesized that the height growth of spruce stands would be positively and significantly correlated to at least some macro-nutrients. Such correlations can be used to build regression equations that can give a set of critical concentration levels. Another hypothesis was that if the correlation between height growth and needle concentration is negative, small concentrations incidate deficiency in spite of the antagonistic and dilution effects, which seem to be common in peatland forests (Veijalainen 1977).

MATERIAL AND METHODS

Sampling plots

Norway spruce needles were sampled from stands growing on drained peatlands in southern Finland, mainly from southern and south western coastal regions and the central lake plateau (n=82), and in more northern regions in Ostrobothnia, northern Karelia, Kainuu and SW part of Lapland (n=80) (Fig. 1). Most of the sites were experimental plots of the Finnish Forest Research Institute and represented nutritional levels I–IV (Huikari 1952) (n=116). Experimental plots on afforested peatland fields, alluvions and fens (n=37) and some spruce stands growing on the edges of pine bogs (n=9) were also included. About 34% of the stands (n=55) had been fertilized (1952–88) with varying amounts of N, PK and NPK with or without micro-nutrients, and of different sources. Some of the sampled spruce stands (n=31) were growing under a shelter wood canopy. The shelter wood had been recently felled in some sample plots (n=19).

In southern Finland many of the spruce stands were so tall that sampling from the canopy was not possible, and the samples were taken from felled trees (n=26). In the more northern regions, young spruce forests are quite rare, and sampling included a considerable part of all known experimental sites. When choosing the sampling sites, a large variation in the nutritional state of sites and height growth of the stands was aimed at.

The condition of the ditches (three categories), ditch spacing and the depth of the peat layer were observed, and the site type classified on the basis of understorey vegetation and tree species (Huikari 1952). Details of fertilization (nutrient combination and date of application) were taken from the records of Forest Research Institute and the Central Forestry Board.

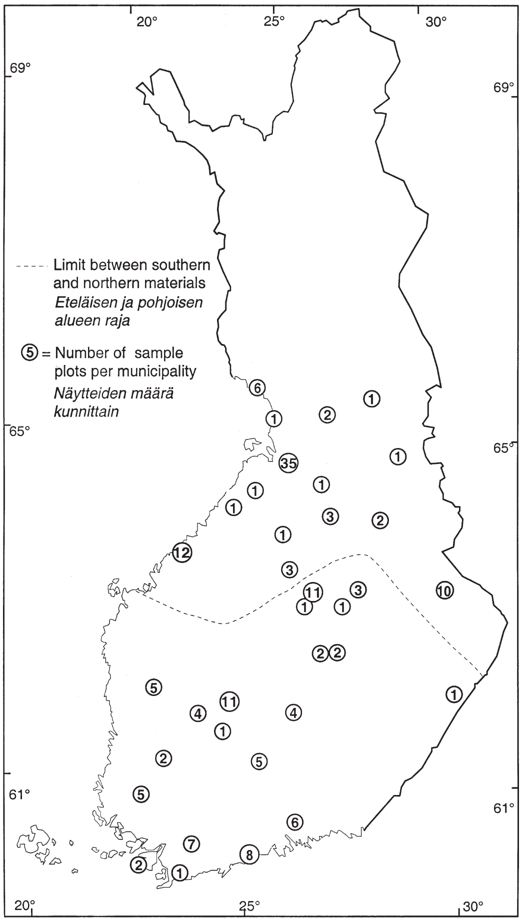

Fig. 1. Location of sample plots and their allocation to the southern and northern populations

Kuva 1. Näytealojen sijainti ja jakautuminen eteläiseen ja pohjoiseen osanäytteeseen

Needle sampling and chemical analyses

The needles were sampled during February–March in 1987–1990 in southern Finland, and in 1991 in northern Finland. The needles were taken from 5–10 sample trees per plot using a special branch hook with cutting steel blades or from freshly felled trees. The sample trees represented the dominant or, in a few cases, the co-dominant canopy layer. Trees growing on ditch banks were excluded. Two south-facing branches from the uppermost branch whorl were selected for sampling. The height growth of two previous growing seasons and the total height of each sample tree were measured.

The branches were kept at room temperature for at least a fortnight in paper bags until dried in a ventilated incubator for 24 h at 70°C. The needles were picked from the shoots, combined into one composite sample per plot, and homogenized by grinding in a stainless steel mill.

