The effect of liming on the mineral nutrition of the mountain Norway spruce (*Picea abies* L.) forest

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ABSTRACT: Mineral nutrition represents the uptake, transport, metabolism and utilization of nutrients by the forest stand. These processes influence all physiological functions of trees. A specific minimum amount of all nutrients is necessary for the healthy development and growth of forest trees. The uptake of nutrients is influenced not only by natural conditions but also by anthropogenic activities. During the period of 2000–2005 the mineral nutrition of mountain Norway spruce stands was studied at the study site Bílý Kříž (Moravian-Silesian Beskids Mts., Czech Republic). Research was carried out in a spruce stand that was limed in the past years (in 1983, 1985 and 1987) and in a spruce stand that was not limed in order to compare the liming effect on the mineral nutrition of spruce stands. A positive liming effect was detected in the calcium, magnesium and phosphorus nutrition because their contents in current needles were higher on the limed plots. No liming effect was determined in the nitrogen, potassium and microelement (Fe, Mn, Cu, Zn, Al) content in current needles. Sufficient nutrition of spruce stands only with calcium was recorded on all studied plots.

Keywords: macroelements and microelements content in needles; Norway spruce; liming; Moravian-Silesian Beskids Mts.; Czech Republic

Forests cover 33% of the Czech Republic's area and they have very important functions (natural habitat for native plants and animals, landscape feature, source of timber, influence on local climate, etc.). But the fulfilment of these functions is limited by the poor condition of Czech forests. Despite the air pollution reduction during the 1990s, air pollution is still one of the causes of this condition. The forests in the border mountains (including the Moravian-Silesian Beskids Mts.) and the forests in the highlands are still exposed to acid deposition. Air pollution caused the acidification of forest ecosystems. Acidification is induced by the transfer of pollutants from the atmosphere to the ecosystem due to filtering processes. Degradation of the health state of forests and damage to forest soils were the results of the long-term influence of air pollution (Anderson 1999; Aamlid et al. 2000; Kulhavý et al. 2001; Nellemann et al. 2003; Purdon et al. 2004; Kulhavý 2004; Bytnerowicz et al. 2005). Extreme weather (high air temperatures or precipitation deficit) is another limiting factor influencing the development of forests (Bodin, Wiman 2007; Granier et al. 2007; Zeppel et al. 2008) while adverse climatic conditions increase the effect of air pollution impact. Synergic effects of air pollution, atmospheric precipitation in the growing season and mean annual air temperature influence the health state of coniferous forests at 90% (Hadaš 2004).

Liming was carried out most frequently in the forest regions with the air pollution impact mainly in the 1970s and 1980s. However, the observation

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of forest conditions after liming showed that liming has both positive and negative effects on the forests. Thus the long-term monitoring of forest conditions after liming is required.

There exist a lot of data on the liming effect on the soil chemistry changes but data on the liming effect on the mineral nutrition of forests are scarce. Thus, the mineral nutrition of mountain Norway spruce stands has been studied at the study site Bílý Kříž (Moravian-Silesian Beskids Mts., Czech Republic) since 2000. Research was carried out in a spruce stand which was limed in the past years and in a spruce stand which was not limed in order to compare the liming effect on the mineral nutrition of spruce stands.

METHOD

Research on the mineral nutrition of limed and not limed Norway spruce stands was conducted at the study site Bílý Kříž (Moravian-Silesian Beskids Mts., Czech Republic). The coordinates of the study site are 49°30'N and 18°32'E. Geological subsoil is composed of the flysch layer with dominant sandstones. The soil type is typical humo-ferric Podzol with the mor-moder form of surface humus. The soils in the studied spruce stands are medium deep to shallow, loamy-sand and sandy-loam with a higher content of the skeleton in the lower layers and with a relatively low nutrient content. Soil depth is 60–80 cm. Recently, surface humus has changed to the moder type, of which a thin layer of Ol and Of soil horizons is typical. The area is moderately cold, humid, with abundance of precipitation. Mean annual air temperature is 5.5°C, mean relative air humidity 80% and mean annual sum of precipitation 1,100 mm (Kratochvílová et al. 1989). Clean to almost clean air is in this time at the study site Bílý Kříž according to the survey of air quality in the region of the Czech Republic (ČHMÚ 2001). The annual arithmetical mean of sulphur dioxide was not higher than the air pollution limit for forest stands ([(1), (2)] 20 μg/m^3) during the studied period of 2000–2005. During the growing season (May–October) the arithmetical mean of SO_2 was in the interval of 3.0–4.9 μg/m^3 (mean value 4.0 μg/m^3, i.e. 20% of the limit). Except for the growing season the arithmetical mean of SO_2 was in the interval of 6.8–10.6 μg/m^3 (mean value 8.7 μg/m^3, i.e. 44% of the limit). The annual arithmetical mean of nitrogen oxides was not higher than the air pollution limit for forest stands ([(1), (2)] 30 μg/m^3). During the growing season the arithmetical mean of NO_x was in the interval of 4.5 to 6.5 μg/m^3 (mean value 5.7 μg/m^3, i.e. 19% of the limit). Except for the growing season the arithmetical mean of NO_x was in the interval of 8.0–11.2 μg/m^3 (mean value 9.9 μg/m^3, i.e. 33% of the limit).

