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CONTENT OF MAIN NUTRIENTS IN NORWAY SPRUCE NEEDLES DEPENDING ON THE ECO-PHYSIOLOGICAL BACKGROUND

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Abstract. In the Estonian area, the Norway spruce studied on permanent plots shows defoliation of a "new type" on both sandy and calcareous soils. In green needles a deficiency of N occurs, but not of K, Ca, Mg, Mn, and B. In discoloured needles a rather low Mg concentration was found in all needle age classes. Other mobile elements show a tendency to translocate from older to younger needles. A deficiency of K occurs in previous-year needles, that of P in third-year needles. Ca, on the contrary, accumulates in older needles and its deficiency may occur in the current-year needles of damaged trees. The N/Mg ratio correlates best with the degree of discolouration. Most likely, however, there does not exist any one main cause of forest decline. All factors taken together are responsible for the disorder in the ecological situation where the weakest specimens of phylogenetically old species, like conifers, do not adapt sufficiently to changes in the climate, pollution, radiation regime, forestry practice, etc., all of which refashion the ecosystem within which the species have so far evolved. The changes in the eco-physiological background force the specimens to shorten their life cycle and may result in abortive developments.

Key words: Norway spruce, nutrition, needles, defoliation.

INTRODUCTION

A "new type" of forest damage in Estonia has been observed during the last decade. It occurred first in Norway spruce (*Picea abies* (L.) Karst.) (Frey, 1985) and, somewhat later, in premature stands of the Scots pine (*Pinus sylvestris* L.) on loamy moraine and sandy soils (Karoles, 1991).

Tentative defoliation assessments (Frey & Palo, 1993) have shown that the average frequencies of moderately to severely damaged spruces within the canopy reveal a gradual increase from 27 (1988) and 30% (1989) to 42 (1990) and 40% (1991).

Besides the unspecific loss of older needles, some discolouration symptoms, e. g. the yellowing of needles from year to year, have been observed in declining spruce crowns. Generally, these symptoms can be attributed to a specific nutrient deficiency. As various investigations have proved, a disordered nutrient supply might be considered one of the most important factors of forest damage.

The results of needle analysis in declining forests indicate that there exists a critical lack of one or some nutrients, frequently of Mg, K, Ca, and Zn (Abrahamsen, 1990; Hüttl, 1988a, 1988b; Materna, 1985; Mead, 1984; Zöttl, 1985). These findings suggest that disorders in tree nutrition are in accordance with certain changes in the properties of forest soils, mostly due to the increase in soil acidity and cation leaching from rooted soil horizons. Changes in the tree nutrition and soil solution, leading to crown damage, are commonly attributed to long-term adverse effects of air pollution, including acid deposition and ozone impact.

The character of air pollution in Estonia differs from that of most European countries. Here the main local emission sources, power plants, burn oil shale in the dust form milled together with about 25% of pure limestone. It is evident that huge amounts of the emitted SO_2 react with alkaline dust. This results in the deposition of mostly neutral or even basic substances, and, consequently, in the fertilization of forest soil with base cations via throughfall (Frey et al., 1992).

Ozone impact in the Estonian area should be negligible as the ozone concentration is in the range from 30 to 50 p.p.b. (Jänes & Sirk, 1994). Nevertheless, damage of coniferous stands persists.

This study presents data on the nutritional status of healthy and discolouring spruces and compares them with earlier (1972) data from the same stands. At that time no visible symptoms of forest decline occurred. The aim is to detect possible causes of disturbances in nutrient cycling.