The Central Laboratory of the Finnish Forest Research Institute performed the chemical analysis of the samples from southern Finland. Total nitrogen (N) was determined using a CHN-Leco analyzer. Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), boron (B), zinc (Zn), manganese (Mn) and iron (Fe) concentrations were determined using plasma emission spectrometry (ICP-AES, ARL 3580) after ashing and digesting the samples in concentrated HCl (Kasvi-ja maa-analyysiohjeet 1995). Some of the felled tree samples were analysed for N using the Kjeldahl method and for P, K, Ca, Mg and B by ICP-AES after HCl digestion by a commercial laboratory.

The northern samples were analysed at Muhos Research Station. Total N was analysed by the Kjeldahl method, and K, Ca, Mg, Cu, Fe, Mn and Zn analyses were made using atomic absorption spectrophotometry after ashing and digestion in HCl. P and B were analysed spectrophotometrically, P by the vanado-molybdate method and B by the azomethine-H staining method (Halonen et al. 1983).

The laboratories had been calibrated for foliar analysis (Tervahauta 1996). The deviations calculated as percentage of the arithmetic mean concentrations produced by the Central Laboratory were N 2.2, P 3.0, K 2.9, Ca 0.3, Mg 2.9, B 9.1, Cu 22.2, Fe 15.5, Mn 2.8 and Zn 16.2.

Statistical analyses

Selective, step-wise linear regression analysis was used to determine, which foliar nutrients were related to the current height growth. Inverse, power, square root and logarithm transformations of the nutrient concentrations were tested but they did not give any better fit (higher r^2). The regression lines were not forced to pass through the origin and the selection criterion for the independent variables was $F>4.0$.

The distribution of each macro-nutrient was divided into 5–7 classes.The percentage of the cases within each class with greater than mean height growth, i.e. "good growth", was used to assess the relationships between the needle concentrations of macro-nutrients and height growth of Norway spruce.

Critical values for *severe* and *moderate* deficiency were determined using simple linear regression equations to describe the relationship between annual height growth and foliar concentrations; only positive and statistically significant ($p<0.05$) relationships were used.

The analysis was performed using the BMDP statistical software package. Significance levels of 5%, 1% and 0.1% are indicated by *, ** and *** respectively.

RESULTS

Interdependence of height growth and foliar nutrient concentrations

The material exhibited substantial variation in nutrient concentrations, tree height, peat layer thickness and ditch spacing (Table 1). Foliar concentrations of N, P, K, Cu and Fe were positively correlated to height growth (Fig. 2). Significant ($p<0.05$) negative correlations were found for Ca, Mg, B and Mn. Positive intercorrelations were observed between the main nutrients (Table 2).

The mean annual height growth (y) was best explained by the following multiple regression equation where the foliar concentrations of all nutrients were allowed as independent variables:

$$y = 29.95 - 0.006Mn^{*} + 1.61K^{**} + 0.20Fe^{*} + 7.53P^{***} - 22.60Mg^{***};\ (n = 128;\ r^2 = 0.63) \quad [1]$$

Foliar concentrations of N, K, Cu and B explained the height growth as follows:

$$y = 24.56N^{***} + 4.09K^{***} - 5.67Cu^{*} - 0.35B^{*} - 5.18;\ (n = 162;\ r^2 = 0.47) \quad [2]$$

Using stepwise regression analysis with only the macro-nutrients gave almost as high a degree of determination as Equation [2], indicating low importance of B and Cu:

$$y = 18.78N^{***} + 3.57K^{***} - 14.8$$
$$(n = 162;\ r^2 = 0.43) \quad [3]$$

Simple regression analysis using individual main nutrient concentrations gave the following models for height growth:

$$y = 33.51N^{***} - 10.04^{***};\ (n = 162;\ r^2 = 0.18) \quad [4]$$

$$y = 10.34P^{***} + 10.75^{***};\ (n = 162;\ r^2 = 0.28) \quad [5]$$

$$y = 4.14K^{***} + 6.01^{***};\ (n = 162;\ r^2 = 0.31) \quad [6]$$

Also correlations between height growth and Cu and height growth and Fe were positive and significant:

$$y = 9.27 + 9.22Cu^{***};\ (n = 162,\ r^2 = 0.11) \quad [7]$$

$$y = 24.42^{***} + 0.29Fe^{***};\ (n = 128,\ r^2 = 0.08) \quad [8]$$

Determination of critical values

Using equations 4–6, the concentration corresponding to the mean height growth (33.9 cm a^{-1}) was chosen as the critical value for *moderate* deficiency, and the concentration corresponding to the lower quartile of height growth (28.2 cm a^{-1}) as the critical values for *severe* deficiency (Table 3).