The limed Norway spruce stand was planted out in 1981 using four-years-old seedlings of *Picea*

Table 1. Characteristics of the Norway spruce stand on the limed plots FD and FS and on the not limed plot FK at the study site Bílý Kříž

		FD	FS	FK
Stand density (trees/ha)	2000	2,600	2,100	2,600
	2001	2,600	1,880*	
	2002	2,500**	1,820**	
	2003	2,440**	1,820	
	2004	2,048	1,652	
	2005	2,044	1,652	2,600
Mean stand height (m)	2000	8.5	7.5	
	2001	9.0	8.3	
	2002	9.7	8.9	7.5
	2003	10.4	9.6	
	2004	10.9	10.3	
	2005	12.2	11.2	11.0

*Thinning, **reduction of tress by the influence of meteorological conditions

[(1)] Air pollution limits for SO_2 and NO_x for forest ecosystems according to EEC OSN and IUFRO for the vegetation protection (Directive for the Air Quality in Europe. Ministry of the Environment of the Czech Republic, Praha 1996) (in Czech).

[(2)] Act No. 86/2002 on Air Protection (Zákon č. 86/2002 Sb., o ochraně ovzduší).

Table 2. Optimum nutrition limits for macro- and microelements in Norway spruce

	Macroelements (%)				
	N	P	K	Ca	Mg
Bergmann (1993)	1.35–1.70	0.25–0.30	0.50–1.20	0.35–0.80	0.10–0.25
Hüttl (1986)	1.30–1.50	0.12–0.15	0.45–0.60	0.08–0.10	0.20–0.30

	Microelements (mg/kg)			
	Mn	Cu	Zn	Fe
Bergmann (1993)	50–500	4–10	15–60	30–180

Table 3. A list of methods used for the analysis of needles removed on the limed plots (FD and FS) and on the plots without liming (FK) at the study site Bílý Kříž in 2000–2005

C, N, S	high temperature oxidation in the dry way (C and N at the temperature of 1,000°C, S at the temperature of 1,350°C) using a CNS-2000 LECO analyzer
Na, K	atomic emissive spectrophotometry
Ca, Mg, Fe, Mn, Cu, Zn, Al	flame atomic absorption spectrophotometry
P	atomic absorption spectrophotometry

abies (L.) Karst. The mean slope of the plot is 13.5°, its exposure is SSE and mean altitude 908 m a.s.l. The age of trees was 28 years in 2005. The spruce stand is divided into two partial plots with different stand density (FD – dense stand, FS – sparse stand). The area of each studied plot is 0.25 ha. Dolomitic limestone (31% CaO, 21% MgO) was used for aerial liming (3 tonnes per hectare at each events). Liming was done in 1983, 1985 and 1987. The spruce stand without liming was established by natural regeneration of *Picea abies* (L.) Karst. The mean slope of the plot is 30°, its exposure SE and mean altitude 850 m a.s.l. The age of trees was 29 years in 2005. The area of the studied not limed plot is 1.16 ha. Selected characteristics of the spruce stands on limed and not limed plots are shown in Table 1.

The evaluation of the mineral nutrition of spruce stands was carried out on the basis of regular collections of needle samples and their chemical analysis. Results of the analysis were compared with Table 2, where optimum nutrition limits for macro- and microelements in Norway spruce according to Hüttl (1986) and Bergmann (1993) are shown. Results were compared with the results of Bergmann because this author also shows optimum limits for microelements.

