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WOOD AND BARK NUTRIENT ANALYSIS OF DAMAGED AND UNDAMAGED NORWAY SPRUCE

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Abstract. Fifteen spruce trees on eight permanent plots were felled for determining their nutrient (ash, N, P, K, Ca, Mg) concentrations, the spatial variation of these concentrations, and their relation to the site and tree crown variables.

Nutrient concentrations in the bark were up to ten times higher than in stemwood. The concentrations of all nutrients (except Ca) increased towards the top of the stem. The nitrogen concentration decreased from the cambium and increased again near the pith. The concentration of P, K, and Mg increased toward the bark, that of Ca showed a diminishing trend toward the bark. All nutrients in the bark showed a decrease in damaged trees. The diminished concentration of N in the tree bark was found to be the best indicator of crown damage, therefore this is a valuable variable in forest monitoring.

Key words: Norway spruce, air pollution, bark, stemwood, nutrient concentrations.

INTRODUCTION

Nitrogen, phosphorus, potassium, calcium, and magnesium are the main nutrients necessary for tree growth. N is one of the main components of the cell structure, P plays a great role in energy exchange, K is necessary for the activity of enzymes, Ca for the strength of cell walls, and Mg is essential for the biosynthesis of chlorophyll (Kramer & Kozlowski, 1979; Libbert, 1974; Elder & Burkhart, 1983).

The tree stem plays an important role in the metabolism of the whole tree. The transport of water, nutrients, and assimilates between the roots and the crown is possible only via the stem. Nutrient concentrations in the stem are controlled by the nutrient demand of different tissues and the availability and supply of nutrients in the soil.

The mobility of nutrients determines the transport pattern of nutrients within the tree and also the distribution of nutrients in different tree compartments. Only mobile nutrients can be translocated within the tree (Helmisaari & Siltala, 1989). In general, the nutrient concentrations of the stemwood and outer bark are very low compared with those of needles. About 3/4 of the total above-ground weight of nutrients is stored in needles and live branches, 1/4 in the bark and wood (Nilsson & Wiklund, 1991). Therefore, most studies of the nutrient concentration deal only with needles while tree rings have often been examined for the purpose of dating historical and natural events by providing a record of changing environmental conditions. A number of investigations have suggested that tree ring analysis is promising for monitoring air pollution patterns in the environment with the aid of analysis of the chemical composition of tree rings (McLaughlin, 1985; Legge et al., 1984). The basic assumption is that annual growth rings are preserved in the wood and reflect exposure to air pollution by their chemical composition. Air pollution reduces the availability of the nutrients in the soil; the size and colour of needles change due to nutrient deficit (Schulze, 1989; Schütt & Cowling, 1985; Tomlinson, 1983; Kramer & Kozlowski, 1979).

The aim of this study was to determine the spatial (vertical and horizontal) variation of the nutrient concentrations in the stemwood and bark of Norway spruce and to ascertain if the variation is related to nutrient mobility and stand site quality class. The nutrient status of the stem with respect to crown damage and soil conditions was also studied.

MATERIAL AND METHODS

The location of eight permanent plots of forest research is shown in Fig. 1. General data on the stands, including soil analysis, have been published earlier (Kask, 1992; Frey et al., 1992; Lôhmus & Lasn, 1991). In September 1990, 15 spruces were felled. Simultaneously the crown condition of the trees was estimated using a system of five damage classes (Kask & Frey, 1993). The sample disks of each stem were cut at breast height, at 1/2 height of the tree, and at 1/2 height of the crown. The sample disks were 5 cm thick; the stemwood and bark were removed from the disks. The horizontal variation of the nutrient concentration was analysed from successive 10-year-old subsamples beginning from the latest annual ring.