The probability of growth exceeding mean height growth was more than 50% when foliar concentrations were N > 1.45%, P > 2.00 mg g^{-1} or K > 7.00 mg g^{-1} (Fig. 3).

Because of negative correlations between height growth and foliar Ca and Mg (Table 2), it was not possible to estimate the critical concentrations using the regressions. In nine cases, with Mg concentrations between 0.70–0.89 mg g^{-1}, visual Mg deficiency symptoms were observed. Stands with foliar Mg concentrations > 0.90 mg g^{-1} were therefore classified as *healthy*, and a deficiency is indicated when concentrations are below 0.8 mg g^{-1}. Mg concentrations below 0.8 mg g^{-1} occurred in 8.0% of the stands.

Table 1. Mean foliar nutrient concentrations in sampled spruce stands and some stand and peat parameters with their deviation estimators.

Taulukko1. Neulasten ravinnepitoisuuksien ja eräiden taustamuuttujien keskiarvot ja hajontatietoja, suokuusikot.

Variables	n	mean ± S.E.	S.D.	Min.	Max.	C.V.
N, %	162	1.31 ± 0.03	0.18	0.92	1.98	14.2
P, mg g^{-1}	162	2.24 ± 0.12	0.70	1.02	4.76	13.2
K, mg g^{-1}	162	6.74 ± 0.35	2.07	2.34	12.90	31.3
Ca, mg g^{-1}	142	3.81 ± 0.16	0.96	1.50	7.41	25.0
Mg, mg g^{-1}	142	1.19 ± 0.05	0.29	0.61	2.20	24.8
B, mg kg^{-1}	162	15.6 ± 0.9	5.3	2.8	28.4	34.0
Cu, mg kg^{-1}	162	2.7 ± 0.1	0.5	1.6	4.8	18.5
Fe, mg kg^{-1}	128	36.2 ± 2.2	13.2	18.0	88.5	36.3
Mn, mg kg^{-1}	142	546 ± 53	325	126	2223	58.7
Zn, mg kg^{-1}	142	28.4 ± 1.5	9.8	12.2	76.5	33.0
i_H, cm a^{-1}	162	33.9 ± 2.0	13.8	7.0	68.0	39.8
H, m	162	6.90 ± 0.62	3.90	0.70	21.00	55.6
T_p, cm	140	63 ± 8	46	10	220	73.8
SL, m	142	45 ± 5	31	10	150	69.5

n = number of sample plots – *näytealojen määrä*, mean – *keskiarvo*, S.E.= standard error – *keskiarvon keskivirhe*, S.D.= standard deviation – *keskihajonta*, C.V. = coefficient of variation – *variaatiokerroin*, i_H = height growth – *pituuskasvu*, H= mean height of sample trees – *näytepuiden keskipituus*, T_p = thickness of peat layer – *turvekerroksen paksuus*, SL = strip width – *sarkaleveys*

Of the micro-nutrients, Cu and Fe correlated positively and B negatively with height growth (Fig. 4). The critical foliar concentrations indicating *severe* deficiency were 2.0 mg kg^{-1} for Cu and 13.0–_mg kg^{-1} for Fe. These values should be regarded with caution, however, because the coefficients of determination in regression equations [7–8] were low. Critical limits for B could not be estimated because of the negative correlation. Based on observations of growth disturbances in peatland spruce stands, Silfverberg (1980) estimated a B deficiency limit of 6–8 mg kg^{-1}. Concentrations as low as this occurred in 5.6–7.4% of the cases in the present study.

Correlations between the foliar concentration of Mn and Zn and height growth were insignificant (Table 2), so suitable regression equations could not be derived for determining critical values. A tentative foliar value for Zn of 16.0 mg kg^{-1} was chosen on the basis that only 2–3% of the stands had foliar concentrations below this limit.

DISCUSSION

The correlations—_between height growth and foliar macro-nutrient concentrations were somewhat higher for Norway spruce (this study) than for Scots pine stands (Paarlahti et al. 1971).