Samples of current needles were taken from eight spruce trees selected on each studied plot during the period from December to March in monthly intervals. Samples were taken from the sunny crown part from the fourth and the fifth whorl. Removed needle samples were pre-desiccated, powdered and

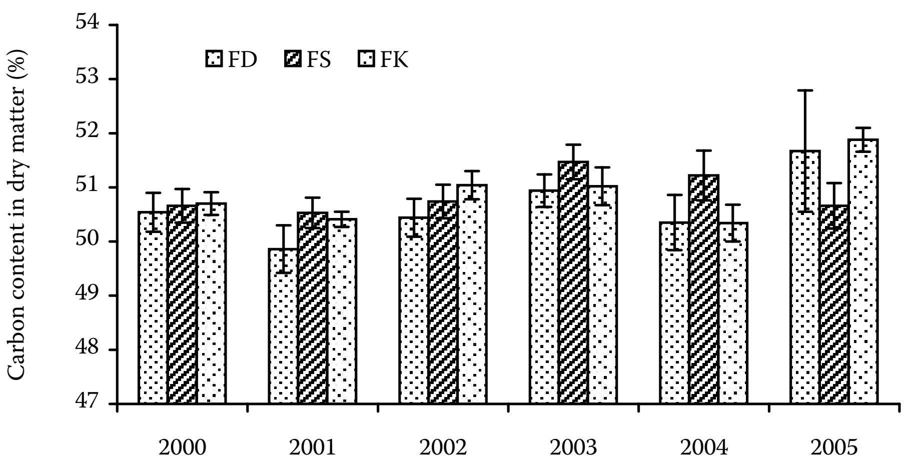

Fig. 1. Carbon content in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (I – confidence interval, α = 0.05)

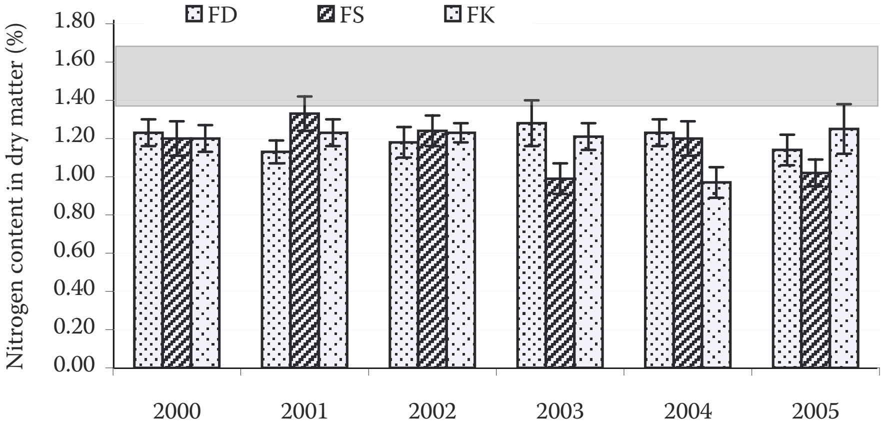

Fig. 2. Nitrogen content in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (interval of sufficient nutrition is marked grey, I – confidence interval, α = 0.05)

dried at the temperature of 80°C. Carbon, nitrogen and sulphur content was determined in all samples, the content of phosphorus, calcium, magnesium, potassium, iron, copper, manganese, zinc and aluminium was determined once a year in the samples from December or March. Nutrients that were determined in the needle samples and the used method are shown in Table 3.

RESULTS AND DISCUSSION

Mineral nutrition represents the uptake, transport, metabolism and utilization of nutrients by the forest stand. These processes influence all physiological functions of trees. A specific minimum amount of all nutrients is necessary for the healthy development and growth of forest trees. The uptake of nutrients is influenced not only by natural conditions but also by anthropogenic activities (acid precipitation, timber harvesting, reclamation, liming, fertilization and so on) (De Visser et al. 1994; Innes 1995; Tichý 1996; Staszewski et al. 1998; Grønflaten et al. 2005). The knowledge of spruce stand nutrition is important for the study of the production and health state of stands and for the assessment of reclamation measures in forest stands.