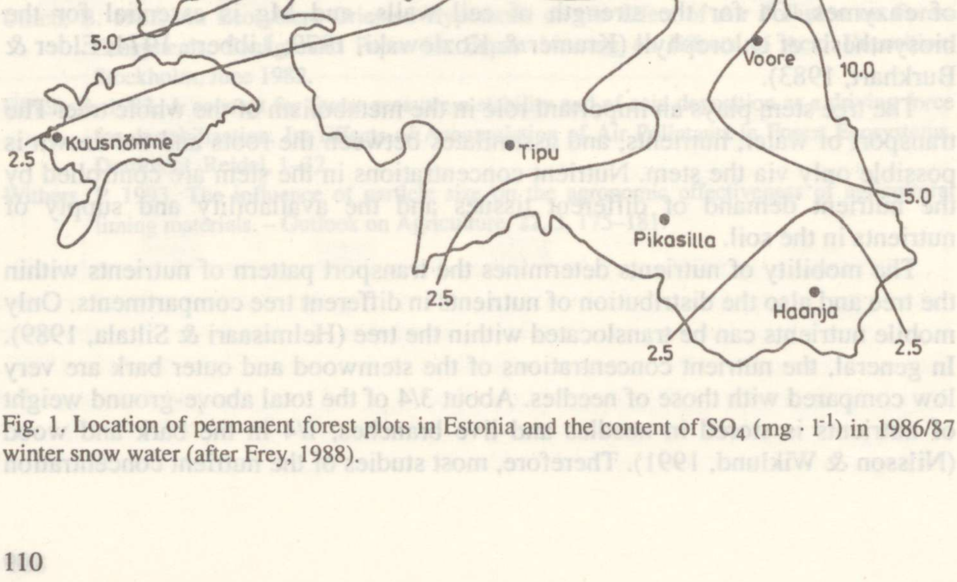


Fig. 1. Location of permanent forest plots in Estonia and the content of SO_4 (mg · l^{-1}) in 1986/87 winter snow water (after Frey, 1988).

The wood and bark samples were chemically analysed at the State Chemical Station at Saku. Nitrogen was determined using the Kjeldahl method, potassium and calcium photometrically, phosphorus was determined using the vanadate–molybdate method, magnesium was determined using the atomic absorption method.

The trees were divided into age classes 21–40, 41–60, and 61–80 years. The thickness of sapwood was calculated for each individual tree, and the sapwood–heartwood boundary was found by means of the following formula (Sellin, 1991):

$$Y = 65.7 \times X/(X + 70.1);$$

$$R^2 = 0.89, p < 0.001,$$

where Y - sapwood thickness, years;
X - tree age, years.

Regression analysis was used to examine horizontal variation in the nutrient concentrations of stemwood and the nutrient–crown class correlation. Analysis of variance was applied to examine the impact of site, vertical height, and crown damage on the nutrient content. The analysis of variance was carried out with the help of the Computer Centre of the University of Tartu.

RESULTS AND DISCUSSION

Vertical variation of nutrient concentrations

Nutrient concentrations in the stemwood were up to 10 times lower than in the bark. According to Helmisaari & Siltala (1989), Mälkonen (1975), and Merill & Cowling (1966) the concentrations of all nutrients are the greatest in the inner bark. The concentrations of all nutrients (except Ca) increased towards the top of the tree stem. A significant difference in N, K, and Mg at different heights was found only in the bark. In old trees the stemwood within the crown is more efficient in storing and cycling nutrients than the lower stem. On Voore, Vigala, Väätsa, and Putkaste plots calcium concentrations decreased towards the top. The decrease of calcium in the tree top may be the result of its poor mobility in woody stems in comparison with the other elements. The notable increase of nutrients in the bark, moving upwards, is caused by a change in the ratio of the living bark to the dead one. High nutrient concentrations in the crown support Mälkonen's (1975) hypothesis that the translocation of N, P, and K from dying needles before their abscission is of greatest importance in satisfying the annual nutrient requirement for the biosynthetic process in the tree.