Foliar concentrations associated with visible deficiency symptoms have been used as critical values for severe deficiency (e.g. Brække 1994). In this study the intention was to determine critical concentrations for latent deficiencies preceding visible symptoms. Therefore, relatively high height growth thresholds were used. The upper limit for *moderate* deficiency would indicate the onset of latent deficiency or a situation in which fertilization by the nutrients in question would be of benefit for growth. An arbitrary limit of 50% of maximum growth was used by Braekke (1994) to determine critical concentrations for moderate deficiency (e.g. Brække 1994). By coincidence, his growth value (34.0 cm a^{-1}) was similar to the mean height growth (33.9 cm a^{-1}) used in this study.

A critical N concentration for spruce stands on Swedish peatlands can be estimated at 1.40% from the data presented by Holmen (1964).

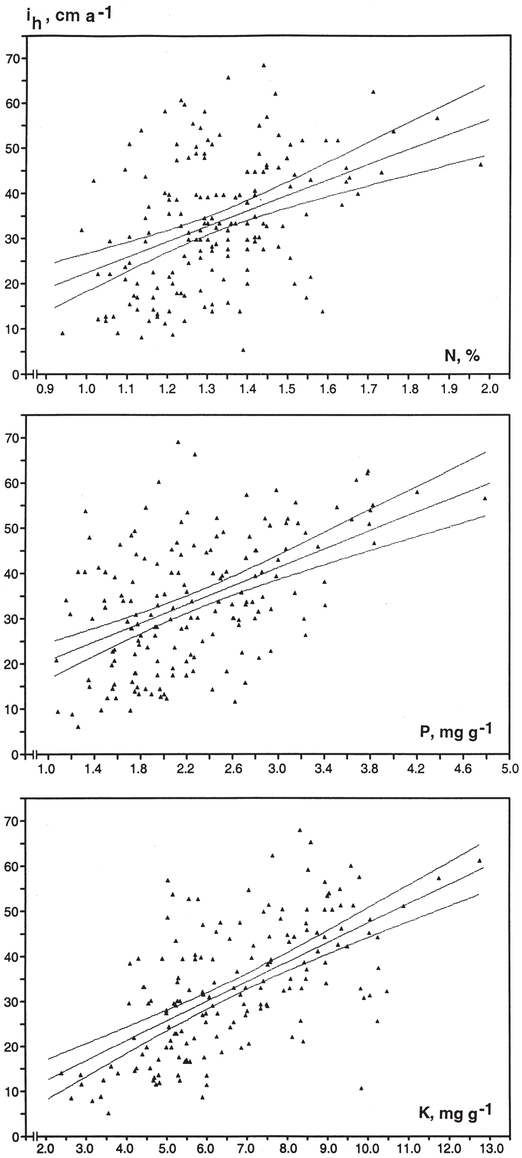

Fig. 2. Simple regressions between Norway spruce height growth and foliar N, P and K concentrations with 95 per cent confidence limits on peatlands.

Kuva 2. Pituuskasvun ja neulasten pääravinnepitoisuuksien väliset riippuvuudet 95 % luotettavuusvöineen turvemaiden kuusiaineistossa.

Paavilainen (1975) put forward a concentration of 1.20% as a preliminary critical value for foliar N. Nitrogen deficiency symptoms are apparent in spruce growing on mineral soils where foliar N concentrations are < 1.00% (Hartmann et al.

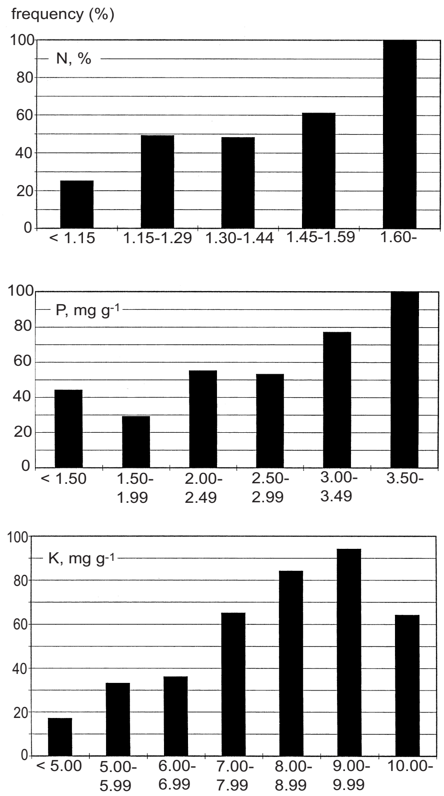

Fig. 3. Frequency of Norway spruce stands with height growths greater than the mean growth in different foliar macro-nutrient levels.