Carbon content in current needles during dormancy fluctuated on all studied plots (limed and not limed) during the period of 2000–2005 (Fig. 1). No statistically significant differences in this content were observed between limed and not limed plots and between dense limed and sparse limed plots (statistical differences were determined on the basis of confidence intervals, α = 0.05). Nitrogen content in current needles during dormancy fluctuated as well (Fig. 2) but no statistically significant differences were found out between the studied plots. Thus no effect of liming on the carbon and nitrogen nutrition of the spruce stand was determined.

The content of calcium, magnesium and phosphorus in current needles during dormancy was always higher on the limed plots than on the not limed plot and statistically significant differences were determined in their content (Figs. 3 to 5). Thus a positive effect of liming on the calcium, magnesium and phosphorus nutrition of the spruce stand was determined. The same results were reported by De Visser et al. (1994), Irgerslev and Hallbäcken (1999), Irgerslev (1999), Huber et al. (2004, 2006), Lomský (2006), Rosberg et al. (2006). No statistically significant differences in the calcium,

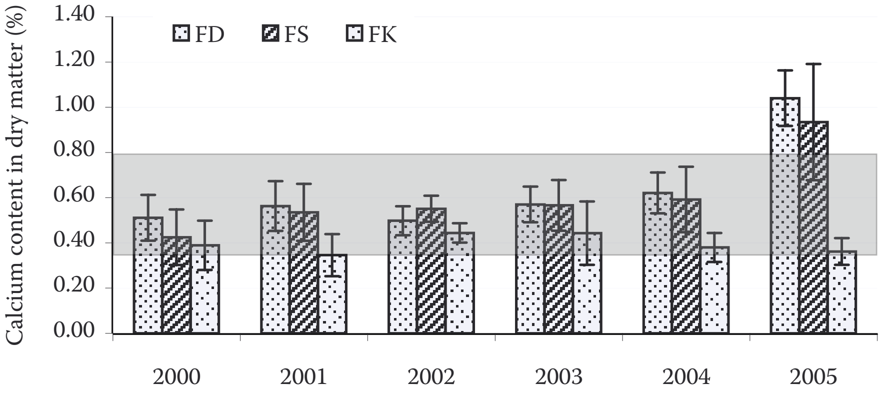

Fig. 3. Calcium content in current needles during dormancy on the limed (FD and FS) and not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (interval of sufficient nutrition is marked grey, I – confidence interval, α = 0.05)

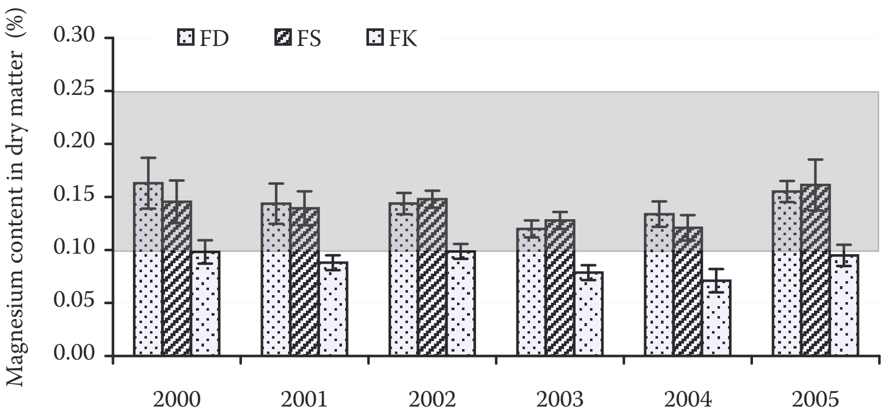

Fig. 4. Magnesium content in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (the interval of sufficient nutrition is marked grey, I – confidence interval, α = 0.05)

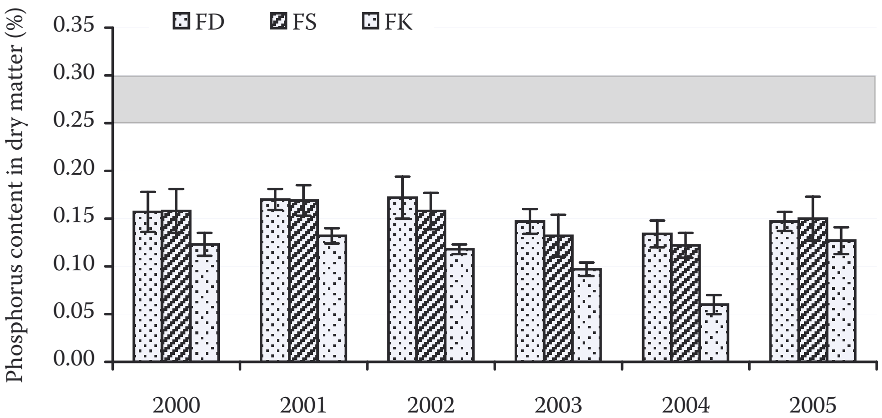

Fig. 5. Phosphorus content in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (the interval of sufficient nutrition is marked grey, I – confidence interval, α = 0.05)