Horizontal variation of nutrient concentrations

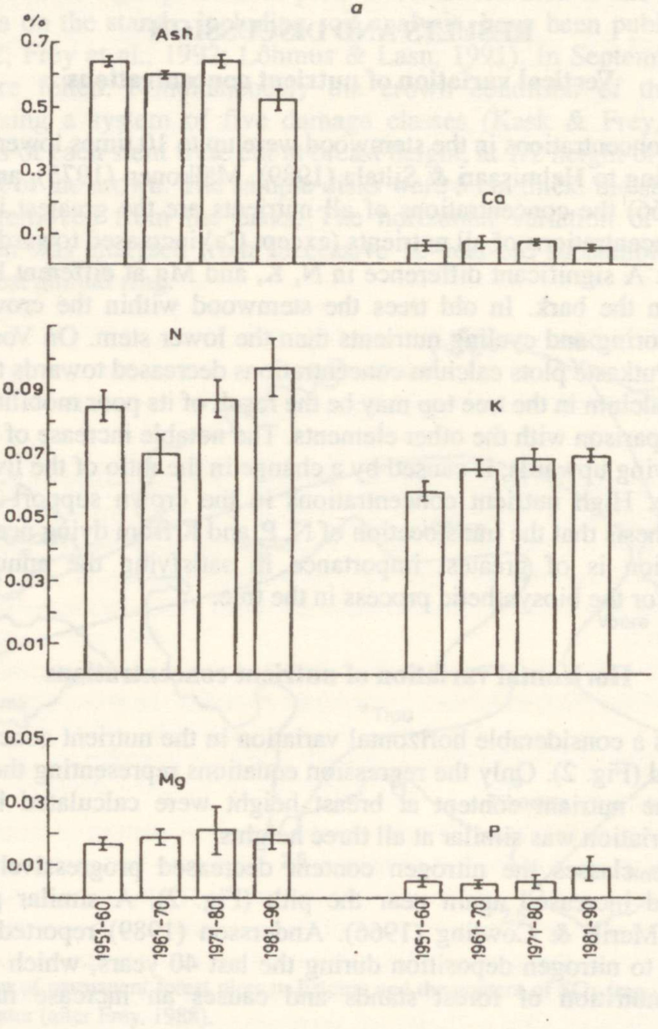
There was a considerable horizontal variation in the nutrient concentration in the stemwood (Fig. 2). Only the regression equations representing the horizontal change in the nutrient content at breast height were calculated because the horizontal variation was similar at all three heights.

In all age classes the nitrogen content decreased progressively from the cambium and increased again near the pith (Fig. 2). A similar pattern was reported by Merill & Cowling (1966). Andersson (1989) reported a nitrogen increase due to nitrogen deposition during the last 40 years, which leads to the unbalanced nutrition of forest stands and causes an increase in biological production.

The concentrations of P, K, and Mg increased toward the bark (Fig. 2). A similar pattern was reported by Long & Davis (1989), Lim & Cousens (1970), as well as Arp & Manasc (1988). Andersson (1989) showed an opposite trend due to additional N supply causing K and P deficit.

The concentrations of Ca showed a decreasing trend toward the youngest xylem tissues, except in the age class 61–80 (Fig. 2). Helmisaari & Siltala (1989), Lim & Cousens (1970), Frelich et al. (1989), and Baes & McLaughlin (1984) suggested that the mobility of Ca was low in the stemwood. Bauch et al. (1985), Arp & Manasc (1988), and Andersson (1989) reported a Ca decrease related to air pollution. Ca uptake by roots may have been reduced by enhanced Al levels in the soil because of soil acidification.

A peak may occur in horizontal variation near the sapwood–heartwood boundary for all nutrients (Fig. 2*c*) due to the intensified metabolism between sapwood and heartwood in the transitional zone.