Kuva 3. Keskimääräistä paremman pituuskasvun esiintymistodennäköisyys eri pääravinnetasoilla suometsien kuusiaineistossa.

1989). The critical values for N derived in this study, 1.15–1.30%, are comparable to critical values produced in Germany for Norway spruce growing on mineral soils (Zöttl 1990).

Holmen (1964) reported foliar P concentrations of 1.4–2.4 of mg g^{-1} in Norway spruce stands in Sweden. Paavilainen (1975) suggested a value of 1.5 mg g^{-1} as a preliminary critical P concentration for peatlands. On the basis of that value, P deficiency would have been present in 11% of the samples in the present study. The critical values for P derived in this study (1.70– 2.30 mg g^{-1}), are also higher than the critical values presented by Zöttl (1990). Armson (1959) reported that a foliar concentration of >2.0 mg g^{-1} for Norway spruce would be adequate. Also Höhne (1963), Nebe and Donov (1969), Swan (1972), Donov and Iorova (1979) and Materna (1989) have reported foliar P values in Norway spruce foliage comparable to the values found in this report.

According to a number of publications the critical foliar concentration of K in Norway spruce lies between 6.80– 8.20 mg g^{-1} (Björkman 1953, Holmen 1964, Evers 1972, Everard 1973, Binns Paavilainen 1975, Zöttl 1990), and the value for severe potassium deficiency suggested by Kaunisto and Sarjala (1997). The relatively high K limit values in this study may partly be due to the use of PK fertilizers in many of the sampled stands. Potassium deficiency symptoms in spruce stands have been reported for mineral soil (Hartmann et al. 1989) and peatland sites

Table 2. Correlation matrix of foliar nutrient concentrations and height growth of spruce stands (n= 128).

Taulukko 2. Ravinnepitoisuuksien ja pituuskasvun väliset korrelaatiot suokuusikoissa (n=128).

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
N	1.00									
P	0.40	1.00								
K	0.41	0.65	1.00							
Ca	–0.11	–0.14	–0.17	1.00						
Mg	–0.29	–0.13	–0.09	0.42	1.00					
Fe	0.46	–0.01	0.28	0.06	–0.05	1.00				
Mn	0.06	–0.29	–0.25	0.39	–0.14	0.01	1.00			
Zn	0.08	0.21	0.39	0.57	0.25	0.21	0.17	1.00		
Cu	0.61	0.34	0.60	-0.00	–0.03	0.43	–0.00	0.30	1.00	
B	–0.15	–0.33	–0.08	0.04	0.13	0.13	0.03	–0.10	–0.10	1.00
iH	0.53	0.51	0.61	-0.32	–0.43	0.27	–0.24	0.11	0.33	–0.22

Significance levels of coefficient of correlation – *korrelaatiokertoimen merkitsevyystasot:* p<0.05: 0.173, p<0.01: 0.226, p<0.001: 0.286

(Saarinen 1996) at K concentrations of < 4.0 mg g^{-1}.

According to this study, almost 30% of the spruce stands were deficient in N, P or both. This is in agreement with the results of Viro (1965), who reported frequent N and P deficiencies in paludifying spruce stands in Finland.

According to Holmen (1964), foliar Mg concentrations of 1.0–1.6 mg g^{-1} are normal for peatland spruces. Hartmann et al. 1989 reported visible deficiency symptoms of Mg at foliar concentrations of Mg <0.30 mg g^{-1}. The value of 0.8 mg g^{-1} used in this study is considered suitable for indicating subnormal Mg status. The critical value for Cu of 2.0 mg kg^{-1} denotes a moderate deficiency in spruce stands growing on mineral soil (Haveraaen 1964) and is the same as the value put forward for spruce in Germany by Zöttl (1990) and for Scots pine growing on peatland in Finland (Veijalainen 1991). Copper deficiency seems to be rare in Finnish forest sites but not as rare as Fe, Mn or Zn deficiencies (Reinikainen et al. 1998).

Mean foliar Fe concentrations in this material were clearly below the optimum values of 41–57 mg kg^{-1} for Norway spruce growing on peatland proposed by Brække (1979), but they did not appear to prevent the stand from growing well.