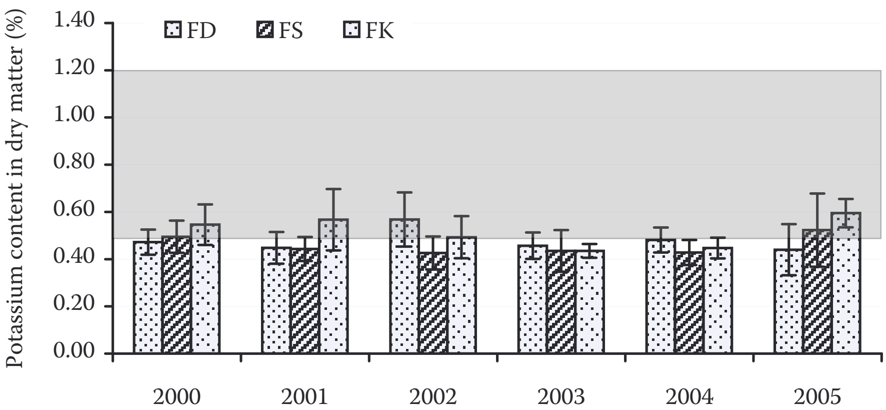

Fig. 6. Potassium content in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (the interval of sufficient nutrition is marked grey, I – confidence interval, α = 0.05)

magnesium and phosphorus content were found out between the dense limed and sparse limed plots.

Potassium content in current needles during dormancy fluctuated on all studied plots during the period of 2000–2005 (Fig. 6) and no statistically significant differences were detected among all studied plots. Thus no liming effect on the potassium nutrition of spruce stand was determined. The same results were reported by Huber et al. (2004).

Only calcium content in current needles during dormancy was sufficient (see Table 2) on all studied plots during the period of 2000–2005. Magnesium content was sufficient only on the limed plots. Nitrogen and phosphorus content was insufficient and potassium content was mostly insufficient on all studied plots.

Sulphur content in current needles during dormancy (Fig. 7) fluctuated on all studied plots (limed and not limed). But this content was mostly higher on the not limed plot than on the limed ones even if no statistically significant differences were observed. It could be caused by the liming effect. Sulphur

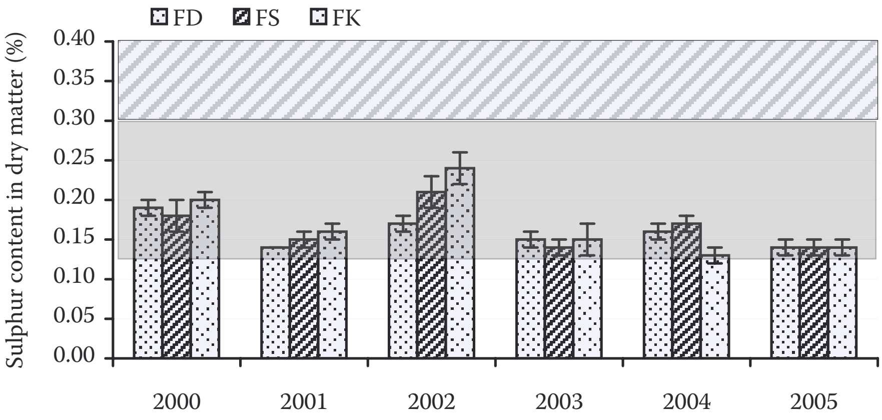

Fig. 7. Sulphur content in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005 (the interval of values representing a small increase in sulphur content is marked grey and representing very high sulphur content is marked lineation, I – confidence interval, α = 0.05)

content was higher than the values representing a small increased sulphur content ([3] > 0.12% S in dry matter) but was not higher than the values representing a very high sulphur content ([3] > 0.30% S in dry matter) on all the studied plots during the whole studied period of 2000–2005. No statistically significant differences were determined between the dense limed and sparse limed plots.