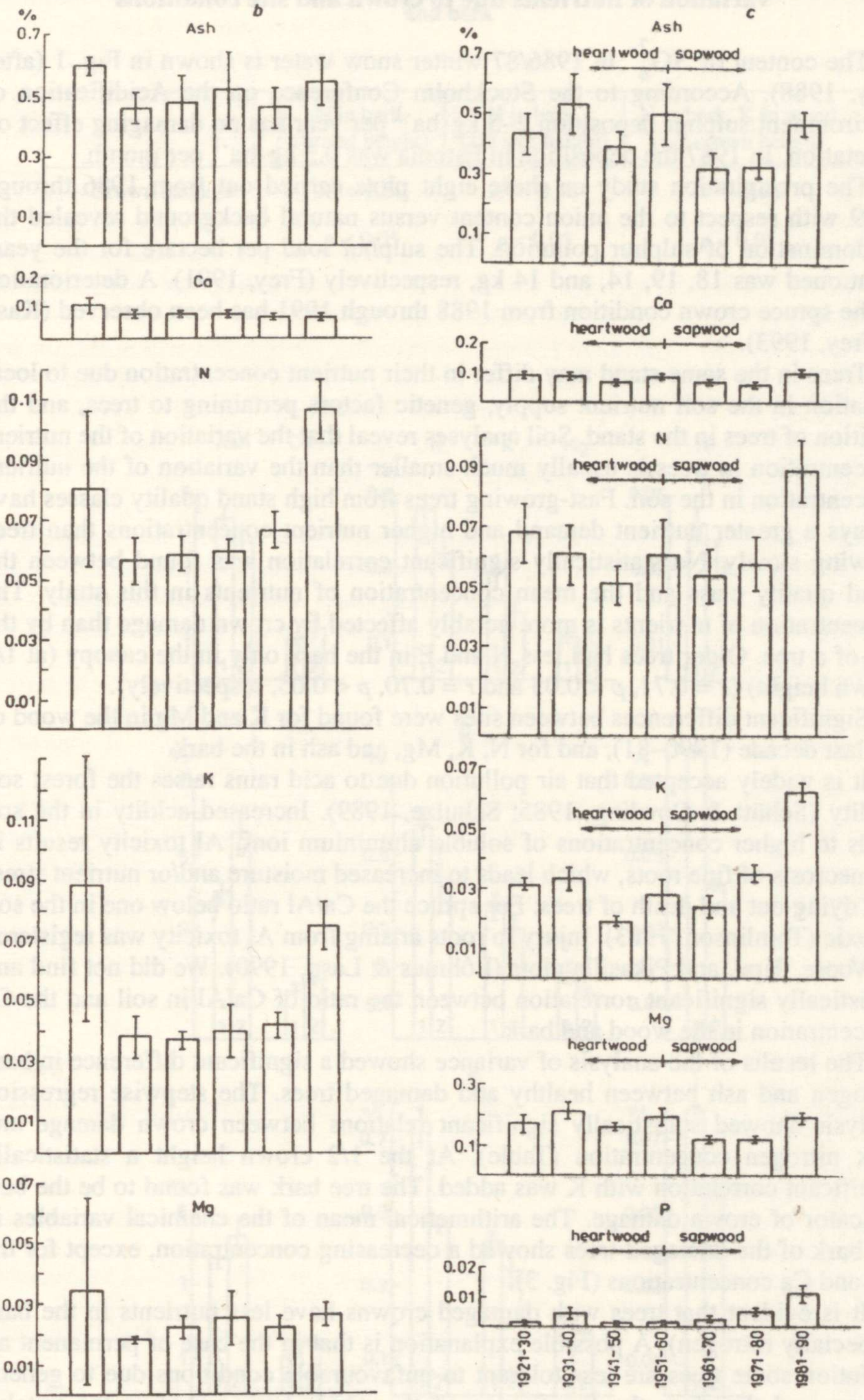


Fig. 2. The mean content of chemicals in the wood in age classes 21–40 (*a*), 41–60 (*b*), and 61–80 (*c*).

Variation of nutrients due to crown and site conditions

The content of SO_4^{2-} in 1986/87 winter snow water is shown in Fig. 1 (after Frey, 1988). According to the Stockholm Conference on the Acidification of Environment sulphur deposition 2–5 $kg \cdot ha^{-1}$ per year has no damaging effect on vegetation. In 1987 the deposition in Estonia was 0.5 $kg \cdot ha^{-1}$ per month.

The precipitation study on these eight plots carried out from 1986 through 1989 with respect to the anion content versus natural background revealed the predomination of sulphur pollution. The sulphur load per hectare for the years mentioned was 18, 19, 14, and 14 kg, respectively (Frey, 1991). A deterioration of the spruce crown condition from 1988 through 1991 has been observed (Kask & Frey, 1993).

Trees in the same stand may differ in their nutrient concentration due to local variation in the soil nutrient supply, genetic factors pertaining to trees, and the position of trees in the stand. Soil analyses reveal that the variation of the nutrient concentration in trees is usually much smaller than the variation of the nutrient concentration in the soil. Fast-growing trees from high stand quality classes have always a greater nutrient demand and higher nutrient concentrations than trees growing slowly. No statistically significant correlation was found between the stand quality class and the mean concentration of nutrients in this study. The concentration of nutrients is more notably affected by crown damage than by the age of a tree. Older trees had less N and P in the bark only in the canopy (at 1/2 crown height) ($r = 0.71$, $p < 0.05$ and $r = 0.70$, $p < 0.05$, respectively).

Significant differences between sites were found for K and Mg in the wood of the last decade (1990–81), and for N, K, Mg, and ash in the bark.

It is widely accepted that air pollution due to acid rains raises the forest soil acidity (Schütt & Cowling, 1985; Schulze, 1989). Increased acidity in the soil leads to higher concentrations of soluble aluminium ions. Al toxicity results in the necrosis of fine roots, which leads to increased moisture and/or nutrient stress and dying out and death of trees. For spruce the Ca/Al ratio below one in the soil is toxic (Tomlinson, 1983). Injury to roots arising from Al toxicity was registered on Voore, Tipu, and Pikasilla plots (Lõhmus & Lasn, 1990). We did not find any statistically significant correlation between the ratio of Ca/Al in soil and the Ca concentration in the wood and bark.