A critical foliar Mn concentration of 20 mg kg^{-1} has been suggested for spruce growing on mineral soil (Ingestad 1958, Kreutzer 1972, Zöttl 1990). The lowest Mn concentration in the present data was 126 mg kg^{-1}, and therefore, any sugges-

Table 3. Critical and low foliar nutrient concentrations for spruce stands growing on peatland.

Taulukko 3. Neulasanalyysin raja-arvot turvemaiden kuuselle.

Nutrient	*Severe* deficiency	*Moderate* deficiency	Low
N, %	< 1.15	< 1.30	-
P, mg g^{-1}	< 1.70	< 2.30	-
K, mg g^{-1}	< 5.40	< 6.60	-
Mg, mg g^{-1}	-	-	< 0.80
B*, mg kg^{-1}	< 6.0	< 8.0	-
Cu, mg kg^{-1}	-	-	< 2.0
Fe, mg kg^{-1}	-	-	< 13.0
Mn, mg kg^{-1}	-	-	< 170
Zn, mg kg^{-1}	-	-	< 16.0

* Silfverberg (1980)

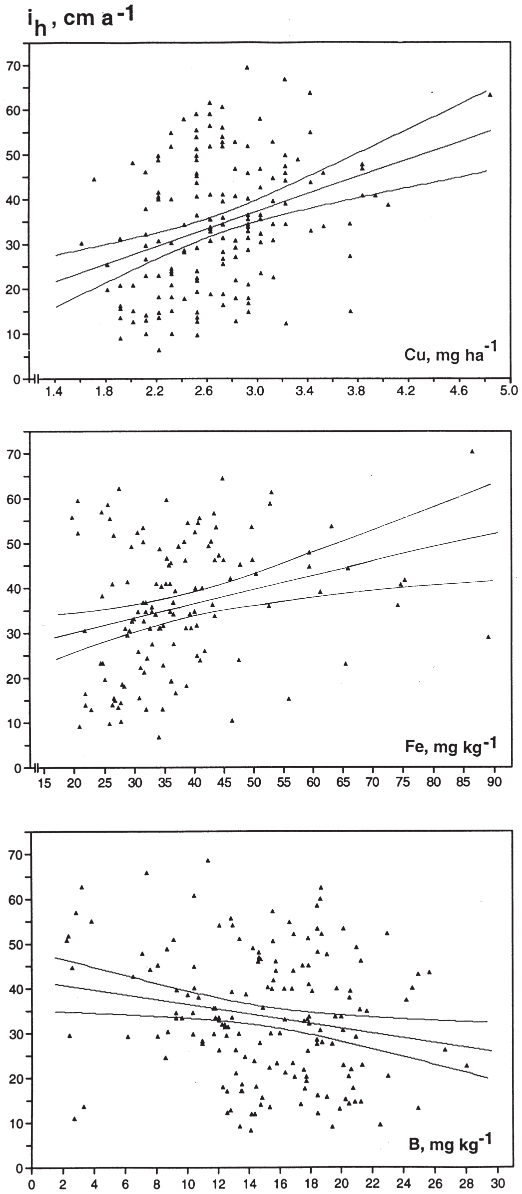

Fig. 4. Simple linear regression between Norway spruce height growth and foliar Cu, Fe and B concentrations with 95 per cent confidence limits on peatlands.

Kuva 4. Pituuskasvun ja eräiden hivenravinnepitoisuuksien väliset riippuvuudet 95 % luotettavuusvöineen suometsien kuusiaineistossa.

tion for even tentative values was difficult to make. Manganese deficiency is rare in Finland and very rare in peatland sites (Reinikainen et al. 1998).

For spruce growing on peatlands foliar Zn concentrations of 32–35 mg kg^{-1} are normal (Brække 1977, 1979). On mineral soils foliar Zn concentrations of 13–50 mg kg^{-1} are considered sufficient (Bergmann 1992, Stoate 1950). The critical Zn concentration of 16.0 mg kg^{-1} proposed in this study is a little higher than the value applied to mineral soils (Zöttl 1990). Zinc deficiency has not been reported in Finland (Reinikainen et al. 1998).

The tentative critical values for the micronutrients in this study were generally lower than the optimal concentrations reported by Brække (1979). Low foliar concentrations of micro-nutrients in coniferous trees may result from deficiency or displacement by other elements, antagonism (Bergmann1992), or dilution due to an increase in the biomass (Veijalainen 1977). These complications also apply to this material.