Table 1

Characteristics of the permanent plots in Estonia

Stand

Plot	Canopy, in 10%	Age, years	Mean height, m	Site quality class	Basal area, m^2
Voore	9S 1B	50	20	I	33.0
Haanja	9S 1B	45	20	I	43.2
Väätsa	9S 1B	63	25	I	29.7
Vigala	6S 3P	43	18	I	35.6
Putkaste	9S 1B	64	19	II	34.0
Kuusnõmme	5S 5P	73	11	IV—V	11.8
Tipu	8S 1P 1B	56	22	I	44.3
Pikasilla	7P 3S	63	11	III	26.8

S, *Picea abies*; P, *Pinus sylvestris*; B, *Betula verrucosa.*

Soil

Plot	Soil type	Parent material	Humus form	pH (H_2O) in 0—20 cm
Voore	Brown lessive	Devonian, moraine	mull	4.4—4.5
Haanja	Soddy podzolic	Devonian, moraine	moder	4.3—5.6
Väätsa	Typical brown	Silurian, moraine	mull	6.5—7.2
Vigala	Greyish brown lessive	Silurian, limestone	mull	4.4—4.9
Putkaste	Gleyed soddy podzolic	Silurian, limestone	mull	5.3—5.8
Kuusnõmme	Pebble rendzina	Silurian, limestone	mull	7.0—8.3
Tipu	Gleyed soddy podzolic	Devonian, moraine	moder	4.5—5.0
Pikasilla	Podzol	Devonian, moraine	mor	4.4—5.3

MATERIAL AND METHODS

In order to evaluate the forest damage rate, eight permanent plots of 50×50 m were laid out in 1987 in middle-aged spruce stands (Table 1) located evenly over the Estonian area.

The plots were studied for the plant species composition, stand structure, forest and soil type, etc. according to internationally agreed methods of integrated monitoring (Pyväläinen, 1993).

Spruce crowns and roots were reinspected for visible damage every year. Needle samples for nutrient analysis were taken in 1990 separately for the current-year and older shoots. Altogether, thirteen seemingly healthy and five moderately defoliated (needle loss 25—60%) trees were sampled at the western side, using two branches (7th and 10th whorl) per tree (Table 2).

Table 2

Needle nutrient concentrations in normal and defoliating spruces (mean ± standard error)

Element	Normal trees ($n=26$) previous year	Normal trees ($n=26$) current year	Defoliating trees ($n=10$) previous year	Defoliating trees ($n=10$) current year	Deficiency threshold range
			in %		
N	1.21±0.03	1.24±0.03	0.91±0.04	1.00±0.07	1.31—1.50
P	0.15±0.01	0.17±7.41	0.13±0.03	0.15±0.03	0.12—0.13
K	0.47±0.02	0.55±0.04	0.42±0.06	0.54±0.10	0.34—0.42
Ca	0.27±0.04	0.16±0.02	0.35±0.06	0.25±0.07	0.11—0.36
Mg	0.13±0.01	0.13±0.01	0.11±0.01	0.12±0.01	0.08—0.11
			in p.p.m.		
Mn	627.7±171	501.9±127	269.0±140	252.2±128	20—80
Zn	19.7±1.37	22.6±0.68	25.6±6.02	25.0±4.2	<13
Al	208.6±18.6	165.6±11.4	151.0±13.7	146.0±16.6	—
Fe	63.3±3.71	52.6±2.35	41.6±1.54	37.0±1.6	—
Cu	2.5±0.14	2.5±0.14	2.0±0.0	2.0±0.0	—
B	17.8±1.56	17.7±1.15	13.8±0.86	14.0±0.84	8—10

— no data available.

The material was dried at 70 °C for 24 hours and homogenized. The chemical analyses were performed at the Chemistry Laboratory of the Horticulture Department, Tallinn. The Ca and K contents were determined photometrically; P, Mg, B, and Al spectrocolorimetrically; and Fe, Cu, Mn, and Zn by the atomabsorbtion spectrometry. The content of N was determined with the micro-Kieldahl apparatus at the Estonian Institute of Animal Breeding and Veterinary, Tartu.

In addition, five defoliated trees with discolouration symptoms were sampled at the Voore plot in December 1991 to reveal the possible nutrient content gradient according to needle age along the branch. For comparison we have used data obtained on the K, Mg, Ca, and P content in the needles of healthy trees belonging to dominant and suppressed spruces from the same stand (Table 3) but collected in "pre-damage time" in April 1972. These needle samples were analysed using classical chemical methods at the Department of Soil Science and Agrochemistry, Estonian Academy of Agriculture, Tartu.