The results of the analysis of variance showed a significant difference in bark nitrogen and ash between healthy and damaged trees. The stepwise regression analysis showed statistically significant relations between crown damage and bark nitrogen concentration (Table). At the 1/2 crown height a statistically significant correlation with K was added. The tree bark was found to be the best indicator of crown damage. The arithmetical mean of the chemical variables in the bark of the damaged trees showed a decreasing concentration, except for the ash and Ca concentrations (Fig. 3).

It is evident that trees with damaged crowns have less nutrients in the bark (especially nitrogen). A possible explanation is that in the case of permanent air pollution some trees are less tolerant to unfavourable conditions due to genetic factors and therefore the functioning of the whole tree, including the uptake, transport, utilization, and storage of nutrients, is disturbed. We can conclude that the bark is a good indicator of tree damage; at the same time, being easier to collect than needles, bark samples are useful in forest monitoring.

Correlation between the crown damage and nutrient concentrations in wood (decade 1990-81) and bark

	N in bark, (breast height)	N in bark, (1/2 tree height)	N in bark, K in wood (1/2 crown height)
Crown damage	$R^2 = 0.30$	$R^2 = 0.32$	$R^2 = 0.61$
	$p < 0.05$	$p < 0.05$	$p < 0.01$

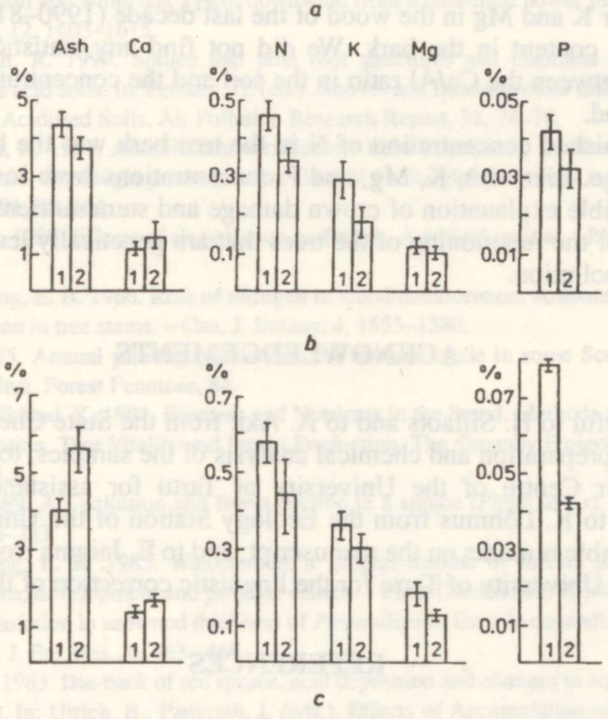


Fig. 3. The mean content of chemicals in the bark in healthy (1) and damaged trees (2) at different heights. *a*, breast height; *b*, 1/2 height of the tree; *c*, 1/2 height of the crown.

CONCLUSIONS

Nutrient concentrations in the bark were up to 10 times higher than in the stemwood. The concentrations of all nutrients (except Ca) increased towards the top of the stem. A statistically significant difference of nutrient concentrations in the bark between heights was found only for N, K, and Mg.

The N content decreased progressively from the cambium and increased again near the pith. The concentrations of P, K, and Mg increased toward the bark; the concentrations of Ca showed a decreasing trend toward the youngest xylem tissues, except for the age class 61–80. There exists a peak for all nutrients in the horizontal variation near the sapwood–heartwood boundary.

No statistically significant correlation between the nutrient concentration and site quality class was observed in our case. A significant difference between plots was found for K and Mg in the wood of the last decade (1990–81), and for N, K, Mg, and ash content in the bark. We did not find any statistically significant correlation between the Ca/Al ratio in the soil and the concentration of Ca in the bark and wood.

The diminished concentration of N in the tree bark was the best indicator of crown damage. Likewise, K, Mg, and P concentrations were lower in damaged trees. A possible explanation of crown damage and stem nutrient decrease is the disturbance of the functioning of the trees that are genetically less tolerant to the effect of air pollution.

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