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TIIVISTELMÄ

Ojitettujen suokuusikoiden ravinnetarpeen määritys neulasanalyysillä

Männyn neulasanalyysin tulkinta on ollut suometsissä mahdollista jo 30 vuotta. Kuusinäytteitäkin on tullut tulkittaviksi, mutta niiden tulkintaa varten ei ole ollut olosuhteisiimme soveltuvia raja-arvoja läheskään kaikille ravinteille.

Raja-arvojen täydentämistä varten kerättiin 162 neulasnäytettä kuusivaltaisista tai puhtaista kuusipuustoista helmi–maaliskuussa 1987–91. Kaikki puustot kasvoivat ojitetuilla turvemailla. Useimmat näytealat olivat Metsäntutkimuslaitoksen koealoja, jotka edustivat erilaisia korpityyppejä. Näytteitä oli myös metsitetyiltä suopelloilta, vesijätöiltä ja ojitetuilta nevoilta ja rämeiden laiteilta.

Näytepuiksi valittiin 5–10 puuta, jotka eivät kasvaneet ojamailla. Kustakin näytepuusta otettiin oksakoukulla kaksi etelänpuoleista ylimmän oksakiehkuran oksaa. Aineisto sisälsi myös muutamia näytteitä yli 15-metrisistä kaadetuista puista. Nekin pyrittiin valitsemaan niin, että puut edustivat vallitsevaa latvuskerrosta. Kaikki näytteet otetiin puiden lepokauden aikana.

Koepuiden pituus ja kahden edellisen kasvukauden pituuskasvu mitattiin. Näytealoista määritettiin eräitä muitakin taustamuuttujia (Taulukko 1).

Aineisto jakautui eteläiseen ja pohjoiseen aineistoon (Kuva 1), jotka myös analysoitiin eri laboratorioissa. Vain eräissä hivenravinneanalyyseissä laboratorioiden väliset erot olivat huomattavia, vaikka ne käyttivät jonkin verran toisistaan poikkeavia analyysimenetelmiä.

Kuusen neulasten P-, K- ja Ca-pitoisuudet poikkesivat selvimmin vastaavista mäntyaineiston keskiarvoista (Taulukko 1).

Pituuskasvun ja monien ravinnepitoisuuksien välillä todettiin kiinteä korrelaatio (Kuvat 2 ja 4). Kun se oli positiivinen, voitiin vastaavaa regressioyhtälöä käyttää raja-arvon määritykseen. Tässä raja-arvot määritettiin asettamalla yhtälöihin puuston keskimääräinen pituuskasvu, jolloin saatiin lievä puutoksen yläraja tai pituuskasvujen alakvartiili, jolloin saatiin ankaran puutoksen ja lievän puutoksen välinen raja. Magnesiumin raja-arvot määritettiin pienehkön näytteisiin merkityn puutosoireaineiston perusteella. Sinkin raja-arvo määritettiin alustavasti sen perusteella, että ko. arvoa pienempiä pitoisuuksia oli aineistossa 3%. Silfverbergin (1980) laajahkosta erillisaineistosta määrittämiä boorin raja-arvoja ei näyttänyt olevan syytä muuttaa.

Muutamat raja-arvot (Taulukko 3) poikkesivat monista aiemmin esitetyistä kuusen neulasten raja-arvoista. Suurimmat erot olivat neulasten kaliumpitoisuuksien raja-arvoissa, mikä ainakin osittain aiheutunee erilaisista raja-arvojen määritysperusteista, joita ovat olleet esim. tässä työssä pituuskasvu ja eräissä muissa kaliumin puutoksen aiheuttama biokemiallinen stressireaktio.

Raja-arvojen määritystä haittasivat jossain määrin pääravinteiden väliset voimakkaat korrelaatiot, joiden merkitystä ei voitu vielä selvittää. Näytti kuitenkin siltä, että korkeat neulasten typpi- ja fosforipitoisuudet takasivat keskimääräistä paremman kasvun, kun taas neulasten kaliumpitoisuuden kohoaminen yli 10 mg g^{-1} alkoi näkyä kasvuedellytysten heikkenemisenä (Kuva 4).

Neulasanalyysi näyttää käyttökelpoiselta ravinnetarpeen määritysmenetelmältä myös kuusivaltaisissa suometsissä. Neulasanalyysin tulkinta vaikeutuu, ellei koepuiden ja näyteoksien valinnassa noudateta samoja ohjeita kuin käsillä olevassa tulkintarajojen määritykseen tarkoitetussa aineistossa.

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