The soil samples were taken at each plot from two pits located at the north and the south corner at depth horizons of 0—5 and 6—20 cm.

Statistical treatment of data was performed using Student's test and standard analysis of variance.

Table 3

Nutrient percentage concentrations in different needle-age classes of discoloured (1991), healthy dominant, and healthy suppressed spruce trees (1972) at Voore Ecology Station, Estonia

Element	Needle age, years				
	1	2	3	4	5—8
	Discoloured				
N	1.20	1.20	1.17	1.15	1.05
P	0.19	0.17	0.12	0.12	0.10
K	0.58	0.37	0.31	0.29	0.26
Ca	0.17	0.50	0.83	0.92	1.08
Mg	0.008	0.006	0.005	0.004	0.005
	Suppressed				
N	1.03	1.05	0.95	0.90	0.87
P	0.20	0.16	0.17	0.16	0.15
K	0.81	0.67	0.60	0.66	0.64
Ca	0.52	0.65	0.69	0.67	0.85
Mg	0.20	0.20	0.15	0.14	0.14
	Dominant				
N	0.88	0.96	0.94	0.99	0.78
P	0.16	0.15	0.13	0.13	0.11
K	0.48	0.34	0.28	0.25	0.25
Ca	0.69	1.00	1.06	1.31	1.54
Mg	0.20	0.26	0.29	0.28	0.33

Table 4

Characteristics of the upper soil horizon (0—20 cm, $n=4$)

Plot	pH KCl	Humus, %	Concentration of nutrients, $mg \cdot 100\ g^{-1}$							Ca/Al, mol/mol
			N-tot	P	K	Ca	Mg	Al	Fe	
Voore	3.9	5.3	160	17	3	38	12	195	151	0.13
Haanja	3.7	3.9	210	3	1	75	9	146	183	0.35
Väätsa	6.4	6.2	190	11	3	169	29	130	131	0.93
Vigala	3.5	10.2	360	2	2	88	14	86	27	0.65
Putkaste	4.3	2.6	400	3	2	413	11	93	62	2.41
Kuusnõmme	7.8	5.5	430	10	4	2500	368	101	918	15.60
Tipu	3.4	5.3	220	2	1	42	7	49	36	0.69
Pikasilla	4.0	3.5	140	18	2	44	7	162	126	0.22

RESULTS

In the soils of the studied plots the nutrient concentrations vary in broad limits (Table 4). The leaching of K seems to be the most intensive in practically all plots. The leaching of Mg in calcareous soils and of P in soils rich in raw humus is also remarkable. The Ca content in the studied soils is less affected by leaching.

The nutrient deficiency threshold of the current-year needles ranges (last column, Table 2) for N, P, K, Ca, and Mg according to the ECE Standard (ECE, 1989) and Glattes (1989); for Mn and Zn according to Hüttl (1988b); and for B according to van den Driessche (1984). We have found no physiologically meaningful threshold values for Al, Fe, and Cu.

According to Table 2 the determined concentrations of chemical elements, with the exception of N, lie well within the threshold range for both normal and defoliated trees for the current year as well as for the older needles. It seems clear that no real deficiency occurs at least in K, Ca, Mg, Mn, and B.

DISCUSSION

Nutritional status of the green needles

The nitrogen content in both current- and previous-year needles of healthy trees is above 1.3% in four out of thirteen cases. However, all defoliated trees are deficient in N.

In comparison with normal healthy trees the concentrations of N and Mn decrease statistically significantly and those of P, K, Al, Fe, and B show a slight decrease in defoliated trees. Ca and Zn, on the contrary, are accumulated in defoliated trees.

Both Table 3 and Table 4 show that in different age classes a gradual change in the nutrient concentrations occurs: N, P, K, and Mg tend to accumulate in young needles, whereas Ca, Mn, Al, and Fe behave in the opposite way. Zn, Cu, and B do not show any remarkable trends.

Differences in nutrient content in needles due to soil type were statistically insignificant. However, the lowest values belong to stands on sandy soil.