Contents of microelements (Fe, Mn, Cu, Zn, Al) in current needles during dormancy markedly fluctuated on all studied plots (Table 4). Their contents (except for copper) were sufficient. No statistically significant differences were mostly found between limed and not limed plots and between dense limed and sparse limed plots. No liming effect on the microelement content in the spruce stand needles was determined. The same results were reported by Grønflaten et al. (2005).

CONCLUSION

Since the year 2000 the mineral nutrition of mountain Norway spruce stands has been studied at the study site Bílý Kříž (Moravian-Silesian Be-

Table 4. Microelement contents in current needles during dormancy on the limed plots (FD and FS) and on the not limed plot (FK) at the study site Bílý Kříž in 2000–2005

		Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Al (mg/kg)
2000	FD	53.3	208.1	60.1	2.9	41.4
	FS	111.9	189.4	50.7	2.8	48.9
	FK	58.8	345.6	42.1	2.5	94.1
2001	FD	50.6	254.4	57.7	2.3	26.0
	FS	55.8	233.0	47.7	2.4	32.9
	FK	54.1	273.4	33.5	2.5	69.0
2002	FD	53.0	253.6	47.3	3.1	52.6
	FS	53.5	280.3	53.5	2.9	51.4
	FK	60.4	360.5	38.4	2.9	83.9
2003	FD	60.1	323.9	57.6	3.0	48.3
	FS	53.3	269.8	56.0	2.7	53.9
	FK	52.6	348.8	31.2	2.8	85.7
2004	FD	227.3	362.7	60.3	3.1	68.6
	FS	218.3	353.2	61.9	2.6	58.7
	FK	199.8	358.8	31.5	2.1	51.3
2005	FD	123.2	679.4	76.3	2.5	104.6
	FS	84.9	562.1	77.9	2.7	84.3
	FK	86.0	323.2	32.4	3.5	95.5

[3] The values of sulphur content are from Materna (1981).

skids Mts., Czech Republic). Research was carried out in the spruce stand that was limed in the past years and in the spruce stand that was not limed in order to compare the liming effect on the mineral nutrition of spruce stands. The aerial liming with dolomitic limestone was carried out in 1983, 1985 and 1987. In this paper results determined during the period of 2000–2005 are shown. A positive liming effect was detected in the calcium, magnesium and phosphorus nutrition because their contents in current needles were higher on the limed plots. No liming effect was determined in the nitrogen, potassium and microelement (Fe, Mn, Cu, Zn, Al) content in current needles. Sufficient nutrition of spruce stands only with calcium was recorded; the content of other macroelements was below the limits of sufficient nutrition. No differences in the mineral nutrition between dense and sparse limed plots were found out. Thus the stand density has no effect on the mineral nutrition conditions.

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Vliv vápnění na minerální výživu horského smrkového porostu

ABSTRAKT: Minerální výživa představuje příjem, transport, metabolismus a využití živin lesním porostem. Tyto procesy ovlivňují všechny fyziologické funkce stromů. Určité minimální množství živin je nutné pro zdravý rozvoj a růst lesních dřevin. Příjem živin je ovlivňován nejen přírodními podmínkami, ale také antropogenními aktivitami. V období let 2000–2005 byla sledována minerální výživa porostů smrku ztepilého na výzkumné ploše Bílý Kříž (Moravskoslezské Beskydy). Výzkum byl prováděn jednak ve smrkovém porostu, který byl v minulosti vápněn (v letech 1983, 1985 a 1987), jednak ve smrkovém porostu, který vápněn nebyl, aby bylo možné srovnat účinky vápnění na minerální výživu smrkových porostů. Byl zjištěn pozitivní účinek vápnění na výživu vápníkem, hořčíkem a fosforem, neboť na vápněných plochách byl jejich obsah v prvním ročníku jehličí vyšší než na nevápněné ploše. Nebyl zjištěn vliv vápnění na obsah dusíku, draslíku a mikroelementů (Fe, Mn, Cu, Zn, Al) v prvním ročníku jehličí. Na všech studovaných plochách byla zjištěna dostatečná výživa smrkových porostů pouze vápníkem.

Klíčová slova: obsah makroelementů a mikroelementů v jehličí; smrk ztepilý; vápnění; Moravskoslezské Beskydy; Česká republika

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