The content of Mn in the needles falls twice in defoliated trees. However, due to its rather wide variability, the difference does not reach 95% level of significance. On the other hand, Mn is the only element whose content in the needle is correlated to its content in soil, in spite of large variability even between the neighbouring pits and depth horizons of the same plot.

The P content exceeds the critical level in all samples from healthy trees but falls below that in the stand on calcareous rendzina soil.

The K content in the needles is the highest (reaching 0.9%) on soils with a high humus content (9—14%). It was below the deficit level only in one case in the current-year needle of a defoliated tree growing on calcareous rendzina soil.

Of the intermediately mobile nutrients the Mg content fell below the critical level only once in the previous-year needle of a defoliated spruce on fertile soil on moraine.

Nutritional status of discoloured needles

Yellowing, discoloured, brown needles or needles with chlorotic flecks show a pronounced deficiency of Mg (Table 2). Surprisingly enough, the N content has an opposite trend—the highest concentrations occur in discoloured needles, intermediate values in the case of healthy suppressed trees, and the lowest in the case of healthy dominant trees.

Of the studied elements P and Ca show no evident trend, while the most interesting situation is connected with the K content in the case of intermediate values for discoloured trees and high values for suppressed healthy trees.

It seems clear that a more detailed eco-physiological study of the nutrient uptake, transportation, and utilization is necessary to explain the observed variation.

Pattern in age classes

It is important to emphasize that regardless of the tree health status the N content falls below the deficiency level in current-year needles, whereas the P, Mg, and K contents do not fall below this level in healthy trees before the needles die due to their physiological senescence.

In discoloured needles the Mg concentration is very low in all age classes; the K content is low beginning from the second year. The same regularity may occur in maturing dominant trees.

On the other hand, Ca shows a strong tendency to accumulate with needle age and its deficiency could be expected only in the current-year needles of damaged trees.

Nutrient ratios

Considering the ranges of the element-balanced nutrition ratio for N, P, K, Ca, and Mg (Hüttl, 1988b), the N/P ratio is nearly at imbalance in the spruce stands studied (Table 5). Probably, it is due to a shortage of N, which is consumed in large amounts in the course of fast vegetative growth (Frey et al., 1992). The subsequent generative growth tends to balance the ratio again. A slight trend to decrease in the N/P ratio in damaged trees may reflect a decrease in the N uptake from soil solution due to root damage.

The N/K ratio falls within normal limits in all health classes, whereas the N/Ca ratio increases gradually in accordance with the extent of damage. An extraordinary increase in the N/Mg ratio due to serious Mg deficit is observed in discoloured trees.

Table 5

Ratios of main nutrients in current-year needles of Norway spruce

Element ratios	Balanced nutrition	Normal trees	Defoliated trees	Discoloured trees at Voore
N : P	6—12	7.3	6.7	6.3
N : K	1—3	2.3	1.9	2.1
N : Ca	2—7	2.3	4.0	7.1
N : Mg	8—30	9.7	8.3	150

CONCLUSIONS

Foliar nutrient concentrations of successive age classes vary. In healthy trees their analysis tends to reflect the physiological status of trees, branches, and twigs according to age, shading, and soil fertility. The overall trend of the content of mobile nutrients to decrease with needle age indicates that nutrients are translocated from older to physiologically most active younger needles (Mead, 1984; van den Driessche, 1984). The Mg deficiency in the crown may have no relation to its deficit either in the soil or soil solution.

Long-term acid deposition may cause an increase in the solubility of minerals and result in a remarkable leaching of nutrients from the rooted horizons to the deeper ones. According to our data the leaching of K has been most intensive at practically all plots. The leaching of Mg in calcareous soils and of P in soils rich in raw humus is also notable. The Ca content in soil is less affected by this process.

However, air pollution and acid precipitation are factors with a very wide dynamics when compared to the life span of trees. Therefore, it is unlikely that any significant relationship or permanent process in soil, responsible for crown shading and needle discolouration, can be established. The buffering capacity of most soils can certainly neutralize a considerable part of the fluctuations on the long-term scale but not in short-term alternations in the eco-physiological background.

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